Measuring environmental sustainability at logistics hubs: an international benchmark of greenhouse gas emissions

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Abstract. Within logistics operations, sustainable warehousing has achieved increasing attention among academics and practitioners. Practitioners like Logistics Service Providers (LSPs) have started to perceive the need for measuring the environmental performance of their logistics hubs and searching for practices and solutions towards greener warehousing processes. Besides, a rising number of academic contributions have emerged addressing sustainable warehousing, especially from a conceptual viewpoint. However, empirical evidence is still lacking on the assessment of warehouse environmental performance, and very few studies offer an in-depth discussion on the quantification of operational greenhouse gas (GHG) emissions at logistics hubs. This paper aims at addressing this research gap. Based on an extensive international market study the paper discusses some preliminary results on energy efficiency and GHG emissions at logistics hubs. Specifically, an initial international benchmark between Italy and Germany is offered in terms of consumption and emission figures split by features of the logistics hub, thus paving the way to the definition of an initial set of relevant GHG emission indicator values that can be taken into account for measuring the sustainability performance of European logistics hubs.

Keywords: Sustainable Warehousing, Decarbonisation, Carbon Footprint.

1 Introduction

Warehouses are key components within supply chains, and the complexity of their operations has increased over time. This brought along significant challenges and necessary improvements not only in terms of efficiency and service level fulfilment but also with reference to their environmental impact. According to [1], logistics and transport activities account for 13% of the overall GHG emissions worldwide, of which logistics sites represent 11%.

Recently, sustainable warehousing and related emission reduction have been receiving rising attention. On the one hand, more demanding regulatory pressures and growing recommendations are coming from national governments, as well as international organizations. Besides, increasing pressures from a variety of stakeholders, such as investors and the entire society, are making sustainability one of the key drivers in logistics decision-making processes [2], also in the case of logistics sites. While the ISO standard 14083 is being finalized and will provide managers with a globally aligned framework for quantifying GHG emissions of transport and hub operations, companies so far had to rely on various standards aiming at certifying their performance in terms of energy efficiency and care for both environmental and social issues expressed through specific measures.

Although academic literature dealing with sustainability at logistics sites has recently been boosted [3], empirical evidence is still lacking on the assessment of warehouse environmental performance, as well as on the green warehousing solutions currently in place to increase the warehouse environmental performance. Also, very few benchmarking values are currently available both at the national and international level. This paper aims to fill this research gap. Based on an extensive international research project (GILA, German, Italian & Latin American consortium for resource efficient logistics hubs & transport) the paper discusses some preliminary results of an international market study on energy efficiency and GHG emissions at logistics hubs. Specifically, an initial international benchmark between Italy and Germany is offered in terms of consumption and emission figures, thus paving the way to the definition of an initial set of relevant GHG emission indicator values that can be taken into account for measuring the sustainability performance of European logistics hubs. Green warehousing logistics solutions and practices in place are also discussed.

The remainder of the paper is as follows. Section 2 provides an outlook of the literature review, and the methodology is hereinafter presented. Findings are discussed in Section 4. Conclusions are finally drawn and streams for future investigation are highlighted.

