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E DELL'INFORMAZIONE

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 DI LAUREA MAGISTRALE IN
MANAGEMENT-ENGINEERING-INGEGNERIA
GESTIONALE

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Abstract

The focus of this Master Thesis is to investigate the topic of energy efficiency at logistics sites and understand how companies are dealing with this challenge. In doing so, a structured, multiple-phase methodology has been adopted. The starting point has been a context overview based on the analysis of secondary sources; then, a systematic literature review (SLR) has been performed to increase robustness of the research and to highlight current academic research gaps on the topic. After this introductory analysis, the core is the empirical analysis conducted through market research. The final result is a consolidated database containing a list of 193 examined warehouses, 127 of which located in Italy and 66 in Germany. The data collection process has been possible thanks to the collaboration with Observatory Contract Logistics "Gino Marchet" of Politecnico di Milano and its involvement in the GILA Project. Two different market researchers have been conducted, leading in the end to consolidated acknowledgements and results. The first analysis is an international benchmark between Italian and German logistics sites, with the main aim of highlighting differences and similarities in energy-efficient solutions implementation between the two samples and the reasons behind them. The second study is a longitudinal analysis among Italian warehouses: in this case, the goal is to identify best-practices of strategies for achieving net-zero warehouses. In the end, limitations and future research directions have been proposed and some theoretical and managerial implications discussed.

Keywords: energy efficiency, green warehous*, longitudinal analysis, international benchmark.

Abstract in lingua italiana

Obiettivo di questa Tesi Magistrale è studiare il tema dell'efficienza energetica nei siti logistici, analizzando come le aziende stanno affrontando questa sfida. Per raggiungere l'obiettivo, è stata adottata una metodologia composta da diverse fasi. Partendo da un'analisi di contesto basata sullo studio di fonti secondarie, è stata poi realizzata una revisione sistematica della letteratura (SLR) in modo da fornire maggiore robustezza alla ricerca ed evidenziare eventuali lacune nelle attuali pubblicazioni scientifiche. Dopo questa analisi introduttiva, è stata condotta un'analisi empirica tramite analisi di mercato che si propone come fulcro di questa Tesi Magistrale. Il risultato finale è un database contenente 193 magazzini analizzati, 127 dei quali localizzati in Italia e 66 in Germania. Il processo di raccolta dati è stato possibile grazie alla collaborazione con l'Osservatorio Contract Logistics "Gino Marchet" del Politecnico di Milano e al suo coinvolgimento nel Progetto GILA. L'analisi di mercato vede sviluppati due filoni separati che porteranno anche a risultati comuni. La prima analisi è un confronto internazionale fra i magazzini tedeschi ed italiani, con obiettivo quello di evidenziare differenze e similitudini nell'implementazione di soluzioni di efficienza energetica e le motivazioni alla base di queste scelte. Il secondo studio è un'analisi longitudinale su magazzini solo italiani. In questo caso, lo scopo è identificare strategie vincenti per il raggiungimento dell'obiettivo emissioni zero dei siti logistici. Alla fine, sono state tratte le conclusioni, evidenziate le limitazioni dell'analisi condotta e suggerite future direzioni di ricerca. Inoltre, sono state discusse potenziali implicazioni teoretiche e manageriali.

Keywords: efficienza energetica, green warehous*, analisi longitudinale, confronto internazionale.

Contents

Executive summary

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 methodological 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 longitudinal study within Italian boundaries. 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 interest on the topic, some aspects were modified or added over time. Besides the usual general information about the buildings 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.

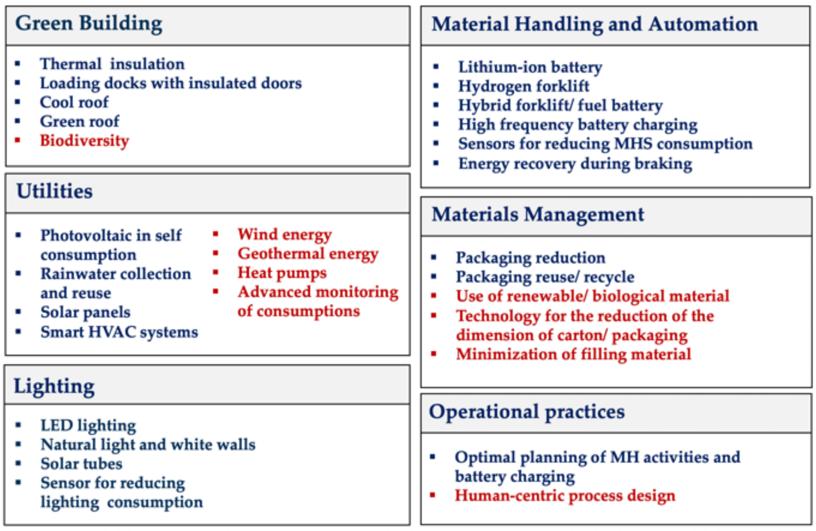

Figure 1. Survey (2021)

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.

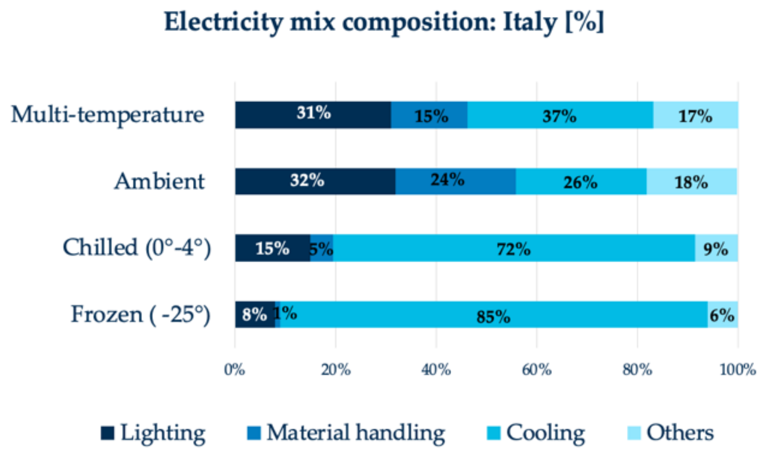

Figure 2. Electricity mix composition: Italy [%]

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_2e] 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 ones 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.

[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

4.1 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.eg., 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 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's 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.

4.2 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.

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1 Research background:

1.1 Overview on sustainability

The terms "sustainability" and "sustainable development" started to be spread during the 20th century. From a historical perspective, they are based on 3 main pillars: the theory of commons by Hardin, the theory of collective action and the prisoner dilemma. These three theories presented a quite negative perspective highlighting the fact that, in the majority of the cases, individual rationality do not lead to collective benefit and human being are egoistic player that only pursue their personal rationality and benefit. To solve this issue Ostrom will propose the concept of informal institution that can help in managing the common and can be defined as bottom-up processes within the communities (Ostrom, 1990). Translated in more practical terms, this means cooperation between new type of stakeholders in addition to the traditional ones (private and public sectors) in order to be successful in sustainability objective.

It's important to present the main steps that bring to the current definition of sustainability. In 1987, the World Commission on Environment and Development proposed the first modern definition of sustainability. It was defined as "the idea that human societies must live and meet their needs without compromising the ability of future generations to meet their own needs". In addition to this first definition, in 1994 it has been formulated the Triple Bottom Line model (TBL model), introduced for the first time by John Elkington. This model defined a new feature about the term, by means the interconnection of three main area: economic, social and environmental. It is the most used and the most complete because it considers all the three dimensions of sustainability.

Today, environmental sustainability is becoming more and more a strategic choice for company. This evolution is driven by two main forces: top-down and bottom-up. For top-down is meant the regulatory pressure and the necessity to respect some standards and target imposed by legislator (Rogeli et al., 2016). For bottom-up, the increasing importance that customers and stakeholders associate to this characteristic (Perotti et al., 2022; Dobers et al., 2019).

In the following lines, the top-down approach will be deepened, with an excursus in all regulations that came in succession in the past years.

One of the first agreement was Kyoto Protocol of the 11th December of 1997. It represented an operationalization of the United Nation Framework convention on climate change by committing industrialized countries and economies in transition to limit and reduce greenhouse gases (GHG) emission. These countries also had to adopt policies and measures on mitigation and to report the results periodically. The regulations envisaged by the Kyoto agreement were extended until 2020 with the signing of a further agreement in Doha in 2012. According to this deal, European Union (EU) aimed at reducing its emission of about 5% before 2012 but EU decided to make this objective even harder increasing this target up to 8%. For what concern Italy, the objective was a reduction of 6.5% but the real outcome has been a contraction just of 4.6% (Kyoto Protocol reference manual).

Another important, but more recent agreement at international level, is the Paris Agreement of 2016. In this case the global leaders set some targets in terms of reduction of temperature to fight against climate change. The target has been fixed to 2° below pre-industrial level. 196 countries signed this agreement. It works on cycles of 5 years during which each country is required to set some strategies, requiring an economic and social transformation, and communicate the results. Countries are becoming more and more sensitive to this topic and several of them are planning to be able to become completely carbon neutral before 2030.

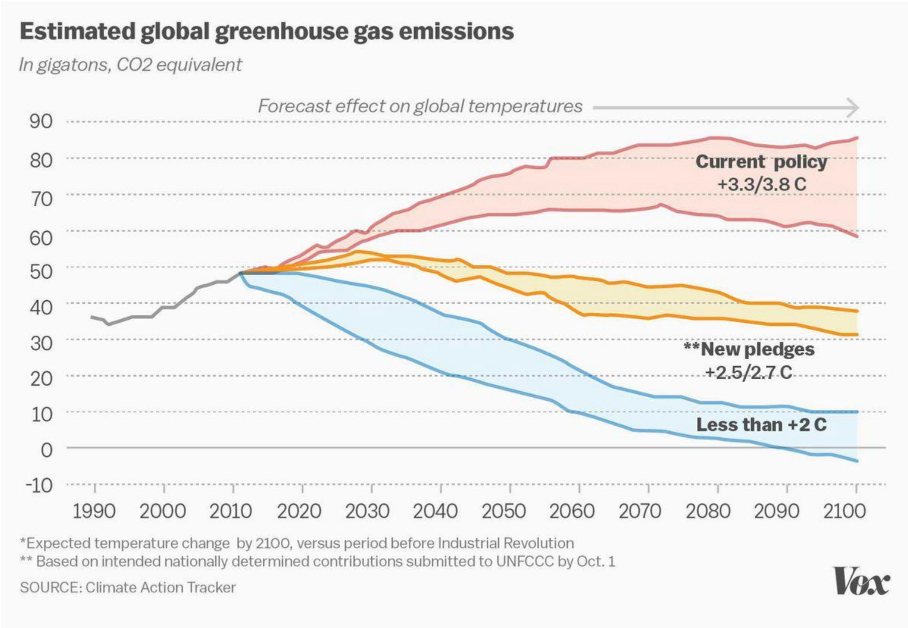


Figure 1.1 Estimated global greenhouses emissions (Source: Climate Action Tracker, 2020)

The Agenda 2030, proposed by the United Nation in 2016, containing the 17 Sustainable Development Goals, can be considered one of the most important achievement for the sustainable development. In fact, differently from the previous mentioned agreements, that mainly focused on the environmental dimension, the Agenda 2030 is the first one that clearly defines targets even in terms of social and economic dimensions. As mentioned, the concept of sustainability as integration between these three main dimensions is relatively new. Up to the ‘90s, the majority of regulations and directives published, both at a European and International level, mainly referred to the mitigation of the climate change and to the reduction of the GHG emission. From the ’90s, the concept of Corporate Social Responsibility (CSR) starts appearing and becoming relevant both for companies and policy makers.

Figure 1.2 Sustainable development goals (Source: UN official website, 2015)

The 17 SDGs reported above, are divided in 5 macro areas, according to the 5P of the sustainable development: people, planet, peace, prosperity and partnership. For each SDG, some sub-objectives are indicated in total 169, and some metrics in order to assess and report the performances.

For what concern the purpose of this study only the objective related to GHG emissions and energy-efficient solutions will be considered. So, for instance, SDG3 "*Good health and well-being*", SDG6 "*Clean water and sanitation*", SDG7 "*Affordable and clean energy*", SDG8 "*Decent work and economic growth*", SDG9 "*Industry, innovation and infrastructure*", SDG11 "*Sustainable cities and communities*", SDG12 "*Responsible consumption and production*", SDG13 "*Climate action*".

It will be analysed in the next sections deepening how COVID-19 has impacted these targets and highlighting the main challenges that the pandemic has brought to humanity.

Narrowing the analysis at a European level, one of the most important agreements, is the *European Green Deal*. Through it, the 27 members of the EU committed themselves and their countries to reduce emissions by at least 55% by 2030 with the final goal to become the first carbon neutral continent.

Keeping the focus on European context, the focus will now move on policies regarding S*ocial Sustainability* It's important to mention the *OECD Global action* for promoting social solidarity economy and ecosystem, launched in 2020. The Action focused on two critical policy levers: the legal framework and the social impact measurement. There are many other important policies that have been adopted by EU. Starting from 2011 with the adoption of the UN guiding Principles on the Business and Human rights, a set of principles proposed by the United Nation to prevent the abuse of human right in businesses. Then, concluding with the EU social taxonomy, an attempt to formalize under a legal point of view the new social and hybrid business model and enterprises.

Another important step toward sustainability reporting has been the publication of the Non-Financial reporting directive, also called Directive 2014/95/EU. This rule currently applies to large public-interest company with more than 500 employees. It obliged these companies to present beside traditional reports, among which the accounting one, also the one about their sustainability practices, covering the following thematic areas: environmental matter, social matter and treatment of employees, human rights, anti-corruption and bribery, diversity on company boards (age, gender, educational and professional background). In addition, in 2017, EU proposed some guidelines in order to help organizations in reporting this information. In 2021 the European Commission adopted a proposal for sustainability reporting, called Corporate Sustainability Reporting Directive (CSRD), which aims to extend the principles of the previous directive to all the large companies listed on regular market and make this reporting method more standardized introducing audit and mandatory reporting requirements. (European Commission website, 2021). In *Figure 1.3*, it's possible to see a sum up of all the regulations published over the years.

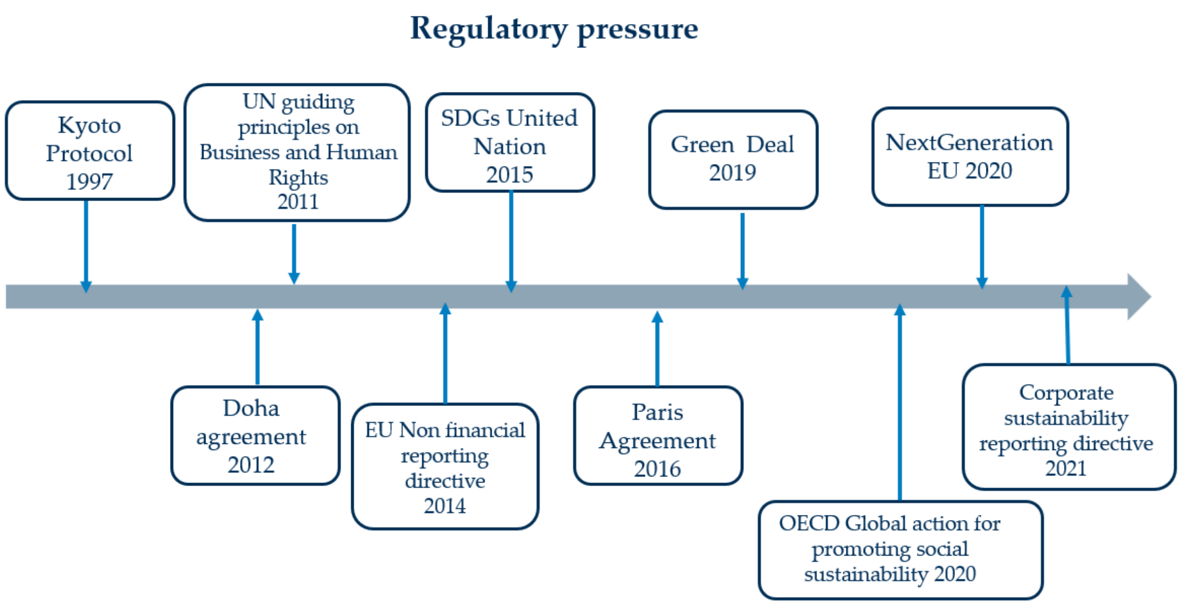


Figure 1.3 Regulatory pressure

It's important to mention that COVID-19 pandemic has, somehow, represented a big opportunity to enhance the push toward a more sustainable development. In fact, in order to recover from the economic and social crisis caused by the spread of the virus, EU set some founds called NextGenerationEU. They constitute a recovery plan to help the Member States to recover after the pandemic and at the same time to push the EU toward a more sustainable and digitalized future. A big portion of these investments will finance the EU Green Deal. For what concern Italy, to exploit these resources, the central government has presented the so-called Piano Nazionale di Ripresa e Resilienza (PNRR). This plan is developed around 3 main pillars: digitalization and innovation, ecologic transition and social inclusivity.

Sustainability is also becoming a strategic lever to assess partners and investments. The financial system is adopting sustainability related KPIs to evaluate the goodness of the investment and to calculate the interest rate (Schoenmaker, 2017). The global number of sustainable investments in 2020 was of 51 billion, more than the double of the number recorded in 2019.

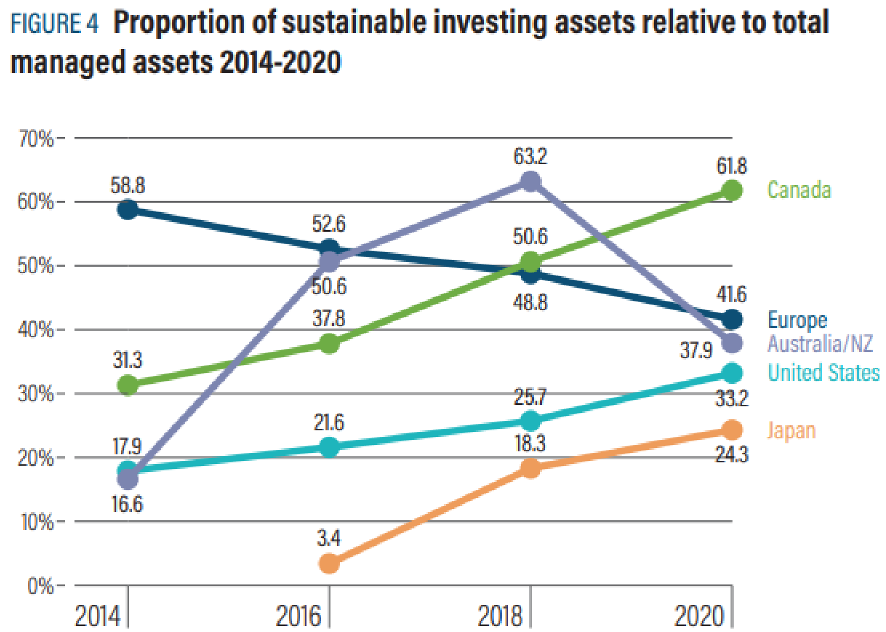


Figure 1.4 Sustainable investment on total assets 2014-2020 (Source: GSRI 2021)

Figure 1.4 shows an overall increasing trend of the percentage of the sustainable assets in comparison to total assets managed. The opposite trend registered in Europe and Australia are mainly driven by a strong legislative push that now set specific standard of sustainable finance products (GSIR, 2021).

1.2 Standard and metrics for assessing company sustainability performances

As stated, sustainability is becoming a priority for companies and a source of competitive advantage. The focus of this section is now to present the main metrics and standards with which company try to assess their impact to exploit them in the decision-making processes and communicate to the external stakeholders.

Despite the several and always more numerous regulations on sustainability reporting, this practice is not yet mandatory, exception made for company that count for more than 500 employees (Directive 2014/95/EU). What's more, companies that try to report it face several difficulties caused by the inability to measure the real impact and linked to the lack of a worldwide standardize procedure.

Impact is defined by 3 main features: intentionality, measurability and additionality and need to be distinguished from outputs and outcomes (OECD official website).

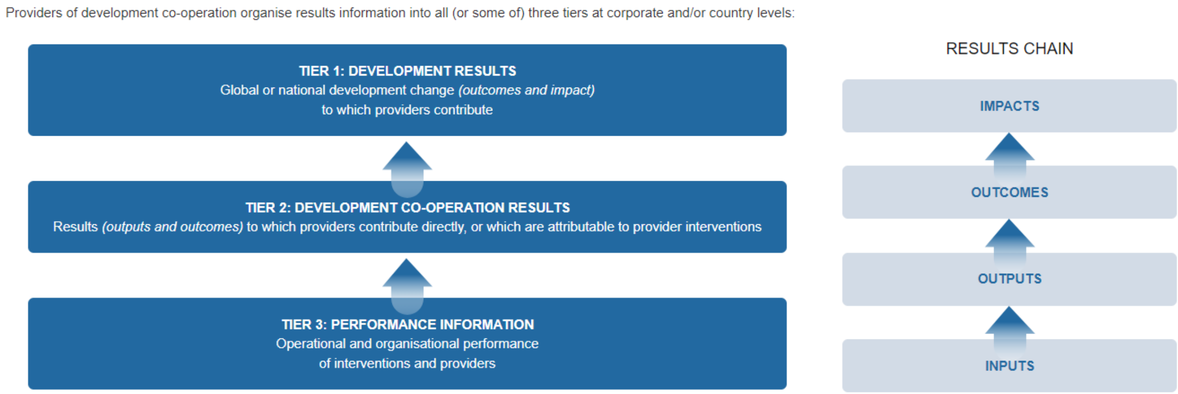


Figure 1.5 Different type of results (Source: OECD website, 2020)

Anyway, companies are not always able to distinguish between impact and positive externalities. An important issue is the inability to adopt a long-term orientation. Impact needs to be considered as the long-term change caused by the activity of the focal company but, in the majority of the cases, companies are only able to measure their output, that can be defined as short-term modification coming from the actions of an organization.

After having seen some of the main difficulties companies usually face in measuring impact, let’s start analysing the main standards. The most used reporting method are Global Reporting Indexes (GRI).

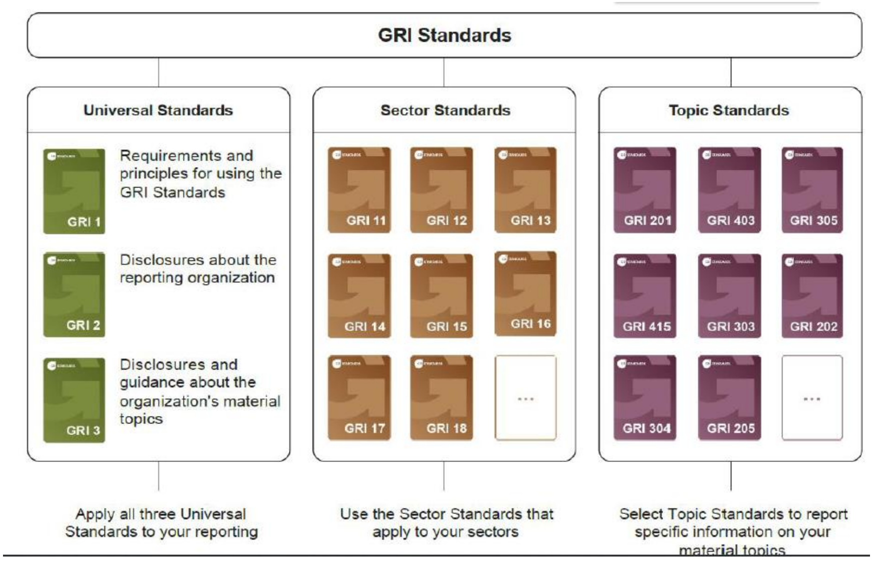


Figure 1.6 GRI standards (Source: GRI official website, 2022)

It is an independent international organization that helps businesses and other organizations to take the responsibility for their impacts providing them with a global common language to communicate them. They provide different types of standards with different levels of details, in particular it's possible to identify two main groups: principles for defining the content and principles for defining the report quality. The first one helps companies to define what to insert in the report and even to include an analysis of the organization activities and of stakeholder expectations. The second one is related to the quality of the information gathered. (GRI reporting standard, official website).

In addition to these guidelines, GRI also provide an implementation manual which specifies protocol of the indicators and technical protocol for the application of the principle and the sectors supplemented.

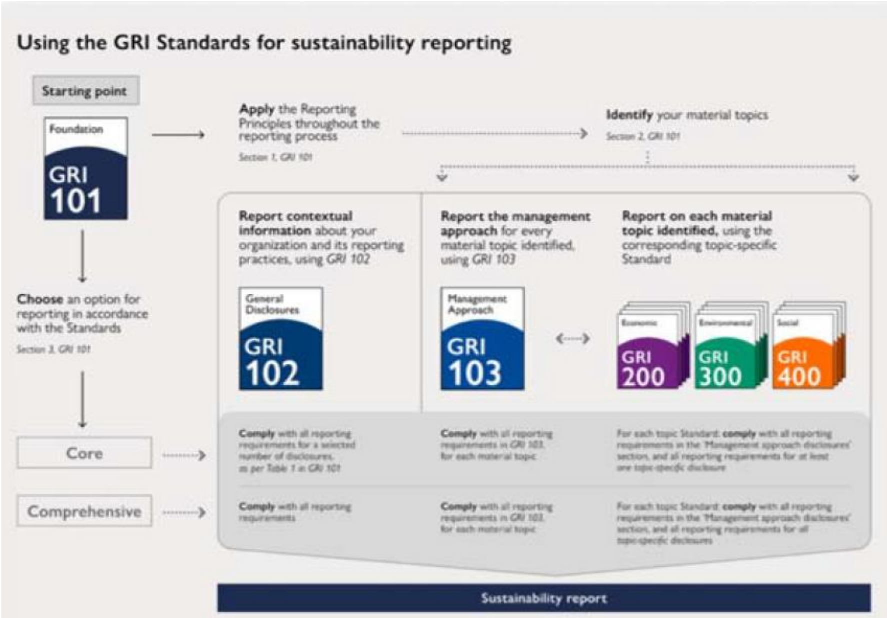


Figure 1.7 GRI standards for sustainability (Source: GRI official website, 2022)

Environmental Social Governance (ESG) performances rating represents another important and well diffused standard. They are over 1000 ratings and indexes that exists globally as of 2018 and continue to grow. The ratings can be divided in 3 main groups: environmental (conservation of the natural world), social (consideration of people and relationships) and governance.

Figure 1.8 ESG performances indicators (Source: Greater Tacome foundation, 2022)

The most trusted one resulted to be MSCI (Morgan Stanley Capital International), which is employed for its quality research, transparency and data quality, while Sustainalytics has been considered for its broad coverage (Social sustainability impact management course, 2021). ESG research ecosystem is characterized by standards setter helps in structuring and organizing ESG reporting, data aggregators, specialized data and rating agencies, that offer the possibility to consult benchmark.

Since in the previous section SDGs have been mentioned, it's important to enter in detail of the SDG Impact standard, whose aim is to integrated impact of SDGs into business and decision making. SDG standard provides different guidelines and practices for private equity funds, bonds and enterprises. They provide common language and best practices to support decision making. It's possible to define 4 main levels of SGDs: strategy, management approach, transparency and governance. For each of these levels the standard proposes different indications accordingly to the type of business that is taking into consideration.

Anther pretty well-known set of standards is the Impact Management Project (IMP). IMP is a global network of standards setting organization that aims to boost the adoption of impact. To operationalize this process, the 5 dimensions are defined: what, who, how much, contribution and risk, that are then translated into 15 impact categories.

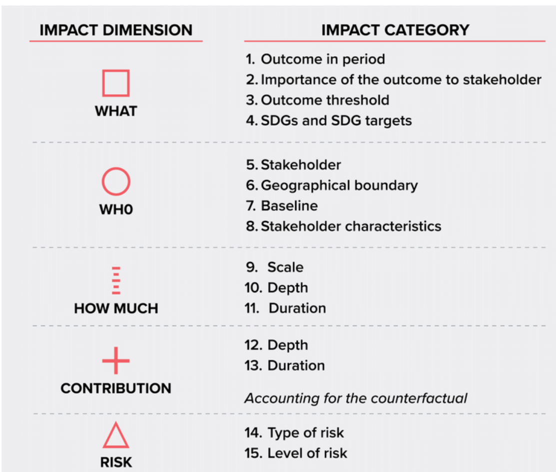


Figure 1.9 Impact category IMP (Source: Research gate, 2019)

An important remark that must be done is that this principle does not aim at replacing other standards but to integrate and complement the measurement practices. It provides a common logic to help organization to understand and manage their impact under the 3 main dimensions of sustainability.

After having presented an overview of the main reporting standards employed by companies and before entering in the details of the environmental dimensions, it's important to highlight two other certifications that can help companies reporting impact under an environmental perspective:

- ISO-14040, proposed in 2002 and the more recent ISO 14044 revised in 2021 and replacing the previous one of 2006. These two directives, referred to Life Cycle Assessment (LCA) studies, details the requirements for conducting this type of study which first aim is to assess the environmental impact of a product during its whole lifecycle considering even production and end-of-life.
- A more recent certification, published in 2019, but important for the following dissertation, is the ISO 14064. This directive specifies the principles and requirements for the quantification, reporting and reduction of GHG emissions.

After having presented the main standards for reporting sustainability in general, the focus will be reporting the main frameworks and regulations on for measuring GHG emissions.

As mentioned before, the state health of the planet and the responsible consumption of virgin resources, linked to the shortage of this latter, has become a big issue. A lot of methodologies and frameworks have been proposed to study the impact of a certain process or product on the environment. Among the different categories considered, one of the most important and diffused is the climate change, also called Global Warming. The objective of this impact category is to monitor and take under control the increase in the global temperature link to human activities. One of the main responsible of this phenomenon are the emissions of greenhouse gas. They create a sort of barrier in the atmosphere increasing the retention of the solar radiation on the heart and thus augmenting the global temperature. To succeed in mapping this effect, the total emission of GHGs is calculated and expressed in CO_2e (its characterization factors) in order to obtain a single result that can be easily compared and analysed.

In the following paragraph, an overview of the main standards and procedures to assess the GHG emissions will be presented, highlighting the context in which they are inserted, the main objectives and the most important data taken into consideration. It's important to underline the absence of a worldwide recognized and employed method so the most used and common will be provided in the next lines.

On the most important and diffused is the GHG protocol, a comprehensive global framework of standards. It was created more than 20 years ago from a partnership between the World Resources Institute (WRI) and the World Business Council for sustainable development (WBSCD). GHG protocol represents the world most widely used greenhouse gas accounting principle. It's possible to identify 4 main reasons for which for companies is becoming important to have a well-designed GHG inventory (GHG Protocol Revised 2021): (1) managing GHG risks and identifying reduction opportunities, (2) public reporting and participation in voluntary GHG programs, (3) participating in mandatory reporting programs and (4) recognition for early voluntary action. GHG reporting is based on 5 main principles: relevance, consistency, completeness, transparency and accuracy. An important step in the first principle is the choice of the boundaries which can be of 3 main types: organizational, operational and business context. Another important feature is the introduction of the scope, which aim to help in delineate direct and indirect emission sources and improve the overall transparency. Particularly, 3 main scopes are defined. First one is direct GHG emissions, emission that occurs from sources that are owned or controlled by the company. In the second scope is possible to find electricity and indirect GHG emissions that accounts for the generation of purchased electricity consumed by the company. In the third scope are reported other indirect emissions, this is an optional category that allows for the treatment of all indirect emissions, and commonly the most difficult to measure. The GHG protocol proposed different types of standards according to the context of application. The main ones are: Corporate standards, GHG protocol for Cities, Mitigation Goal standard, Corporate Value Chain (scope 3) standards, Policy and Action standards and Product standards. Each of these scopes contains guidelines specific for each field of application. The most applied one, the Corporate standard, covers the accounting and reporting of seven greenhouse gases covered by the Kyoto Protocol: carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PCFs), Sulphur hexafluoride (SF6) and nitrogen trifluoride (NF3).

In *Image 1.10,* it's possible to see the main steps that are necessary to be performed in order to calculate emissions. For what concern calculation approach, a lot of tools are present on the site of GHG protocol website.

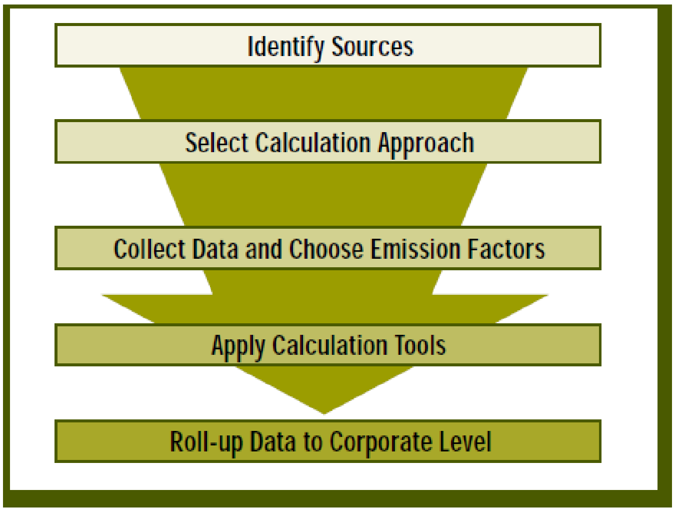


Figure 1.10 Steps of GHG emissions (Source: GHG protocol Revised 2021)

Another pretty diffused type of analysis is the Carbon Footprint methodology. This methodology has been recognized by the IPCC guidelines, the World Resource Institute (WRI) GHG protocol and the International Financial Institution (IFI)'s Harmonized protocol to GHG accounting. The objective is to calculate and report carbon footprint for the project to be financed, to provide transparency on the GHG emissions. For those projects causing significant emission, a threshold has been fixed to a minimum of 100,000tonnes of CO_2e per year for absolute emissions. The guiding principle and the boundaries (division in scope) are the same of the GHG protocol, but for some specific projects, in particular regarding scope 3, the boundaries can change considering the different industry and type of processes considered.

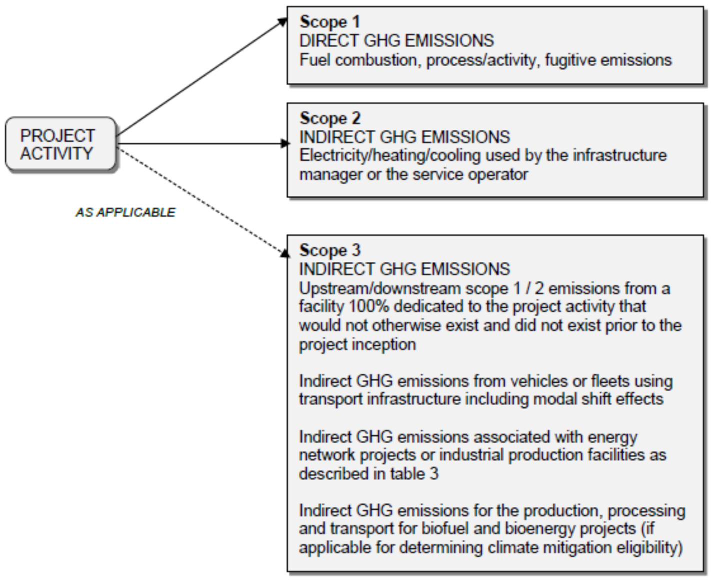


Figure 1.11 Scope definition Carbon footprint methodology (Source: Carbon footprint methodology official report, 2020)

A remark that is common to all these frameworks is the necessity to have access to good, precise and reliable data. This activity is, in the majority of the cases, given for granted, but in reality, represents the trickiest and most difficult part. It's important that companies set some sustainability related KPIs and start monitoring them to obtain the data necessary to perform correctly this type of analysis. To help the different organizations in this objective, there are international online databases accessible to find secondary data (in case of the unavailability of primary data measured on the field).

Later in the next section, some specific standards for logistics will be presented. To conclude, it would be useful in order to have the clear picture to recap the main reporting standards and their description (*Table 1.1*)

Type of standard	Description
GRI	The most diffused standard framework for reporting sustainability performances.
ESG	Important rating used for reporting sustainability, pretty exploited in the financial sector for evaluating investments.
IMP	Set of standards that aims to boost the adoption of impact measurement process.
GHG protocol	Most used comprehensive framework for measuring GHG emissions.
Carbon Footprint methodology	Methodologies that aim to measure the footprint of a project, particularly used in the financial sector.

Table 1.1 Recap of main sustainability reporting standards

To understand better the context in which this Master Thesis in inserted GHG emissions at Italian and European level will be presented to investigate the objectives reached by these countries. In Italy, as presented in *Figure 1.12*, the general trend of GHG emissions is decreasing since 2004, the main factor contributing to emissions is the energy sector followed by industrial processes and product use (*ISPRA Energy efficiency report, 2021*). Unfortunately, in the report used to get this information are not yet reported the GHG for 2020 and 2021 and it's not possible to assess the impact of the pandemic on emission values.