2 Literature review

The number of papers addressing green warehousing revealed a considerable evolution from 2015 onwards [4], as a symptom of the emerging awareness of the need for transitioning towards more sustainable logistics networks and nodes. The existing literature has tackled two main streams so far: firstly, the development of KPIs and frameworks in order to monitor sustainability and energy efficiency in the warehouse (e.g. [2], [5]), and, secondly, the available energy-efficient solutions and green practices that can be leveraged to increase warehouse environmental performance and energy-efficiency [6]. Looking at the first research stream, various indicators have been developed which either refer to buildings in general terms by focusing on specific facets of sustainability (e.g., environmental, social), or else that are specific to warehouse operations. On the one hand, examples of warehouse-specific frameworks of KPIs to be used for monitoring the performance of their warehouse can be found in [7]. Another example is provided by [8], where the proposed indicators have been included as part of a more comprehensive Sustainable Logistics Initiative (SLI). Further work on warehouse emissions accounting has been carried out by e.g. [2] where emissions were broken down by activity and then summed up by using carbon dioxide equivalents (CO_2e) as a common metric for all the different warehousing processes. Some case studies concerning GHG emissions accounting at logistics sites can be found in [9], where CO_2e is also used as unit of measure for the total emissions, and intensity values of resource consumption are measured such as kWh/(pallet*day) or kg CO_2e/(pallet*day). On the other hand, some papers offer indicators with the broader scope of green buildings in general terms, such as [10] where indicators are introduced for the embodied carbon (i.e., CO_2 emissions associated to the building construction phase) and for the impact of the building's operations. Focusing on the second research stream (i.e., available energy-efficient solutions and green practices that can be leveraged), Table 1 reports a summary of the main green warehousing solutions addressed by the literature so far.

Table 1. Main green warehousing solutions emerged from the literature.

Macro area	Solutions
Green Building	Thermal insulation; Loading docks with insulated doors; Cool roof; Green roof; Biodiversity
Utilities	Photovoltaic panels; Rainwater collection / reuse systems; Solar panels; Smart HVAC systems; Wind systems; Geothermal heat pump systems
Lighting	LED lighting; Natural lighting and white walls; Solar tubes; Sensors for reducing lighting consumption
Material Handling and Automation	Sensors for reducing MHS consumption; Energy recovery during braking
Materials Management	Packaging reduction; Packaging reuse / recycle; Use of renewable / biological materials; Minimization filling packaging material; Technologies for optimizing the packaging size
Operational Practices	Travel distance optimization for MHS; Optimal planning for MH activities and battery charging; Process design optimization with a focus on ergonomics

3 Methodology

3.1 Design of international surveys

This research bases on an international market study which is a core part of the GILA project. The market study was survey-based and has been performed so far over two consecutive years, i.e. 2021 ([11]; [5]) and 2022. The partners' individual networks have served as three main starting points. Data collected by each institution were processed, anonymised and finally merged into one database that allowed researchers to elaborate the collected information. As a result, the 2022 database covers 605 logistics hubs and terminals from 44 countries worldwide, with 82% from Europe.

3.2 Questionnaire structure and data analysis

The questionnaire for logistics hubs was structured into the following main sections. Operators of logistics hubs were initially asked to provide general information on the warehouse and its specific features, such as location, industry sector(s), year of construction, building floorspace, clear operating height, temperature. Respondents were then asked to specify annual data on warehouse consumptions in terms of electric energy, fuels, refill of refrigerants, as well as packaging material used, and waste generated. A final section was devoted to data collection on throughput and details related to each warehouse area (e.g., size, activities performed, material handling solutions used, lighting system in place). Information related to the solutions in place for improving energy efficiency and environmental sustainability at logistics hubs was also collected, together with the related companies' investment priorities for the near future (i.e., next 5-year timeframe). The green warehousing solutions being examined were based on the literature review, as per Table 1, and were further validated by company managers. The survey was designed to balance the wish of research organizations to receive as detailed information as possible and the willingness and readiness of participating companies to dedicate general resources to this extra survey and workload. This was addressed by the fact that, firstly, all participating sites were sent their individual results; secondly, the publication of all anonymized results (e.g. on emission intensity values and benchmarks) was ensured; thirdly, many questions were set as optional, and only core mandatory information was required to complete the survey (i.e. identify site type, country of location, qualitative selection of resources consumed). The assessment Scope used for calculating average emission intensity values is aligned with [12], [4] and [13]. Thus, the following GHG emissions categories are considered for the purpose of the study: Direct emission from burned fuels and leakage of refrigerants (Scope 1); Indirect emissions from purchased electricity and other energy (Scope 2); Indirect emissions from production and supply of fuels and electricity distribution, from production and supply of transport packaging and related waste collection, disposal, and recycling (Scope 3). GHG emissions caused by electricity consumption were calculated applying the location-based approach [4].