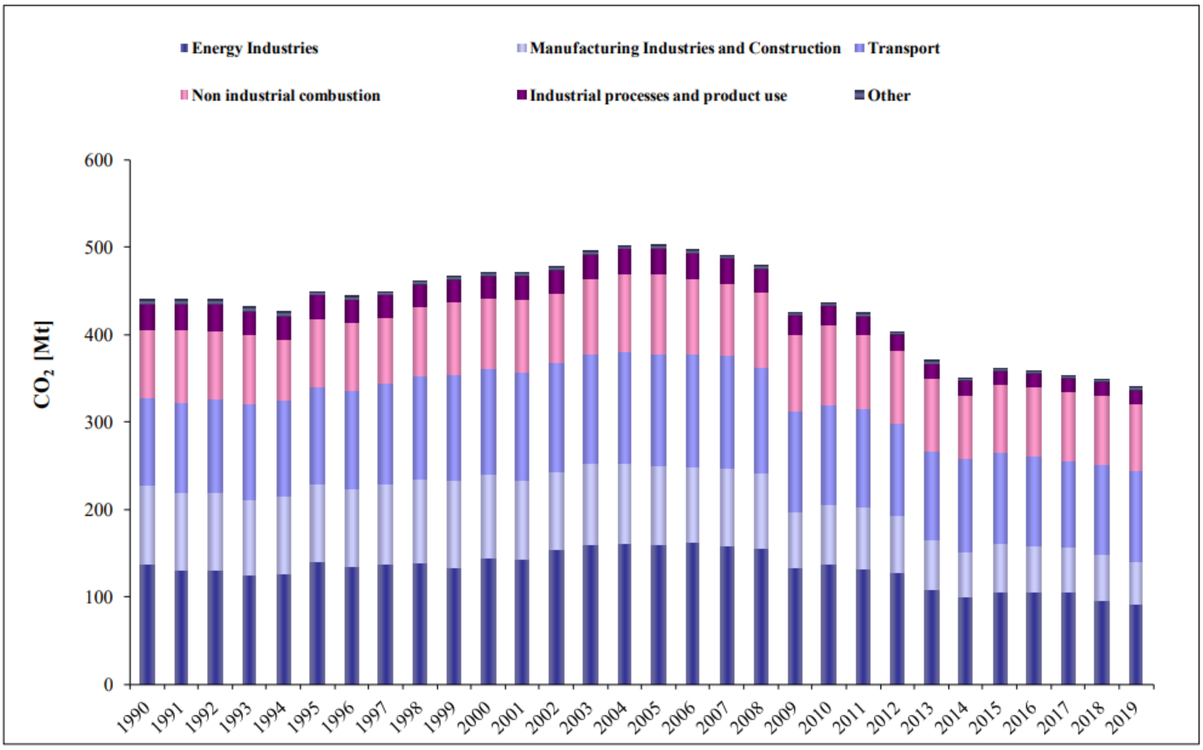


Figure 2.3 National CO_2 emissions by sector from 1990 to 2019 (Mt)

Figure 1.12 CO_2 emission Italy (Source: ISPRA report, 2021)

It can be even interesting to compare the trend in Italy with the general trend in Europe and worldwide. The decreasing trend are aligned, being Italy part of the European commission need to respect the target imposed by the central authority (*IEA, 2020*).

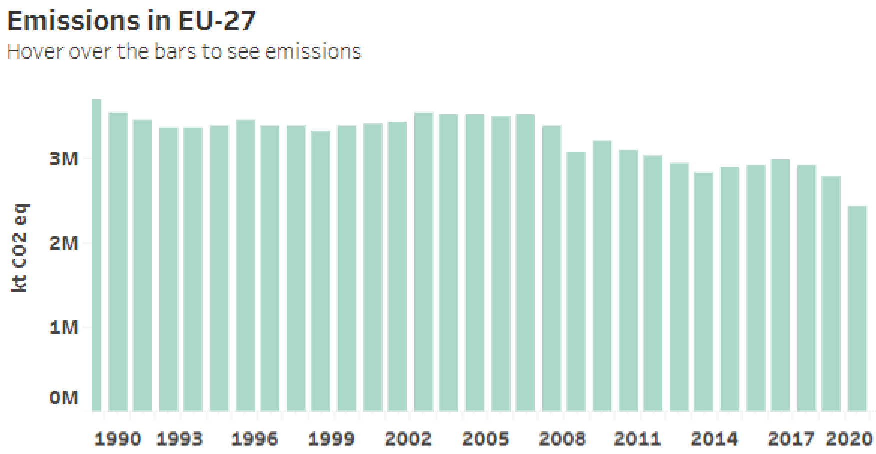


Figure 1.13 CO_2 emissions European Union (Source: IEA, 2022)

Considering these two *Figures 1.14* and *1.15*, that highlight the composition of the CO_2 emission at a European and global level in 2019, it's possible to see that more or less the components are the same and in the same percentage. In detail one the most impactful category is electricity and heat generation, followed by industry and transport.

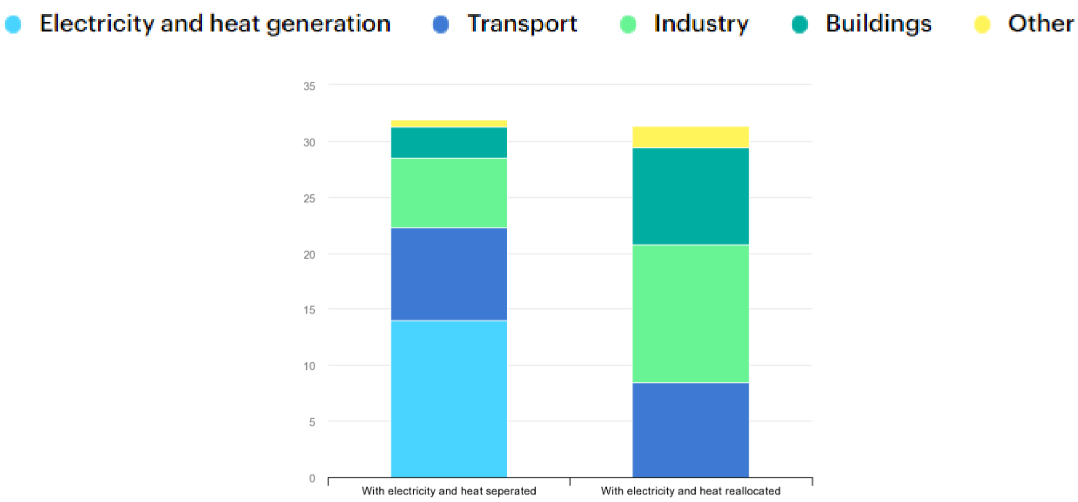


Figure 1.14 CO_2 global emissions composition (Source: IEA, 2022)

At European level, a similar trend can be observed, energy supply is the most impactful sector followed by transport and in third position industry sector.

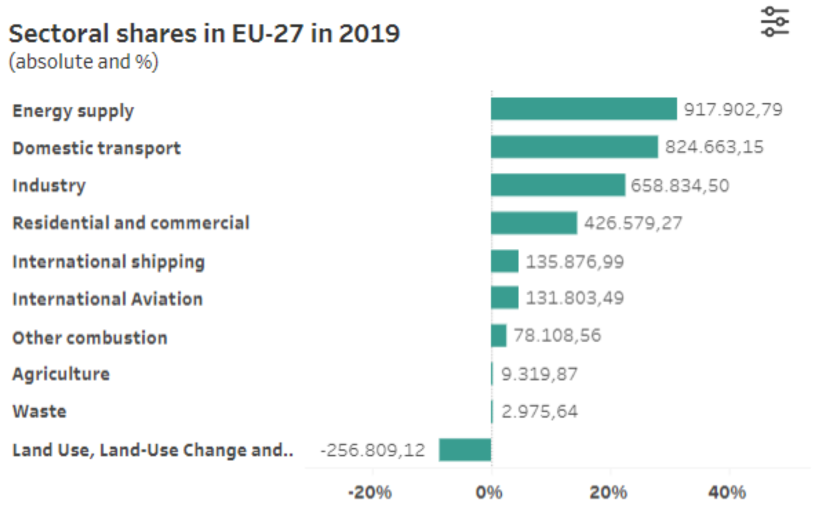


Figure 1.15 CO_2 European Union emissions composition. (Source: EEA, 2022)

1.3 Sustainability in Logistics as a strategic priority for companies

Once assessed how important sustainability is for businesses in general, the logistics sector specifically will be the focus from now on.

The logistics term in the business concept was born after the second world war, before it was known only in the military field. Anyway, it took time before it arrived at the current meaning of logistics. It was necessary to wait until late 90's, when the concept of Supply Chain Management was born.

This evolution process finds its most recent stage in what is called nowadays Sustainable supply chain. In 2008, it was defined by Carter and Rogers as "The strategic, transparent integration and achievement of an organization's social, environmental and economic goals in the system coordination of key inter-organizational business performances for improving the long-term economic performance of the individual company and its supply chain". The definition has more than one interesting point: first of all, it refers to a long-term vision demonstrating that the strategic adoption of sustainable practices does not only have implications in daily performances but needs to be considered in a broader perspective; then, it deals with an integration among social, environmental and economic goals recalling the TBL model by John Elkington already discussed.

The reason why companies are acting having the TBL as a guiding light is, among the others, the rising interest and concern that multiple stakeholders are placing on them, not only customers but also investors, competitors, institutions, and the society as a whole. Logistics and transport activities account for 13% of the overall GHG emissions worldwide of which the 11% is represented by emissions linked to buildings, thus an increasing number of regulations have been set.

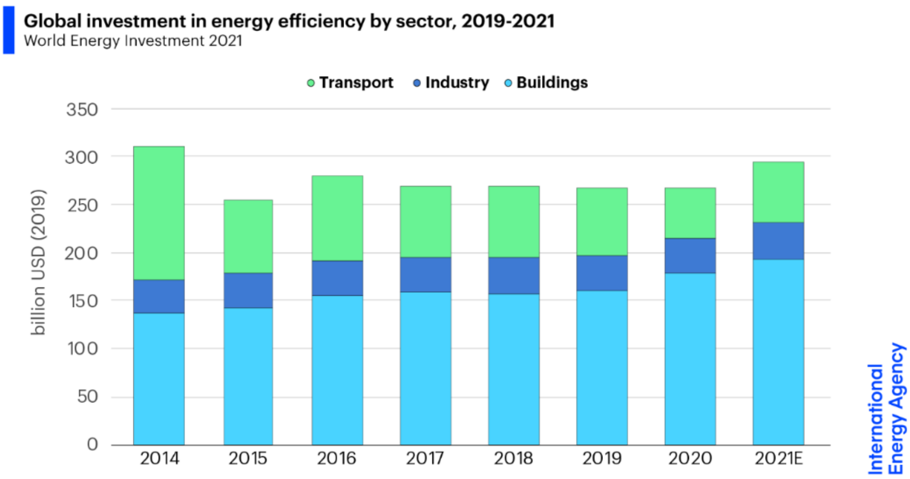


Figure 1.16 Global investment in energy efficiency by sector (Source: IEA, 2020)

It’s important to specify that while referring to Green Logistics, the emphasis is mostly placed on both the environmental and economic effect, rather than the social side. More specifically, Green Logistics has been defined in 2015 by one of its main scholars, A. McKinnon, as “The study of the environmental effects of all the activities involved in the transport, storage and handling of physical products as they move through supply chain in both forward and reverse directions. It assesses the nature and scale of these effects and examines the various ways in which they can be reduced”.

There are some recent logistics trends that are affecting sustainability and green logistics, increasing their importance and fostering the spread. Among the others, COVID-19 pandemic situation really challenged the logistics sector, the huge disruption called the supply chain for being more resilient in order to continue moving goods all around the world. Connected to this last point are the issues related to globalization. Global container trade increased, and air freight volumes and prices raised. For this reason, more and more companies are thinking about reshoring, defined as a voluntary corporate strategy regarding the home-country’s relocation of production (Fratocchi et al., 2014). The conditions for doing offshoring and manage global value chains are hardly met in the recent scenario: oil transportation cost has raised, cost of labour in low-cost countries has increased, a faster response time to meet consumers’ desires it’s needed since they are becoming more demanding and quicker recoveries in case of supply chain disruptions.

Another important trend is the outsourcing of logistics activities to third parties. Companies generally do so for being more efficient and more effective in meeting consumers’ demand. By decentralizing, they can only focus on their core businesses achieving the best result. The throwback is that they need to coordinate with all the players involved and they need to monitor their performances. Visibility on the supply chain is a must in order to assess the sustainability of the final product, and this can be achieved, for example, through information sharing or through a rating assessment while deciding to which company outsource.

Digital technologies and Industry 4.0 applications are affecting logistics practices. There is an increase in the use of communication technologies and automation having as a con the complexity created. This aspect will be deepened afterwards in the specific paragraph about digital technologies.

Lastly, the spread of ecommerce and omnichannel retail. Even in this case COVID-19 can be considered an enabler. The last ten years, especially the most recent two, have seen a huge increase in ecommerce purchases, even in sector that were not used to, like the fast food. In the European Union's 27 member countries, online retail sales increased by 30% from April 2019 to April 2020, especially in urban context, where demand for online fulfilment is steadily growing (Italian Ministry of Transport, 2021). This has a huge impact of logistics because calls for the movement of single small pieces instead of full pallet load.

Seems clear, therefore, the key role of logistics activities in determining the environmental sustainability performances of companies and supply chains. However, there is still uncertainty about how to integrate sustainable logistics-related decisions into the overall corporate strategy. It's difficult for companies to understand how to improve their supply chain's sustainability since there are many issues involved. Anyway, there are still in place different Green Supply Chain Practices (GSCP) tackling different companies' aspect.

There is the possibility to act also on the procurement side. As mentioned before, it's possible to go for an environmental audit for supplier's internal management, asking them to provide design specifications that include environmental requirements for purchased items. In this perspective, an example is the Italian leading company ENI. The energy giant, in fact, recently launched eniSpace - an interactive platform dedicated to those who, or would like, collaborate with Eni. Among the sections of which the platform is composed, one is JUST (acronym for Join Us in a Sustainable Transition): which introduces substantial innovations in the procurement process, providing selection criteria based on the 17 SDGs. In this way, suppliers will also play a primary role in the equitable and sustainable transition process that ENI has undertaken in recent years.

Reverse logistics could be another action point. This concept is linked to the role that logistics has in recycle, reuse, waste disposal and hazardous materials management. It implies an efficient product return management and activities for value recovery so that secondary materials can be used as input for "new" customer product. To ease this process, it's important to act on the design phase of the products. Around the 80% of all environmental impacts of a product during its lifecycle is originated in its design phase, that's why products should be sustainably sourced and designed for re-use and recycling, especially if we are speaking about Waste of Electrical and Electronic Equipment (WEEE). In this sense is fundamental a strong cooperation with customers, who need to be equally engaged as companies in the sustainable path in order to ease the reverse logistics processes.

More or less connected to reverse logistics is investment recovery. Here, practices aim at recouping the value of unused or end of life surplus assets that a company generated while pursuing its primary business. It encompasses sales of excess inventories, materials, capital equipment, scrap or used materials.

Another category of GSCP can be addressed to companies' internal management. It's fundamental that not only senior managers are committed into sustainable practices, but the potential that sustainability has as a game changer needs to perceive also by mid-level managers and all cross-functions teams. An example is provided by some Unilever factory workers, that inspired by the company motto "Small actions can make a big difference" personally suggested to reduce by 3 millimetres the end seals. By doing so, it has been possible to save 15 reels of paper per day and since its launch in 2015, this has resulted in savings of €47,500 and 9.3 tons of paper. Then, still about internal management is fundamental to have an Environmental Management System, measure and monitor environmental performances, promote the use of green IT, industry cooperation and use of 14000 certifications.

The last two points about transportation and warehousing with all their practices will be better deepen in the next two paragraphs, but before tackling this new topic it's important to go back to the concept previously presented of GHG accounting measures. In this case though, a framework specifically designed for the logistics sector will be mentioned: the GLEC framework. The goal is to account for all the relevant logistics emissions within a company operations and supply chain (GLEC Framework report, 2019). In particular, it has been designed to be compliant with the previous mentioned GHG protocol and with the Intergovernmental Panel in Climate Change good practice guidance and uncertainty management in national greenhouse gas emission (IPCC guidance). So, differently from the GHG the field of application of GLEC is specifically the logistics sectors. In addition to the 7 main gases taken into account in the Kyoto Agreement there is a specific methodology for assess black carbon in the logistics sectors. Black carbon is the term used for particulate matter emitted form impartial fossil fuel combustion.

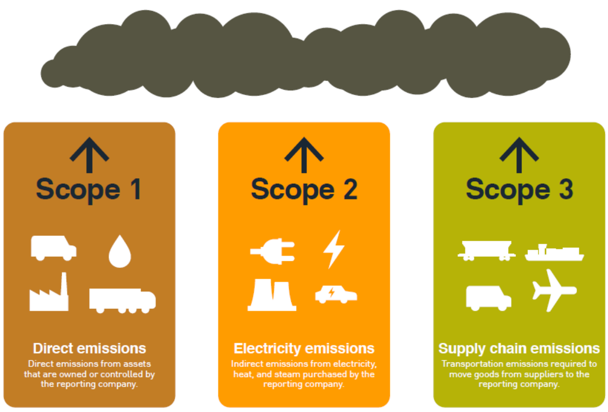


Figure 1.17 GLEC framework Scopes (Source: GLEC framework official report, 2021)

In *Figure 1.17*, the main scopes of this framework are presented, they are all compliant with what reported in the GHG protocol. It's important to highlight that GLEC framework is not a formal standard that provide a step-by-step approach to the calculation and reporting of emission, but it provides some boundaries and guidance on how to deliver the best output from the information available. The framework is structured to communicate specific information for each specific mode of transport. For instance, the modes include in the framework are air, inland waterways, logistics site, rail, road and sea.

The framework considers emissions from logistics sites and those emitted by the fuel and electricity used to handling material in the sites, as the direct losses of refrigerant used in control temperature condition. On the contrary, inbound and outbound transportation to-from the logistics centre are not included in logistics sites' emission.

In addition, it could be interesting to report ISO 14083. This certification, that will be applied starting by the end of 2022, will regulate the GHG emissions coming from transportation, giving a particular attention even to emission linked to logistics node.

1.3.1 Sustainable logistics network and green transport

Transportation constitutes the physical link between the nodes of the logistics network. Very rarely the location of production is the same of the location of consumption. Global transport enables businesses to buy or manufacture worldwide and sell worldwide, even because with globalization the local for local configuration is not anymore in place. The key modes of transport are road, rail, air, water, inland water, pipeline and intermodal transports. This last is a combination of different transportation ways, it uses standardized unit load that can be easily moved from one means of transport to another.

Transportation directly employs 10 million people in the EU, and accounts for about 5% of gross domestic product (GDP). On average, 13.2% of a household budget is spent on transport goods and services. The transport sector is key to be addressed even from a sustainable perspective since the share of emissions due to transport in Europe is around 29% in 2018, and projection based on existing policy measures in the EU Member States indicate that transport emissions will increase by 32% by 2030 compared with 19990 levels. (European Environmental Agency, 2021).

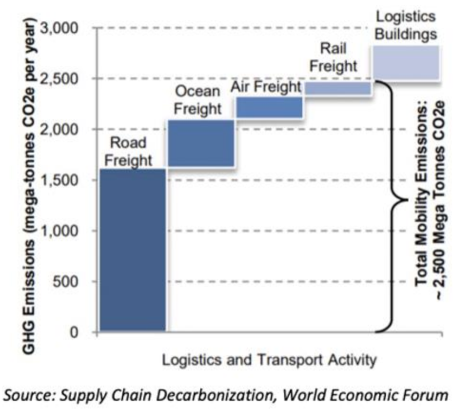


Figure 1.18 GHG emissions (Source: Supply chain Decarbonization, World Economic Forum, 2009)

Particularly, road transport accounts for about 71% of the overall transport-related emissions (EEA, 2021). Of course, air freight per se is more impacting but in the picture road freight has the highest impact because it's the most used one. Transportation emissions growth is exacerbated by the growth of e-commerce fulfilment services, which create considerable pressure on road transport for middle-mile and last-mile deliveries.

There are different companies' actions that can be put in place.

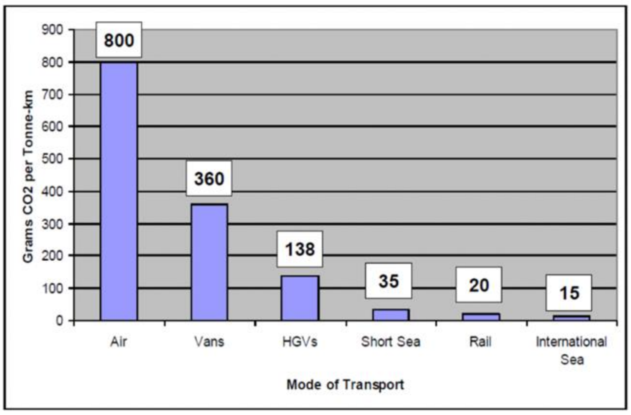
1. Move less freight
2. Moving freights over shorter distances
3. Moving goods using the least impacting means
4. Reduce the emissions from the current mode
5. Increase vehicle load utilization
6. Moving freight in cities via less intrusive means

Figure 1.19 Companies' Actions (Source: Green Logistics course, Perotti Sara, 2021)

The first action that companies can put in place to reduce the impact of transportations is "moving less freight". It means restructuring the supply chain relocating production and distribution facilities and going, for example, with local sourcing. In this last regard is interesting the study about the CO_2 released by importing a basket of vegetable (Jones, 2001). It was founded that is equivalent, in terms of emissions, to the average household products through cooking for eight months.

The possibility to do local sourcing is connected to another action companies can put in place: "moving freights over shorter distances". This can be achieved through vehicle routing and scheduling and also by doing some vertical and horizontal collaborations with competitors. This last point can also help in achieving full track load that is difficult to reach by working at a single company level.

The third action is about "moving goods using the least impacting means". For example, going for a greater use of coastal shipping, switching from road to rail and find ways to reduce the emissions per vehicle-km or tone-km. In the picture below we see that air has the highest value in terms of grams of CO_2 per tonne-km.



McKinnon (2007) and International Chamber of Shipping (2009)

Figure 1.20 Grams of CO_2 per Tonne-km deriving from transportation activities (Source: McKinnon 2007, International Chamber of Shipping 2009)

If switching the way of transport is not possible, what can be done is to "reduce the emissions from the current mode". It's possible to directly operate on trucks by improving their aerodynamics, reducing the average age profile, increasing the regulatory compliance of inspection and maintenance and, furthermore, monitoring fuels performances. Traditional fuels can be substitutes with improved engines or alternative fuels, as the biofuel - made from vegetable oil or animal fat – or bioethanol – made from wheat and sugar beet or cane. Lastly, to reduce emissions, it's convenient to go for night deliveries to avoid congestion and improve the driver behaviour through training.

The fifth action that can be put in place is to "increase the vehicle load utilization". It should be avoided to move unsaturated trucks: in 2020, the percentage of trucks' empty running was to 20,2% and this value has a huge impact in terms of sustainability. In order to saturate them as much as possible, among the possible measures it's possible to mention delivery only on nominated days, utilization of hub consolidation or change of vehicle specifications like switching to double deck trucks.

Last point also involves a social perspective, it's about "moving freight in cities via less intrusive means". Here the focus is on enhancing the local quality of life, intended as air quality, road safety and reduction of visual intrusion. This can be achieved using some low emission vehicles (LEV) which use natural gas as a fuel, zero emission vehicle (ZEV) for example electric-powered vehicles.

1.3.2 Energy-efficient solutions for warehousing

After having spoken about transport, it's time to focus on warehouses. Warehouses have a critical role in supply chain and logistics operations, since they account for the 20% of the total logistics costs (Dhooma and Baker, 2012). By the way, historically their importance has not always been recognized: in the past they were simple repositories for inventories while now, warehouses are real multi-functional logistics hubs, with increasing complexity to manage. With the recognition of logistics node importance, the focus started being on how to optimize them in terms of efficiency, service level fulfilment and even in terms of environmental impact. The reason why for this last point is that logistics sites represent the 11% of the total GHG emissions caused by logistics and transport activities, which account for the 13% of the total worldwide emissions (World Economic Forum, 2009).

Among the main sustainability issues associated to warehouses there are: land occupied, direct energy used (kWh/m^2), emissions produced (CO_2/m^2), water consumed, and building materials used. Among those, electric energy use is the major source of impact and pollution for the building. The areas in which energy is mostly used are HVAC (Heating, Ventilating and air conditioning), lighting, process equipment operation, transportation and process heating and cooling. The problem with energy is that companies do not have always the tools to monitor energy consumption. The cost of energy use is not always visible to managers because they are rolled up into facility overhead costs, rather than assigned to production areas. Tracking costs associated with individual processes or equipment can encourage energy conservation. One of the primary sources for energy cost data is the facility utility bill, which often includes the consumption charges, the demand charges and the fuel costs. Looking at it, it is a good way to start an energy audit, that is a procedure for analysing the energy balance of a building to identify possible improvements to its energy efficiency, to achieve the mitigation of environmental impact and to reduce energy costs. The steps in order to conduct an energy audit are analysis of the plant subsystems; identification of wastes; definition of solution for improving energy use or reduce wastes; identification of a continuous monitoring process and systematic plan for defining energy-efficient new projects (National technical recommendation, UNI CEI TR 1142). The ultimate goal in conducting this kind of analysis is to increase the energy efficiency, computed as the ratio between the production output and the total energy input. In other words, trying to reduce as much as possible the non-valuable energy, which is the energy waste not embedded in the final product.

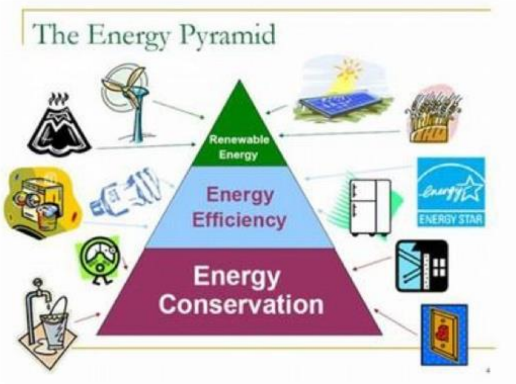


Figure 1.21 Energy Pyramid (Source: Comorin Solar, 2021)

In general, companies are trying to make their businesses more sustainable making decisions about their assets. One of the main assets for companies are buildings, that's why they are putting greater attention on their design, management and construction material. At an international level, various protocols are now widely used to assess energy efficiency and environmental footprint of buildings, including the US Leadership in energy and environmental design (LEED) and UK Building research establishment environmental assessment method (BREEM) standards, with a focus on the entire design and construction processes. The aim of the certification is to encompass all the phases of the building's life cycle, from the design to the construction. The assessment can be joined on a voluntary basis: if a company decide to join a certification, then it has a number of questions, referred to different area of the building, to fulfil and based on those values the building is rated. The reason why companies are willing to join such certification standards is, beside the environmental issue, even for being perceived as strategic from investors and from the other players involved in the supply chain. Buildings that can be assessed are not only industrial ones but any type, even commercial and residential.

In the following table, the LEED and BREEAM evaluation aspects with their share of importance.

LEED	
Evaluation aspect	**Share of importance**
location and transportation	14,50%
sustainable sites	9%
water efficiency	10%
energy and atmosphere	30%
materials and resources	11,80%
Indoor environmental quality	14,50%
Innovation	5,40%
Integrative process	3,60%

Figure 1.22 LEED-Evaluation criteria

	BREEM
Evaluation aspect	**Share of importance**
Responsible construction practices, commissioning and delivery	11%
Visual, thermal and acoustic comfort, indoor air quality	16%
Energy monitoring, CO2 emissions, use of efficient transport systems	16%
Accessibility of public transport, facilities for bikes	9%
Control of water consumption, efficient equipment	9%
Life cycle impact, durability and resilience, efficiency	11%
Construction waste management	5%
Site assessment, impact on the ecology of the existing site	13%
Impact monitoring of refrigerants, night light pollution, noise pollution	9%
Innovative practices that contribute to the sustainability of the building	1%

Figure 1.23 BREEAM-Evaluation criteria

Those assessment criteria impact the achievement of some SDGs, specifically: Good health and well-being (3), Clean water and sanitation (6), Affordable and clean energy (7), Industry, innovation and infrastructure (9), Sustainable cities and communities (11), Responsible consumption and production (12), Climate action (13), Life on land (15).

It's possible to identify 6 main areas of intervention for going toward Green Warehousing and they are: Green Building; Utilities; Lighting; Material Handling and Automation; Materials Management and Operational practices. In the next paragraphs, some of the solutions of the aforementioned families will be presented.

The most common practices for Green Building are cool roof, green roof, thermal insulation, loading docks with insulated doors and can also be included recovery, reuse and architectural enhancement of existing buildings. Cool roof is a roofing system that uses materials with high reflecting potential to reflect the heat of the sun and avoid this to enter the warehouse. White roofs are one type of cool roof. Green roofs are living vegetative systems located on rooftops. In some cases, there can also be green walls. This can be done for shading, for improving insulation of the building itself, but also for improving the well-being of employees because they can meet there in open spaces.

Utilities that can be implemented are photovoltaic panels, rainwater collection and reuse systems, solar panels and smart HVAC systems. Photovoltaic panels are one of the easiest tools in terms of installation, but they provide huge benefits in terms of savings for energy. Smart systems include Building Management System (BMS) for monitoring energy consumption and system remote control. It has the ownership of everything happens within the building. For lightening, recent warehouses can have Digital Addressable Lightening Interface (DALI) which is a communication protocol for lighting applications in buildings and is used for communication between light control devices, such as electronic ballasts, light sensors or motion detectors.

Acting on Lighting is a very easy fix and that's why many companies have started from it in their path toward Green Warehousing. Just substituting bulbs can lead up to an 80% in energy savings and 20% emission reduction (Ries et al., 2017). There exist also specific sensors able to reduce lighting consumption because, for example, they can understand the absence of operators and turn automatically the light off. Other tools are solar tubes which capture the light of the sun and put it in the building as it is artificial light. In Italy, an example, is L'Oréal warehouse in which motion sensor are able not only to turn the light on and off but also to adjust the intensity. It achieved the LEED Gold standard.

Among the solution about Material Handling and Automation, there is the adoption of high performing lithium-ion batteries for electric forklifts, replacing the traditional lead-acid ones. The problem of the latter is that, while charging, they produce pollutants emissions and for this reason warehouses need to be equipped with separate rooms for charging with specific ventilation system. Additionally, in charging them you are forced to reach the 100% of charge and the more they are charged the more the performance decreases over time. Lithium-ion batteries, instead, do not produce pollution while charging and, additionally, they can be partially charged thus the charging process is more flexible and can be adapted to the workers shift (e.g., it can be done during operators' breaks). Then, still about forklift, companies are starting to think about other sources of fuels for material handling. Hydrogen could be an option. One of the pros of it is the fast-charging procedure, one of the main cons on the other side is that hydrogen process of production is very energy-intensive. Beside forklift, which is the most adopted type of technology for material handling, there are other solutions like the Automated Storage and Retrieval System (AS/RS). They are automatic handling systems with high storage density and - typically - with strong vertical development to maximize surface performance.

Another way for making warehouses greener is working on Materials Management. Companies may adopt two different approaches: the first one is to go for material reduction, reuse and recycle in packaging procedures, and the other one is to choose renewable and biological materials as pack. A common problem while packing is the amount of material used just to protect products, many times casings are much bigger than the real dimension of the products and this implies saturating means of transport with papers. A Johnson and Johnson warehouse in Belgium uses an automated packing procedure able to measure the height of the product and cut the pack item according to it.

Lastly, there are some Operational practices that can be put in place. They include a number of interventions and managerial solutions like the optimization of the travel distance for Material Handling Systems and Opportunity charging batteries.

1.4 Change in logistics after COVID-19 pandemic and sustainability implications.

Sustainability and resilience are two concept that are usually discussed together (Larrea-Gallegos et al., 2022) and that are becoming year by year important strategic levers for the companies. COVID-19 pandemic will be analysed as an example of possible disruption that can occurs to company, with the aim to highlight the important role of the two previous mentioned levers in the recovery process.

The presence of a multitude of definitions for both the term may, in some case, create confusion about their meaning. In some papers, (Marchese et al., 2018) they are even coupled: resilience is considered part of the sustainability and vice versa. If sustainability has been broader discussed in the previous paragraph, resilience can be defined as the ability of a company or supply chains to recover from a disruptive event quickly minimizing the damage after the disruption and the time needed to return to the original situation (Supply chain management course, 2021)

COVID-19 pandemic has represented an enormous challenge for companies, but at the same time can be considered an enabler for a radical change. This crisis has, in fact, risen awareness on the importance of sustainability and has highlighted the central role of logistics inside human activities. For this scope it's possible to identify two main types of situations, caused by the pandemic, regarding logistics: interruption of supply chains, due to the closure of business and its consequences discussed before; or disruption due to an increase in complexity for business kept open (e.g., change demand path and increasing difficulties in procurement due to the closure of the borders). The main objective of this chapter is to understand how companies are trying to react and try to quantify the effects of the pandemic in term of impact on SDGs.

The spread of the pandemic of COVID-19 has represented one of the main challenges that companies, and central authorities, had to face after the second world war. This is the first pandemic of this magnitude during the modern era. The virus has been originated in Wuhan Province of Hubei in China; the first case has been recorded in December 2019. Despite many initial restrictions, the virus rapidly spread due to the high infectious, for this reason many central governments impose some additional rules to slow it down and reduce the pressure on the healthcare system. The most applied have been lockdowns, the shutdown of all the activities not considered of primary necessity. Moreover, some countries have introduced other type of norms as quarantine for suspected cases and mandatory testing for a part of the population. Companies react to lockdown with remote working to keep their business running. The reduction in transportation and the shutdown of many business (warehouse and production site), due to the decrease in demand, caused an overall reduction in the emission of GHG. Reduction of CO_2 emissions caused by transport fell about 40% after lockdown (Lafarge and Couzineau, 2021). On the other side, the increased pressure on the health sector and the exploitation of means of self-protection (chirurgical mask, gloves…) have generated a huge amount of biomedical and hazardous waste that needed to be treated in a certain way due to the danger that they represented. These phenomena represented a big challenge in particular for countries in which there are not yet in place correct process to manage waste.

Focusing more on the logistics aspect, COVID-19 has represented an important disruption for this sector. The pandemic put under pressure the whole system of procurement in particular for the food sector that need to face picks of demands due to the change in customer behaviour, called by Lafarge and Couzineau in their publication. Secondly the deletion of many passengers flight, due to the travel restriction, forced logistics companies to find other way to transport freight, so on freight flight or switching to rail and ship transport. In addition to this the boost of e-commerce force companies to adopt an omnichannel way of selling product. All these aspects determine a reorganization of the logistics activities and of the supply chain network to be able to face them.

Despite these difficulties, this situation highlighted the central and fundamental role of logistics in the human activity making company and organization more aware of the importance of logistics activities.

This pandemic has risen awareness on the Corporate Social Responsibility (CSR), as mentioned before a lot of business were shut down because of the sanitary emergency but many others, logistics sites and providers, remained open to assure primary services. In this case companies where responsible for the protection and the state of health of their employees and need to adopt some practices in order to succeed in this objective. Considering activities in the warehouses, companies needed to redesign the layout in order to assure at least 6 feet of distance between two operators, specifically splitting workstation, simplify the traffic flow, integrate sanitary tools, implement distribution with zero contact. (Dube, 2021). Companies have been obliged to manage the trade-off between respect the new regulation imposed by the sanitary emergence and at the same time keep a very high service level, requested by customers. As regards to transportation, few sanitary protocols were implemented before the pandemic, and this could in some ways have been one of the causes of the rapid spread of the pandemic (Lafarge and Couzineau, 2021).

An important concept to consider in this section about the impact of the pandemic on logistics is Logistics Social responsibility. It can be defined as a set of practices to manage in a socially responsible and sustainable way the supply chain under an inter-functional perspective (Carter and Jennings, 2002). For logistics the adaption of this practices does not only represent a source of competitive advantage and positive brand reputation but even a way to work on efficiency and cutting costs. This set of practices cover 5 main areas: purchasing, transportation, reverse logistics, packaging and warehousing (Maggi and Crotti, 2021). While the practices regarding environmental sustainability are consider important and tackle by company in different way the social sustainability is not so widely implemented and need further improvements, COVID-19 has for sure highlight its importance making it even more important under a competitive point of view.

Try to enter briefly in the topic of impact of SDGs, it’s possible to see that the total effect of COVID-19 on the SDGs has been transversal, from one side, under a socio-economic point of view, the pandemic has caused a slowdown of the advancement of these SDGs (i.e 1-5), on the other side the pandemic has represented a disruptive element that has highlighted the problem connected with the actual paradigm and the necessity of a radical change. COVID-19 disease has increased the push toward energy efficiency, digitalization and innovation and toward a general awareness of the necessity to a more sustainable development (Vota, 2021).

1.4.1 COVID-19 as a source of Resilience and Innovation.

What's emerge from the previous analysis, in which COVID-19 has been used as an example of a possible disruption, the ability to recover quickly from unexpected events is becoming essential for companies. Moreover, the complexity and ecosystem that surround companies is increasing and companies need to react to it. In this section the objective is to show the element that can support companies in these changes, devoting particular attention to digital technologies.

Under a technological point of view (Sarkis at al., 2020), the pandemic has been an enabler for digitalization and innovation. The necessity to developed CPS system, IoT technology, data analytics has been identified as one of the most important levers to respond to COVID-19 disruption (Sarkis et al, 2020). In particular, the awareness of the importance of data gathering and analytics has become crucial. This aspect is fundamental to a have a clear view on the situation and to base decision making thus helping companies to respond quicky to crises and augmenting resilience. COVID-19 has also shown the importance of connectivity and data sharing even thanks to agreements to build more resilience supply chain (Institute for Supply Management, 2020).

The mandatory exploitation of digital tools (as remote working, zooms, AI and augmented for reality for maintenance and repairing activities) during the period of lockdown forced the companies to see the potential of these tools, thus entraining long lasting change in how company run their business.

An additional important point to tackle is the safety at the workplace. Social distancing provided some lessons for future health and safety operational concerns inside the company. As presented before not all the different types of business have been shut down some of them have been keep open in order to assure good of primary necessity to final consumers. Company have been so forced to deal with the virus and the related regulations in term of security (individual protection mean and social distancing). More specifically this meant to redesign the layout in order to minimize the contact between workers, so for instance, single way aisle, designated working area and specific routes and paths for picking activities. The awareness toward workforce safety and security increased a lot. In addition, the increase in the fluctuation of demand and the shortage of manpower (that was a problem even before COVID-19, but that worsen with the spread of virus) push the warehouses to adopt some strategies in order to cope with this increasing complexity, for example the adoption of scalable process and picking strategy. Using a combination of material handling technology and software solution it has been possible to deploy a flexible order picking strategy that will make more easy-to-handle fast change in the demand (Dube, 2021). The exploitation of AI and other similar algorithm help in the creation of safe path and monitoring the temperature This last point, together with the push toward automation and the substitution of human workers with robots and cobots will be better deepen in the next paragraph about Digitalization in logistics.

The impact of the pandemic on logistics and more specifically on warehouses has been transversal in the sense that has entrained not only social implications for workers, but even a deep change in operations, in the level of automation present and in the general organization of the warehouses. For mentioning some example COVID-19 had completely change the paradigm concerning lean practices and caused an increase in the level of stocks, and a consequence upsizing of the capacity of the warehouses. The boost of ecommerce especially for grocery and fresh product bring out the necessity to potentiate the cold storage capacity and the cold chain (Dube, 2021).

To conclude, it could be interesting to present the main impacts of COVID-19 pandemic on logistics in order to have a clearer picture of the general contest of this Master Thesis.

Impact of COVID-19 pandemic on logistics
Boost of awareness on sustainability related topic
Increasing consciousness of the importance of logistic activities in actual economy
Necessity to redesign the layout of the warehouses
Increasing attention on safety conditions of workers inside the logistic site
Push toward automation and digitalization to deal with social distancing and increasing service level required by customers.

Table 1.2 Recap of COVID-19 pandemic on logistics

1.5 Digitalization supporting Green Logistics

After having analysed the main actions and change that company did in order to recover from COVID-19 disruption and to increase the resilience of their supply chain, the focus of this section will be present the main technology that can support company in this change.

Digitalization is one of the trends affecting businesses in the last years. It is about the integration of technology in all companies' fields, services and channels, affecting their business models and thus the ways of interacting with customers and other stakeholders. The process involves not only the adoption of technological tools but a real commitment from the entire organization, complement by a change in the mindset. Even if it's challenging for companies, especially for SMEs, this is required by the fast-evolving market which calls for higher efficiency and effectiveness.

Digitalization is strongly powered by information sharing; thus, information technologies tools play a key role. IT systems potentially influence all the steps of the supply chain, from the very beginning up to deliveries. Anyway, they only provide data without a process that is able to effectively transform information into knowledge and decisions (Heinrich/Simchi-Levi, 2005*)*, that's why they need to be adjusted and interpreted in order to be used as a strategic support.

As stated, the process is challenging for companies and that's why an assessment maturity level from an IT perspective can be done, following the model by Heinrich/Simchi-Levi. The first step is the so-called disconnected process: in this configuration the firm works as different independent systems in which everyone works on its own. For example, if the production system is decoupled from the inventory one, the units produced do not automatically flow as input data in inventory, you have to manually duplicate the date thus leading to redundant data within the organization. The second step is internal integration. Here, there is data sharing within the internal value chain and in this creates awareness of the structure of how the process works.

Third step is full internal integration and some external integration. It means processes involve all affected internal organizations and then, only key customers and suppliers are involved in supply chain planning. Lastly, extensive integration among many organizations in which it's possible to speak about sharing business objectives with partners and integrated collaboration across the entire supply chain.

The same study by Heinrich/Simchi-Levi of 2005 demonstrated that the more companies where mature in implementing the IT tools, the higher was the minimization of costs. This demonstrate that IT is an important enabler for effective supply chain management

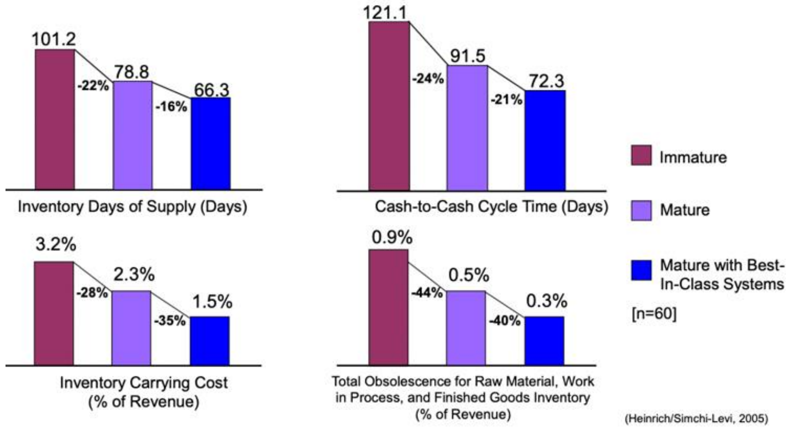


Figure 1.24 Maturity level of IT tools implementation and related benefits (Source: Heinrich/Simchi-Levi, 2005)

There are different IT-integrated supply chain tools which help not only from an economic perspective but also from a sustainable one. For example, they help in better managing inventories over time, leading to lower waste. This is the case of the Quick response, Advanced continuous replenishment and Vendor-Managed Inventory (VMI).

In quick response vendors receive POS data from retailers and use these data to synchronize production and inventory activities at the supplier. In this strategy, the retailer still prepares individual orders, but the POS data are used by the supplier to improve forecasting and scheduling.

In Advanced Continuous Replenishment inventory levels are continuously improved in a structured way. Vendor receives POS data and use it to prepare shipments at previously agreed upon interval, but he may gradually decrease inventory levels at the retailer’s store or distribution center as long as service levels are met.

Vendor-Managed Inventory (VMI) in which the manufacturer manages the inventory of its product at the retailer outlet and therefore determines for itself how much inventory to keep on hand and how much to ship to the retailer in every period. Therefore, the manufacturer does not rely on the orders placed by a retailer, entirely avoiding the bullwhip effect. This strategy has been implemented at Dillard's Department Stores, J.C. Penney, and Walmart showing a 20% sales increase and 30% inventory turnover improvements.

A step further is done by the Collaborative Planning, Forecasting and Replenishment (CPFR) is a method of cooperation between suppliers and customers to align forecasts, production, and orders more accurately to reduce the amount of inventory. In fall 1996, Warner-Lambert, the consumer goods manufacturer, and Walmart began a pilot study of the CPFR system. From that moment on, software companies have reacted to this concept by launching competing versions of CPFR software (collaborative systems).

A more recent concept with respect to the ones just treated is Industry 4.0 one and all the related technologies. This concept is translated in the logistics sector with the name of Logistics 4.0. It's a vision of the future of Industry and Manufacturing in which Informational and Operational Technologies are going to boost competitiveness and efficiency by interconnecting every resource - data, people and machinery -in the Value Chain.

One of the Industry 4.0 tools is Robotic Process Automation (RPA). It denotes a software system, which imitates the steps that humans perform, to carry out repetitive activities. In this way humans can focus on conducting tasks, in which they are better than software. Among the functions that RPA can perform, there are data extraction from structured documents such as Excel tables, data scraping from the web, data merging from different application, opening emails and attachments and searching by means of keywords and doing tasks while executing "if/Then" rules. There is also the possibility to embed Artificial Intelligence (AI) into RPA tools. They can be or just combined in order to improve the efficiency of execution processes – this is generally said AI Assisted RPA - or there can be a strong integration of the two components aiming at guiding the process, optimizing paths and creating new connection between the tasks – AI Driven RPA (Digital Innovation Observatory on AI).

Against this backdrop, robots and cobots are placed. It's possible to differentiate between industrial and collaborative robots. Industrial ones are used to automate processes and to execute them almost entirely without human help, they free up employees for more meaningful activities that are less prone to repetitiveness. Collaborative robots do not substitute employees but help them creating a safer and more efficient workplace. They are programmed to work with humans, and for this reason, they have more security protocols and sensors in comparison to industrial ones in order to avoid dangerous physical interactions with workers.

Lastly, AI can help optimizing AGVs routings in *Warehouse Automation* practices, as it has already been deepened while speaking about energy-efficient solutions for warehousing.

The next paragraph will deepen another important tool of Industry 4.0 which is *Industrial analytics*.

1.5.1 Big Data and Supply chain analytics supporting companies' environmental performances

Organizations today are able to access more data than ever before. Anyway, it's of no value unless you know how to put them working, and that's why companies more and more focus on how to interpret and exploit data. The concepts of Big Data and Supply chain analytics, strongly connected one with each other, have been elaborated as a consequence of this new trend.

Big Data is the term used to refer to the huge set of unstructured and semi-structured data which are coming from different sources, such as web traffic, social media, sensors and so on. The amount is so large – terabytes or petabytes - that traditional databases management systems (DBMS) are not developed enough to cope with them. The constant bombardment put a challenge even for marketers who need to get their message heard through the storm of data that they received. "Content shock" is the term coined by Mark Schaefer to speak about this phenomenon. Just to mention some numbers, every minute of the day we have 26K apps downloaded, 15.2MM texts sent, 210MM emails sent, 4.2MM Google research and 283K$ spent online shopping on Amazon.

Big data can be defined by the so-called 3Vs, recently becoming 6Vs. Respectively: Volume, Variety, Velocity and then Value, Veracity and Variability. Volume is not only a matter of quantity, but it's even about the relationship between this quantity and the company processing capacity. Walmart, for example, is building the largest private cloud in the world, able to handle large amounts of data per hour. Variety refers to the different data formats available, often unstructured, and thus not manageable in traditional relational databases, leading to an increase in complexity. Velocity is a measure of the amount of time data are valuable. Big data are fast changing and in order to exploit them it's important to process data within minutes or seconds to get the result desired. Value refers to the informational gain it's possible to extract from data and it relates directly to what organizations can do with collected data. Veracity is about the truth and the accuracy of the data; whether they have missing pieces thus not being able to provide valuable insights. Lastly, variability refers to how often does the meaning of the data changes, it's connected to the possible inconsistency of the analysed data.

From what we have said, it's clear that the problem is not to find data, since we're all covered in it, but rather how to use them to gain competitive advantage. It's not a secret that Google, Amazon, Apple or Facebook became global giants for their capability to exploit information. Through AI recommendation engine, Netflix is able to provide users with the kind of contents they want in their own homepages thanks to the analysis of past data about what they have watched. This technique allowed Netflix to save 1bln$ annually since it reduced the user churn.

Anyway, the awareness that data is the new oil is spreading even among smaller realities. The application of sensors and other method for collecting data is becoming more and more common in the industrial sector and, as a consequence of this phenomenon, Supply chain analytics were born as the analysis of information that companies draw from a number of applications tied to their supply chain.

There are different types of analytics that businesses use to drive their decision making, and they differ according to the technological complexity and organizational change.

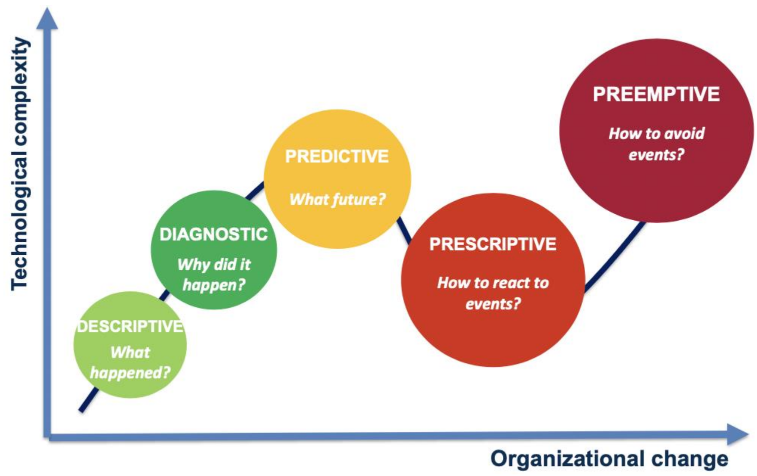


Figure 1.237 Correlation between Technological complexity and Organizational Change of Big data solutions (Source: Digital Technologies Course, Barbara Pernici, 2021)

The starting point in Business Intelligence is Descriptive analytics. It's concerned with representing what happened in the past through data mining, data aggregation and KPIs definition. The aim is to provide with some visual tools (like bar charts or line graphs) without doing any interpretation. For example, understanding which was the machine with the highest downtime. Diagnostic analytics is a kind of root-cause analysis: once what happened is known, the reason why want to be found. This research is done through continuous data collection, multivariate statistical analysis and unsupervised machine learning. It's the first step in which AI takes place. Predictive is about what could happen in the future, identifying some trends and making forecasts. It helps organization in doing a better planning, like scheduling predictive maintenance, and set realistic goals avoiding unnecessary risks. Prescriptive analytics is about what to do now: predictions are used to analyse different scenarios, choose the best one and act. Both advanced AI techniques and simulation and optimization techniques are used. Lastly, pre-emptive is about how to avoid issues. After choosing the scenario, it possible to do not be in the ideal situation and an interruption might happen, it's important to be resilient and know how to react.

Particularly referring to Supply chains, the steps forward they are doing is to include external sources of information beside the usual internal ones coming from Enterprise Resource Planning (ERP) and supply chain management (SCM) systems, and then apply analytics interpretation techniques. As it's possible to see in the following *Figure 1.26* the different steps of the supply chain differently have the potential to benefit from Industrial analytics to improve their performance.

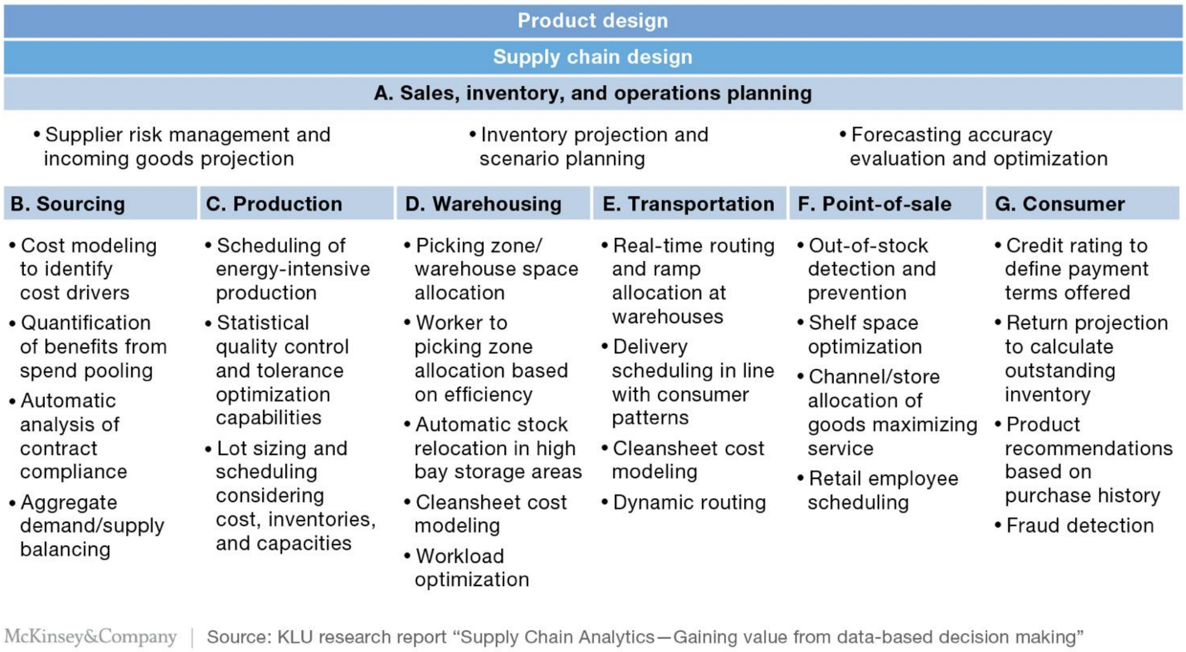


Figure 1.26 Impact of industrial analytics on different supply chain steps (Source: McKinsey&Company, 2016)

Keeping a focus on warehousing, historically it already had huge progresses by using ERP data available. In particular Information Systems (IS) are evolving following the sustainability trend and in the recent year has been developed some specific IS for monitoring environmental performances, the so-called Environmental information system, that has been designed ad hoc for measuring sustainability performances. Other more specific examples are the Recycling information system, that enables to keep track about recycling and disassembling processes requirements of single product to be recycled, or the Eco Agents, that allows monitor product/ product modules use to evaluate in advance request for reuse, recycling or remanufacturing.

As of 2019, the global warehouse automation market was worth about $15 billion. Already established technologies are, for example, possibility to monitor pickers performances in different zones to optimize their future allocation, or high-rack bay warehouses that automatically during the night reshuffle pallets to optimize the schedule for the next day. Those techniques already had a positive impact on warehouse efficiency, allowing a better management of resources and supporting the sustainability agenda.

Anyway, data analytics are creating even more opportunities for warehouse practices optimization. A leading forklift supplier is evaluating the possibility to use forklift as a big data hub collecting real time data - to be managed together with the ones from the ERP and the WMS - in order to identify additional waste in the warehouse process. For example, images and videos coming from AGVs, together with sensors inputs (such as temperature, shelf weight, and the weight on the forklift), can be used for a real-time monitoring of picking accuracy and warehouse productivity. Same way, the driving behaviour and the routes can be optimized dynamically and, additionally, data can be used to conduct root-cause analysis of picking errors by colour, shape, or weight to help making more robust processes.

Another example of exploitation of data analytics inside warehouse is the optimization of inventory placement across the warehouse to create the fastest pick paths and cluster together the items which are likely to be purchased together. Big data about purchases are easily available to companies, both thanks to the spread of e-commerce and thanks to reviews and comments that users leave on the web. Predictive analytics help understanding the demand for specific products, leading to a better inventory management.

New 3D modelling technologies can also help optimizing warehouse design and simulate new configurations of space to further improve storage efficiency and picking productivity. An example in this regard is he German company Logivations, which offers a cloud-based 3D warehouse layout planning and optimization tool.

Amazon is also betting a lot in the use of Big Data analytics in three separate areas of its logistics operations: pre-packing of outbound items prior to receives customer orders; robotics automation for transporting items from the storage to forward picking; and drone-based delivery to locations within 30 minutes of the warehouses.

Having, thus, understood that *Big Data analytics* positively influence efficiency and resources' use, generalizing, it's possible to understand that they can have a positive impact even on SDGs achievement.

1.5.2 Social impact of technologies on workplaces

It's clear that the digitalization era has only just begun, both in general terms in the everyday life but also specifically applied to the warehousing sector. The above reported number about 2019 is expected to double within the next four years, with supply chain leaders in an internal Accenture survey citing warehouse automation as one of their top three priorities for digital investment. But what are the implications for the millions of workers who are currently working in warehouses around the world?

Only in the US, 1.5 million workers are employed in the warehouse and storage sector. The UK's transportation and storage sector employs 1.8 million, and millions more work in warehouses all around the world. While some prior work has explored the impact of automation on these workers, there is still limited understanding of how automated technologies are changing these employees' daily lives.

Every time in history humanity has been in front of an industrial revolution, as in this case with Industry 4.0, the industrial revolution is coupled with a social revolution, changing the way workers interact with machines.

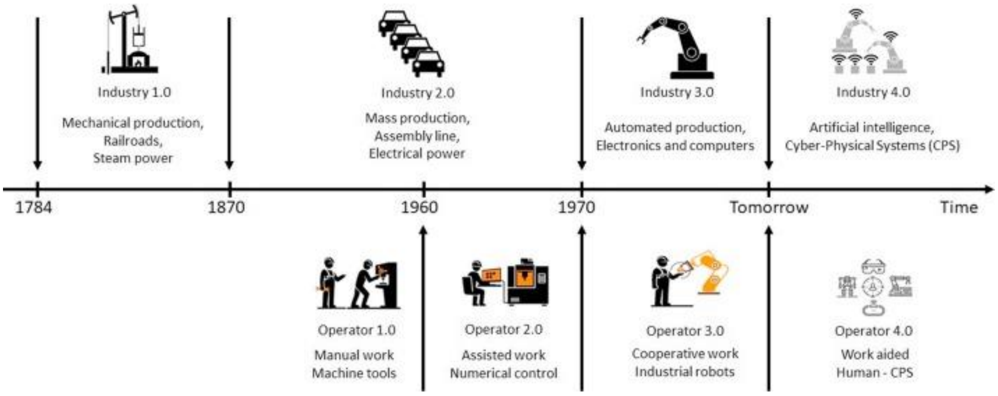


Figure 1.27 Evolutions of industrial revolutions (Source: Sustainable Manufacturing course, Marco Taisch, 2021)

As it's possible to see in *Figure 1.27*, operator 1.0 work was still manual, he was the one loading and unloading machines, but then was supported by tools doing some operations. Operators' work in 2.0 started to be assisted by computers in numerical control activities. With 3.0 workers was supported in a physical assistance by robot, computers do not only have numerical control tasks. In the most recent Industry 4.0 revolution, instead, Cyber Physical Systems (CPSs) are working side by side with human being.

An interesting model by Hirsch-Kreinsen published in 2016 highlights that workers are likely to have two opposite attitudes towards automation, or digitalization in general: he identified the constructive and the worrisome approach. As it's easy to guess, the first one considers technologies an opportunity to grow; the second as a threat and a potential cause of social disease. Let's go deeper trying to understand which are the feelings in both of them through a study conducted by Accenture into warehouse automation with a series of in-depth video interviews with 34 warehouse workers and 33 front-line supervisors across the U.S., UK, France, Spain, and China.

Among the interviewed, employees having a positive approach towards technologies feel higher safety in the workplace, increase in speed and efficiency and higher-quality work. For what concern the first point of the study, in many cases, safety referred to reducing wear-and-tear on the body: a forklift operator reported that he used to be on sick leave several times due to severe back pain, but then the automated forklift truck replaced his heavy work. It's fair to consider that if workers do not have to spend time in mechanical and repetitive work, they can focus on more strategic tasks, helping them stay motivated and engaged. On the other side, though, some new applications, like the use of big data, can be seen as a support tool even for strategic decisions because they provide decision makers with important insights. Many employees realized how the efficiency and productivity increased as a consequence of automation. Thirty-eight percent of the positive responses fell into this category. Lastly, workers focused on how support from automated tools enabled for higher-quality work, even increasing the service level. A supervisor in a warehouse in China that had not yet invested in automation lamented that he received many customer complaints about "sorting errors and the shipment of expired foods." With the simple implementation of barcodes system this problem could be avoided.

Let's now turn into the worrisome approach. Almost half of people taking part in the Accenture study, among the ones having a negative feeling towards technology, was scared about losing their job. With the same phrase "the use of robots may cause us to face unemployment" answered a warehouse packer and a warehouse supervisor from China. They were not afraid to work with robots but to be replaced by them: machines do not go strike, they do not complain, and they do not get sick. This fear is not for sure unjustified. Honeywell, for example, has developed robotic unloading machines that reduce the offloading time and concomitantly the role of workers in the process. It's possible, though, that in the short run this trend will be mitigated by the continued growth in demand for workforce in warehouses, even caused by the spread of e-commerce. The second concern is about the inadequate training employees are subjected to do, which does not allow them to properly deal with the new environment. A warehouse supervisor in Madrid reflected about the fact, even if it's true that machines have the potential to increase warehouse productivity, if workers do not know how to manage them, they're hardly going to do any good. In this regard, another point to consider is the demographic makeup of workers in warehouses, which can be made up by old people for who is challenging learn how to operate new smart equipment. The last concern among interviewed was related to fear that if automated tools broke down, workers would have no way to fix the problem, and would thus be unable to get their work done effectively. Especially if this is coupled with inadequate training sessions, employees are afraid to be unable to even diagnostic the problem, rather than solving it. It usually happens that workers know for the first-time coding errors only when the problem arises. In this situation, the only possible thing is to make operators do what the machine was doing, when possible, while waiting for a technician solving the problem. Or, when this is not possible, for example in big production lines, companies are forced to maintain high level of safety stock next to the line to cope with possible machines breakdowns.

Concluding, technologies are neither inherently good nor bad, they need to be properly managed in order to fairly share the gains in efficiency not creating heavy drawbacks for workers. An example in this regard is the wholesale retailer *Boxed* who, once introduced cutting-edge automated processes into its warehouses, retrained existing workers to fill new roles around these processes instead of laying them off.

2 Analysis of the scientific literature: a Systematic Literature Review (SLR)

2.1 Introduction

After having presented a general introduction on the topic through secondary sources, a systematic literature review is conducted to summarize the current results and insights coming from the scientific community. The study has a double purpose:

- Provide a detailed analysis of the scientific literature finding the most relevant papers which address the aforementioned topics.
- Underline existing gaps in the literature with the aim of suggesting future studies.

The chapter is divided into different sub-sections. Sub-section 1 describes how the Research Questions (RQs) of the literature review have been formulated, sub-section 2 regards the searching phase of documents in literature, sub-section 3 describes the criteria that have been used to select the final papers of analysis, sub-section 4 provides some insights about the selected studies and, finally, sub-section 5 offers a critical analysis and discussion of the findings. To conclude, the third paragraph summaries the main conclusions, along with an outlining of the gaps identified in literature in the fourth paragraph and last of this chapter.

2.2 Methodology: systematic literature review approach

The literature review is conducted in order to highlight the actual academic contributions to the topics discussed in this Master Thesis. Among the different methods to conduct a literature review, for example "narrative", "systematic" and "meta-analysis" (Hochrein and Glock, 2012), the systematic one has been chosen. It was proposed by Tranfield et al. in 2003 and it employs a predefined evaluation procedure that allows to reduce any kind of bias and ensures an objective and scientific output (Denyer and Tranfield, 2009). SLR aims at exploring existing studies, selecting, evaluating and analysing their contribution to the specific topic under discussion. The reason why this method has been chosen is mainly due to the principles on which it is built: transparency, inclusivity, explanatory and heuristics. Transparency because all the steps of a SLR needs to be clear and analytically described so that, in case someone wants to replicate the analysis, has to obtain the same result. As a consequence, each step needs to be reported together with reasonings and justifications. Summarising, a SLR is a replicable, scientific and transparent approach which brings a high level of robustness and reliability. The two main objectives of this method are:

- Discuss and analyse the current scientific literature on a specific topic
- Detect existing gaps and suggest future research studies

Conducting a SLR is good starting point for each kind of analysis. Even more, in the case in which the topic is a fairly new one, as Green Warehousing is.

The supporting tool to develop the analysis is the five-step methodology *(Figure 2.1)* by Denyer and Tranfield (2009), in which each phase is characterised by well-defined rules. Each step is described more in detail in the following sub-paragraphs.

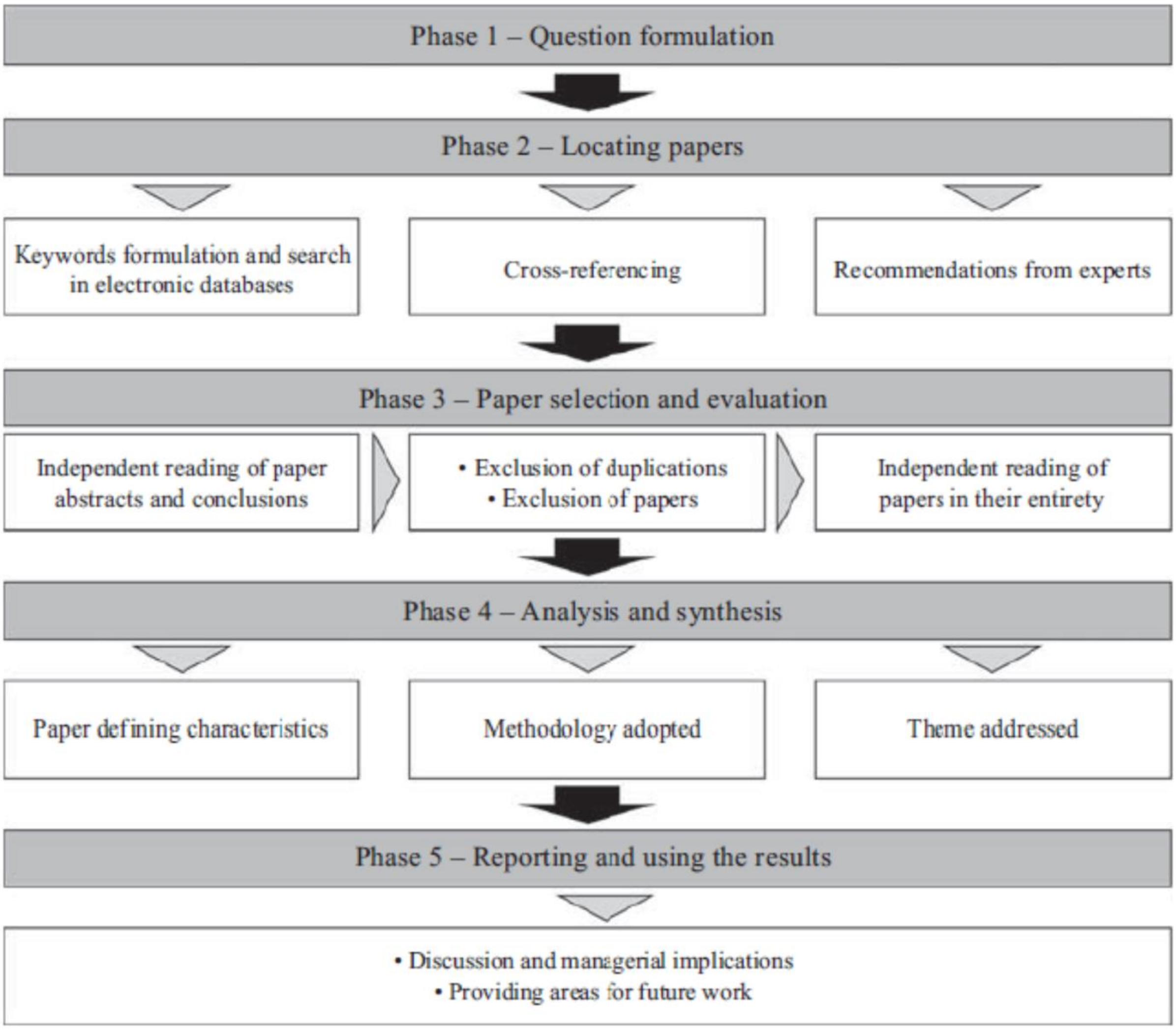


Figure 2.1 Five step methodology schema (Source: Denyer and Tranfield, 2009)

2.2.1 Question formulation

The starting point of an in-depth literature review is the development of a clear focus, formulating precise and answerable questions (Light et al., 1984). Questions formulation guides the review, it defines which studies will be considered and which will be excluded, the poorer the question is, the poorer the review (Tranfield et at., 2004).

In order to formulate robust questions, the "CIMO" logic proposed by Denyer et al. (2008) has been followed. The acronym stands for "Context", "Intervention", "Mechanism", "Outcome", and it specifies the four critical sections of a well-built SLR. The purpose is to match problematic "Context" with certain "Interventions", which follow determined "Mechanism", for obtaining specified "Outcomes" (F*igure 2.2*).

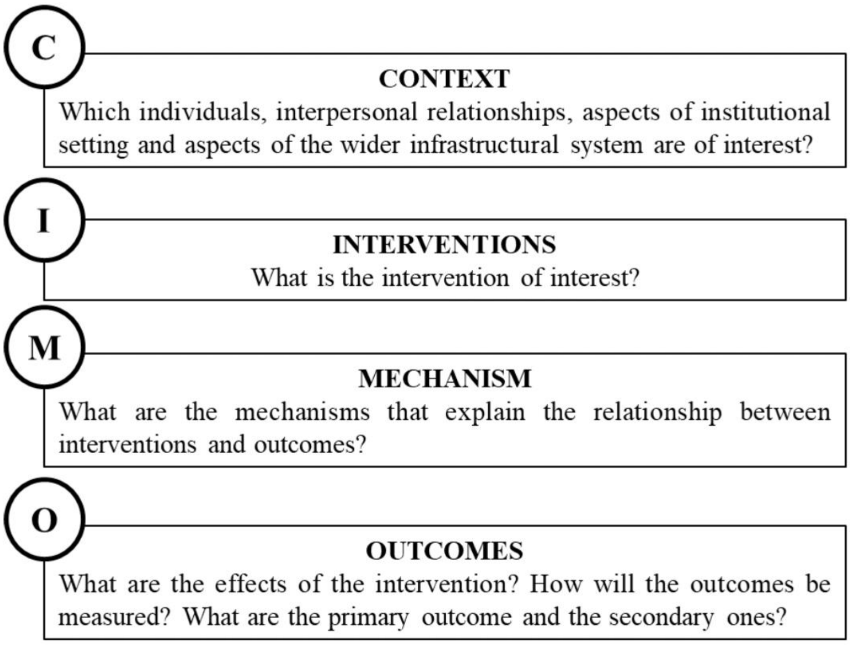


Figure 2.2 CIMO logic (Source: Denyer et al., 2008)

The application of the above-mentioned tool has allowed to obtain the following evidence.

- Context: *Sustainability and environmental performance assessment in warehousing*

The increasing external pressure from stakeholders is pushing companies and supply chains to commit themselves and invest in energy-efficient solutions for warehousing to improve environmental performance. Despite the considerable environmental impact of warehouses in terms of carbon footprint, the topic has often been neglected in the past. Now, managers understood the importance of this critical areas and the number of green-related projects have been intensified.

- Interventions: *Latest tools and best practices for environmental performance improvements*

In order to understand how companies can improve their environmental performance, it is fundamental to investigate which are the currently available tools, to be read in most of the cases as technologies, and which benefits they can bring to companies. Additionally, what can be done is to look at best practices on the market and emulate them. By seeing the results that companies have obtained, other actors can feel willing to embrace the same path.

- Mechanism: *Performance monitoring and improvement*

Performance measurement and monitoring is fundamental to obtain results. It is important to understand which are the tools that best fit the specific context, apply them and monitor the results. Additionally, it needs to be understood how those new tools fit with existing systems to optimize performances while reducing companies' environmental impact.

- Outcome: *Consumption reduction and environmental performance improvement at warehouses*

The combination of new solutions together with the emulation of the best practices on the market are expected to improve both operational aspects and, above all, the environmental performance.

As a result, the following research questions have been formulated:

- 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 digital tools are helping companies improving efficiency and effectiveness of their warehousing processes and, therefore, their environmental performance?*

2.2.2 Locating papers

The second phase regards the collection of papers on the topic, answering the above-mentioned questions. The aim is to create a comprehensive list of contributions to understand which kind of investigations have already been done by the scientific community. The search was performed in three different reliable databases, which are Scopus, ScienceDirect and Web of Science, as they have some of the largest business research repositories. Aiming to define some search criteria, pre-defined keywords have been selected with great attention in order to ensure and conduct an efficient and effective searching phase.

Some groups of keywords have been identified and grouped together depending on the questions they would have answered. The truncation character "*" has allowed to consider in the search all the terms, nouns, adjectives or verbs, with the same root word.

- *Group A* includes terms referring to logistics sites and warehouses: "warehous*", "logistic* site", "logistic* hub", "logistic* facilit*".
- *Group B* considers terms linked to energy efficiency and sustainability: "sustainab*", "green", "decarbon*", "GHG", "CO2", "energy efficienc*", "social sustainab*" "CSR".
- *Group C* comprises all the terms relating to business cases: "business case", "case stud*", "real case".
- *Group D* includes the terms related to disruption and resilience: "disruption" "resilien*" "shock" "crisis" "pandemic" "COVID-19".
- *Group E* considers words which are linked to digitalization: "technolog*", "digitaliz*" "technological innovat*", "logistic* 4.0", "data", "data analy*".

- *Group F* comprises all the data collection and performance assessment terms: "performance", "measur*", "KPI*", "indicator*", "assess*", "monitor*", "track*".

These groups have been combined through Boolean operators and parentheses. Two different queries have been created to answer the research questions, the first one to answer RQ1 and the second one to answer RQ2 and RQ3 together.

The final query for RQ1 is:

[('*Group A*' AND '*Group B*') AND ('*Group C*')]

TITLE-ABS-KEY: (("warehous*" OR "logistic* site" OR "logistic hub" OR "logistic facilit*") AND ("sustainab*" OR "green" OR "decarbon*" OR "GHG" OR "CO2" OR "energy efficienc*" OR "social sustainab*" OR "CSR")) AND ("business case" OR "application" OR "practic*" OR "implement*" OR "real case").

Grouping together Group A and Group B is needed in order to consider simultaneously sustainability topic applied to warehouses or logistics sites. Then, both have been combined with Group C in order to search for case studies.

The final query for RQ2 and RQ3 is:

[('*Group A*' AND '*Group B*') AND ('*Group D*' OR ('*Group E*' AND '*Group F*'))]

In particular, the first parenthesis (A and B), including words referring to warehouses and environmental sustainability, has been combined with the keywords of group D or those of Group E and F together. If combined with Group D, the main goal is to answer RQ2; if the AND operator goes with Group E AND Group F, papers better answer RQ3. Papers were considered relevant if at least one search deriving from the combination was in Title, Abstract or Keyword. The final result was:

TITLE-ABS-KEY: ((“warehous*” OR “logistic* site” OR “logistic* hub” OR “logistic facilit*”) AND (“sustainab*” OR “green” OR “decarbon*” OR “GHG” OR “CO2” OR “energy efficienc*” OR “social sustainab*” OR “CSR”)) AND ((“disruption” OR “resilien*” OR “shock” OR “crisis” OR “pandemic” OR “COVID-19”) OR ((“technolog*” OR “digitaliz*” OR “technological innovat*” OR “logistic* 4.0” OR “data” OR “data analy*”) AND (“performance” OR “measur*” OR “KPI*” OR “indicator*” OR “assess*” OR “monitor*” “track*”))).

Moreover, a cross-referencing procedure has been executed to include, in the final list, some other potential papers that were omitted from previous string search. This has allowed to avoid neglecting any relevant scientific documents which could not be included in the defined keywords or in the selected databases, as suggested by Marchet et al. (2014). The output of the search is a comprehensive listing of papers which addresses the review questions (Denyer and Tranfield, 2009).

2.2.3 Papers selection and evaluation

The procedure of the SLR encompasses different steps to assure transparency. Thus, a selection of criteria has been used and need to be explained. The goal was to assess the relevance of each paper found and evaluate whether it addresses the question or not. Three consequential selection stages have been performed:

1. Screening stage: two initial filters have been considered. Papers selected needed to be published in relevant conference proceedings or peer-reviewed international journal and had to be written in English. This selection was to ensure a high-quality level. After this phase, 489 papers were included.

2. Eligibility stage: inclusion and exclusion criteria have been formulated (*Table 2.1*) in order to accept only papers falling under certain requirements. Particularly, the paper needed to tackle the energy efficiency topic applied to logistics sites or warehouses and not in general or at a supply chain level. Then, sustainability topic had to be related to energy efficiency and not to environmental sustainability themes in general. For what concern IT solutions, papers needed to reason about how IT tools can help improving energy efficiency in warehouses, and not about IT solution at a general level. Additionally, have been included all the papers about the effect of disruptions on warehouses sustainability and excluded the ones which spoke about the consequences of disruptions on supply chains. Concluding, for the section about case studies emulation, only the ones related to real life examples have been included. All the purely theoretical dissertations have been excluded. The selection of papers to be included has been conducted checking the inclusion and exclusion criteria by the reading of abstracts. In case of ambiguity, the decision has been taken after having read introduction and conclusion. After this stage 82 were included.