4 Results

4.1 Sample features

Focusing on logistics hubs, the 2022 database comprises in total 539 sites, covering facilities that offer transhipment (159) or warehousing (193) as main service, and 187 offering both storage and transhipment. As outlined in the previous section, the survey approach allowed participation with qualitative consumption information (i.e. selection of relevant resources consumed at the sites) as well as with quantitative (i.e. individual consumption data). As starting point for further analysis, the specification of the annual electricity consumption has been defined as minimum criterion for being included in the analysis, which was realised by 513 sites. Out of this sample size, further resource clusters were also investigated, namely heating energy (excluding electricity used for heating), other energy sources e.g. used for material handling on the yard, refill of refrigerants or materials used for transport packaging and related waste. In particular, 269 sites (52%) outlined, that they use heating energy, thereof 93% provided consumption data (Fig. 1). A few more sites, i.e. 341 (66%) specified the use of additional energy sources 86% of those sites provided annual consumption data. 51 sites refilled refrigerants (10%) and 63% of those also provided data. As optional part of the survey and regarding sites offering warehousing and/or transhipment, 120 sites specified the use of transport packaging, thereof 39% provided quantitative data.

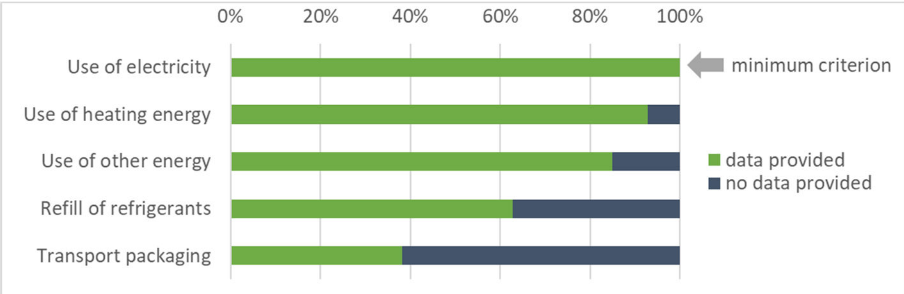

Fig. 1. Data access for GHG emissions accounting of logistics sites per resource cluster.

For elaborating consumption and emission key performance indicators, complete data sets are key. The figures above outline the varying sample size for different resource clusters. Overall, only 263 sites (51%) have provided a complete data set for all resource clusters as required by [13], i.e. covering all energy and refrigerants related greenhouse gas emissions.

In this research an international comparison of Italian and German logistics hubs is focused. In the above outlined 2022 database covering 539 sites, a total of 300 logistics hubs are encompassed, out of which 131 sites are in Italy and 169 sites in Germany. As outlined in Fig. 2, most of these sites are ambient sites or sites with mixed temperature levels, e.g. sites with both ambient and chilled areas.

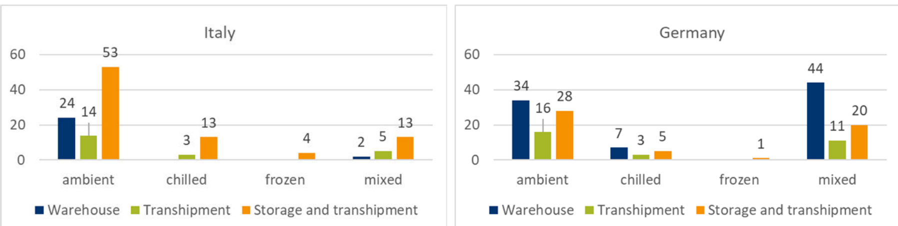

Fig. 2. Site categories covered in the comparison of Italian and German logistics hubs (n=300).

These hubs offering transhipment and/or storage of goods vary significantly in size (from 700 to 180,000 m² indoor floorspace in Italy; from 1,100 to 73,000 m² indoor floorspace in Germany) and throughput (from 18 to 700,000 million tons with 35,000 tons as median value in Italy; from 275 to 1.1 million tons with 340,000 tons as median value in Germany). Only 130 sites have specified the individual year of construction: according to this information, 35 of the Italian sites (38%) have been built after 2010 (64 sites, 70% after 2000), whereas 14 of the German sites (36%) have been built after 2010 (24 sites, 62% after 2000).

4.2 Resource consumption and GHG emission figures

For analyzing the resource consumption and elaborating GHG emission key performance indicators, the provision of complete quantitative data sets is required. In the sample at hand, only 126 Italian and 29 German sites have realized this prerequisite.

As per Fig. 3, at the German ambient hubs, greenhouse gas emissions are caused equally from electricity use (51%) and heating fuels (48%). For heating, mainly natural gas, biogas, or district heating is used. At the ambient hubs located in Italy, GHG gases results mainly, i.e., 71%, from electricity. Further emissions are caused due to the use of heating (14%) and transport packaging (13%). Heating is realized using natural gas, biogas, or LPG. The sample does not cover German hubs with chilled goods only. Comparing, however, the ambient and chilled sites in Italy, a higher share of electricity use (82%) and refrigerant leakage can be stated: 8% of the GHG emissions of chilled sites in Italy can be allocated to the leakage of refrigerants.

Due to the large impact of electricity used, the site operators have been asked if they can allocate the consumption to defined activity clusters. Data referred to the entire sample (i.e., Italy- and German-based logistics sites) are presented in Fig.4. In Germany, only few sites (8%) can provide such allocation, whereas in Italy, almost all answering sites outlined having such transparency. For the Italian sites, however, it is necessary to outline, that either they have already been asked in previous years for such an allocation and/or received a general starting point for allocation (i.e. 42% lighting, 20% material handling, 6% chilling of goods, 32% others) that has been derived from feedback in previous years [14].

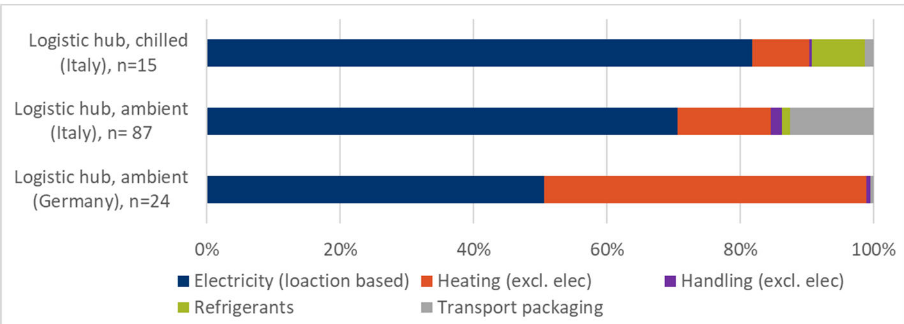

Fig. 3. Greenhouse gas emission sources at selected Italian and German logistics hubs (n= 126).

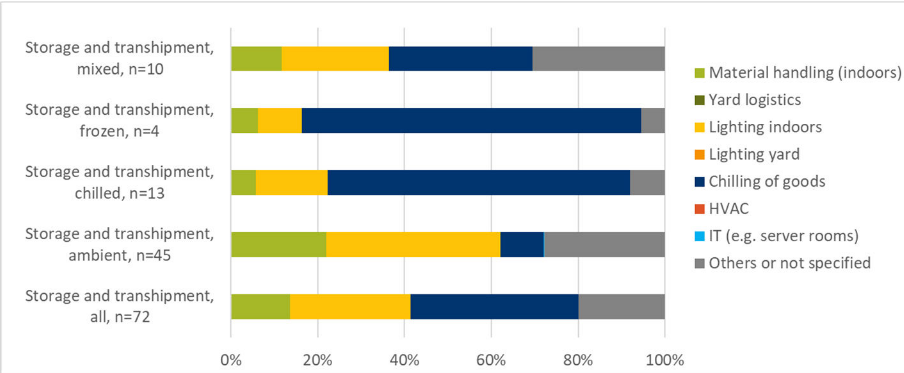

Fig. 4. Allocation of electricity consumption to activity clusters at sample hubs (n=72).