Inclusion criteria	**Exclusion criteria**
Energy efficiency at logistic sites or warehouses	Energy efficiency in general or at a supply chain level
Sustainability including environmental perspective or energy efficiency	Sustainability in general
Solutions for energy efficiency in warehouses	Warehousing solutions in general
Effects of disruption on warehouses sustainability	Disruptions linked to supply chains in general

Table 2.1 Inclusion and exclusion criteria

3. Final selection: a detailed reading of the whole paper brought to a final selection of 18 papers. Additionally, 13 have been added through cross-reference activity. The goal was not to exclude any potentially relevant document which was not included in the sample of papers previously obtained. In the end, the final list encompasses 31 documents. The not huge number of papers founded, reflects the fact that the topic is quite recent and not deeply analysed.

Table 2.2 shows the phases of the paper selection process adopted and the number of documents obtained as output of each phase.

PHASE	CRITERIA	OUTPUT [Number of papers]
Electronic database research	▪ String search	616
Screening	▪ English language ▪ Peer reviewed international journal or international conference proceedings	489
Eligibility	▪ Inclusion criteria ▪ Exclusion criteria	82
Final inclusion	▪ Adherence with RQs ▪ Cross-references	31

Table 2.2 Paper selection process

2.2.4 Analysis and synthesis

All the papers initially selected for this study were inserted in a Microsoft Excel spreadsheet and enumerated in chronological order. For each document the following information was reported:

- Title
- Authors
- Year
- Source
- First author's country

This database was the basis of the analysis carried out. Then, after reading the selected papers in their entirety, the two readers indicated which of them were pertinent to the study and to which research question each paper could answer. Using Excel filters, the documents that reached the last selection stage were finally obtained. In *Table 2.3* a complete list of the chosen papers is reported.

Number	Author	Title	Year	First author's country	Source	Method	RQ1	RQ2	RQ3
1	Ali S.S. et al.	Evaluating sustainability initiatives in warehouse for measuring sustainability performance: an emerging economy perspective"	2022	Saudi Arabia	Annals of Operations Research	Case study	X		
2	Hanafiah R. et al.	Innovative Risk matrix model for warehousing productivity performance	2022	Malasya	Sustainability	Case study		X	
3	Aravindaraj K., Rajan Chinna P.	A systematic literature review of integration of industry 4.0 and warehouse management to achieve Sustainable Development Goals (SDGs)	2022	Karaikudi	Cleaner Logistics and Supply Chain	SLR			X
4	Ali I., Phan H. M.	Industry 4.0 technologies and sustainable warehousing: a systematic literature review and future research agenda	2022	Melbourne	International Journal of Logistics Management	SLR			X
5	Watson B.C., Bras B	Connections between System of System Sustainability and Resilience in an Electric Motor Manufacturing Supply Chain	2022	USA	Procedia CIRP	Case study		X	

6	Klumpp M., Loske D.	Sustainability and resilience revisited: Impact of information technology disruptions on empirical retail logistics efficiency	2021	Germany	Sustainability	Theory		X	
7	Ahmed K. et al.	Critical Factors of Digital Supply Chains for Organizational Performance Improvement	2021	Sharja	IEEE Transactions on Engineering Management	Theory			X
8	Nantee N., Sureeyatanapas, P.	The impact of Logistics 4.0 on corporate sustainability: a performance assessment of automated warehouse operations	2021	Khon Kaen	Benchmarking	Case study			X
9	Baghizadeh K. et al.	Closed-Loop Supply Chain Design with Sustainability Aspects and Network Resilience under Uncertainty: Modelling and Application	2021	Iran	Mathematical problems in engineering	Model		X	

10	Moshood T.D., Sorooshian S.	The Physical Internet: A means towards achieving global logistics sustainability	2021	Malaysia	Open Engineering	Theory		X	X
11	Correia D.M. et al.	Smart Supply Chain Management: The 5W1H Open and Collaborative Framework	2021	Aveiro	IEEE 8th International Conference on Industrial Engineering and Applications	Model			X
12	Spieske A. and Birkel H.	Improving supply chain resilience through industry 4.0: A systematic literature review under the impressions of the COVID-19 pandemic	2021	Germany	Computer and industrial engineering	SLR		X	
13	Modica T. et al.	Green Warehousing: Exploration of Organisational Variables Fostering the Adoption of Energy-Efficient Material Handling Equipment	2021	Italy	Sustainability (Switzerland)	Model	X		

14	Lewczuk K. et al.	Energy Consumption in a Distributional Warehouse: A Practical Case Study for Different Warehouse Technologies	2021	Poland	Energies	Case study	X		
15	Almutairi K. et al.	Policy to Optimize Energy Consumption for Dairy Product Warehouses: A Case Study	2021	Saudi Arabia	Sustainability (Switzerland)	Case study	X		
16	Miceli A. et al.	Thriving, Not Just Surviving in Changing Times: How Sustainability, Agility and Digitalization Intertwine with Organizational Resilience	2021	Italy	Sustainability (Switzerland)	Theory		X	
17	Balugani E. et al.	Empirical evaluation of the impact of resilience and sustainability on firm performance	2020	Italy	Mathematical problem in engineering	Model		X	
18	Ivanov D., Das A.	Coronavirus (COVID-19/SARS-CoV-2) and supply chain resilience: a research note	2020	USA	International Journal of integrated supply chain management	Model		X	

19	Gölgeci I. et al.	The rising tensions between efficiency and resilience in global value chains in the post-COVID-19 world	2020	Denmark	Transnational Corporation	Theory		X	
20	Galgaro A. et al.	Underground warehouses for food storage in the Dolomites (Eastern alps – Italy) and energy efficiency	2020	Italy	Tunnelling and underground space	Case study	X		
21	Opalic S.M. et al.	ANN modelling of CO2 refrigerant cooling system COP in a smart warehouse	2020	Norway	Journal for Cleaner Production	Model	X		
22	Sahar D.P. et al.	Review of green supply chain management in manufacturing: a case study	2020	Indonesia	IOP Conference series: Earth and Environmental sciences	SLR	X		
23	Sanmamed V. P. et al.	Ground-source energy systems for building heating and cooling—A case study	2019	Portugal	Energy reports	Case study	X		**23**

24	Kusrini E. et al.	Design Key Performance Indicator for Sustainable Warehouse: A Case Study in a Leather Manufacturer	2019	USA	IOP conference series: Materials science and Engineering	Case study	X		
25	Goh S. H.	Barriers to low-carbon warehousing and the link to carbon abatement: A case from emerging Asia	2019	Singapore	International Journal of Physical, Distribution and Logistics management.	Survey	X		
26	La Scalia G. et al.	Reducing waste and ecological impacts through a sustainable and efficient management of perishable food based on the Monte Carlo simulation	2019	Italy	Ecological Indicators	Model	X		
27	Mostafa N. et al.	Impacts of internet of things on supply chains: A framework for warehousing	2019	Zagazig	Social sciences	Model			X
28	Karunarathna N. et al.	A study of the implications of logistics 4.0 in future warehousing: A Sri Lankan perspective	2019	Kelaniya	Proceedings of the International Conference on Industrial Engineering and Operations Management	Case study			X

29	Seifhashemia M. et al.	The potential for cool roofs to improve the energy efficiency of single storey warehouse-type retail buildings in Australia: A simulation case study	2018	United Kingdom	Energy and Buildings	Case study	X		
30	Marcehse D. et al.	Sustainability and resilience: Similarities and differences in environmental management applications	2018	Italy	Science of total environment	Theory		X	
31	Fosso Wamba S., Takeoka Chatfield A.	The impact of RFID technology on warehouse process innovation: A pilot project in the TPL industry	2011	Wollongong	Information Systems Frontiers	Case study			X

Table 2.3 Paper shortlist

This procedure has allowed to conduct efficiently and coherently the nest steps of analysis. In the following sub-sections, the main characteristics and features of the examined documents are described in detail.

Publications by year

Figure 2.3 confirms that only recently the scientific community is focusing on Green Warehousing related topics. The large majority of the selected papers are published from 2018 onwards. This development reflects the spread of awareness among companies regarding the theme of energy efficiency in warehousing. Leaving aside 2022, which is the current year and thus many researchers still have to publish their works, it's interesting to notice that the trend representing the growing interest is not even linear, but rather exponential. This again demonstrates that companies are rapidly moving in the direction of improving their environmental performances, both because of external pressure from stakeholders and both because, in many cases, energy efficiency is synonymous of cost saving.

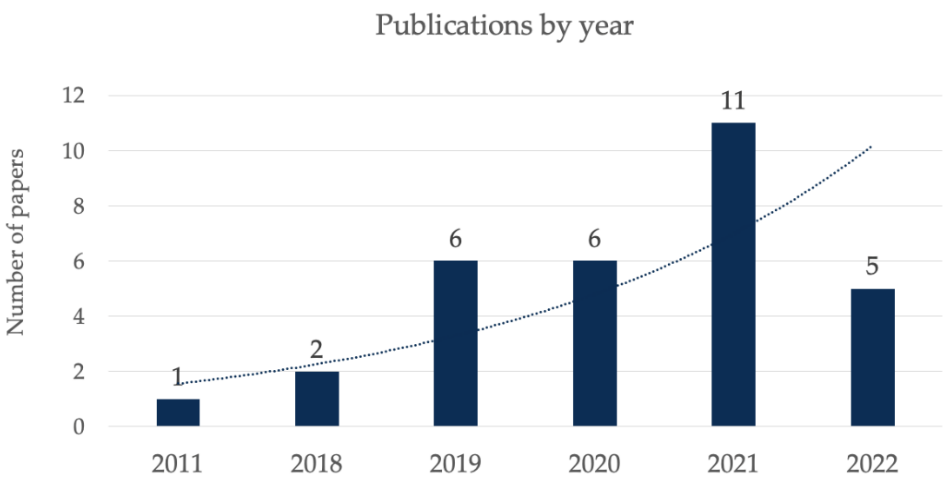


Figure 2.3 Publications by year

Publications by method

Considering the document methods, they are quite heterogeneous: 12 case studies, 4 Systematic Literature Reviews, 6 theoretical dissertations, 8 models and 1 survey. In *Figure 2.4* are presented the percentage of each method.

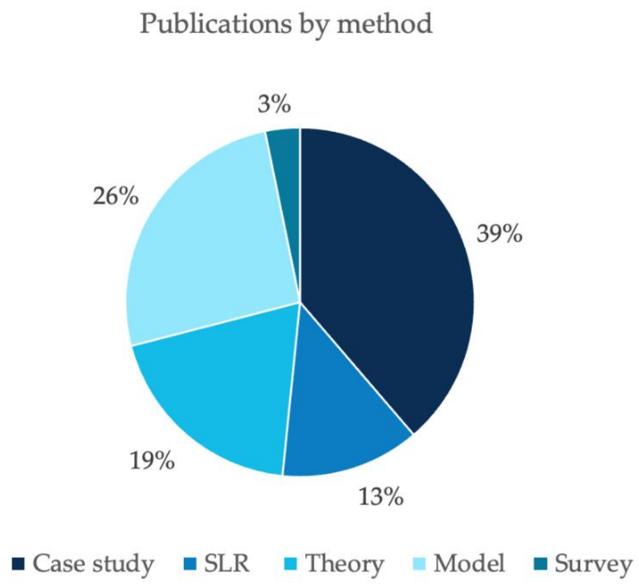


Figure 2.4 Publications by method

Publications by country

For conducting this kind of analysis, the affiliation of the first author has been considered, as a proxy of the geographical origin of the papers. By doing so it has been discovered that most of them are coming from Italy, with 6 papers out of 31. Then, it is followed by USA with 4 papers and Malasya, Germany, Saudi Arabia and Portugal with two papers each. All the other papers are coming from different countries as show in *Figure 2.5*.

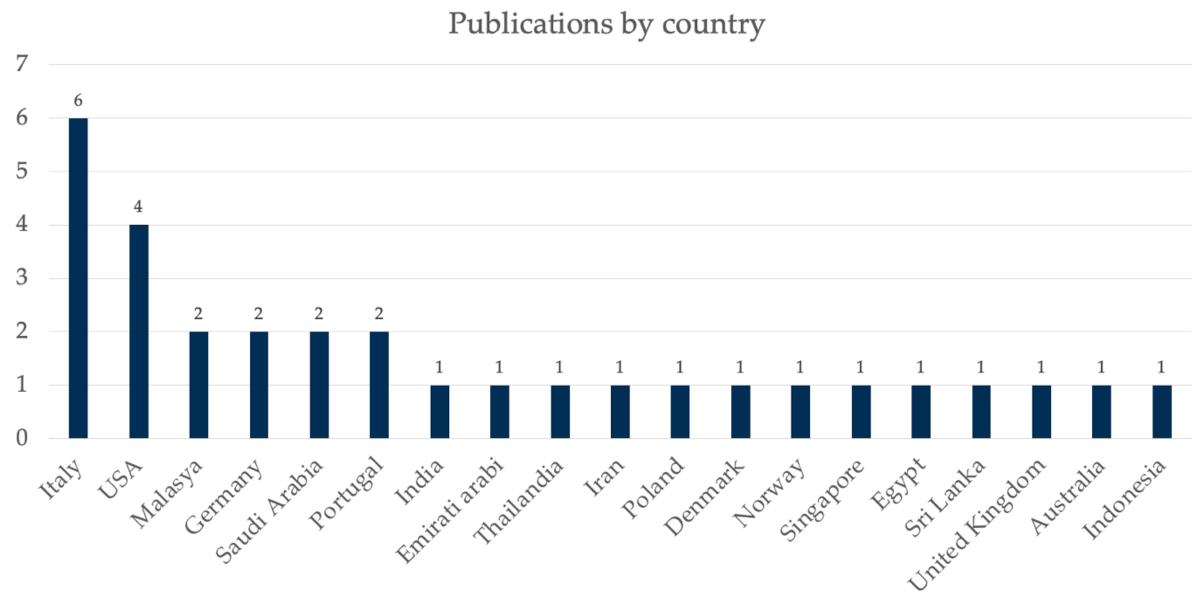


Figure 2.5 Publications by country

Publications by investigated area

Figure 2.6 shows the number of papers which have been considered to answer the questions. The three different RQs try to tackle different aspects of the more general Green Warehousing topic, thus there is not a big overlapping of the papers used among the three RQs. The number of papers used is shown below.

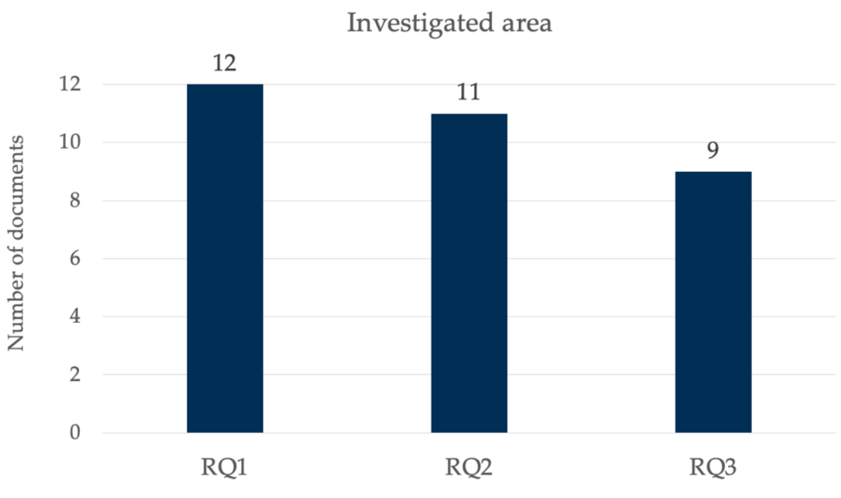


Figure 2.6 Publications by investigated area

2.2.5 Reporting and using the results

This section aims at answering the RQs defined through the critical analysis of the selected papers. For the sake of clarity and readability, each research question is addressed in a specific sub-section.

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

The first RQ entails the analysis of the latest solutions applied by companies in Green Warehousing, especially considering energy-efficient solutions. In this section, the results of the analysis will be presented following the model that will be exploit even in the next chapter: each solution will be associated to a "class". The different clusters that have been considered are Green Buildings solution, Utilities, Lighting, Materials Handling and Automation systems, Materials Management and Operational practices.

Due to the increasing awareness on climate change and the increasing complexity of the warehousing activities in the supply chains, warehouse emissions have come into a focus. Warehouse are getting larger, are increasingly being run for 24 hours a day to meet real-time fulfilment requirements and have more power need from and increasing utilization of information technology (Baker and Marchant, 2015). In several cases, green logistics practices contribute to improve environmental performances because for companies it's possible to identify a positive relationship between these two aspects, in terms of energy, water consumption, waste and air emissions (Sahar et al., 2018). Despite this consciousness and the increasing regulatory pressure, there are still some barriers that prevent the implementation of low carbon solutions in warehousing. In particular, the barriers to sustainable practices can be classified into eight major categories. Four of these barriers (-cost, -complexity, -communications and knowledge) are internal to the organization, while the others (-government, -suppliers, -customers and technology) are external (Goh, 2019). The results of the study; conducted through a survey on one of the largest providers of contract logistics services operating in more 13 markets in Asia Pacific; must be interpreted considering the geographical location and the level of maturity of the economies that have been considered. In fact, the analysis highlights that "government" and "technology" are the most important barriers in case of emerging market (Goh, 2019). Moreover, in this case, even customer and supplier related barriers are relevant, probably due to the lack of general awareness on sustainability. On the other side, in the mature market several respondents underline the lack of communication and employee engagement on sustainability. After having presented in rough term the situation, the results will be deepened, analysing the different case studies found. Since the beginning it's important to mention that has been identified a gap in literature related to business case applied in mature economy and so more in focus with the scope of this dissertation, the majority of paper refers to emerging countries.

Starting from the cluster of Green Building some interesting papers have been found regarding three construction techniques cool roofs, green roofs and underground warehouses. Seifhashemia et al. (2018) present a case study on the application of cool roof in Australia. After having built a simulation starting by the real implementation, they replicate it considering different climate conditions in Australia. What emerges is that this type of solution maximizes the benefits in term of energy saving when applied in hot weather condition. The aspect of adopting the best fitting solution according to the external variables is highlighted in other papers, for example Almutairi et al. (2021) state that using passive techniques, that involve no mechanical means to maintain thermal comfort indoors, is one of the most effective methods of benefiting from renewable energy in the climate condition of Iran. The article tries to find the best solution to reduce the emissions linked to a cooling system for dairy products by proposing 9 types of warehouse mixing techniques of building construction and renewable energy sources. The finding of the study shows up that for each season there is a different scenario but considering the whole year the two best solutions are the mix of underground warehouse and cool or green roof. Galgaro et al. (2020) present another interesting case of underground warehouse for apple in the Dolomites. The authors state that the containment and isolation capacities of underground spaces offer an ideal place to store food, fuel or other strategic materials, with limited energy costs. Caves and caverns are characterized by specific microclimatic conditions and chemical isolation depending on the surrounding rock properties. This solution not only keep the apple in good condition saving a lot of energy cost but even reduce the exploitation of land, another important aspect in Green Warehousing.

After having considered the structural choice of the warehouse the analysis will continue by focusing on Utilities. Another important pollutant aspect to do not neglect is the exploitation of refrigerants. Nowadays, this aspect is becoming more and more important because, within the built environment, cooling demand is continually increasing as the weather grows warmer and a larger part of the world's population and industrial enterprises gain access to air conditioning equipment and cooled building space (IEA, 2019). This trend can be mainly alleviated through a two-fold focus on energy-efficient operation (Li et al., 2020; Zhu et al., 2019) and use of increasingly viable environmentally friendly refrigerants, such as carbon dioxide (CO2), in the Cooling Systems (Mohammadi and McGowan, 2019; Sarkar et al., 2004; Neksa et al., 1998). In addition, it's important to be able to control the consumptions, not only related to refrigerants, but even the electricity absorbed by the system, due that in temperature-controlled warehouse emissions linked to cooling system represent the large majority of the total value. At this regard, Opalic et al. (2020) try to model a compressor in an operational, industrial cooling system using artificial neuron network with the objective to measure the electrical consumption and the mass of refrigerants consumed. The presented technique is relatively superior to a general theoretical model, both in terms of accuracy, flexibility, cost effectiveness, and implementability in the real-world application (Opalic et al., 2020). Always considering cooling and heating system, Sanmamed et al. (2019) explore an interesting solution for warehouse in Norway studying the application of a borehole thermal energy storage (BTES) system in this context. More in detail, the solution considered consists of the hybridization of several technologies: PV-T solar panels, air, heat pumps and 8 geothermal wells. The results are promising, even if still in the implementation phase, with great result in term of energy savings.

Other important aspects considered by literature are Material Handling and Automation systems. Since these equipment's accounts for one-third of the energy used for material handling, the adoption of eco-efficient forklift trucks could be a valuable solution for minimising energy consumption (Evangelista et al., 2017). To verify it, a case study has been performed considering a labour-intensive warehouse located in the north of Italy. By monitoring the adoption of 76 straddle reach lithium-ion battery forklift trucks, different scenarios have been analysed using as variables the range of the battery chosen and the slot of recharge. The main interesting result has been a bi-directional relationship between the type of power source selected for the MHE and the design and management of the warehouse (Modica et al., 2021). It's possible to say that this conclusion has been underline by many authors and will be deepen later. In this context the level of automation of the warehouse has a big impact on the overall energy consumption, Lewczuk et al. (2021) propose a case study in which six variants of warehouse systems realizing common warehouse processes are proposed and compared. The variants differ in terms of automation level, efficiency, effectiveness, initial investment, operating costs, area and cubic capacity of buildings, as well as the electric energy consumption. In fact, the energy consumption by warehouse processes may be determined not only by implementing energy-saving technologies and buildings but also, above all, by the selection of core warehouse technologies (Lewczuk et al., 2021). Moreover, this selection entrains many technical and economic considerations, most of which related to investment and periodical operating costs, especially to return on investments.

Focusing now on Operational practices, an interesting case study related to food sector shows the effectiveness of shelf-life based policy for managing inventory to prevent food waste, trough the exploitation of Montecarlo simulation (La Scalia et al., 2019). This is even more interesting considering that food sector is one of the most complex in term of storage and level of traceability required.

Another important aspect that emerges from the literature is the necessity to define some KPIs that are able to monitor the implementation of these solutions thus assessing their efficiency and effectiveness. Kursini et al. (2019) conducted a case study on leather manufacturing company in Indonesia for identifying some sustainable KPIs and ranking them according to their importance. The result shows that the most important KPIs are the economic one, followed by the social (human rights and security on the plant) and the environmental one. In between this last cluster the most important are energy efficiency one. These results are coherent if analysed accordingly to the fact that Indonesia is still under development and the importance attribute to sustainability is not as strong as the one in mature economy. On this topic Ali et al., (2022) - by analysing a sample of company operating in frozen food supply chain in the region of Jeddah - try to identify the link between sustainable practices and performance in warehouse considering an emerging technology perspective. The results have identified crucial sustainable-green warehousing practices: green operations, green policies and employee training of green integrations or practices, are mentioned as the main and most favoured or adopted practices that are integrated in the targeted organizations (Ali et al., 2022). In addition, they have identified as crucial the integration of technology inside the warehouse.

Warehouse measurement which considers social, economic and environment aspect is still limited and becomes something new in sustainable warehousing performance. The creation of KPI that let the possibility to monitor the effectiveness of a solution are fundamental in order to activate action of monitoring and improvements.

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

The aimed objective of this research question is trying to understand how the term sustainability and resilience are connected the one with the other and to understand how COVID-19 pandemic has influence the priority of the company, obviously under a Green Warehousing perspective. It's important to highlight since the beginning the presence of a quite big gap on this topic. As presented by other dissertation is difficult to find article related to Green Warehousing since is a quite new topic and it's even harder to find them considering the post-pandemic situation. COVID-19 pandemic's severe and simultaneous impact on multiple supply chain tiers and geographies, as well as its unprecedented long duration (Ivanov 2020 and Xu et al. (2020)), has increase the interest of academics on the topic of resilience coupling it with the term sustainability. More in detail, the pandemic highlighted the correlation between these two aspects and showed that companies were not ready to face a disruption as COVID-19 pandemic (Miceli et al., 2021). Scientists argued a lot on the meaning of these two terms. Different authors present different definitions, for Miceli et al. (2021) it's fundamental to analyse resilience and sustainability exploiting an holistic perspective and to consider the two term as interdependent, one can influences the others both positively and negatively. For Watson and Bras (2022) resilience is somehow integrated in sustainability since if a system is not enough resilient, it takes the risk to see its sustainability compromised due to the flow of money and resources needed to restore it to its original condition after the disruption (Watson and Bras, 2022). While for Balugani et al. (2020), in the field of business and supply chain management, sustainability is a factor contributing to resilience, so the opposite of the previous definition.

The results of this analysis are confirmed by the article by Marchese et al. (2018) that affirm that the analysis of the existing literature on how sustainability and resilience can be integrate show three main type of scenario: (1) resilience as a component of sustainability; (2) sustainability as a component of resilience; and (3) and resilience and sustainability as separate objective. Marchese et al. propose an additional interpretation by suggesting considering sustainability as a critical function of a project which is to be maintain during and after a disturbance. This definition is particularly interesting if connected with the lack of theoretical exploration regarding how resilient organizations can prepare for and respond to change in a sustainable way (Carmeli et al., 2020)

The analysis performed on existing literature shows two main levels of analysis: in the first case a macro level considering the whole supply chain, the authors present a model for designing the supply chain taking into account both sustainability and resilience aspect (Baghizadeh et al., 2021). In this context it is important to remember that global supply chain can be considered systems of systems and an unexpected event can influence in unpredictable way the other nodes. Watson and Bras (2022) try to study this phenomenon through the analysis of a case study on disruption caused by a hacker attack on an electric manufacturing supply chain. Since this is not the main scope of the dissertation this topic will be not deepen.

In the second case a micro level, considering the single warehouse. The literature presents two main types of articles: authors try to propose method for the evaluation of the risk (Hanafiah et al. 2022) or proposed computer-based simulation of unexpected events, like the pandemic (Ivanov and Das, 2020) or IT disruptions (Klumpp and Loske 2021). Hanafiah et al. (2022) propose and innovative risk matrix that considered 10 main categories of risk (-Physical environmental risk, -operational risk, -human risk, -market risk, -resource risk, -managerial risk, -financial risk, -security risk, -regulatory risk, -inventory risk), they exploit different method as AHP and Borda method to calculate the different weights to assign to each risk category and they validate the model applying it to 12 logistics players in Malaysia. Klumpp and Loke (2021) try to assess the impact that an IT system interruption would have on a retail logistics efficiency. In both the case, the main objective of the authors is to minimize the risk and maximize the performances of the system. For succeeding in it, sustainability and resilience are considered fundamental. COVID-19 was mentioned as a future improvement, but it was not directly studied.

Another factor that emerges from the literature is the role of technologies. Industry 4.0 is considered by Spieske and Birkel (2021) one of the main enablers of recovery. What's can be added is that technologies can be considered a great enabler even for sustainability, not only concerning the environmental sphere, but even as regard to the social one. For example, it's enough to think to all the innovations proposed during the lockdown to protect workers in the warehouse (such as remote control). The pandemic has influenced a lot the role of sustainability and resilience, in particular the tension between resilience and efficiency. Gölgeci et al. (2020) try to analyse the existing literature on this topic and conclude supporting their thesis that efficiency and resilience may be in opposition in the short term, but this is not true in the long run, in fact the interaction of this two is essential to survive and remain competitive.

2.2.5.3 *How digital tools are helping companies improving efficiency and effectiveness of their warehousing processes and, as a consequence, their environmental performance?*

As discussed in Chapter 1, in recent years, many technologies supporting logistics and warehousing operations have emerged and are still gaining increasing attention. That logistics 4.0 technologies – classified between automation, digitization and analytics' tools – have an impact on digitalization and, thus, on transformation of processes inside companies. The implementation of those solutions does not have to be seen in an isolated way, as a single incremental improvement in some fields; instead, is a game changer situation in which all the decision-making, execution and monitoring processes are modified. Even though the topic is quite new, and so the research is in the initial phase of development, the increasing interests from the companies' point of view let the literature results increase in a considerable way in the last few years. For what strictly concern warehousing, the frequency analysis of the Systematic Literature Review by Aravindaraj and Rajan Chinna (2022) shows that over a total of 63 publication tackling Industry 4.0 from the perspective of warehouse management, 26 of them have been published in 2021.

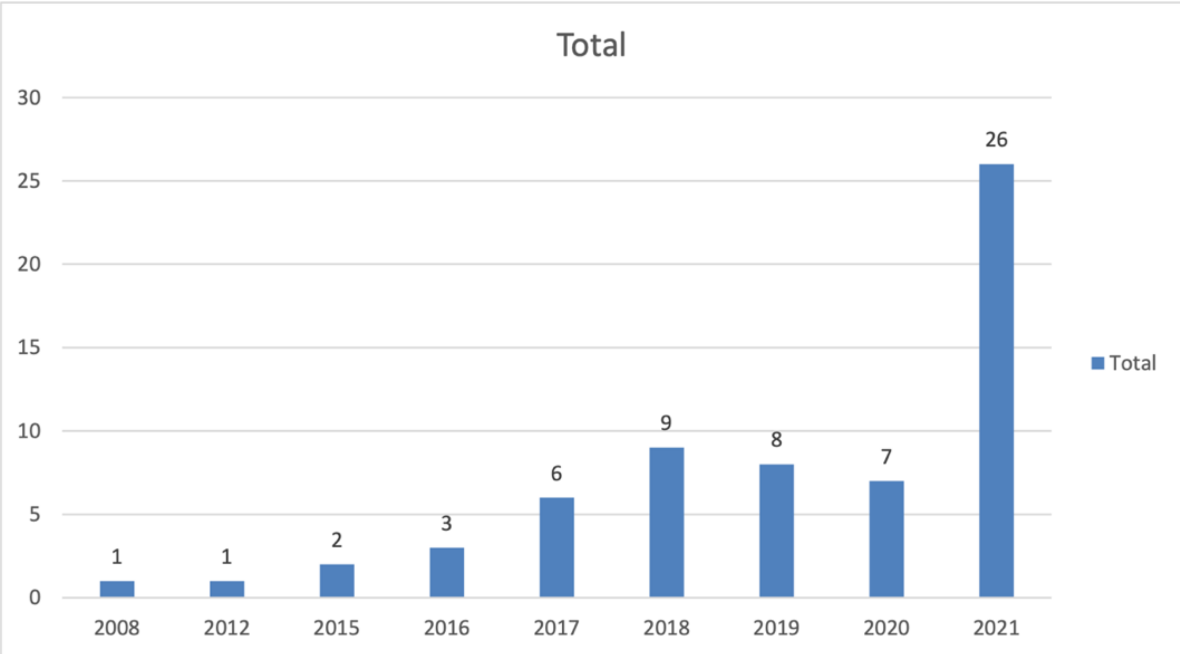


Fig. 3. Year-wise distribution of Industry 4.0 in warehouse management.

Figure 2.7 Year-wise distribution of Industry .4.0 in warehouse management (Source: Aravindaraj and Chinna, 2022)

Anyway, if the link between Logistics 4.0 solutions and their impact on companies' processes is starting to be deepened in terms of efficiency and effectiveness, very few results are available about the environmental implications coming from the implementation of those. The extent to which Logistics 4.0 is able to improve the Triple Bottom Line of corporate sustainability remains unclear. The purpose of this research is to reduce the lack of knowledge in this field, matching Logistics 4.0

technologies not only with their operational benefits but also with the environmental ones, if present. This is needed because the increasing awareness on environmentally related topics, the current energy scarcity situation, let all the supply chain actors take care not only about costs, time and efficiency but also about their social and environmental impact along the supply chain (Ferreira et al., 2016; Maslaric et al., 2016).

The structure that will be followed for answering this third research question is to go through the specific company activity – decision making, execution and monitoring – understanding which Logistics 4.0 tools can be used, connect them with their operational benefits first, and environmental ones then, if present. The final result will be a comprehensive view on all the implications coming from the implementation of Logistics 4.0 solutions in warehouse management. As said, the Triple Bottom Line (TBL) also encompasses social sustainability; in this Master thesis it will be tackled only shortly since it is not the core aspect.

For what concern the decision-making phases, the Logistics 4.0 solutions to be exploited are, mainly, analytics. The process of taking decisions can be speeded up using AI and the decision itself could be more accurate since it is based on a huge amount of input data coming from the use of Big Data analytics. Moreover, the simulation process, created through the use of Digital twin technologies, can help evaluating simultaneously different scenarios and go for the most appropriate one.

Dubey at al. (2019b), reported that Big Data analytics technologies are positively correlated with companies' environmental performances. Thanks to the exploitation of analytics is also possible to understand potential gap in the warehouse layout and take decisions to change it. A well-done layout is fundamental to optimize charging, storage and picking activities and to better schedule vehicle routings. Going for combined-cycles and reducing as much as possible empty running has, as a consequence, a reduction in the amount of fuel used and related emissions generated. Lastly, by combining real time data with the information coming from the

WMS is possible to dynamically allocate tasks to operators and vehicles, improving workload balance.

In support of the execution phase, many digitization solutions come in. Above all, Internet-of-Things. IoT is one of the most promising technologies in the context of the fourth industrial revolution. It accommodates the digital connectivity of the physical and digital components (Rondero et al, 2019). IoT supporting information sharing and visibility on warehousing activities, such as picking or loading, significantly reduces the chance of errors, damages and product rejections, thus limiting the risks of wasting a huge number of resources (Ding et al., 2020).

In order to reduce the energy consumption in the execution phase, a useful tool are sensors. As reported by Mostafa et al. (2019), sensors can control environmental conditions of warehouses by monitoring the heating, ventilation and air conditioning system. They capture real-time data regarding the surrounding environment, transfer to the WMS for processing and converting them into useful information and, consequently, proper actions. The result is a reduction in the use of resources, not only energy but could be also water or the refrigerants employed, again reducing emissions.

Another IoT technology for improving the environmental performance of warehouses in the execution phase are RFID. They solve inventory inaccuracy issues by taking track of all the items coming in and out the warehouse. Then, by communicating those data to the WMS, the decision-making process can also be optimized (Zhong et al., 2013). The economic benefits of this technology are not a recent finding. Capone et al. (2004) stated that RFID has the potential to reduce the put-away process – intended as moving and placing products into their specific storage location - by 20 to 30% and the picking labor cost by some 30 to 50%. Lefebvre et al. (2005), through a pilot study, demonstrated that RFID facilitate collaboration among supply chain actors, thus allowing collaborating planning scenarios, forecasting and facilitating practices such as the vendor managed inventory (VMI). García et al. (2007) showed that RFID enables the automatic input of orders in the supply chain system in the receiving phases, allowing real-time checking of bin availability during the put-away and picking processes and also reduces the process time. On the other side, RFID technology implementation costs, together with its perceived complexity are key inhibitor of its widespread adoption and usage. Concluding, despite the high potential economic benefits demonstrated in these studies, no significant literature is explicitly focused on the environmental implication of RFID. Anyhow, the possibility to better take track of all the items and the possibility to share those data with all the supply chain actors needs to be read as good news for sustainability because tracking and collaborating means lower resources utilization and better monitoring process.

Still for what concern execution, a big question mark, that Logistics 4.0 bring with it, is the degree of automation to be adopted. In the literature, there are many conflicting opinions around the choice to automatize as much as possible and, so, moving human operators into more sophisticated and strategic positions or, on the opposite, maintain a good balance between automation and human work. Since the purpose of this research, as said, is to deepen the environmental implication of Logistics 4.0 technologies, the social part will be treated later in a separate section. Considering the automation level inside, there are different points of view. There is a first school of thought stating that the replacement of humans with machines or robots may increase fuel and electricity consumption (Edirisuriya et al., 2018; Ejsmont et al., 2020). On the contrary, Bag et al. (2021a) report a positive relation between the degree of Logistics 4.0 implementation and the capability of a company in performing the 10R (refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle and recover), thus helping in achieving sustainable development goals (SDGs). For understanding implications coming from the use of AS/RS, empirical research by Nantee and Sureeyatanapas (2021) will be used. The study is a comparison between two companies, for the sake of simplicity called Company A and Company B, both implementing AS/RS. Company A is a distribution centre (DC) for a large-scale retail business and company B is a large-scale warehousing service provider in the automotive industry. What immediately emerged is that the implementation of AS/RS decreased the use of forklift by around 80-90%. The numerous forklifts employed before, operated on internal combustion engines that burned liquid petroleum gas (LPG), which generated a strong odour and substantial CO_2 emissions. Consequently, company A and company B agree that air emissions, dust from fuel combustion and rubber smells from forklift wheels rubbing against the floor decreased after the implementation of the above-mentioned solution. For what concern wastes, anyway, AS/RS didn’t give any contribution in reducing it. The stretch film used to wrap pallets and protect products during transit and storage remained unchanged. Speaking about electricity and non-renewable energy consumption, the two companies reported different experiences. According to company B, the implementation of AS/RS increased electricity consumption, due to the use of electronic machines and control systems. On the opposite, company A’s manager affirmed that demand for electricity had declined because the implementation of automation systems entailed replacing human efforts to store and track data with machines and robots. Consequently, most of the lights in the storage areas became unnecessary and were switched off. It is also reported that connecting solar energy to the company’s automation systems had significantly lowered its electricity bill. In terms of the criterion ‘non-renewable energy consumption”, Company A reported that the implementation of AS/RS significantly reduced the use of LPG (because, as previously stated, it reduced reliance on combustion-powered forklifts). By contrast, Company B explained that the level of non-renewable energy use remained unchanged because the company had already utilised electric (battery-powered) forklifts, rather than forklifts powered by fossil fuel or natural gas, before the transition to automated systems. Therefore, no significant change of energy consumption was reported.