But even having the same starting point, the Italian hubs outlined different shares varying regarding the temperature level and site types. Fig. 4 provides the average shares for storage and transhipment sites in Italy. One can see that more electricity is used for the temperature-control of goods at chilled and frozen sites (70% and 78% resp.), whereas the electricity use of lighting and material handling at ambient sites account for more than 60%. On average, the shares are the following for the Italian storage and transhipment sites: 29% lighting, 14% material handling, 39% chilling of goods, 17% others. The elaboration of average greenhouse gas emission key performance indicators for logistics hubs is a further objective of this research. As discussed already before, those average KPIs strongly depend on the sample size used and the following results can only serve as an initial set of average values. Table 2 summarizes the results on calculated GHG emission intensity values for ambient logistics hubs in Germany, Italy, and Europe, expressed in kilogram CO_2-equivalents per tonne throughput outbound and per square meter logistics area.

Table 2. Preliminary emission KPIs for ambient logistics hubs.

Site type	Germany		Italy		Europe		Unit for KPI
Transhipment	0.8	n=3	4.9	n=10	0.5	n=54	kg CO_2e/t
	24.3	n=2	17.4	n=14	10.5	n=57	kg CO_2e/m²
Storage and transhipment	6.1	n=12	1.9	n=17	2.1	n=44	kg CO_2e/t
	16.8	n=12	12.7	n=51	14.6	n=78	kg CO_2e/m²
Warehouse	23.9	n=5	17.7	n=19	17.7	n=25	kg CO_2e/t
	18.1	n=9	12.6	n=22	15.6	n=32	kg CO_2e/m²

The outlined average values represent the median of the available sample size. Looking more closely at the data for ambient storage and transhipment sites, the sample size results in KPIs ranging from below 0.001 to around 125 kg CO_2e/t for Italian sites, and from 0.4 to more than 700 kg CO_2e/t for German sites. This underpins the need for further research establishing an extended database. The European values hint at warehouses having the highest GHG emission intensity values and transhipment sites the lowest, both for tonne- and m²-based indicators. Considering though the constrained sample size, no further interpretation of the data is established here. Instead, we want to emphasize the relevance of further research to extend the underlying data base and, thus, establish reliable average emission intensity values for logistics hubs in the future.

4.3 Green warehousing solutions in place

Sites in Germany and Italy have been analysed regarding whether they have answered the status of implementation or any priority for future investments in green warehousing measures. Some example answers are summarised in Figure 5, where sample size (n) refers to the number of German and Italian sites (sum of both countries).

Measures related to Green Building appear quite widespread in both samples, with insulation – either related to the building shell or to loading/unloading docks – being prevalent (82% and 50% respectively for Italy; 61% for both measures for Germany), followed by cool roof and green roof. As per Utilities, photovoltaic and solar panels are often adopted in Italy (80 and 44% respectively) also due to both country location and incentives. Smart HVAC systems (67% Italy, 41% Germany), rainwater collection and reuse systems (34% Italy, 29% Germany) and smart metering (38% Italy, 12% Germany) have been also detected in both samples. Specific attention is devoted to Lightning which often appears as an easy fix and a win-win option. From this viewpoint, LED lighting (97% Italy, 69% Germany), sensors for reducing light consumption (85% Italy, 83% Germany), natural lighting and white walls (62% Italy, 42% Germany) are generally widespread.