Concluding the analysis and switching to the monitoring phase, again the use of analytics comes into play. Bait et al. (2020) state that Industry 4.0 technologies, improving data-tracking capabilities, enable a complete monitoring of product life cycle and thus the carbon footprint assessment. Then, another tool in support of the monitoring process is the Warehouse Management System (WMS). The above-mentioned study by Nantee and Sureeyatanapas (2021) also made a comparison between the results Company A had after having implemented WMS and the ones obtained by Company B. Even in this case, both Company A and B agree that paper waste haven't been reduced because, although the WMS could record all the information online, the two companies continued to print all important files for backup purposes. This is a signal that, together with the digital revolution, also a cultural one needs to come in order to let the technologies create real benefits for companies. This dual perspective demonstrates that the positive or negative impacts depend on the implementers' management policies and supporting strategies.

Concluding, to briefly tackle the social sustainability aspect, in literature there are some conflicting opinions about the possibility that digital technologies can improve the working conditions in warehouses or worsening them. On one side, there is a pessimistic attitude which considers machines as potential substitutes of human workers. On the others side, the role of machine is seen as a help for operators, both because it can ease operational and practical activities and also because it can empower them, giving the possibility to leave repetitive work position and do more strategic works with higher responsibility. In addition, these types of technology can reduce significantly the number of accidents and increase security of workers (Mostafa et al., 2019). For example, the use of RFID tags should be positively seen by workers since this technology reduce the number of mistakes thus making them surer to do not commit mistakes while performing their task and they can be more relaxed (Fosso Wamba and Chatfiled, 2011) Another example, the use of robots during COVID-19 pandemic, to check acceptance of the freight in warehouses instead of personnel, has entrain great healthy advantages. In fact, drivers could spoke in his native language, making the operations easier - there are no limits to the languages recorded on robots - and protection from COVID-19.

2.3 Conclusions

The topic of sustainability applied to supply chain management and logistics is not a recent topic. The scientific community, anyhow, has focused itself mostly on transportation rather than warehousing activities up to some years ago. By the way, as it has been shown in *Figure 2.3*, there is an increasing interest on the topic, with a number of publications which is growing exponentially. The interest of the academia has grown over years, as stated by Bartolini et al. (2019), the number of papers published considerably grew from 2015, symptom of the new awareness on the theme. This is a sign of the growing importance that Green Warehousing has in improving companies' environmental performances.

For what concern RQ1, some real case examples have been found out. Multiple factors are behind this trend. On one side, the increasing pressure from different stakeholders - such as investors and the entire society in general - are making sustainability one of the key drivers in logistics decision-making processes (Dobers et al.,2019a; Perotti et al., 2022). On the other side, more demanding regulatory pressures and growing recommendations are coming from national governments and international organizations (Rogelj et al., 2016). In addition, is clearly emerging the importance to find a solution that will create the greater benefits considering the geographical and climate condition of the location of warehouse. Several types of energy-efficient solutions have been detected going from building technique to operational strategies, highlighting the importance to intervene in all the different areas and aspects of the warehouse to obtain real benefits in terms of sustainable performances.

By answering the RQ2, as expected, it has been understood that the topic still has to be deepened. A reason for that could be the fact that the theme of resilience in supply chains emerged clearly only after COVID-19 and so, if the consequences of the disruption are already evident, scientific documents have not been written yet. Moving in this direction is fundamental because, being resilient, also a better resources management is possible and so, again, moving in the direction of an improvement in environmental performance for companies.

Concluding, for what concern RQ3, it is evident that depending on the type of technology, scientific documents have a certain degree of maturity. The oldest document in the sample used to answer the RQs was the one of 2011 speaking about RFID solutions. The application of the aforementioned technological solution is not a recent discovery, and many papers about it are available. Different reasonings needs to be done for newer solutions such as the ones exploiting data mining techniques or cyber physical systems. At a general level, by the way, what emerged is that there are different papers tackling the technical aspect of those solutions, how to implement them, some case studies and, possibly, the economic assessment of those. What is missing is an evaluation of the environmental impact coming from those solutions.

2.4 Research gaps and future improvements

The SLR has revealed some gaps that must be highlighted in a proper way to understand the context in which this Master Thesis is inserted. For each research question, the main lacks will be presented, and some possible future research will be suggested starting from these gaps. Before entering in detail, it worth to be underlined the absence of a holistic perspective while speaking about environmental sustainability. Most of the papers focuses on a single energy-efficient solution or consider just limited areas of impact for a technology. This is not enough if the final objective is to obtain improvements in all the dimensions, even the economic one. In fact, it's becoming clear, from real cases, that the only way to do so, is the combination of different type of solutions, technologies and operational practices. The academia should follow the examples coming from real cases and, starting from them, develop some theoretical models in this direction.

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

As a first point, the majority of papers identified refers to emerging economies, rather than mature ones, with generally a lower degree of sensibility related to sustainability-related topics. This trend could be explained looking at the nature of the climate conditions described in the papers above, usually harsh hot or cold. In this climate context, especially considering Green Building clusters, energy-efficient solutions could represent a significant source of savings and thus several scientists have tackled the topic. Secondly, a big portion of the case studies presented a focus on a single solution implementation rather than presenting a structured plan and roadmap towards sustainability. This is an important gap considering the increasing uncertainty around energy procurement and the increasing costs of this latter. It's becoming more and more important for companies being able to combine different types of solutions to maximize the benefits and to become able to manage multiple sources of energy simultaneously and in a flexible way. For this reason, it would be interesting to more deeply investigate this aspect, adopting a pluriannual approach in order to be able to show the improvements that a path towards sustainability could generate for a company - not only in terms of environmental performances and savings but even for brand reputation and image.

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

The review of literature shows a gap of papers linked to Green Warehousing in the post pandemic situation. In general, the main changes recorded are linked to the identification and mitigation of risks. Digital technologies and Industry 4.0 are more and more considered the main option to pursue. From a purely theoretical point of view, several papers have been found about the role of sustainability and resilience and their mutual relation. For sure, the pandemic and the other disruption episodes (among the others, Ukraine war for procurement uncertainty) have boosted the interest of scientists on this topic but have not been possible to identify clear response actions in term of operations and objectives linked to warehousing. A new possible field of research would be to understand if and how the relation between sustainability and resilience changed after the pandemic. It would be even more interesting if considering logistics sectors, since this is one of the most affected by the pandemic and the one that will face more long-term consequences. In addition, energy-efficient solutions, an important part of sustainability in logistics sector, are translated into cost savings, for this characteristic it will be particularly interesting to investigate.

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

As stated by Aravindaraj and Rajan Chinna (2022), the number of papers discussing Industry 4.0 from the perspective of warehouse management has grown over years, symptom of the increasing interest over the topic. Anyhow, a big portion of the literature found out, treated the potential benefits of the Logistics 4.0 technologies in terms of efficiency, effectiveness and cost savings, rather than focusing on the mitigation of the environmental impact of logistics sites. Additionally, in the few publications in which the topic was deepened, the point of view of the academia about the emission figures of those technologies is not unanimous. It could be useful instead, as new area of investigation, to create a commonly agreed and shared framework that shows the impact of technologies on warehouses environmental performances. This is even more important considering the increasing importance that ESG ratings are obtaining as determinants factors in the evaluation of investments - thus including environmental, social and governance aspects - differently from traditional finance which focuses only of financial return and risk (Schoenmaker, 2017).

To help in the comprehension of this section, the main gaps will be summarized in a bullet point:

- Lack of well-defined and universally agreed best practices to implement among businesses for what concern environmental performances.
- Lack of case studies on well performing logistics buildings in developed economics.
- Lack of papers treating the post-pandemic situation in warehouses and how it affected sustainability inside logistics building.
- Lack of a comparison among different Green Warehousing solutions and the related environmental benefits deriving from them.
- Lack of a complete framework grouping together all the IT and Logistics 4.0 solutions applicable to warehouses.
- Lack of a guideline on how to quantify environmental benefits coming from the implementation of Green Warehousing solution.

3 Research questions and methodology

This chapter will describe the methodology and tools used in order to develop this Master Thesis, starting from the context analysis up to the collection and analysis of final results.

3.1 Research objectives and questions

As stated, this Master Thesis tackles the topic of energy efficiency in warehouses, how it can be achieved, which are the best practices to boost the process, and how companies are working towards the net-zero target at their logistics facilities.

To do so, as a first step, a context analysis has been conducted and has already been presented in Chapter 1 and Chapter 2. The basis was the search through grey literature: reports, institutional websites, and other secondary sources. After that, a Systematic Literature Review (SLR) was performed to map the current state-of-art of the above-mentioned topic and identify existing gaps.

From these preliminary analysis and results, the objectives and directions of the Master Thesis have been settled. In particular, as suggested by Light et al. (1986), to clearly define the scope and the focus of the research, some precise and objectively answerable questions have been formulated:

- RQ1: *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*?

- RQ2: *Which roadmap have companies undergone to transition towards net-zero warehouses?*

The core of the Master Thesis, so, is made up by two different areas of investigation, the first one has an international perspective and the second one is within Italian boundaries. The international analysis has been possible thanks to the participation of Politecnico di Milano in the GILA project: a joint project research between Fraunofher Institute, Politecnico di Milano and Universidad de Los Andes (respectively: Germany, Italy and Latin America from which is derived the acronym). The objective of this consortium is twofold: present best practices and future requirements in the field of energy and resource efficient transport chain; then, to propose a methodological framework for describing detailed environmental performance of logistics sites. Anyhow, the sample analyzed for this Master Thesis comprehends only Italian and German warehouses, being the largest datasets in term of buildings mapped. The second section deepens the Italian scenario, proposing a longitudinal analysis of excellent examples of Italian warehouses to identify which are the best practices that contribute to companies' environmental performances.

3.2 Methodology

In order to develop what has been described above, a sequential flow of three main stages has been followed. Each phase is characterized by specific objectives, research methodologies, analysis and outputs. In the next paragraphs each step will be deepened.

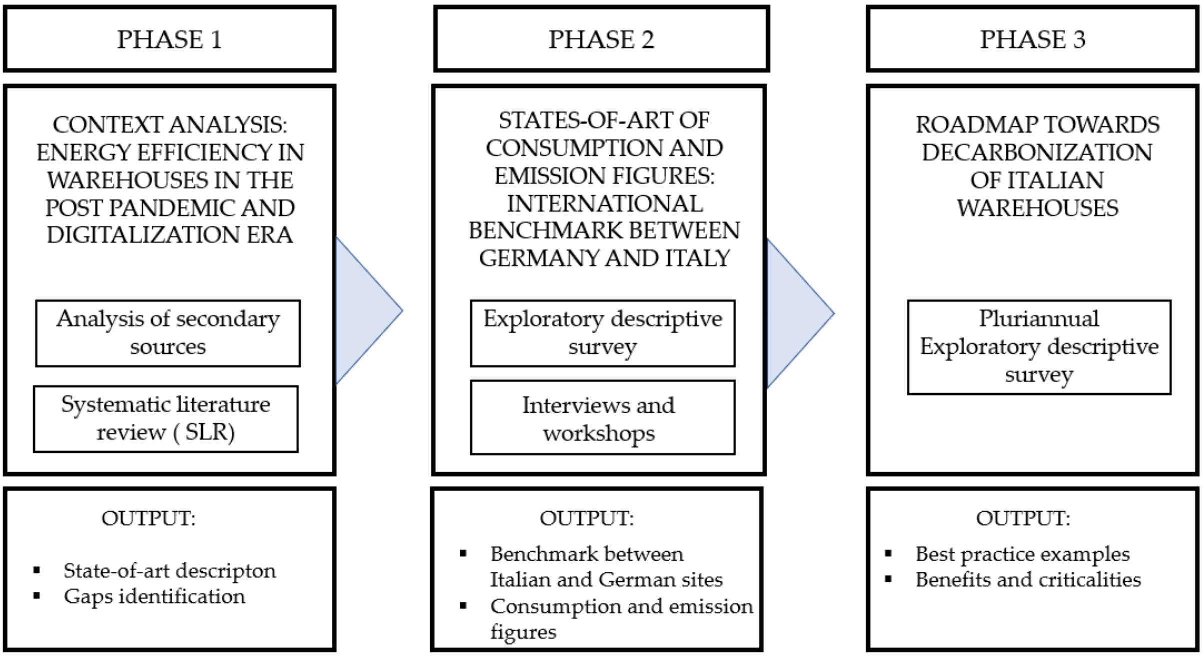


Figure 3.1 Master Thesis methodology: sequential flow

3.2.1 Context analysis: energy efficiency in warehouses in the post-pandemic and digitalization era

The objective of this section is to understand the context in which the study is inserted; deepening how sustainability is translated in logistics sites and which are the guidelines and frameworks to track emissions and consumption data. In performing this analysis, some other investigations have been conducted. First, it has been assessed the availability of academic papers presenting best practices of logistics buildings in terms of energy-efficient solutions implemented. Then, it has been assessed how companies are adapting their sustainability strategy as a response of recent supply chain disruptions, such as COVID-19. Lastly, another topic that this Master Thesis treats is the link between Logistics 4.0 solutions and the benefits generated in terms of environmental performances.

3.2.1.1 Analysis of secondary sources

The examined secondary sources include international reporting frameworks and standards, companies' sustainability reports, institutional websites and universities' textbooks. To present the results obtained, Chapter 1 has been divided into 3 main sections.

The first section provided an overview on logistics sustainability in general terms, together with the main reporting standards. Afterwards, the logistics sector has been tackled, inserting its evolution over time and the most important definitions in order to create a common language to be used in the whole Master Thesis.

Second section's focus was the link between sustainability and resilience: particularly, COVID-19 pandemic and the analysis of its consequences on logistics, both at macro level and micro level. At macro level considering warehouse as single node of a more complex supply chain system. At micro level, more in terms of social sustainability, looking at the consequences of disruptions on workers inside warehouses.

Concluding, topic of section three was the application of Logistics 4.0 solutions and the potential benefits that they can generate for companies' environmental performance.

ANALYSIS OF SECONDARY SOURCES	
REASERCH METHOD	Analysis of data about sustainability performance assessment in warehouse, impact of COVID-19 pandemic and of digitalization, collected through company and institutional websites, logistic magazines and papers.
SOURCES	• Companies' websites • EU and Italian government websites • Logistic papers • Consultancy reports • Politecnico di Milano researches and articles
OUTPUT	Overview on the current guidelines for sustainability reporting and on the effect of disruptions on warehouses and the interpretation of sustainability in logistics, focusing on the role of digital technologies.

Figure 3.2 Schema: Analysis of secondary sources

3.2.1.2 Scientific literature analysis: SLR

As stated in Chapter 2, the systematic literature review (SLR) method has been chosen to present the scientific literature analysis. This method was proposed by Tranfield et al. (2003) and it employs a predefined evaluation procedure that allows to reduce any kind bias and ensure an objectives and scientific output (Denyer and Tranfield, 2009). This structured methodology was chosen to support the literature review because of the principles on which it is built, namely transparency, inclusivity, explanatory and heuristics (Torraco, 2005; Meline 2006; Denyer and Tranfield, 2009; Rhoades 2011). The two main objectives of these types of reviews are:

- Discuss and analyse the current scientific literature on a specific topic
- Detect existing gaps and suggest future research studies

As a first step, SLR requires the formulation of precise and clearly answerable research questions, in order to set the direction of the study. This aim has been reached by adopting a "CIMO logic" (Denyer and Tranfield, 2009), whose acronym stands for “Context”, “Intervention”, “Mechanism”, “Outcome”. The idea is to combine problematic Contexts with certain Intervention types, which follow determined generative Mechanisms, to deliver specific Outcomes. In the specific case, the application of the tool has allowed to obtain the following result:

- Context: *Sustainability and environmental performance assessment in warehousing*

The increasing external pressure from stakeholders is pushing companies and supply chains to commit themselves and invest in energy-efficient solutions for warehousing in order to improve their environmental performance. Despite the considerable environmental impact of warehouses in terms of carbon footprint, the topic has often been neglected in the past. Now, managers understood the importance of this critical areas and the number of green-related projects have been intensified.

- Interventions: *Latest tools and best practices for environmental performance improvements*

In order to understand how companies can improve their environmental performance, it is fundamental to investigate which are the currently available tools, to be read in most of the cases as technologies, and which benefits they can bring to companies. Additionally, what can be done is to look at best practices on the market and emulate them. By seeing the results that companies have obtained, other actors can feel willing to embrace the same path.

- Mechanism: *Performance monitoring and improvement*

Performance measurement and monitoring is fundamental to obtain results. It is important to understand which are the tools that best fit the specific context, apply them and monitor the results. Additionally, it needs to be understood how those new tools fit with existing systems to optimize performances while reducing companies’ environmental impact.

- Outcome: *Consumption reduction and environmental performance improvement at warehouses*

The combination of new solutions together with the emulation of the best practices on the market, are expected to improve both operational aspects and, above all, the environmental performance.

From the application of this framework, the following research questions have been formulated:

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

To answer the above listed questions, scientific literature papers have been searched in electronic databased through the formulation of specific keywords. Great attention has been given to the combination of those keywords using some Boolean operators and parentheses. The truncation character "*" has allowed to consider in the search all the terms, nouns, adjectives or verbs, with the same root word. The following groups have been identified:

- *Group A* includes terms referring to logistics sites and warehouses: "warehous*", "logistic* site", "logistics hub", "logistics facilit*".
- *Group B* considers terms linked to energy efficiency and sustainability: "sustainab*", "green", "decarbon*", "GHG", "CO2", "energy efficienc*", "social sustainab*" "CSR".

- *Group C* comprises all the terms relating to business cases: "business case", "case stud*", "real case".
- *Group D* includes the terms related to disruption and resilience: "disruption" "resilien*" "shock" "crisis" "pandemic" "COVID-19".
- *Group E* considers words which are linked to digitalization: "technolog*", "digitaliz*" "technological innovat*", "logistic* 4.0", "data", "data analy*".
- *Group F* comprises all the data collection and performance assessment terms: "performance", "measur*", "KPI*", "indicator*", "assess*", "monitor*", "track*".

In order to answer the three RQs, two different logical structures have been used: the first one to answer RQ1 and the second one to answer RQ2 and RQ3 together.

The final query for RQ1 is:

[('*Group A*' AND '*Group B*') AND ('*Group C*')]

TITLE-ABS-KEY: (("warehous*" OR "logistic* site" OR "logistics hub" OR "logistics facilit*") AND ("sustainab*" OR "green" OR "decarbon*" OR "GHG" OR "CO2" OR "energy efficienc*" OR "social sustainab*" OR "CSR")) AND ("business case" OR "application" OR "practic*" OR "implement*" OR "real case").

Grouping together *Group A* and *Group B* is needed to consider simultaneously sustainability topics applied to warehouses or logistics sites. Then, both have been combined with Group C in order to search for case studies.

The final query for RQ2 and RQ3 is:

[('*Group A*' AND '*Group B*') AND ('*Group D*' OR ('*Group E*' AND '*Group F*'))]

The first parenthesis (A and B) has been combined with the keywords of group D or those of Group E and F together. If combined with *Group D*, the main goal is to answer RQ2; if the AND operator goes with *Group E* AND *Group F*, papers better answer RQ3. The final result was:

TITLE-ABS-KEY: ((“warehous*” OR “logistic* site” OR “logistic* hub” OR “logistics facilit*”) AND (“sustainab*” OR “green” OR “decarbon*” OR “GHG” OR “CO2” OR “energy efficienc*” OR “social sustainab*” OR “CSR”)) AND ((“disruption” OR “resilien*” OR “shock” OR “crisis” OR “pandemic” OR “COVID-19”) OR ((“technolog*” OR “digitaliz*” OR “technological innovat*” OR “logistics 4.0” OR “data” OR “data analy*”) AND (“performance” OR “measur*” OR “KPI*” OR “indicator*” OR “assess*” OR “monitor*” “track*”))).

Once the searching phase was completed, all the papers collected have been organized into an Excel database, writing down authors, title, year, source, first author’s country, and document type. The goal was to create a shortlist that would have constituted the basis of the SLR. Three selection stages have been performed: screening, eligibility and final inclusion. In particular, in the screening phase, two filters have been set: papers had to be published in relevant conference proceedings or peer-reviewed international journal, to ensure high quality, and had to be written in English.

In the eligibility step, inclusion and exclusion criteria has been defined. For example, have been excluded all the papers tackling environmental sustainability of supply chain in general and, instead, included all the ones strictly related to warehouses. Then, the papers that have passed the first two steps have been carefully read in order to really understand if they were answering the research questions or they were out of scope. Moreover, a cross-referencing procedure has been conducted in order to include papers that were omitted from previous string search. The above-mentioned procedure has brought to a collection of 34 publications, starting from 616 documents. The chosen ones have been enumerated in chronological order into a table and, for each of them, the general characteristics were reported together with the indication of which research questions that paper was answering.

Finally, a critical analysis has been performed in order to outline the state of art of Green Warehousing related topics, identify research gaps and suggest managerial and future research. It has been defined the context in which this Master Thesis will be developed and the direction the work will have in trying to fill the gaps founded. In particular, from the analysis of secondary sources and from the SLR, some important gaps in the literature emerged, starting from these an empirical analysis will be presented in the next section together with the main objectives of this Master Thesis.

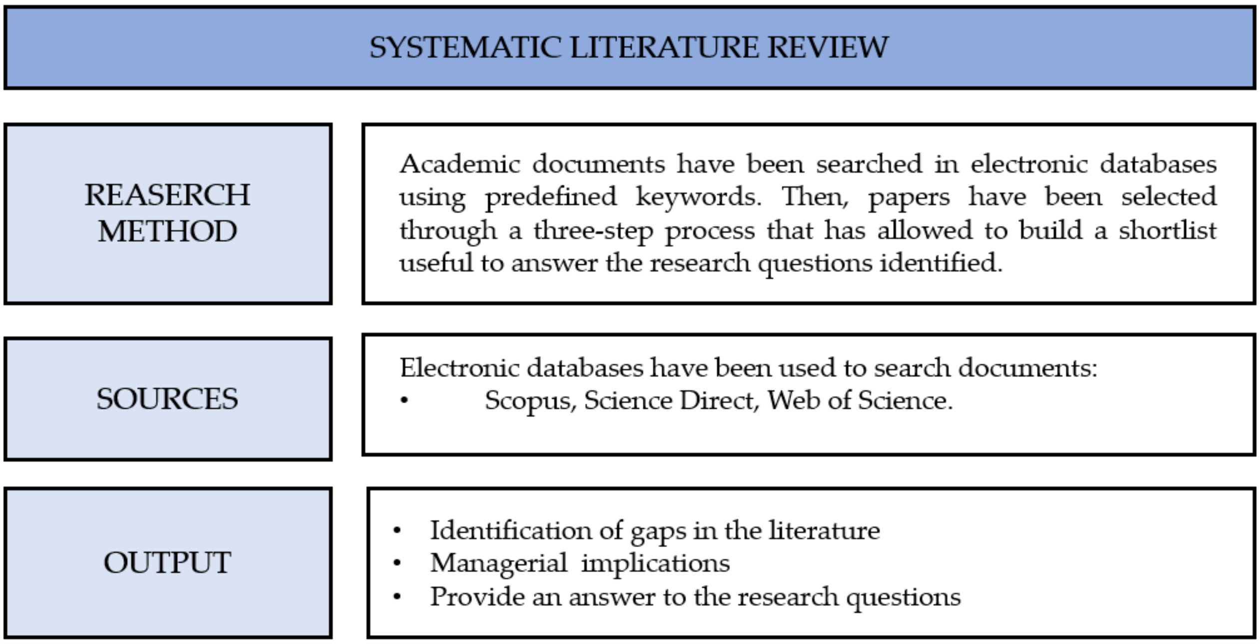


Figure 3.3 Schema of the systematic literature review

3.2.2 States-of-art of consumption and emission figures: international benchmark between Germany and Italy

The international perspective, as stated, has been allowed by the involvement of Politecnico di Milano in the GILA project. In order to benchmark Italian and German warehouses' data, an exploratory survey through a questionnaire has been designed. Moreover, some answers of managers have been furtherly explored through interviews to better deepen the sample and provide some examples of best practices.

3.2.2.1 Exploratory survey

The survey needs to be considered the tool for collecting the information from companies about the energy-efficient solutions implemented at their logistics sites, as well as to collect data on consumption figures related to electric energy, fuels. For the Italian sites, the questionnaire was sent to a set of companies belonging to the Observatory of Contract Logistics "Gino Marchet" of Politecnico di Milano. Since 2017, the Observatory has set up a research group with some of its main partners to look at the latest trends and insights of Contact Logistics. The survey diffused by the Fraunhofer Institute, for the German sites, is very similar in terms of contents to the Italian on and all the data collected have been analysed following the same criteria. For this last reason, in the next section only the Italian questionnaire will be presented in detail.

3.2.2.1.1 The questionnaire

The questionnaire, provided through a Microsoft Excel file, is made up by three spreadsheets. The first spreadsheet incudes both general questions – such as type of warehouse, location and other building features – and more specific ones - as energy consumption data, types of refrigerants or waste amount from packaging. The second spreadsheet is constituted by 3 sections regarding the daily product flow, number of forklifts owned, and information about the different functional areas in which the warehouse is divided. Lastly, the third page shows an example of a pre-filled questionnaire with the aim of reducing mistakes or any kind of misunderstanding.

Some cells of the questionnaire are drop-down menus, where the company can choose among the suggested options. Moreover, a column "notes" is provided to give companies the possibility to enrich the information presented.

General information

The first section gathers general information about the company and the type of warehouse. This includes:

- Name of the company
- Warehouse code
- Warehouse type: plant warehouse, central warehouse, peripherical warehouse, transit point, mass-market retailer distribution centers
- Address of the site
- City of the site
- Province of the Site
- Certification: LEED Platinum, LEED Gold, LEED Silver, BREEAM, Other (Specify)

Questionnaire: Energy Efficiency in warehouses (Dati referred to year 2021)		Answer	UdM	Source	Notes
1. General information	Name of the company				
	Warehouse code				
	Warehouse type				
	Warehouse address				
	City				
	Province				
	Certification				Other specification: Specificy ____

Figure 3.4 Questionnaire: General information

Warehouse features

In this part, all the characteristics of the warehouse are presented - like dimension, industry and temperature. Actually, all the features which are fundamental to understand and interpret the result of the analysis. More in detail it is possible to find:

- Industry Sector: Frozen Food, Chilled Food, Dry Food, Automotive, Beauty & Personal Care, Consumer Electronics, Pharma, Fashion, Hospital, Retail No-Food, Beverage, Agri-Food, Furniture and Other
- Surface of the Building [m^2]
- Height [m] or Volume [m^3]
- Capacity of the Building [PL Places]

- Temperature: Room-Temperature, Multi-Temperature, 0°-4°C, 7°-15°C, 15°-18°C, -25°C
- Refrigerate Cell Volume [m^3]
- Year of Construction
- Inbound/Outbound Flow of Goods [kg/year] or [PL/year]
- Loading/Unloading Bays
- Type of activity carried out within the site: storage and/or cross-docking, picking, other activities
- Presence of Automation Systems in the Warehouse

2. Warehouse features	Industry sector				Ohter: Specify __________
	Building's floorspace		m^2		
	Height (or alternatevely volume in m3)		m		
	Capacity of the building		Pl place		
	Temperature		°C		Multi-temperatura
	Refrigerate cell volume		m^3		
	Year of construction				
	Flow of goods		kg/anno		
	Loading/unloading bays				
	Types of activities performed				
	Stock and and/or cross-docking				
	Picking				
	Others				
	Presence of automation systems				**(OPEN ASWER. For each: LIST SHORT DESCRIPTION)**

Figure 3.5 Questionnaire: Warehouse's features

Electrical consumption

Companies were asked to report the annual consumption of electric energy and indicate if they were able to self-produce it - like through photovoltaic panels - or if they bought it from certified renewable sources. In addition, electrical consumption mix was asked: meaning specify the share of electricity used for lighting, handling, cooling or for other purposes.

3. Electrical Consumption	**Total electrical consumption**		kWh/anno		
	Of which produced by photovoltaic systems in self-consumption		kWh/anno		**ONLY if energy is produced for self-consumption; self-generated energy sold to third parties should be excluded.**
	Of which purchased from certified renewable sources		kWh/anno		
	Indicate the breakdown (mix) of electricity consumption (total 100%):				
	Lighting		%		
	Material Handling		%		
	Cooling		%		
	Other: Specify ___________		%		

Figure 3.6 Questionnaire: Electrical consumption

In case companies were not able to fill this point, some standardized shares have been used. As showed in *Figure 3.7*, the shares are differentiated for ambient temperature, chilled and frozen warehouse areas. Those values are taken from Green Router, a managerial tool allowing to estimate and monitor the environmental impact of transport, storage and other logistics activities over time.

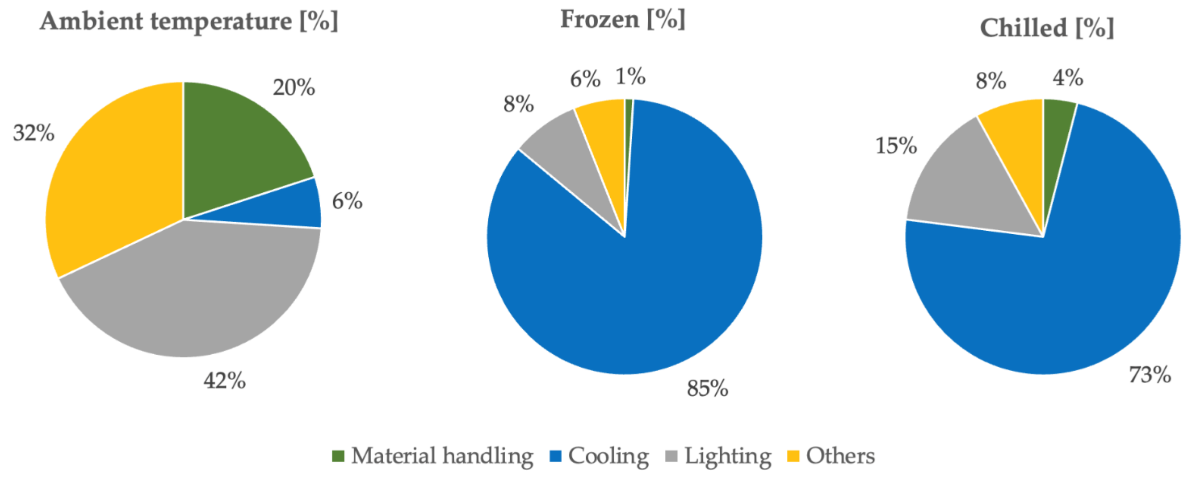


Figure 3.7 Green Router Standardize energy mix

Fuels

The use of fuels is both connected to material handling and heating. In this section companies are asked to provide separately the quantities related to those two activities. In the survey, just the most common types of combustible have been explicitly reported, for instance: GPL, diesel, CNG or hydrogen. In case the company

uses fuels that are not present in the list, there was a line called "Other: specify" to insert it together with the respective amount.

4. Fuels	**Material handling**		
	GPL		l / year
	Diesel		l / year
	CNG		m3 / year
	Hydrogen		
	Other: Specify ___________		
	Heating		
	LPG		
	Diesel		
	CNG		
	Other: Specify ___________		
	Other: Specify ___________		

Figure 3.8 Questionnaire: Fuels Consumption

Refrigerants

Similar to fuels, the most common refrigerants are listed: R134A, R404A, R407A, R507A, Ammonia and CO2. In this case the unit of measure is fixed [kg/year], and company are asked to insert the amount used for each of them.

5. Refrigerants	R134a		kg /year*	*Expressed in kg recharged in the system in one year. **NB: Consider only the quantity for the annual refill and not the replacement.**
	R404A		kg /year*	
	R407A		kg /year*	
	R507A		kg /year*	
	Ammonia		kg /year*	
	CO_2		kg /year*	
	Other: Specify ___________		kg /year*	

Figure 3.9 Questionnaire: Refrigerants Consumption

Packaging and material waste

Last section about consumption values is related to packaging and waste. In particular, companies were asked to provide the amount of plastic and carbon packaging and of pallets loads used in warehousing operations. Same way, the quantity of plastic, carton and wood waste generated was requested.

6. Packaging materials and generated waste	Use of plastic packaging		kg / year		Average distance from suppliers: __
	Use of paper packaging		kg / year		Average distance from suppliers: __
	Use of pallets		pallet / year		Average distance from suppliers: __
	Waste from plastic packaging		kg / year		
	Waste from paper packaging		kg / year		
	Wood waste		pallet / year		
	Other: Specify ___________		kg / year		

Figure 3.10 Questionnaire: packaging Materials and Waste Section

Solutions for energy efficiency

Another big portion of the survey is about the energy-efficient solutions implemented. The different solutions are presented in a framework made up by 6 main clusters: Green Building, Utilities, Lighting, Material Handling and Automation systems, Materials Management and Operational practices. Within each cluster has been created a pre-defined set of solutions, so that companies could have directly marked the ones implemented and, in case, add the others not listed. To do so, different sources has been consulted: literature and secondary sources, workshops with companies collaborating with Observatory Contract Logistics "Gino Marchet" or other hints from Fraunhofer institute research group. The final list includes a total of 30 energy-efficient solutions. In red it's possible notice the solutions that have been added this year.

has been consulted: literature and secondary sources, workshops with companies collaborating with Observatory Contract Logistics "Gino Marchet" or other hints from Fraunhofer institute research group. The final list includes a total of 30 energy-efficient solutions. In red it's possible notice the solutions that have been added this year.

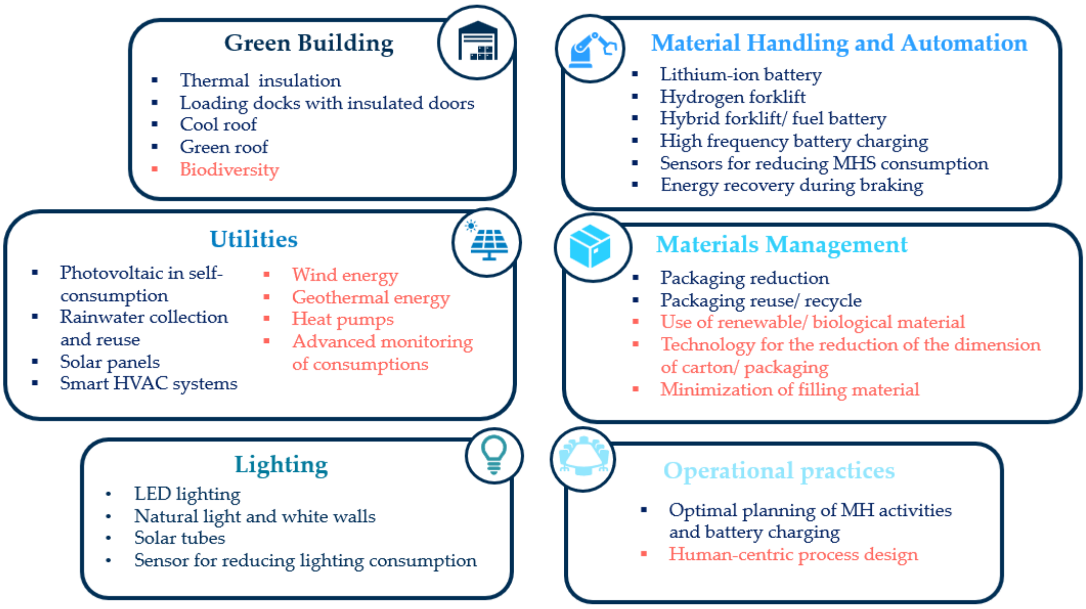


Figure 3.11 Framework of energy-efficient solutions in warehouses

Companies were asked to tell if the solution was implemented into their sites or not. In case of negative answer, they were asked to indicate if the solution under discussion could have represented a priority for them for the future. In doing so, a number from 1 to 5 should have been inserted, where 1 represented the maximum priority and 5 the minimum.

		Adoption to date	(Insert a X for the solution adopted)	Priority for future intervention (1=max priority; 5=min)
6. Energy efficiency solutions	"Green Building"	Thermal insulation/ Renovation		
		Loading dock with insulated doors		
		Cool roof		
		Green roof		
		Biodiverstiy		
		Others		
	Utilities	Phtovoltaic in self-consumption		
		Solar panels		
		Rainwater collection and reuse		
		SMART HVAC system		
		Wind energy		
		Gheotermal energy		
		Heat pumps		
		Other		
	Lighting	LED lights		
		Natural light and white walls		
		Solar tubes		
		Sensor for reducing lighting consumption		
		Ohters		
	Material handling and automation systems	Lithium-ion battery		
		Hydrogen forklift		
		Hybrid forklift/ fuel battery		
		High frequency battery charging		
		Energy recovery during braking		
		Sensor for reducing MH consumption		
		Other		
	Materials	Packaging reduction		
		Reuse/ recycle packaging		
		Use of renewable/biological materials		
		Technology for the optmization of the carton dimension		
		Minization of filling materials		
		Other		
	Operational practices	Optimal planning of MH activities and battery		
		Human centric process design		
		Other		

Figure 3.12 Questionnaire: Energy-efficient solutions

Inbound/ outbound flow details

Turning into the second page of the questionnaire, the subject is inbound and outbound flows. Particularly, the first section collects information regarding the inbound and outbound flows of pallets in the warehouse. Those data are essential order to allocate the total emissions of the sites to the different functional areas of which the building is composed. It is also asked the percentage of pallets related to outward flows coming from storage activities, the ones of inward pallets managed in transit and the average number of pallets per day that are subject to transit only.

8. IN/OUT Flow Details		
To facilitate the filling of the table, see the notes on the right		**Notes**
% PALLET OUT coming from storage	%	**Average % of pallets** coming out of **storage**
% PALLET IN transit only	%	**Average % of pallets** that are managed **in transit**
Number of pallets transit only [pallet/day]		**Average number of pallets/day** that are subject to **transit only**

Figure 3.13 Questionnaire: Inbound/Outbound Flow Details Section

Functional area details

Companies can provide detailed information about the different areas of the warehouse. For each, it is asked:

- Activity carried out in the area: Inbound/Outbound, Storage, Picking, Cross-docking & Sorting, Offices.
- Surface [m^2]
- Height [m]
- Volume [m^3]
- Temperature [°C]: Ambient Temperature, 0°-4°C, 7°-15°C, 15°-18°C, -25°C
- Type of Lamp: Neon, LED, Halogen, Incandescent

- Number of Lamps

Respondents have to insert an "x" in the cells corresponding to the functions carried out in that area. Finally, the Excel spreadsheet automatically performs a check comparing the total surface of the warehouse, inserted in the first page, to the sum of the surfaces of the areas described in this section. If the values correspond, the check cell will show "correct", otherwise "error".

9. AREAS Details: Subdivision of the mapped warehouse into functional areas (useful for functional efficiency benchamrk)
To facilitate the filling of the table, see the notes on the right

	Activities carried out in the area *					Surface	Height	Volume **	Temperature	Type of Lamp	Number of Lamps	Notes
	IN/OUT	STORAGE	PICKING	TRANSHIPMENT (cross-docking)	OFFICES	m²	m	m³	°C			**Activities carried out in the Area***= insert one or more "x" to indicate the activities in the area. **Volume** **= enter value only if the temerature in the area is NOT ambient temperature.
Area 1												
Area 2												
Area 3												
Area 4												
Area 5												
Area 6												
Area 7												
Area 8												
Area 9												
Area 10												
Sum						*0*						*The function returns "correct" if the covered area of the site corresponds to the sum of the measurements of the different areas*
Check						*correct*						

Figure 3.14 Questionnaire: Functional areas Details section

Material Handling Details

As shown in *Figure 3.15*, a list of Material handling systems (MHS) is proposed. The company has to specify the number of units handled by each type of equipment.

10. MATERIAL HANDLING Details
Specify the number of units for each type of material handling system — **Notes**

TYPOLOGY	Transpallet	Order Picker	Straddle Reach Truck	Counterbalance Forklift	VNA Forklift	Other	
NUMBER OF UNITS							

Figure 3.15 Questionnaire: Materials Handling details

EXPLORATORY DESCRIPTIVE SURVEY	
REASERCH METHOD	Descriptive survey through a questionnaire with the objective to gather real information from companies.
SOURCES	Data referring to a total of 193 warehouses, of which 127 Italian and 66 German, for a total surface covered of more than 4,8 mln square meters.
OUTPUT	• Energy-efficient solutions adopted and related prioritized ones for future • Resource consumption and emission • Benchmark between Italian and German sites

Figure 3.16 Schema of exploratory descriptive survey

3.2.2.2 Interviews and workshops

To give a complete picture of the Italian scenario in terms of consumption and emission figures at logistics sites and warehouse energy-efficient solutions in place, two case studies have been subsequently investigated. Those case histories have been chosen as an example of excellent application of Green Warehousing solutions which have brought to a significant improvement in environmental performances. This aspect has been considered particularly important and value adding for this Master Thesis also based on what has emerged from the SLR: poor scientific evidence of successful case histories having a holistic perspective about what can be obtained from the implementation of Green Warehousing solutions.

To get the information needed to develop the cases, both online interviews and the workshop of the Observatory Contact Logistics "Gino Marchet" of Politecnico di Milano were useful. During the interview, some general and more specific questions have been asked to the data subject

INTERVIEWS AND WORKSHOPS	
REASERCH METHOD	Data were gathered in two ways: • Online interview • Presentation during workshop supported by a Power Point presentation
SOURCES	Data referring to two company, the first is a logistics service provider operating at a national scale, the other is a manufacturer of electric components.
OUTPUT	Presentation of some excellent examples to get the overall strategy and philosophy adopted for increasing the sustainability of a logistics building, rather then single solutions as in the previous section.

Figure 3.17 Schema of interviews and workshops

3.2.3 Roadmap towards decarbonization of Italian warehouses

Starting from the analysis of the responses to the questionnaire collected over a 5-year timeframe during the different editions of the research connected to the Observatory Contract Logistics, an in-depth investigation has been performed of those warehouses whose data were available for at least 3 years. The purpose was to start analyzing companies' choices and related warehouse environmental performance over time, thus examining the roadmap towards net-zero warehouses that companies have put in place. For the purposes of the present Master Thesis, four different successful case histories will be specifically presented, performing a longitudinal analysis over years. The goal is to analyse the evolution of consumption and emission figures over time, linking the letters to the implementation of Green Warehousing solutions. This longitudinal analysis is particularly interesting considering that energy-efficient solutions, as all sustainability topics, are new and fast evolving themes characterized by continuous improvements and changes.

3.2.3.1 Case selection

Some criteria have been adopted to select the case studies that will presented in the next chapters. 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 considered, in terms of tenant (two LSPs and two retailers), warehouse temperature, warehouse size and year of construction.

3.2.3.2 Case analysis

As suggested by Eisenhardt (1989), the approach through which building theories from case studies includes a "within case analysis" and a "cross-case analysis". In the first phase, each case is analysed in an isolated way, independently from all the others. The second phase, then, aim at identifying common patterns, synthetizing the information obtained and capturing new insights to be applied at an industry-level. Data computation (i.e., consumption and emission figures) was supported by MS Excel.

ROADMAP TOWARDS DECARBONIZATION OF ITALIAN WAREHOUSES	
REASERCH METHOD	4 case studies among dozen of different warehouses have been selected according to 3 main criteria: • Clear path toward sustainability • More than 3 years of data availability • Heterogeneity of the sample
SOURCES	Data referring to four companies operating in the logistic sector, two as logistic service providers two as commitments, gathered through a multi year database
OUTPUT	Presentation of the evolution of emissions and consumption according to the strategic choice on sustainability taken by the companies and on the energy efficient solutions installed

Figure 3.18 Schema Roadmap towards decarbonization of Italian Warehouses

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

Objective of this chapter is to answer the first RQ1, thus presenting the current situation of warehouses in terms of consumption and emission figures and the type and number of energy-efficient solutions adopted. This goal will be achieved benchmarking Italian data - coming from the exploratory survey spread by the Observatory Contract Logistics "Gino Marchet" - and German data coming from GILA project, more deeply presented in the previous Chapter. The information collected have been exploited to calculate the emissions, thanks to the use of Green Router software, then the data have been analysed through Excel to obtain the results that will be presented in the next pages.

The chapter will be organized as follows: first, a description of the data sample will be provided; then, the different type of energy-efficient solutions implemented will be discussed and this information will be used to investigate the main consumption and emission sources. The whole dissertation will highlight, step by step, the differences between Italian and the German sites, trying to provide specific discussion. Lastly, to offer a deeper comprehension some best practices in terms of green warehouses, two specific cases will be in depth described.

4.1 Sample analysis

The total sample is composed by a total of 193 buildings, where 127 are located in Italy and 66 in Germany, equal to an overall floorspace of more than 4,823,000 m^2 examined. In *Figure 4.1* and *4.2,* it's possible to see the composition of GILA sample data in term of countries covered and the geographical location of the Italian sites. The corresponding information is missing in the German database since data received have been anonymized. In the latter, the names of the companies and the addresses have not been provided.

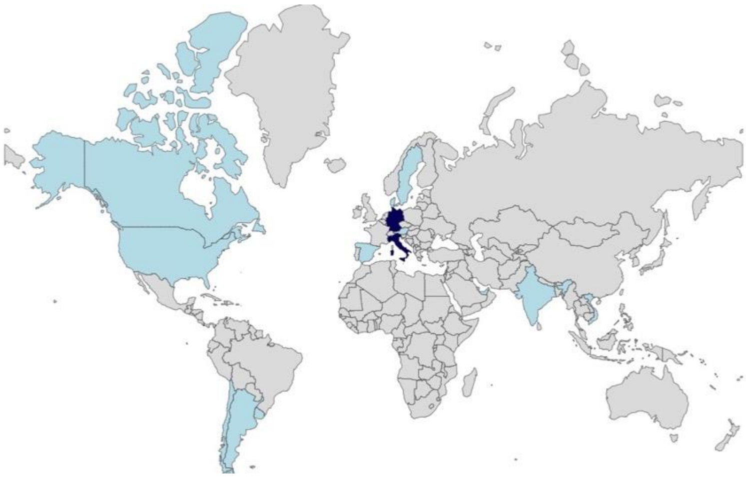


Figure 4.1 Location of examamined warehouses belonging to GILA database

Figure 4.2 Location of Italian warehouses

As far as the **warehouse floorspace** is concerned, as shown in *Figure 4.3*, the Italian sample is quite homogeneous in terms of size of the sites. The German one, instead, encompasses mostly big buildings, with more than the 40% warehouses exceeding 60,000 m².

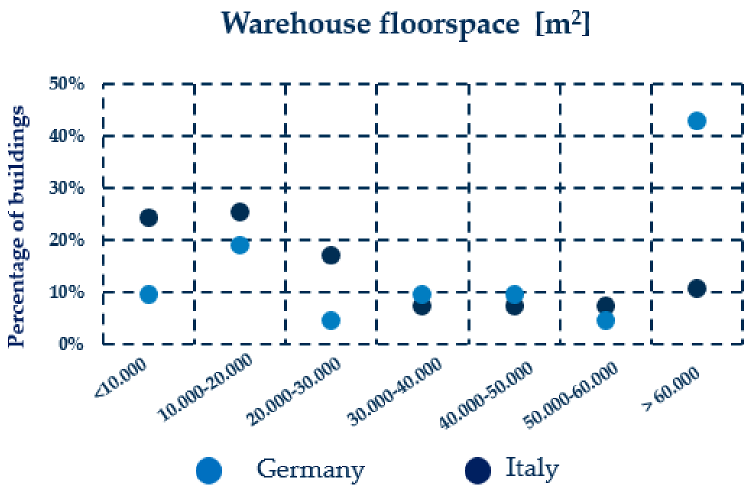


Figure 4.3 Warehouse floorspace

For what concern the **warehouse height**, the two samples are similar: the average is respectively 10,6 m and 10,3 m for Germany and Italy. The Italian sample, then, is the one covering a wider range in term height, thus reflecting different types of logistics buildings being considered (e.g., from transit points to central distribution centers).

Figure 4.4 Warehouse height

Considering **year of construction**, the sample is composed by recent warehouses: more than half was built after 2000. In any case, the presence of older logistics hubs is interesting to investigate how energy-efficient solutions are managed for these buildings.

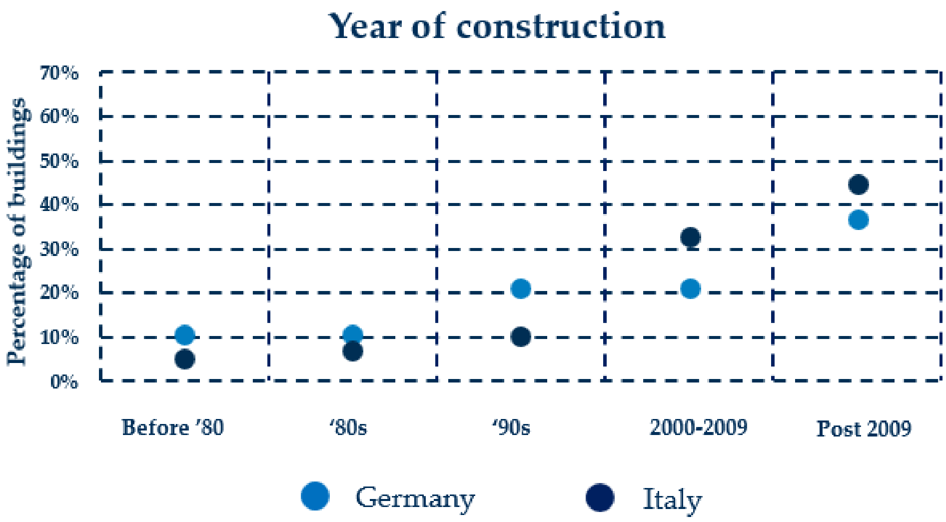


Figure 4.5 Year of construction

Focusing on **temperature**, *Figure 4.6*, it's possible to notice a difference between the two samples: the German one appears equally divided between multitemperature (44%) and ambient warehouses (46%), while the Italian one is characterized by a majority of ambient warehouses (67%). It has also to be considered that the presence of temperature-controlled warehouses in the Italian sample is higher than in the German one: respectively, 20% and 10%. This is mainly due to the different composition of these two: in the Italian one there is a remarkable presence shipper operating in the food sector, and in the German one there is a bigger portion of real estate constructors.

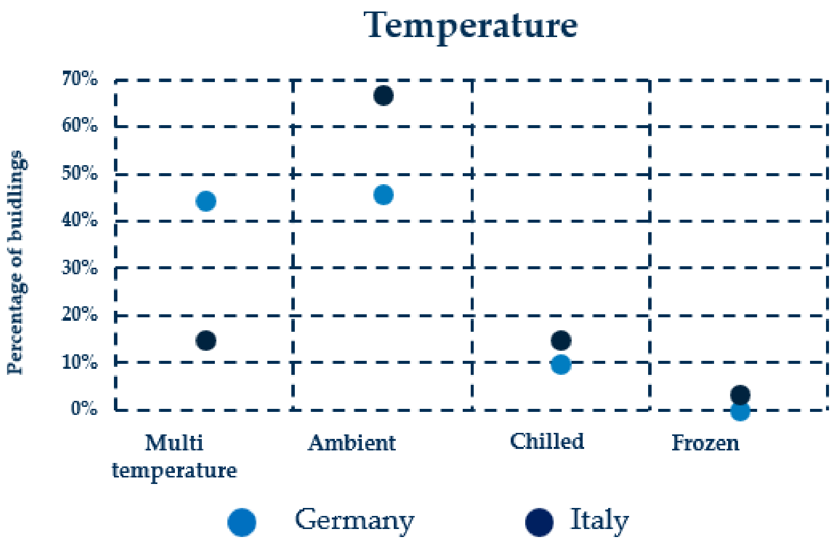


Figure 4.6 Warehouse Temperature

Before focusing on the types of solutions adopted, another important information to report is the **industry sector** of the sample considered. The Italian sample is characterized by quite a good number of players operating in the food sector, dry and chilled. The German one, instead, is composed of a majority of multi-sectors warehouses.

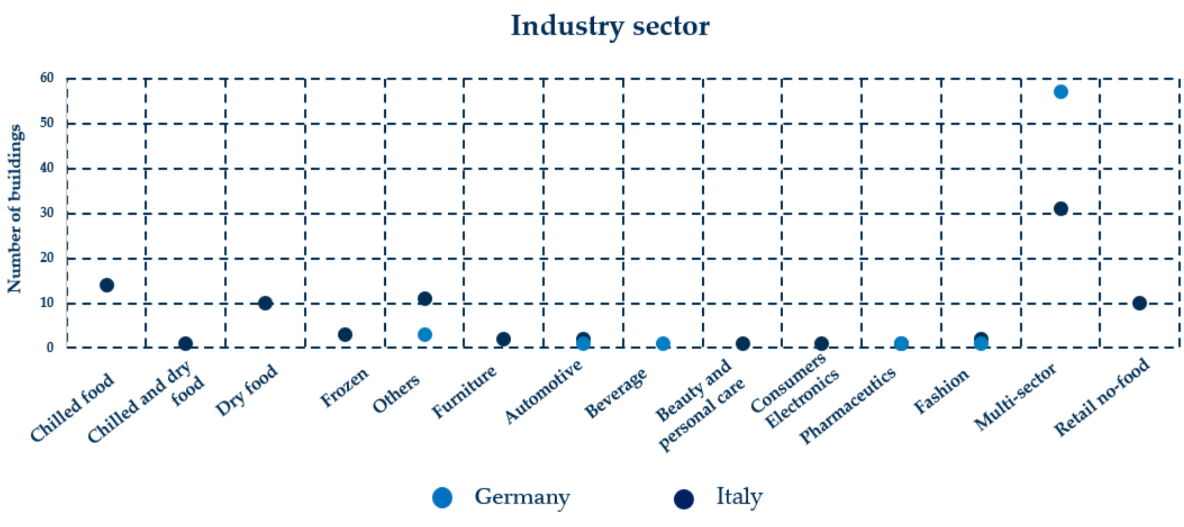


Figure 4.7 Warehouse market sector

4.2 Implementation of energy-efficient solutions: international benchmark

After having presented the main characteristics of the sample, the focus from now on will be the degree of adoption of the different energy-efficient solutions. This part will be divided into two main sections: in the first one, a general presentation of the current adoption and prospective scenario will be performed; then, a more in-depth analysis will be presented going through each cluster of solutions separately.

4.2.1 Introductory remarks

As shown in *Figure 4.8*, Lighting is currently the priority for companies in both countries: in Italy, Lighting solutions are the 23% of the total solutions implemented; in Germany this percentage equals 26%. Those numbers have been computed by dividing lighting solutions implemented over the total number of solutions in place. This logic will be followed in all the other graphs of this chapter.

In the Italian sample, it's possible to notice an increasing interest in Material Handling and Automation system and Utilities solutions, both with a percentage of adoption above 20%, while in the German sample greater importance is given to Green Building solutions. These differences are coherent with the different climate conditions of the two countries and the different composition of the samples in terms of building type.

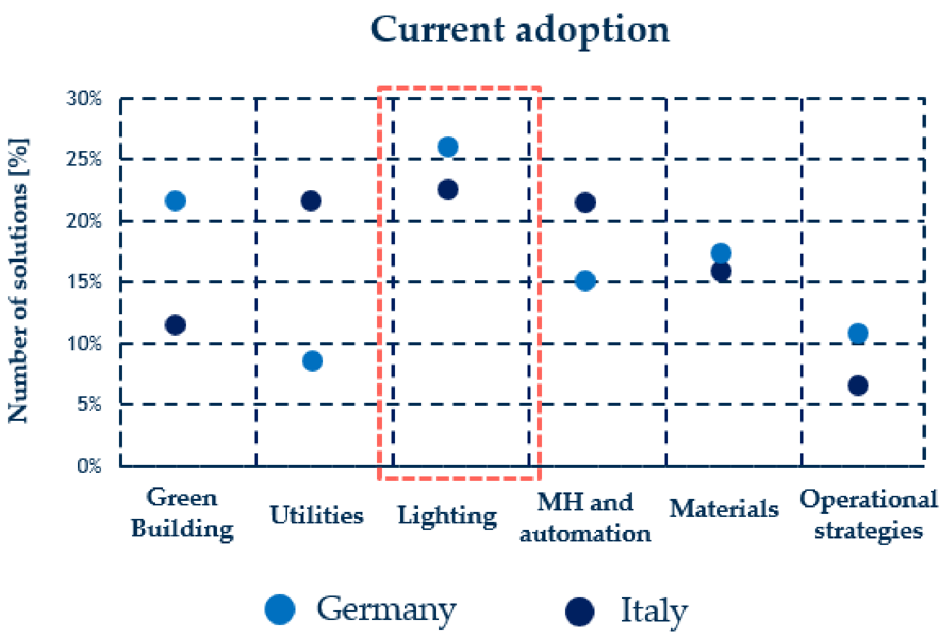


Figure 4.8 Energy-efficient solution: current adoption

Looking at the prospect scenario (*Figure 4.9*), intended as the solutions that companies prioritize for the near future (i.e., in 5 year-time), a similar pattern to the one highlighted in the current scenario can be identified for Green Building and Material Handling and Automation solutions. Particular attention needs to be given to Materials Management, especially for the German sample: the importance associated by companies to those topics is rising significantly, also because, as stated by Das et al. (2022), Materials Management is not only linked to an improvement in the environmental performance but even to important cost savings, both in terms resources consumed and transportation costs. This is even more meaningful if linked by companies to those topics is rising significantly, also because, as stated by Das et al. (2022).

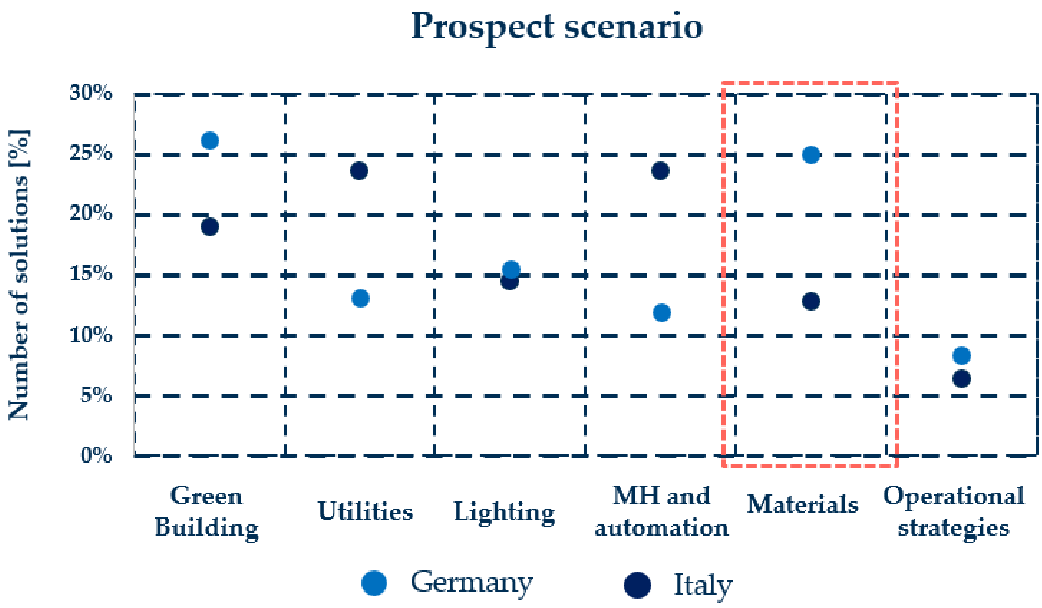


Figure 4.9 Energy-efficient solutions: prospect scenario

4.2.2 Green building solutions

Considering the Italian scenario, the most spread solutions are thermal insulation and loading docks with insulated doors: respectively, 49% and 43% of sites in the sample are implementing them. As stated, Green Building solutions are more implemented in Germany due to the harsher climate conditions. Looking in detail, the most applied solution is thermal insulation with a percentage of adoption of 40%, followed by a green roof (30%). The predominance of thermal insulation in both the samples is even more interesting if considering Ries et al. publication (2017). In fact, this type of interventions assures a reduction in energy required by HVAC from 6% to 15% and a reduction in CO_2 emissions from 4% to 12%.

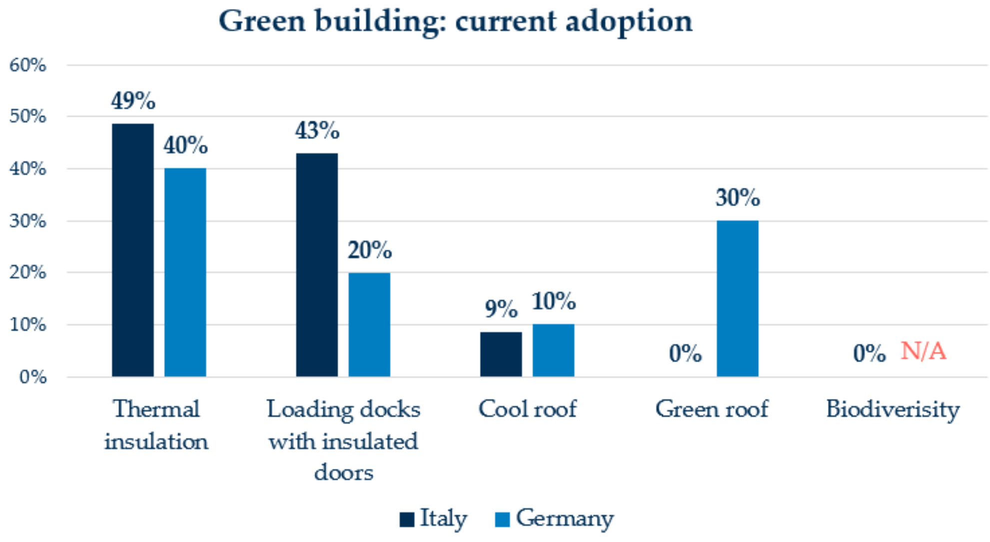


Figure 4.10 Green Building solutions: current adoption

Focusing on the prospective scenario, in Italy, all the different solutions are considered equally important. While thermal insulation, loading docks with insulated doors, and green roof are considered priorities for German companies.

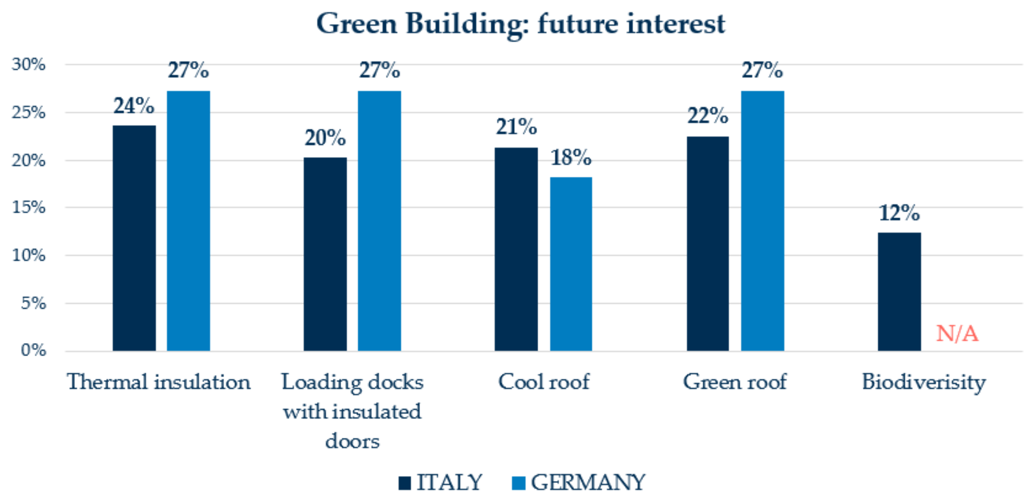


Figure 4.11 Green Building solutions: future interest

4.2.3 Utilities

In general, this cluster is more spread in Italy, again for climate condition reasons. The most applied solution within the Italian sample is photovoltaic panels (29%) followed by solar panels (15%) and smart HVAC (17%). It worth to be underlined the increasing interest towards renewable energy sources, also considering the increasing uncertainty related to energy procurement. Coherently with what argued before, and differently from Italy, photovoltaic panels are not widely spread in German buildings - the radiation is not strong enough to make it economically sustainable. The most applied solutions are, instead, smart HVAC (50%) followed by solar panels and rainwater collection and reuse (25% both).

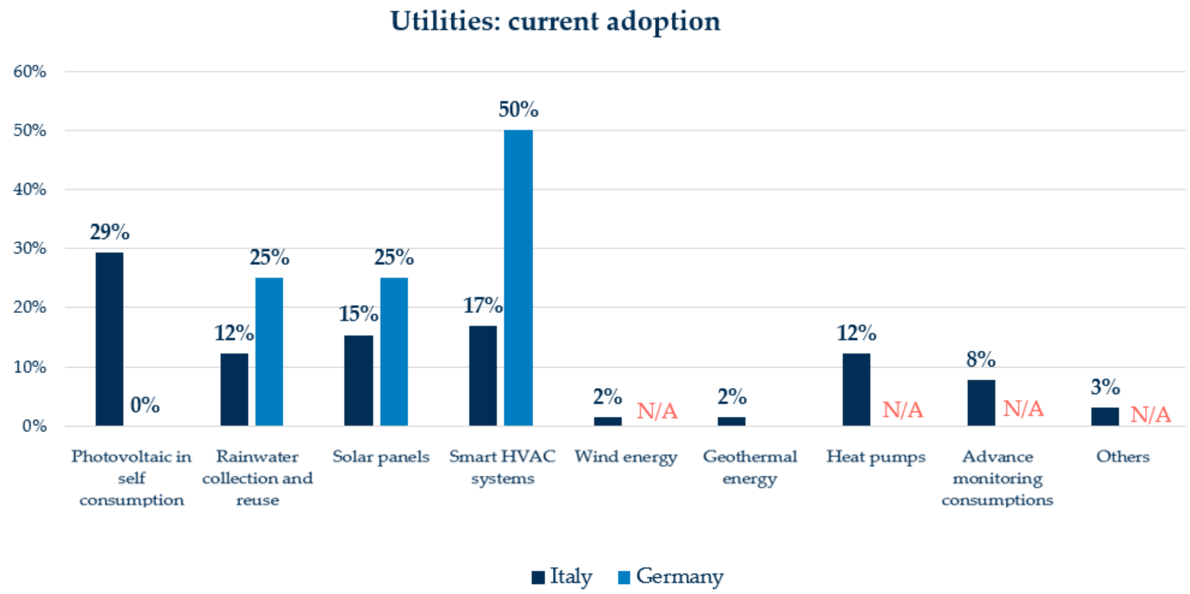


Figure 4.12 Utilities solutions: current adoption

Focusing on the future, in Italy the interest in renewable source energy is confirmed. Indeed, wind energy, heat pumps and geothermal energy are considered important opportunities for the future (respectively 10%,10% and 7%). In Germany, despite what argued before photovoltaic panels are identified as the most important priority

(36%) to be implemented in the future hoping technological progress could make them affordable and effective in less favourable climate conditions.

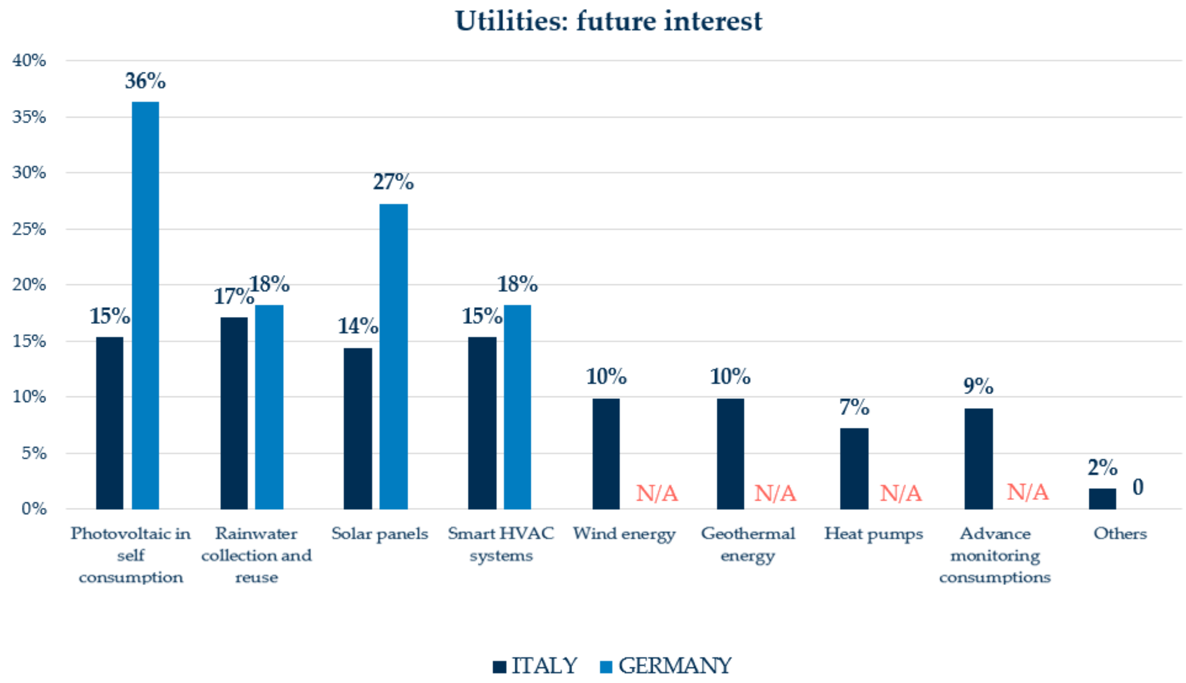


Figure 4.13 Utilities solutions: future interest

4.2.4 Lighting

Lighting solutions are generally the ones companies implement more since they require lower investments in comparison to the other cluster of solutions. At the same time, though, they lead to important savings: for instance, using LED bulbs instead of incandescent ones entrains energy savings up to 80% and emission reduction up to 20% (Ries et al., 2017). In Italy, the most adopted solution is LED lighting (50%), followed by natural light and white walls (25%) and sensors (22%). The German sample shows similar patterns with respect to the Italian one: LED lighting is the most implemented solution (33%), followed by natural light and white walls and sensors for reducing consumption (25%).

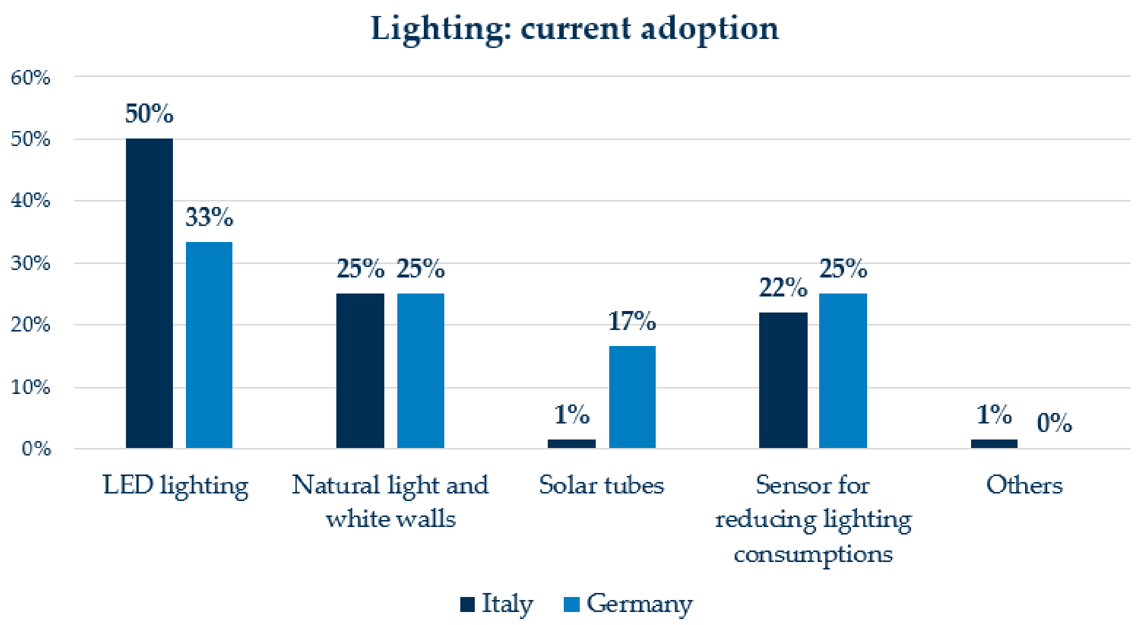


Figure 4.14 Lighting solutions: current adoption

Looking at the prospective scenario, sensors are considered the most attractive solution (31%) in both the countries. An important difference among the sample regards solar tubes: in Italy is almost absent, while 17% of German sites are using them. Anyhow, it's considered an important lever for the future (31%) by Italian companies.

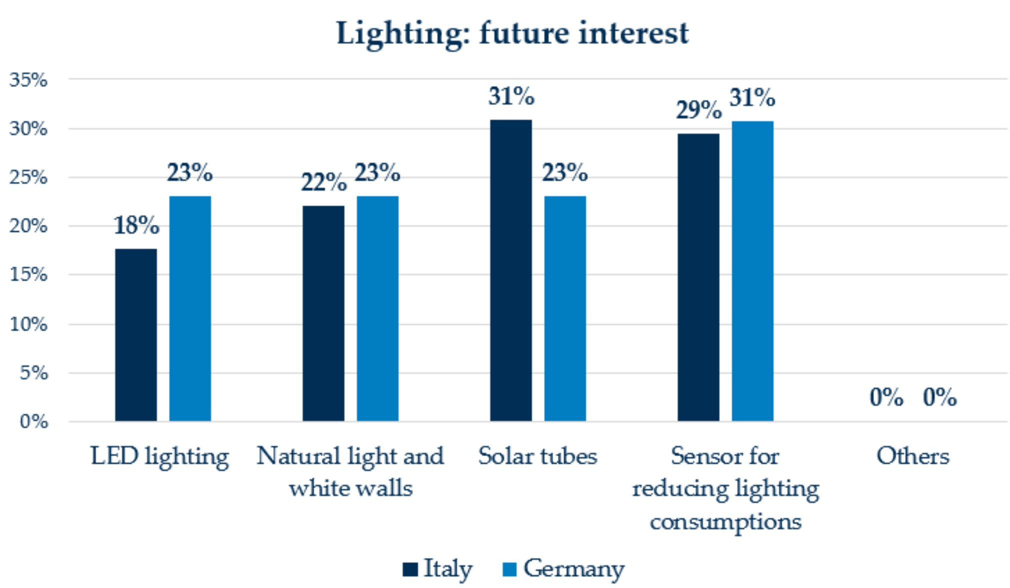


Figure 4.15 Lighting solutions: future interest

4.2.5 Materials handling and Automation systems

Focusing on the Italian sample, it's possible to identify high-frequency batteries charging and lithium-ion batteries as the most applied solutions, respectively with 38% and 32% share of adoption. There is a growing interest on hydrogen forklifts 11% of current implementation. In Germany, the most implemented solution is lithium-ion battery (57%), which currently represents the only technological option for fuel-powered forklifts.

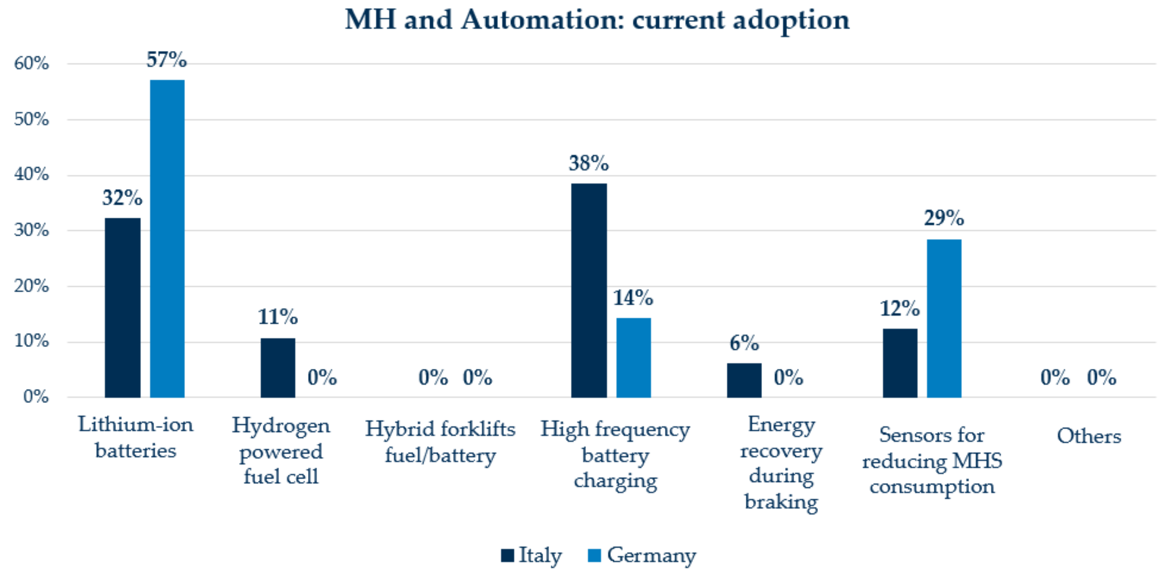


Figure 4.16 MH and Automation solutions: current adoption

Considering the prospect scenario, in Italy the interest on hydrogen-forklift trucks is validated (21%). Even in Germany differently from the current situation, powered fuel cells and fuel cell/ battery hybrid forklifts are prioritized for the future.