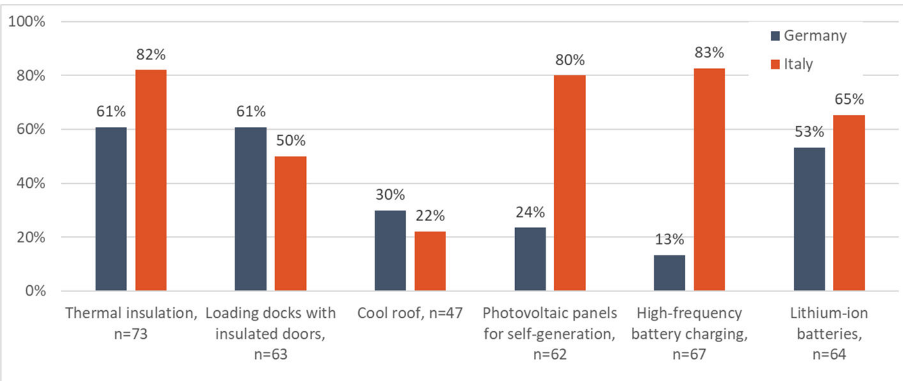

Fig. 5. Current adoption of exemplary green warehousing measures.

Conversely, measures in the field of Material Handling and Automation are generally less common. If high-frequency battery charging, Lithium-ion batteries and braking systems with energy recovery start to be implemented particularly among Italian sites (83%, 65%, and 47% respectively), the situation differs in Germany where only Lithium-ion batteries seem the more established option (53%). As per Materials

Management, separation of waste fraction for better recycling (both 100% Italy and Germany), packaging reduction (91% Italy, 62% Germany), packaging reuse and recycling (94% Italy, 54% Germany), and renewable/bio-based materials (67% Italy, 12% Germany) are the most common measures, with local sourcing of materials only adopted in German sites (60%). Finally, looking at Operational Practices, in Italian sites current adoption mostly refers to travel distance optimization and optimal scheduling of material handling activities and battery charging (100% and 61% respectively), whereas German sites implement a wider array of measures that also include energy-efficient behavior (87%), support of sustainable commuting (68%), and optimized location of charging equipment (38%).

5 Conclusions and future developments

The aim of the paper was to shed light on the assessment of warehouse environmental performance. Empirical evidence on the quantification of operational GHG emissions at logistics hubs was provided based on an extensive international research project (GILA). German and Italian logistics hubs were examined in terms of consumption and emissions figures, as well as green warehousing measures in place. Results on consumption data highlighted that warehouse operators in both countries have a good overview on their energy consumption at a general level, few information is available at the more detailed, activity-clusters level though. Only half of the participating sites are ready to implement the ISO 14083 requirements. One may conclude that further research is needed in this field. Firstly, to support companies in getting better transparency in their resource consumption at activity or process level and, thus, in identifying potential fields of resource use and emission reduction. And secondly, such transparency will enable the combined analysis of resource consumption, implemented energy efficiency measures and their impact on overall resource consumption and possible emission reduction roadmaps.

Regarding the green warehousing measures in place, the solutions adopted mainly refer to Green Building, Lighting, Materials management and Operational practices. Increasing interest in existing and new sustainability measures can be stated.

The main limitation of the research is related to the still limited sample, especially for German sites, that prevent the results from being fully generalisable. Additionally, data can be partially biased by the fact that questions were not all mandatory. Finally, the study focuses on two specific countries, and results may differ for other countries.

Despite the above-highlighted limitations, this study opens promising streams for future investigation in the arena of green 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 on an international scale) and a temporal (i.e., longer timespan under examination) perspectives. On the other hand, future research is recommended on the impact assessment and evaluation of specific sustainability measures along the full life cycle of hubs, so that logistics hubs owners and operators can be given decision-making support in the selection and implementation of sustainability measures.

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