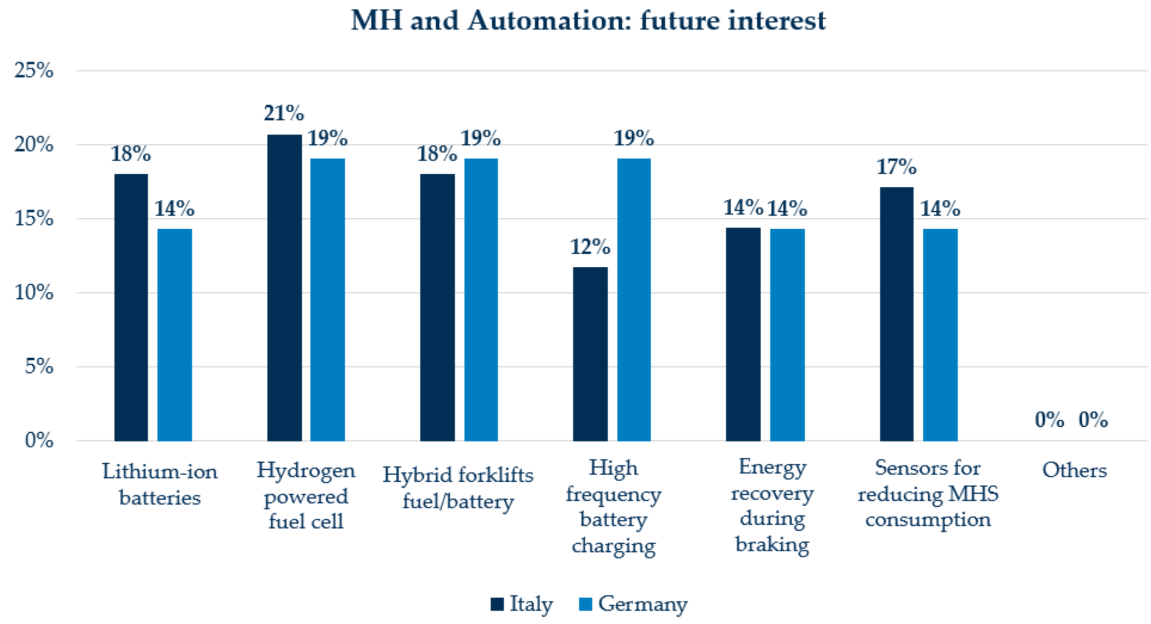


Figure 4.17 MH and Automation solutions: future interest

4.2.6 Materials Management

The number of solutions pertaining to this cluster has almost doubled in comparison to the previous year, as presented in the methodology Chapter, symptom of the acknowledge of the importance of the topic.

Deepening the Italian situation, the most applied solutions are packaging reduction (27%) and packaging reuse or recycle (35%). In addition, it worth to be underlined the interest in technologies for materials management optimization, such as the ones for carton dimensions or filling material reduction. In Germany too, the most adopted solutions are packaging reduction and packaging reuse/recycle (respectively 38% and 50%).

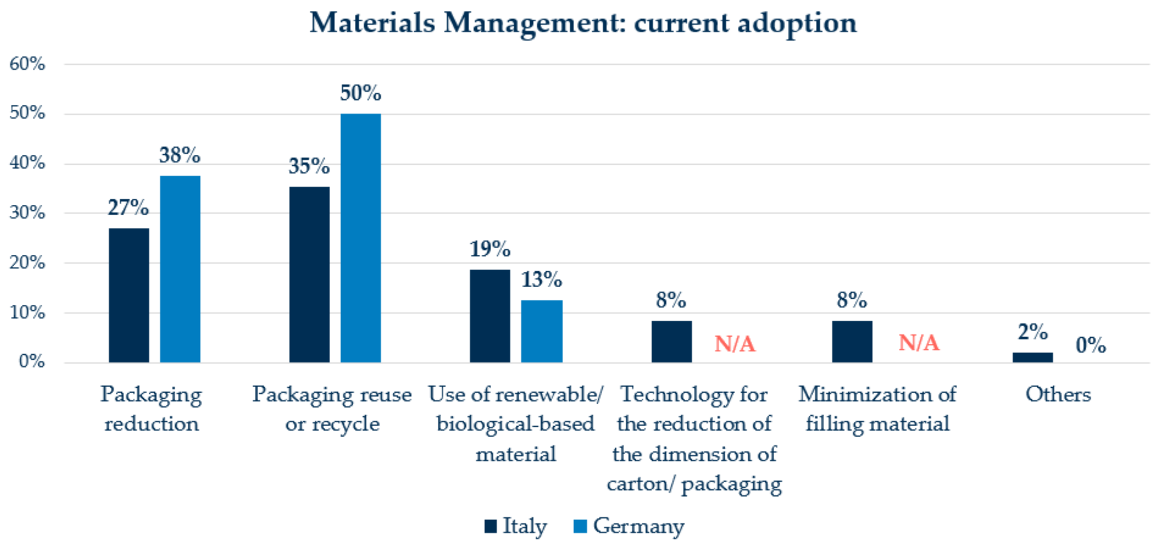


Figure 4.18 Materials Management solutions: current adoption

Considering the prospective scenario, the exploitation of more renewable/biological based materials seems to be a priority both for German and Italian companies respectively 30% and 28%). In addition, the latter prioritize technologies for materials management optimization also in the future (15%).

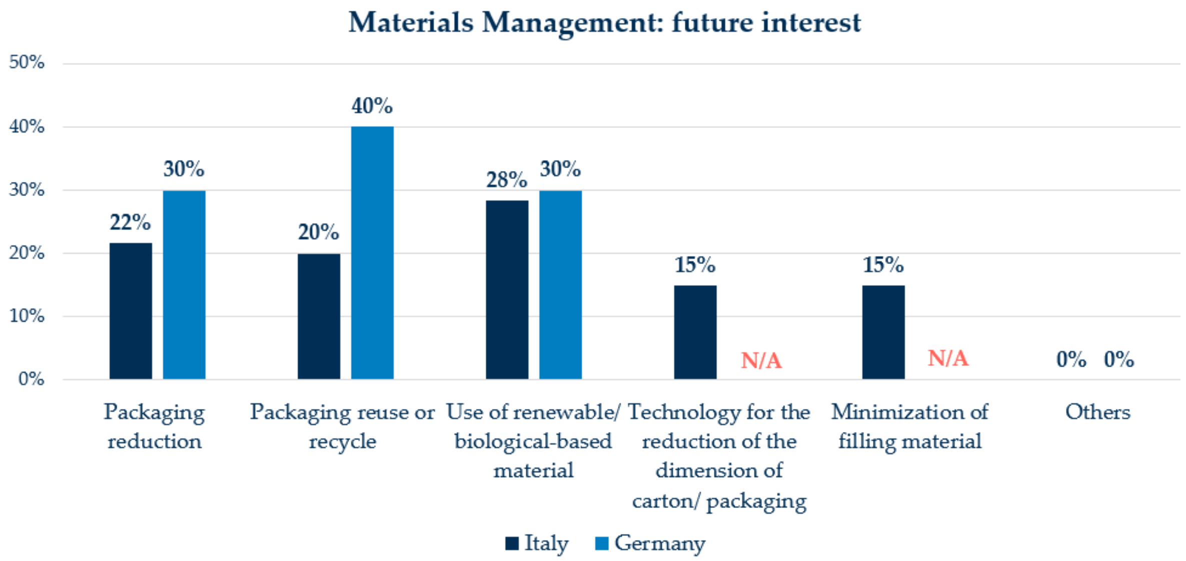


Figure 4.19 Materials Management solutions: future interest

4.2.7 Operational Practices

Before going into detail of the section, an important methodological remark needs to be mentioned. It is the only case in which two surveys, the Italian and the German one, considerably differ. In any case, the answers have been consolidated considering, not the names of the categories which are different, but the content of the questions.

Among companies within the Italian sample, optimal planning of MH activities and battery charging is the most implemented solutions. It's also interesting to highlight the importance that ergonomics is acquiring in the design process. The implementation is homogenous among the current and the future scenario. In *Figure 4.20*, N/A for Travel optimization is due to the absence, in the Italian survey, of the latter section. The same can be said for Human-centric design process for the German one. For what concern the German sample, the only type of solution already implemented is the travel distance optimization.

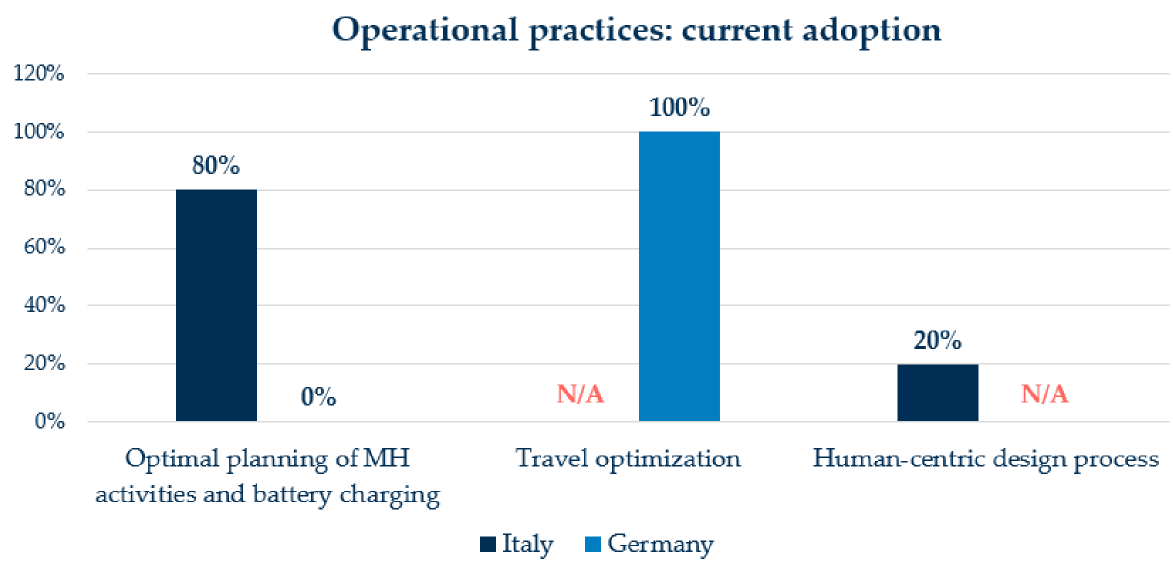


Figure 4.20 Operational practices solutions: current adoption

In Italy the pattern highlighted for the current adoption are confirmed for the future. In Germany, as a future priority, instead, optimal scheduling is considered by many companies (57%). As before, in *Figure 4.21*, N/A for Human-centric design process is due to the absence, in the German survey, of the latter section.

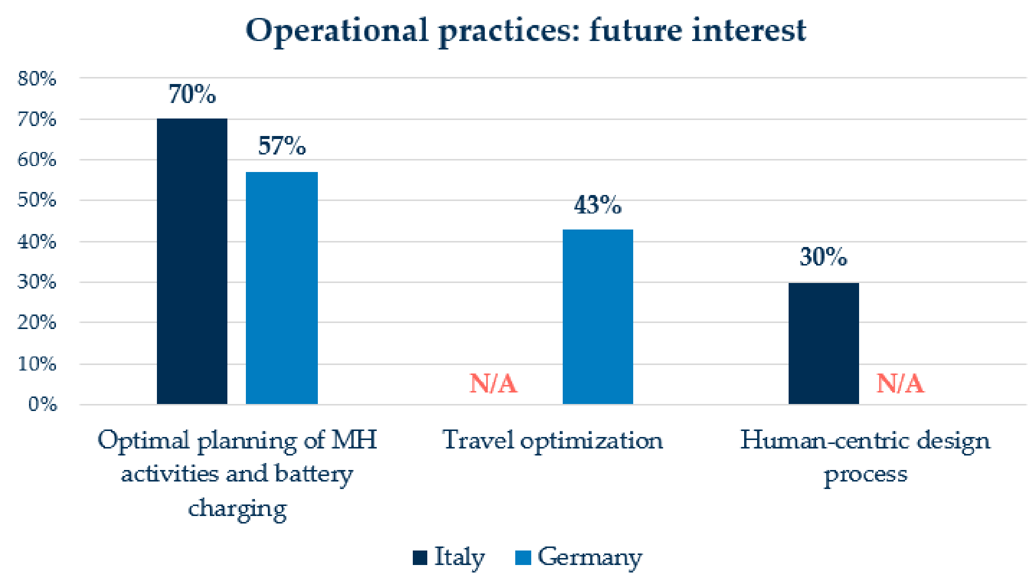


Figure 4.21 Operational practices solutions: future interest

4.3 Analysis of consumption patterns

In this section, the objective is to go through the main consumption figures considering separately electricity, fuels and refrigerants. For each of them, two subsections will be presented: the first one aims at analysing the Italian situation, the second section the German one. It must be underlined that, due to the differences between the two databases from which data have been taken, it has not been possible to perform exactly the same type of analysis.

4.3.1 Electricity consumption

Electricity is fundamental for making the warehouse running. Its role is even more important considering the recent geopolitical disruptions and the consequent increase in energy cost and rising uncertainty around energy procurement. Some figures will be presented to understand how companies are sustainable in purchasing electricity and how electricity consumption change according to the characteristics of the building.

Figure 4.22 shows the yearly average consumption of Italian warehouses, corresponding to 1,996 MW. Of this total amount then, it is shown the quantity which is self-produced through photovoltaic panels (444 MW) and the amount purchased by certified renewable sources (480MW). Putting together those latter values, it is fair to conclude that a considerable amount of the total electricity consumption is coming from sustainable sources, equal to the 46,3%. This value is expected to grow over years due to the increasing procurement costs and regulations to be compliant with.

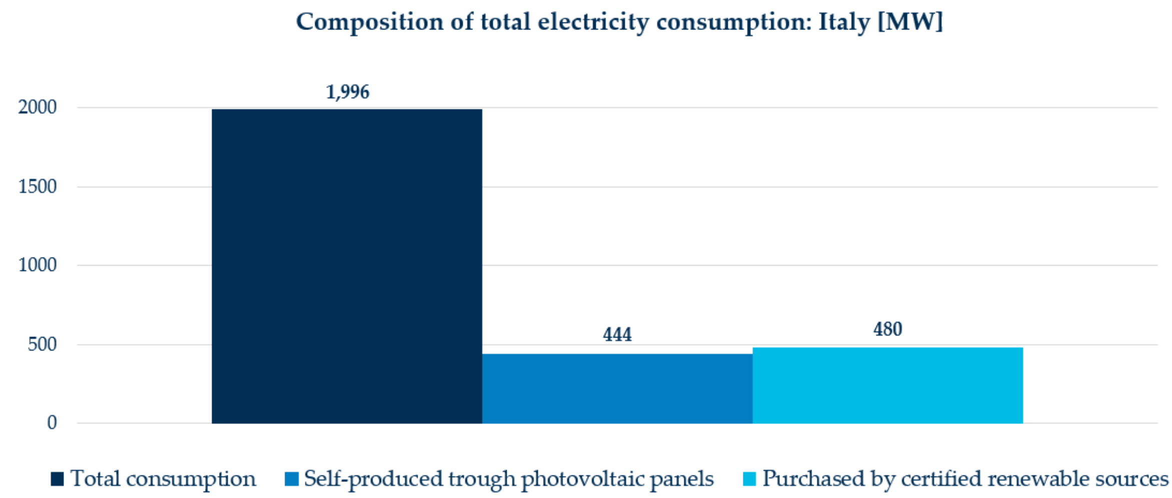


Figure 4.22 Composition of total electricity consumption: Italy

The situation in Germany is quite different: a smaller portion is produced on-site (5%) due to the lower diffusion and efficiency of photovoltaic panels. Moreover, it has not been possible. Moreover, it has not been possible to report the exact amount of electricity purchased from renewable sources because of a difference in reporting data in the two databases.

The situation in Germany is quite different: a smaller portion is produced on-site (5%) due to the lower diffusion and efficiency of photovoltaic panels. Moreover, it has not been possible. Moreover, it has not been possible to report the exact amount of electricity purchased from renewable sources because of a difference in reporting data in the two databases.

Anyhow, what is possible to report is that the 20% of German respondents affirm to buy electricity from certified renewable source – with no amount specified.

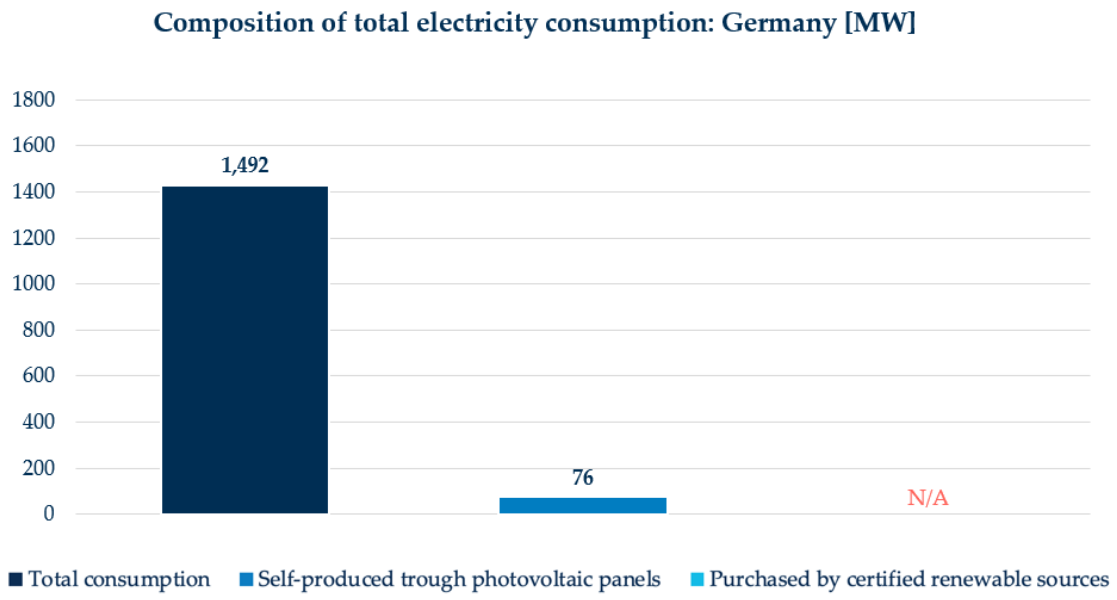


Figure 4.23 Composition of total electricity consumption: Germany

The second part of the section aims at understanding how the characteristics of the warehouses influence energy consumption figures. Only findings linked to the Italian sample will be discussed; the results obtained for Germany have been considered not representative of the real situation and thus, not reported. This is probably due to the smaller dimension and lower heterogeneity of the German sample in terms of warehouse characteristics, if compared to the Italian one. The analysis has been performed through pivot tables in Microsoft Excel.

Not surprisingly, frozen warehouses are the most energy-intensive type of building, due to the cooling system. They consume more than 4 times the average electricity needs of ambient warehouses.

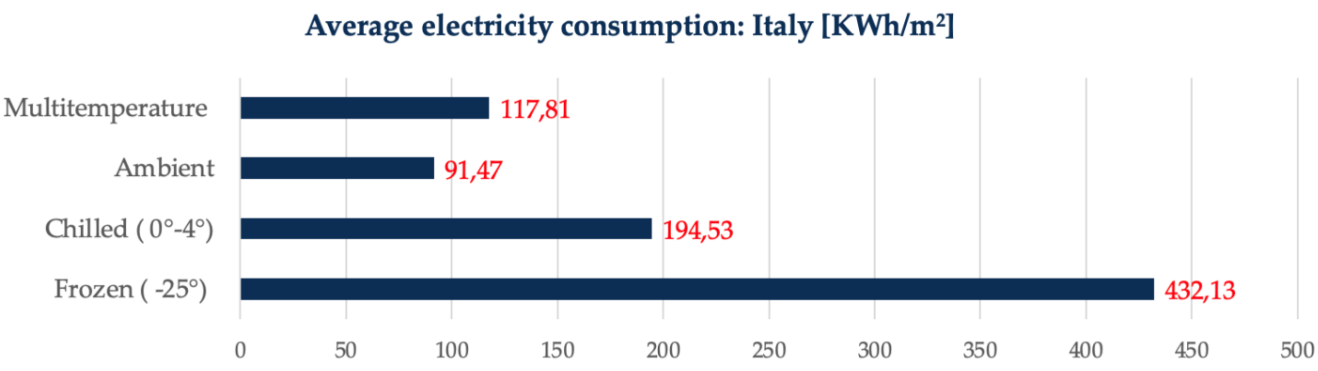


Figure 4.24 Average electricity consumption per unit area (kWh/m2)

To further investigate the topic, it will be examined the distribution of electricity consumption among 4 main functional areas: lighting, materials handling, cooling, and others (i.e., offices). In *Figure 4.25,* it is possible to see the average mix indicated by managers while completing the explorative survey. In case they were not able to fill this part, as explained in Chapter 3, the default mix present on Green Router has been used.

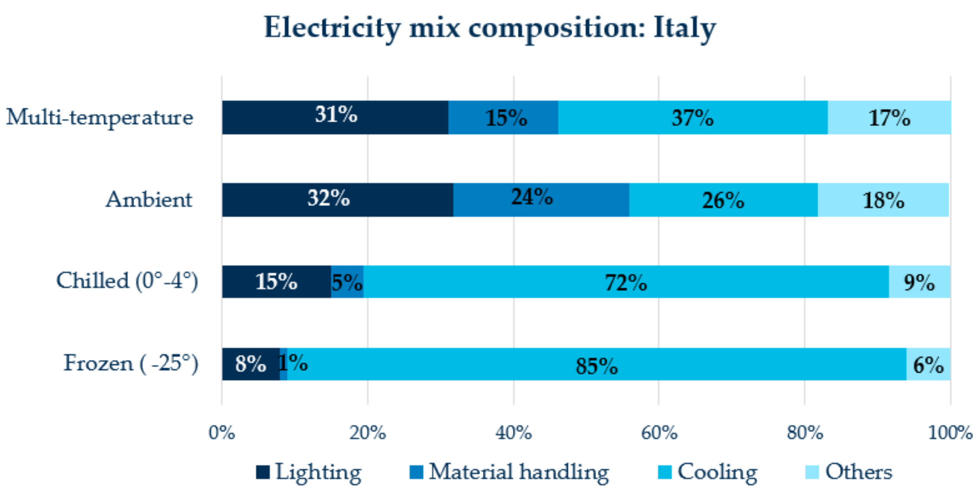


Figure 4.25 Electricity mix composition Italy [%]

To better understand the results of this analysis, it could be useful to compare them with the ones obtained by the Observatory Contract Logistics "Gino Marchet" of Politecnico di Milano. The latter results, collected over 5 years of research, have also been consolidated and inserted in the latest version of GLEC framework, as benchmark values.

WEIGHTED AVERAGE (2017-2021)				
Type of warehouse	**Lighting**	**Material Handling**	**Cooling**	**Others**
Ambient	43%	30%	5%	22%
0°-4°	13%	4%	73%	9%
-25°	8%	1%	85%	6%

Table 4.1 Weighted Average (Source: Observatory Contact Logistics "Gino Marchet", 2020)

Comparing results of this year analysis *(Figure 4.25)* with benchmark values of Observatory Contract Logistics "Gino Marchet" of Politecnico di Milano *(Table 4.1)*, it is possible to notice an alignment. The only exception are ambient warehouse results: the reason could be that the 5-years analysis values are closer to real ones, as based on more data; differently, the 1-year analysis could comprehend outliers which generate a shift from the others. In fact, it can be noted that cooling in 2021 data accounts for 26% of total electricity consumption, while in the 5-years analysis only 5%. As stated by Opalic et al. (2020), giving an estimation for colling is not easy and could be that 2021 value has been over-estimated, while over years it is possible to obtain values which are closer to reality.

4.3.2 Fuel consumption

The majority of fuel's need, in Italy, is met by natural gas, the values reported refer the overall amount employed, with no distinction between heating or materials handling purpose. To better deepen the result: 99,9% of total fuel used is represented by natural gas, while the remaining 0,1% is made of gasoline and LPG. Those values are in line with the acknowledgement that the most employed fuel for heating purposes is natural gas, thanks to its low environmental impact – especially if compared to the other fossil fuels. In addition, diffusion of electric forklift trucks for materials handling operations has as a consequence a decrease in gasoline or other substitutive products needed for carrying out this activity.

The Germany scenario is very similar to the Italian one: 99,9% of total fuel used is made up by natural gas, the remaining part by gasoline, LPG and others. Hydrogen can be considered an important resource for the future, the main issue to face is the production process that is very energy intensive and since now few companies can afford it.

4.3.3 Refrigerants consumption

Refrigerants represent an important aspect to be monitored considering their high pollutant potential. Because of global warming, the number of the temperature-controlled warehouses is increasing (Opalic et al., 2020) and, thus, having a look and trying to reduce as much as possible refrigerants consumption is essential.

Figure 4.26 shows the most used refrigerants by Italian warehouses in the sample is ammonia (892 kg/year). The latter finding represents the willingness of Italian companies to improve their environmental performance since NH_3 is carbon neutral - meaning its conversion factor equals 0. The second most used are a group of refrigerants under the label "Others" which contains the following substances: R448a, 744 (in proportion respectively 31% and 69%).

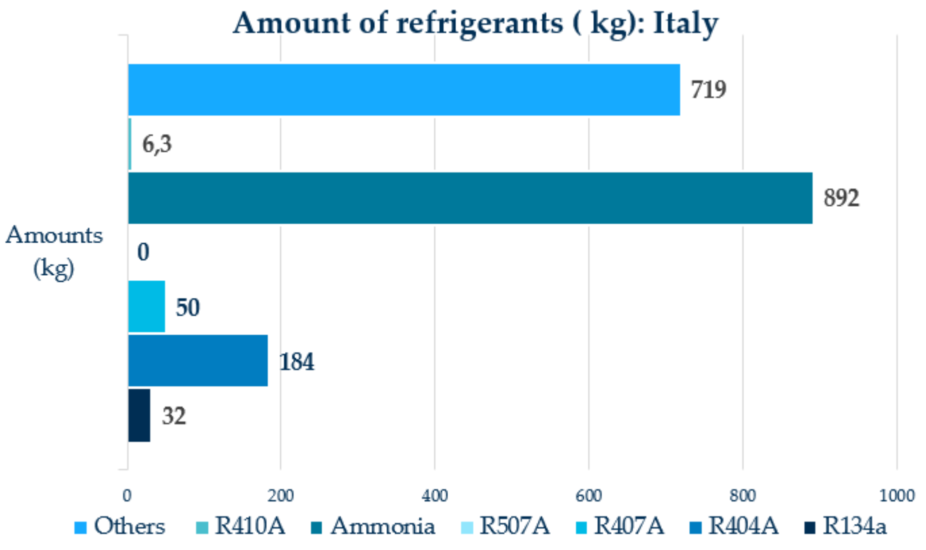


Figure 4.26 Amount of refrigerants (kg): Italy

What is worth to be highlighted is that the total amount of refrigerants used by companies in the German sample is lower than the Italian one. This is due to the fact that no frozen warehouses have been analysed in Germany and a smaller number of chilled ones have been included. Anyhow, refrigerants employed are different. In this case, the most employed are R-717 and R448a that are grouped under the label "Others" with 616 kg/year (respectively in proportion 83% and 17%), followed by R134 (84,5 kg/year).

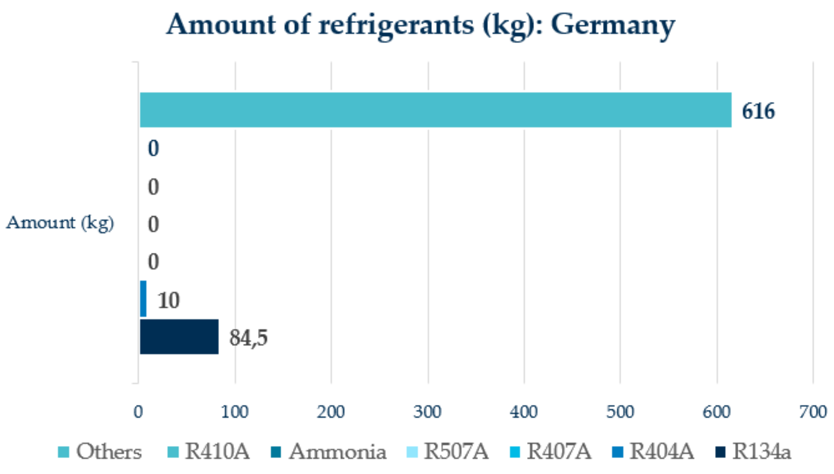


Figure 4.27 Amount of refrigerants (kg): Germany

4.3.4 Packaging consumption and waste generation

For what concern packaging, some differences in the results of the two samples can be highlighted. In Italy the most consumed resource is wood (58%), while in Germany is plastic (64%). Similar percentage, instead, is highlighted for carton packaging: both Italy and Germany are aligned at around 30%.

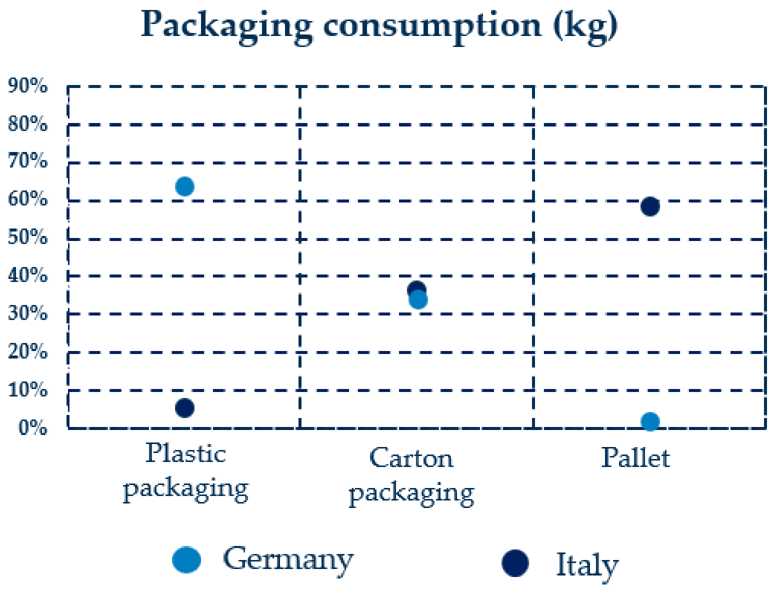


Figure 4.28 Packaging consumption (kg)

In terms of waste generation, similar patterns have been found too. Both in Italy and Germany carton waste is the one present at a greater extent: more than 80% in Germany and 50% in Italy. Plastic waste, on the opposite side, represent the least present kind of waste – less than 15% in both samples examined. This last result is probably due to the strong committeemen that companies started to put in fighting against plastic waste. Recyclability of plastic is still a hot topic for businesses, also because of external pressure coming from stakeholders. As a last remark, it is worth to mention that Italy still has to improve the percentage of waste coming from wood, since today it is 37% of total waste generated.

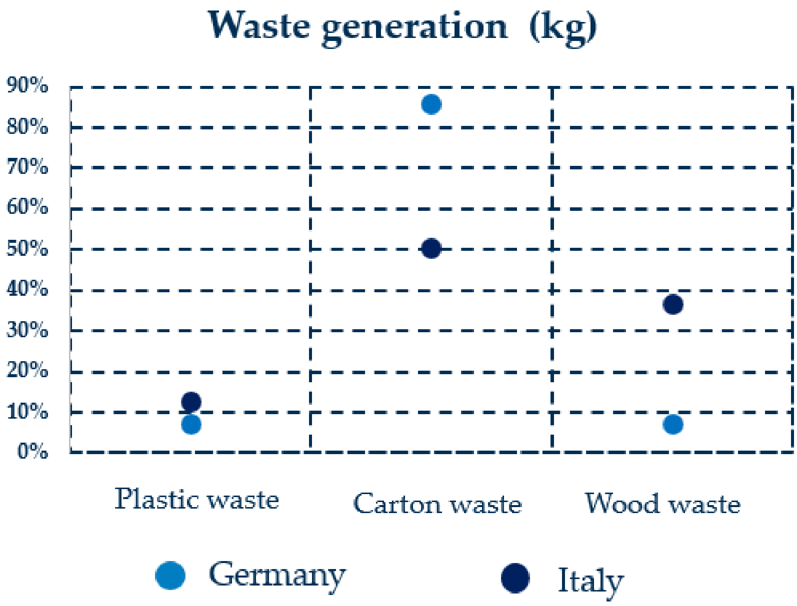


Figure 4.29 Waste generation (kg)

4.4 Emission figures

In this last section of the international benchmark, some emission figures will be presented. As briefly discussed in the introduction, data have been obtained through the use of Green Router software, which determines companies' emissions starting from consumption data (e.g., electricity, fuels and refrigerants). The software, applying a specific characterization model (IPCC GWP100), calculate emissions values grouped by sources, in kg/ton CO_2e. The following detailed analysis has been performed only for Italy. For the German sample, it has not been possible because of the same issues highlighted in the electric consumption module (i.e., lower dimension and heterogeneity). Anyhow, the composition of sources of emission will be presented for both samples. In Italy, the majority of emissions (59%) is linked to electric energy which, as stated, is one of the most consumed resources in buildings. Another big portion of emissions is generated by refrigerants (28%), due to the significant presence in the sample of players working in the chilled and frozen food sector. Fuel-linked emissions just account for 13%.

In Germany electricity remains the main source of emissions, with 56% of the total amount. Differently from the previous sample, instead, the second bigger source is linked fuels (43%) and the least impacting one are refrigerants (1%). This is again coherent with the composition of the sample.

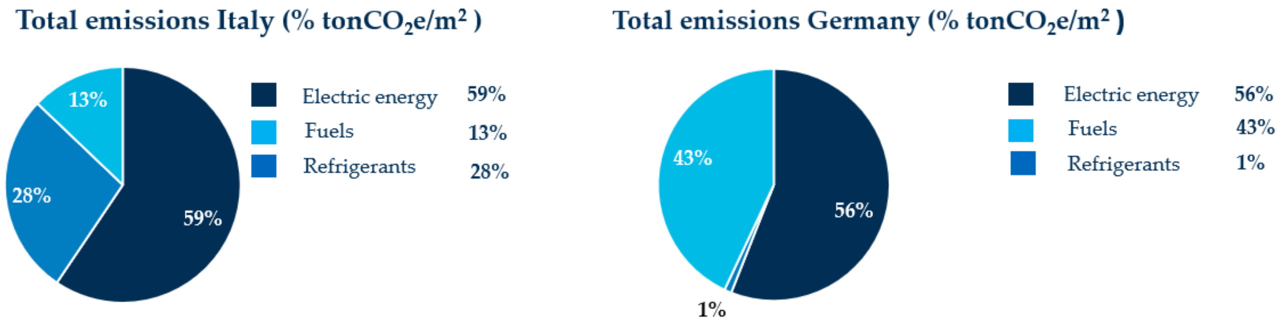


Figure 4.30 Total emission composition: Italy vs Germany

As it has been done with electricity consumption, it is interesting analyse how emissions figures change according to the characteristic of the buildings: for instance, according to temperature level and product type.

The most pollutant warehouses are the frozen ones, with an average of 111.1 $kgCO_2e/m^2$. They are followed by the chilled ones with 59.4 kg CO_2e/m^2 and, in the last position, ambient warehouses with 23.5 $kgCO_2e/m^2$. It needs to be noted the maximum value of ambient temperature warehouses: 185.3 kg CO_2e/m^2, not so far from the one of chilled ones. This is a sign that also these types of buildings have a high polluting potential and so, also in those cases and not only in energy-intensive ones energy-efficient solutions are fundamental to be implemented.

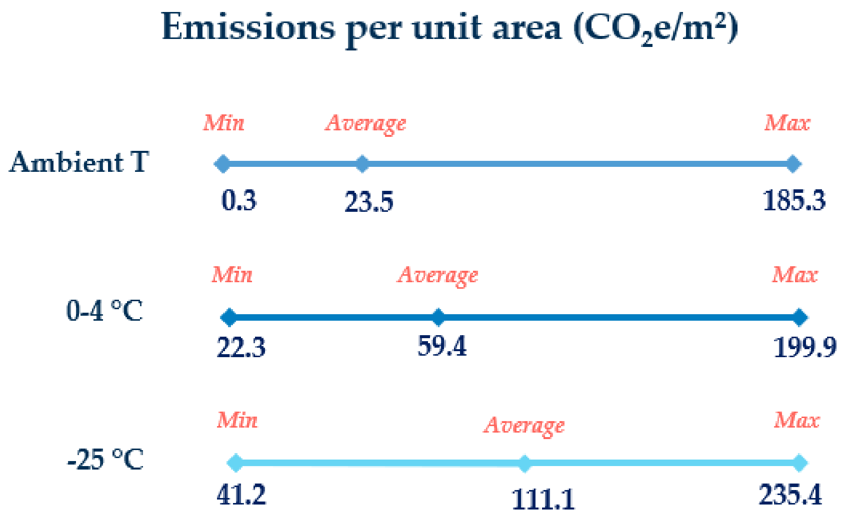


Figure 4.31 Emission per unit area ($kgCO_2e/m^2$)

The next overview *(Figure 4.32)* confirms the aforementioned findings: the most polluting in term of industry sector is the frozen food one, followed by the chilled food sector and by multisector warehouses. In between, according to the data available and considering GWP impact categories, it's possible to find consumer electronics, furniture and fashion.

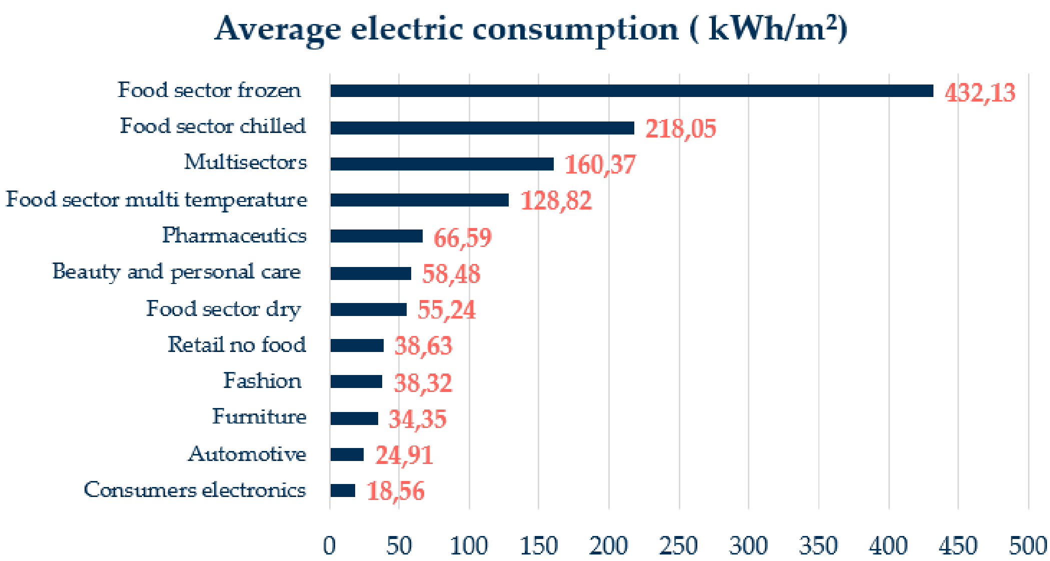


Figure 4.32 Average electric consumption (kWh/m^2)

4.5 In-depth investigation from the explorative survey:

In order to give a complete and accurate picture in terms of consumptions and emissions figures, two excellent examples of environmental performances of warehouses will be presented. The first one, is a logistics service provider (LSP) operating at the national level; the second one is a shipper (i.e., a manufacturer of electronic components).

Business case A

As presented in Chapter 3, the information has been gathered through an online interview with the regional manager of the company.

One of the aspects the company takes care the most is energy management and the latter it is subject to focus under three main perspectives:

- First, underlying the necessity to manage different energy sources at the same time (e.g., electricity, hydrogen and gasoline). Energy diversification is becoming fundamental, especially considering the necessity to reduce fossil fuels consumption. Additionally, the absence of a competitive substitute with the same performance level in all the application areas – as last mile, full truck load, material handling or heating – increases complexity. The concept of warehouse as energy hub is becoming the most suitable for managing this uncertainty (Raza et al., 2019)
- Secondly, relying as much as possible on self-produced energy in order to be self-sufficient. This is done both considering the increasing cost of energy and also considering the difficulties in energy supply. The company aims at producing 4,5 MW of electricity from photovoltaic panels by the end of 2022.
- Third and last point, linked to the previous one, trying to invest in energy storage systems. At the moment, of the total energy produced by their photovoltaic panels, only the 57% is used by the company during daylight hours; the remaining 43% is reinserted in the national grid. Over night shifts,

instead, they are obliged to consume energy coming from national grid. For the latter, they pay a higher price with respect to the one obtained for the release of the electric energy produced by themselves over the day. Consequently, investing in energy storage system is necessary to solve the aforementioned issue.

Photovoltaic plants: power installed and main characteristics	
Activated power*	2 MW
Activated by the end of 2022	4,5 MW
Produced in the first trimester of 2022	1,6 MWH
Self-consumption share	57%
Share released in the national grid	43%

*data update to 22 September 2022

Table 4.2 Photovoltaic plants: power installed and main characteristics

The second pillar of this project is the collaboration with a no-profit company whose objectives are also linked to social sustainability topics. The main goal is to recycle scrap materials originated from supply chain: for instance, wood. The latter is the one produced in bigger quantities, and, inside the project, this is employed to create furniture that are then used to adorn the external spaces of the logistics site. Those spaces are created with the purpose to counterbalance damages caused by logistics activities to the environment. In fact, together with wood furniture, there are plants and shrubs to increase ground biodiversity.

As a first step, the goal was to clean up the area inside the warehouses owned by the company and create some spaces where drivers and workers can rest. Then, the objective became wider, extending this clean-up process to the area close to the logistics sites, including public parks and schools. Those activities are run by hiring refugees, training them, and empowering them in the work world. All these operations are self-financed by the company thanks to the realization of a similar projects for their customers.

Business case B

The second case refers to a warehouse built in the north of Italy in 2017. As said, the player is a shipper and so the building is composed by two separate parts: warehouse and production site for a total surface of 50.000 m^2.

What is innovative is the mindset that the company adopted in building the site. The objective is to increase as much as possible flexibility: not only in the logistics area but even in the manufacturing one. Several energy-efficient solutions can be founded analysing this building. Among the others: thermal insulation, natural light, green roof, geothermal energy, radiant panels as heating system, smart systems for performance monitoring and photovoltaic panels. The latter produce more than 1.2 mln of kWh per year, corresponding to the 45% of the whole consumption of the building.

An innovative feature is the choice to build the production site on two different levels. This is not a common choice but very clever in the view of reducing land occupation. Strategic has been the choice of the level of automation inside the warehouse: AS/RS systems and 7 mini loads. Side by side with the level of automation, the necessity of a strong information system that can support a huge quantity of data and that is able to resist and recover quickly from disruptions.

4.6 Closing remarks

Some important conclusions can be drawn by combining the empirical analysis with the key messages emerged from the two business cases. First, the increasing attention that companies are showing towards sustainability topics is translated into a multitude of energy-efficiency solutions covering several areas of the warehouses -

from building construction techniques to automation systems or materials management.

Secondly, those interventions are not effective only in highly energy-intensive buildings but even in ambient temperature warehouses. As possible to deduce from *Figure 4.31*, emissions of ambient warehouses can reach high values (185,3 $KgCO2/m^2$), not so far from temperature-controlled warehouses' ones.

Another important aspect that emerged is the necessity to manage simultaneously different energy carriers and to adopt a risk-hedging strategy for energy procurement. This not only emerged from literature (Raza et al., 2019), but clearly from Business case A: the manager interviewed insisted on the topic and how the company is trying to react.

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.

5 Roadmap towards decarbonization of Italian warehouses[2]

Based on the outcome of the previous stages of the study, the aim of this chapter is to present a longitudinal analysis on a set of logistics sites to illustrate their roadmap to improve environmental sustainability and energy efficiency. The drive to develop a longitudinal analysis arises from awakening that, although on the academic side is increasing the number of papers addressing sustainable warehousing, empirical evidence is lacking and few of papers are adopting a longitudinal perspective, studying the warehouse for more than 1 year. The following chapter of the Master Thesis aims at addressing this literature gap. Based on an extensive longitudinal study in Italy, it discusses four best practice examples and illustrates their roadmap towards net-zero logistics facilities. Some key messages are elaborated, and streams for future investigation are highlighted.

5.1 Methodology

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 of the Logistics Real Estate and Intralogistics Workgroup, part of the Observatory Contract Logistics "Gino Marchet" at Politecnico di Milano. From the dataset, which includes

[2]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.

127 heterogeneous logistics facilities, it has been possible to select the four sites to be deepened. 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 (CO_2e) have been also computed, according to the methodology proposed by Perotti et al. (2022).

5.1.1 Case selection

The business cases have been identified with three main criteria considered. 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 5.1*.

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

Table 5.1 Overview of the selected business cases

5.1.2 Data collection

The main source for data collection 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.

5.1.3 Data analysis

According to Eisenhardt (1989) proposed investigation method, the analysis includes a within case analysis and a cross case analysis. In the first one each case is analysed independently. Goal of the second analysis, instead, is 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.

5.2 Findings and discussions

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 (Dobers et al., 2022); (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.

5.2.1 Within-case analysis

Business case C1

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 m² 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 5.1*.

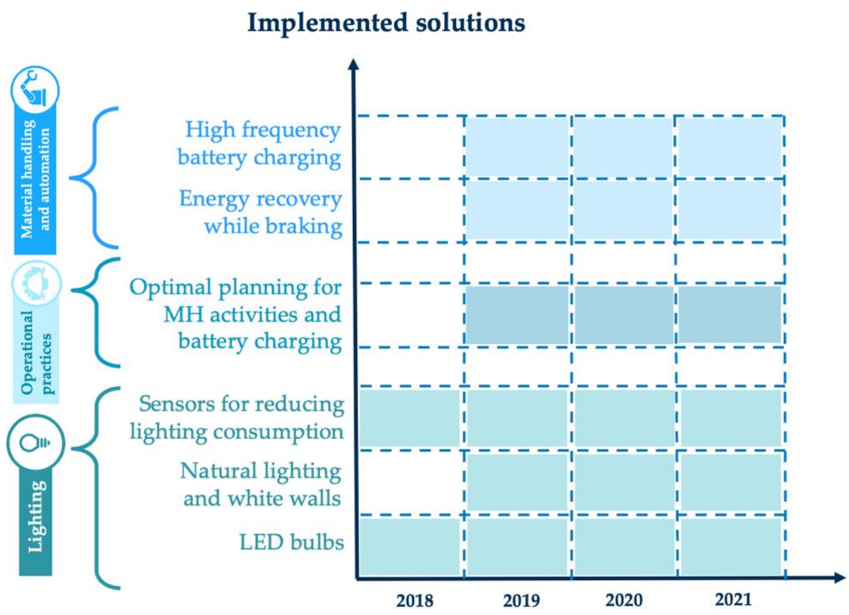


Figure 5.1 C1: Implemented solutions over time

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 tonCO_2e in 2018 to 51 tonCO_2e in 2021 (-29%).

All the solutions implemented 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 5.2*).

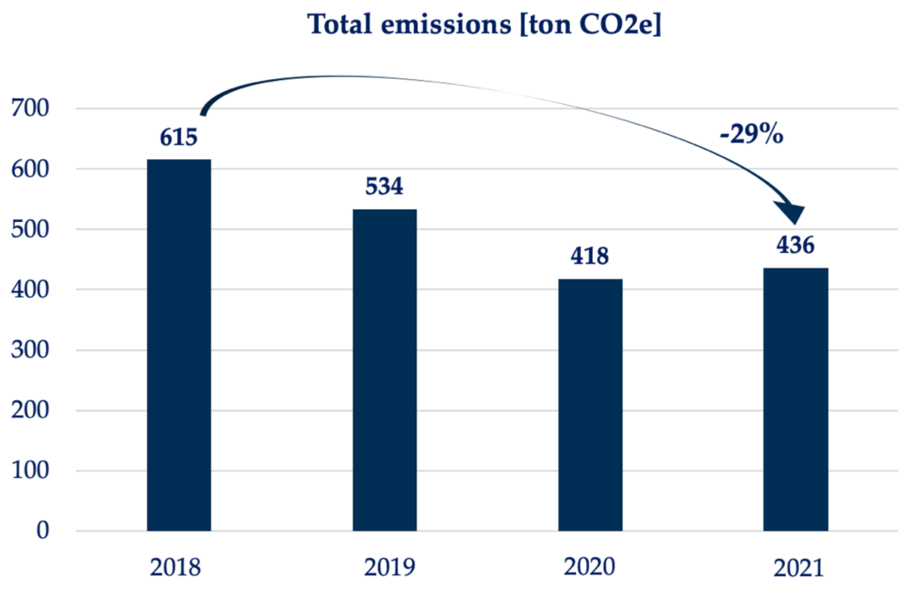
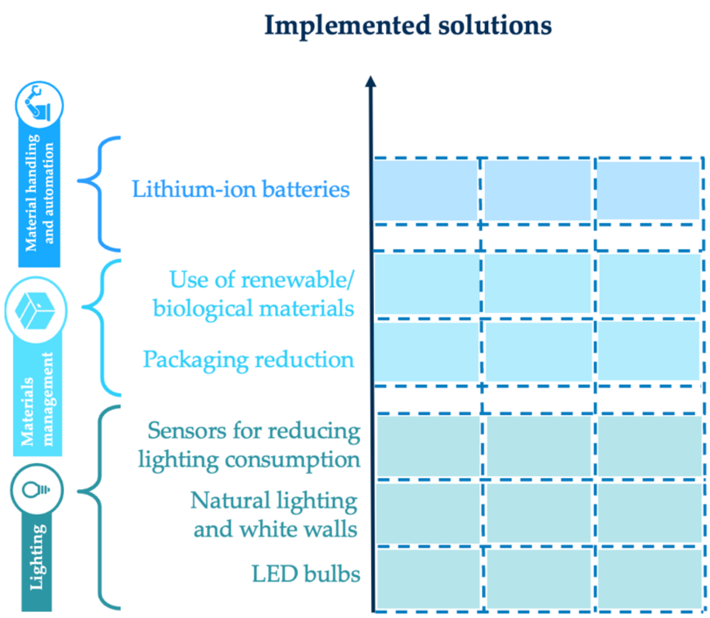


Figure 5.2 C1: Total emissions [ton CO_2e]

Business case C2

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 m² floorspace and 12.5 m clear building height. The warehouse is quite recent, built in 2017, and achieved the BREEAM certification (Very Good). The breakdown of electric energy consumption is 60% referred to material handling, 20% to lighting, and 20% to other sources (e.g., offices, car parking areas). This split seems overall aligned to the average values for ambient logistics facilities underlined by Dobers et al. (2022).

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.



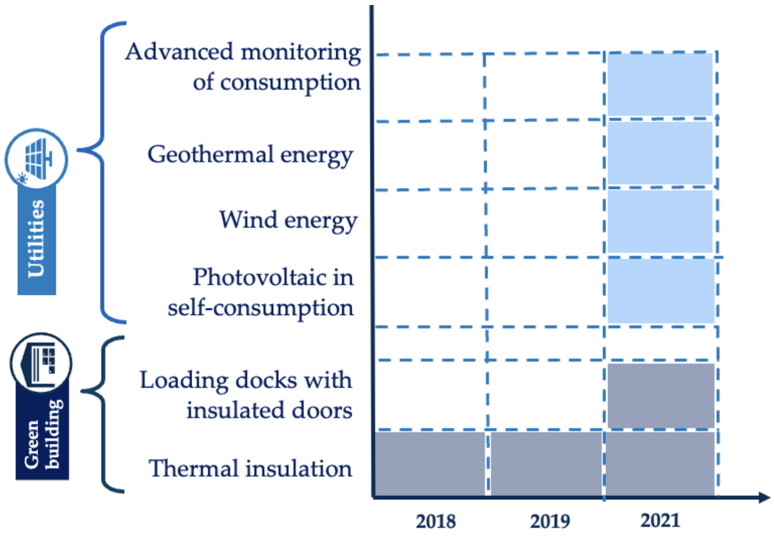


Figure 5.3 C2: Implemented solutions over time

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 tonCO_2e in 2018 to 969.31 tonCO_2e in 2021 (-3%).

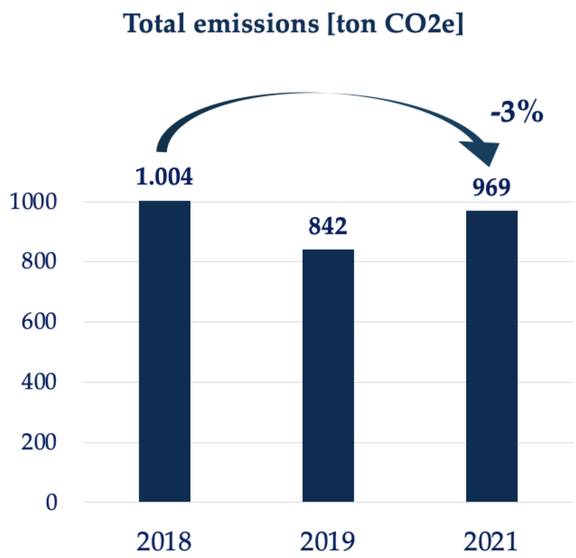


Figure 5.4 C2: Total emissions [ton CO_2e]

Business case C3

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 m² 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 5.5*) 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).

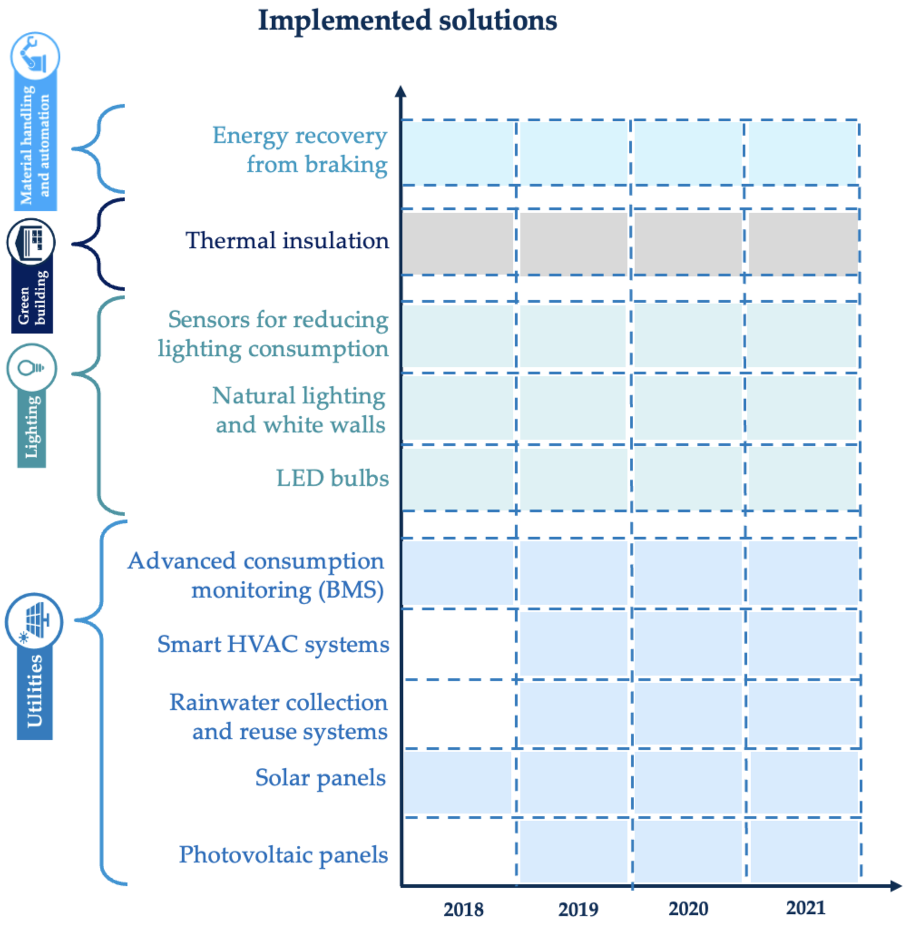


Figure 5.5 C3: Implemented solutions over time

The solutions in place have helped this warehouse achieve a considerable performance in terms of emissions per square metre, i.e., 8.1 $kgCO_2e/m^2$, 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 5.6*, total emissions shifted from 456 $tonCO_2e$ in 2018 to 226 $tonCO_2e$ in 2019, with a progressive reduction up to 2021 (200 $tonCO_2e$, i.e., -56% with respect to 2018).

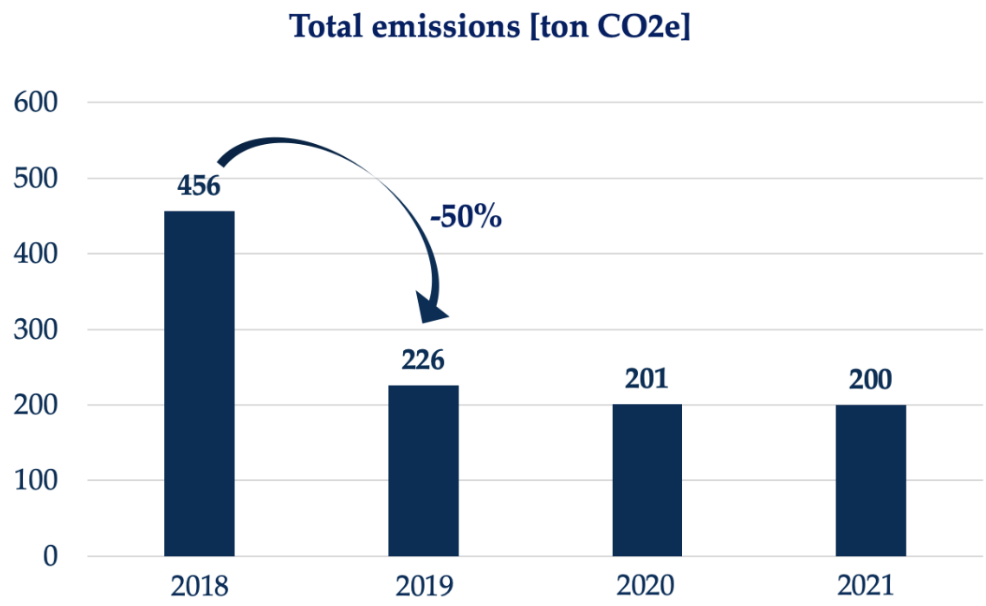


Figure 5.6 Total emissions over time [ton CO_2e]

Business case C4

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% is occupied by frozen goods, with temperatures even below -25°C. This has obviously substantial implications in terms consumption and emission figures: 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. Specifically, NH3 is carbon neutral, and the other two refrigerants have also good environmental performance and low Global Warming Potential (GWP) values. Conversion factors are also well below the average of common refrigerants such as R134a, R404A, R407A or R507A whose value, according to IPCC GWP100 AR4, is 2,554 kgCO_2e/kg.

Refrigerant	Conversion factor [kg CO2e/kg]
NH_3	0
CO_2	1
CH_4	25
Average of common refrigerants	2.554

Table 5.2 C4: Refrigerants conversion factors

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, which are ambient temperature, 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.

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 reducing energy required by HVAC systems of 6-15% (Ries et al., 2017), 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.

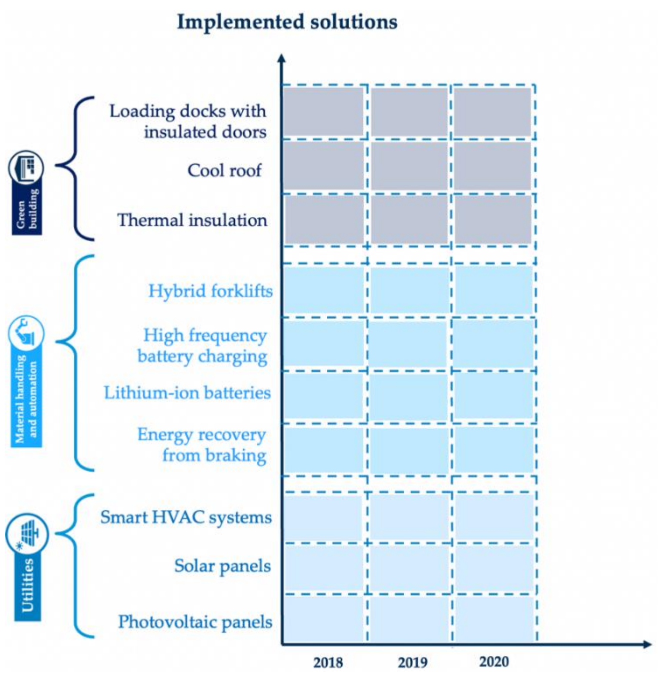


Figure 5.7 C4: Implemented solutions over time

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 5.8*.

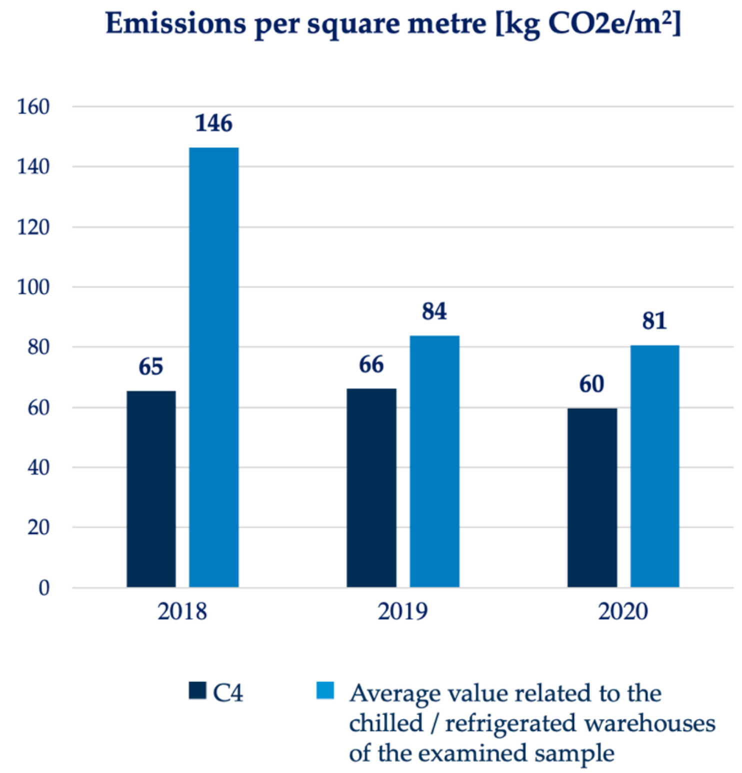


Figure 5.8 C4: Emissions per square metre over time [kg CO_2e/m^2]

Overall, the solutions implemented in the examined timeframe have concurred to a reduction of - 9% total emissions, shifting from 1,920 tonCO_2e in 2018 to 1,750 tonCO_2e in 2020.

5.2.2 Cross-case analysis

The cross-case analysis allowed synthesizing 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 what argued by Lewczuk et al., (2021), 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 Seifhashemia et al., (2018), discussing the potential of cool roof and Green Building solutions in retrofitting.

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 what expressed by Dobers et al., (2019). 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.

5.3 Conclusions and further developments

The objective of the chapter 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 chapter 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 analysis 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 Dobers et al., (2022), 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.

6 Conclusion

6.1 Main findings

The focus of this Master Thesis was to investigate the topic of energy efficiency at logistics sites. The interest showed by companies towards sustainability has increased exponentially under the pressure of multiple pressures, among which those by external stakeholders, for whom is becoming an important driver of purchasing, and governments that are increasing the regulations to be compliant with (Rogeli et al., 2016).

In the first part of the Master Thesis, a context overview has been performed describing the roadmap that led to the current definition of sustainability. Important milestones that have been mentioned are Kyoto Protocol, Paris Agreement, United Nation Agenda 2030 and Non-Financial reporting Directive of European Union. Similarly, the evolution of logistics-related topics up to green logistics definition has been done.

Up to few years ago, the academia has only focused on transportation as the main source of emissions of logistics processes, considered the most impactful one among logistics activities. Only recently Green Warehousing has become the focus of studies and researchers. From 2015 the number of papers about the topic has grown exponentially (Bartolini et al., 2019). In addition, the positive correlation between energy-efficient solutions and cost savings (Sahar et al., 2018) lead companies to invest more on Green Warehousing. Still connected to the economic dimension, sustainability is also becoming an important driver in investments evaluation. (Perotti et al., 2022; Dobers et al., 2019)

After the context overview, a SLR was performed, and some important elements emerged. Firstly, the evolution and diversification of energy-efficient interventions are translated into a multitude of different solutions covering all the area of the logistics site. Secondly, the importance that Green Warehousing and sustainability are acquiring as sources of resilience. As a matter of fact, the mutual relationship between sustainability and resilience during disruptions has often been studied. Third important element that emerged is the central role of digital technologies in the sustainable transition, as a way to reduce and monitor emissions but also to increase workers safety.

To deeply investigate those topics, a clear and structured methodology has been followed. From the gaps identified, two research questions have been formulated:

RQ1: *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?*

This international benchmark has been possible thanks to the involvement of Politecnico di Milano in the GILA project: a joint research project with Fraunhofer Institute and Universidad de Los Andes. This collaboration has led to the possibility to access to international data. For instance, only the German and Italian samples have been compared being the one encompassing the bigger number of logistics sites. The main focus was to understand in which way energy-efficient solutions influence emissions and consumption figures, highlighting the main differences between the two samples and related them to the changes in exogenous variables.

RQ2: *Which roadmap have companies undergone to transition towards net-zero warehouses?*

From the SLR, emerged clearly a lack of pluriannual studies on logistics site. The aim was, by exploiting the significant database of buildings, to narrow these gaps by presenting the sustainability interventions over the years and the consequent changes in emission and consumption figures of some Italian logistics sites.

In the following sections will be presented a summary of the main findings addressing the methodological questions. Then, some general remarks supported by theoretical and managerial implications and, concluding, gaps and future research will be highlighted.

RQ1: *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***?**

To answer RQ1 two databases have been used: the first one has been created thanks to the collaboration with the Observatory Contract Logistics "Gino Marchet" of Politecnico di Milano; the second one has been inherited by GILA project, the joint research project between Politecnico di Milano, Fraunhofer Institute and the Universad de Los Andes. Both databases have been consolidated through the spread of a survey that companies answered. The whole sample was composed by 193 warehouses: 127 located in Italy and 66 located in Germany, for a total of floorspace mapped of more than 4.8 mln of m^2.

After having presented the samples in terms of warehouse characteristics, the analysis continued on two different levels. First, Italian and German values have been benchmarked; then, a more in-dept analysis has been performed only for Italian warehouses. Some analysis that led to coherent results in the Italian sample, have not bring to the same results in the German one, probably due to the lower dimension and heterogeneity of the latter.

The two samples had different characteristics and it was fundamental to describe them in order to correctly interpret the results. The Italian one was characterized by a majority of ambient temperature warehouses and presented a remarkable number of players operating in the food sector. The German one, on the other side, seemed to be equally divided between ambient and temperature-controlled warehouses and comprised larger buildings (more than 40% overcomes 60,000 m^2).

Focusing now on the level of adoption of energy-efficient solutions, it's possible to say that Lighting remained a priority for companies in both countries. In Italy, then, a great interest for Utilities and Material Handling and Automation solutions have been noticed, while in Germany towards Green Building ones. Looking at the prospect scenario, intended as the solutions that companies prioritize for the future, the pattern was similar to the one highlighted in the current scenario: Green Building and Material Handling and Automation solutions are prioritized. Particular attention needed to be given to Materials Management, especially for the German sample for which this type of solution represented an important priority (25%).

After having presented the type of energy-efficient solutions and their level of adoption, the main emission and consumption figures have been discussed. The objective was, first, to give a general view on companies' consumption and emissions figures and then, understanding how those change according to the characteristics of the buildings. Starting from the electricity consumption analysis, it was noted that in Italy almost half of the total need of electricity (46%) is obtained in a sustainable way (i.e., produced in self-consumption or purchased from renewable certified sources). In Germany these values were much lower: the share of energy produced on site was around 5%, due to the smaller diffusion of photovoltaic panels and only 20% of German respondents affirmed they purchase energy from renewable sources (no data about the effective amount was provided).

Going deeply in the Italian scenario, frozen warehouses were the most energy-intensive ones with an average electric consumption of 423 kWh/m^2 versus 91.47 kWh/m^2 of ambient one. Easy to deduce, frozen food sector was the most impactful in terms of electric consumption. As regards fuels, Italy and Germany showed similar trends: the 99,9% of total requirements was met by natural gas and the remaining by gasoline and LPG.

The scenario was quite different for refrigerants: in Italy, ammonia represented the most used one with an average of 892 kg/year; in Germany, the most employed were R-717 and R448a (grouped under label "Others") with 616 kg/year.

To conclude, packaging type and related waste have been examined. In Italy, the most used packaging type was wood (58%) while in Germany was plastic (64%). Considering waste, the most spread was carton waste for both samples.

Focusing on emission figures, electricity was for both countries the main source of emissions, respectively representing 59% of total emissions in Italy and 56% in Germany. The 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 fuels' ones (43%). Those values were coherent with the different composition of the samples.

Then a more in-depth investigation on the explorative survey has been performed, presenting two business cases. One tenant and one shipper were presented to offer additional and more complete empirical evidence. Combining these two business cases with the previous analysis, some important conclusions can be drawn.

Firstly, the increasing importance that sustainability is acquiring among companies can be translated into the multitude of different type of energy-efficient solutions that cover all the different areas of the warehouse.

Second important aspect to mention is the increasing importance of energy management, and thus the necessity to be able to manage different energy carriers simultaneously. In this context emerged another important theme that is energy self-sufficiency, since seems it brings important benefits in terms of economics savings and risk hedging strategy. The concept of warehouse as energy node is becoming the most appropriate way to manage uncertainty in energy procurement. Energy storage systems emerged as a lever to succeed in this energetic transition. As additional signal of the spread of energy system, the cost of this type of solution has decreased from more than 1000 € to 150 € for kWh of energy stored in 10 years (Bloomberg, BNEF, 2022), making it more economically affordable and more attractive for companies. In the light of these considerations, monitoring of consumption become essential to identify the correct size of the battery.

Lastly, it has been underlined the necessity to combine different types of solutions that perfectly fit with external variables - like climate conditions - to obtain real environmental performances improvements. Spot solutions implemented to solve specific issues and not interconnected and inserted in a wider sustainability plan are not effective.

RQ2*: Which is the roadmap that companies have undergone to transition towards net-zero warehouses?*

From a methodological point of view, data analysed in this part have been taken from the database collected by the Observatory Contract Logistics "Gino Marchet" in 5 years of research. Among dozens of different buildings, the 4 cases have been selected according to 3 main criteria: data available for at least 3 years, a clear roadmap demonstrated by companies toward sustainability and heterogeneity criterion of characteristics of the buildings.

The approach followed for analysing data encompassed a within the case analysis - each case study is separately discussed – then, a cross-sectional analysis in which the main common findings have been reported.

Based on the longitudinal analysis, some initial key elements seem to emerge. The first element to mention is the importance to tackle environmental strategy with a multidimensional approach, this means to look for different types of solutions in different field of actions. The multitude of different energy-efficient solutions can be seen as a symptom of this necessity. In this sense, being sustainable not necessarily means new buildings from greenfield, but retrofitting of existing sites and materials recovery seem valuable ways for achieving good environmental performance. Furthermore, the different cases presented are evidence of the effectiveness of energy-efficient solutions in ambient warehouse and not only in temperature controlled one.

The second aspect is the long-term benefit that energy-efficient solutions provide. The cases highlighted significant reduction in terms of emissions in the considered timeframe, ranging from -3% to -56%, not only the year after the interventions but during the whole period monitored. For this reason, it is important to adopt a long-term perspective toward this type of solutions and put in action a constant monitoring in order to control their effectiveness.

A third important change to reported is the new meaning that warehouses are acquiring: they are starting to be consider not anymore as management node of the supply chain, but the concept of logistics node as energy hub is becoming more and more spread. This transition is mainly driven by the increasing cost and uncertainty around energy procurement and, of course, by the sustainable transition and the necessity to switch to more renewable sources of energy.

The last important key message is about the relevance to put in place a systemic planification of sustainability interventions and monitoring systems. This emerged clearly as the only way to obtain real environmental benefits. This structured action plan can not only lead the company to achieved predetermined targets but even to acquire certifications (e.g., LEED, BREEAM) that can contribute to substantiate the communication of its commitment towards environmental sustainability.

6.2 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 of this dissertation is having highlighted the level of adoption of energy-efficient solutions in Italy and Germany, thus creating the base for further international benchmark and development of reference values for the sector. The main objective was trying to compare the implementation of different types of energy-efficient solutions and their effectiveness according to exogenous variables, identifying some commons practices to realize these interventions.

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. Moreover, a great emphasis has been put in trying to assess the relative impact of the different type of energy-efficient solutions, to compare them. 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. Going on in pushing companies to answer to the survey exploit for this Master Thesis' is an effective way to obliged them to calculate emission and consumption and other specific data, thus incentivizing them to set internal guidelines for doing it. Moreover, the case studies considered for the longitudinal analysis represent an important evidence of business case treating Green Warehousing strategies in mature economy.

All in all, it can be noted that a holistic approach has been used to answer the two methodological questions. Different energy- efficient solutions have been considered at the same time and over years, both for what concern the international benchmark (presenting the prospective scenario) and the longitudinal analysis (considering at least 3-years analysis). The path towards sustainability encompasses different impact areas and thus different kinds of solutions need to be implemented over years.

Academic papers tackling single implementation are not enough to set the base for the roadmap towards decarbonization of logistics.

6.3 Managerial implications

Having now a more practical approach, the objective of this section 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 (e.g., in terms of temperature or dimension). If emission figures would be higher than the benchmarked one, this could be a wakeup call for better investigating main sources of emission to reduce them. Additionally, looking at which are the most performing solutions, depending on the various exogenous factors, can be source of advantage for other companies: following similar paths, they 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. Even though, also on yearly basis, some benefits were achieved, the long-term vision is fundamental. Additionally, it has been highlighted the importance of having a structured roadmap that considers at the same time different families of solutions. As an example, Case 4 warehouse, being also refrigerated, combined utilities solutions with Green Building ones for not losing the benefits coming from the first cluster. 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.

6.4 Limitations and future studies

In this section the main limitations of this study will be presented and some future lines of research will be proposed.

The first immediate limitation is the geographical scope: not only with respect to the benchmark but even to 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 replicate for longitudinal analysis: having access to more data, it could be useful to perform a pluriannual investigation on foreign warehouses, in order to understand how the sustainability strategy changes and which are the exogenous factors influencing it (i.e., cultural background, legislations)

Always focusing on the longitudinal analysis, other two remarks can be highlighted: the first one referring to the time frame considered and the second to the level of details of data. 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: logistics sector has been strongly impacted by the disruption of COVID-19. As seen in the longitudinal analysis, for example, some data were missing because of this situation, and it is fair to think that also other answers to questionnaires have been influenced by the pandemic. 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.

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