Analyzing Forklift and Drone Applications in Sustainable Logistics: A Bibliometric Review

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Abstract: Nowadays organizations are under increasing pressure to adopt sustainable solutions for material handling and management due to growing environmental awareness. This drive has spurred advancements in innovative technologies, optimizing logistic processes to reduce energy usage and emissions, and enhancing overall supply chain sustainability. This approach extends to internal material handling with forklifts and the emerging use of drones for last-mile operations. Despite the importance of sustainable logistic practices, the literature lacks a comprehensive review of research on forklifts and drones in logistic activities. Through a Systematic Literature Network Analysis (SLNA), this paper addresses this gap by conducting a comparative analysis of two bibliometric reviews: one on forklifts' sustainable logistic applications and the other on drones'. This analysis aims to identify key contributors, countries, journals, and research themes in both areas. The SLNA results seek to highlight existing literature, productive countries, influential authors, and research themes. This paper provides theoretical contributions by identifying gaps in the current literature and highlighting key research themes related to sustainable logistic practices. Furthermore, it offers practical insights to industry stakeholders on integrating these practices using forklifts and drones, while also laying the groundwork for future research through a comparative analysis.

Keywords: forklifts, drones, sustainable logistics, sustainable supply chain, literature review.

1. INTRODUCTION

In today's industrial landscape, characterized by a growing environmental awareness and the urgent need to reduce the impact of production activities on the ecosystem (Vieira et al. 2021), organizations are called upon to adopt increasingly sustainable practices also considering material handling and management solutions (Boenzi et al., 2015). This heightened awareness has spurred significant advancements through the implementation of innovative technologies, enabling businesses to achieve both environmental and economic benefits (Ferraro et al., 2023). Particularly, the optimization of logistic processes plays a crucial role in reducing energy consumption and emissions, thereby enhancing the overall sustainability of supply chains. This sustainability-driven approach extends to both internal material handling processes, such as those managed through the use of forklifts (Kohei et al., 2023), and last-mile operations, where the use of drones emerges as a promising solution (Li et al., 2022). While drones are commonly associated with external delivery and transportation operations, their utilization within warehouses represents a highly promising sector (Ali et al., 2023). Their characteristics, including dimensional flexibility and flight autonomy, offer a significant operational advantage over conventional robots, which often lack the ability to operate in multi-dimensional contexts (She and Ouyang, 2023). Furthermore, in line with the increasing focus on environmental sustainability in warehousing activities (Bartolini et al., 20219), there is a further evolution in the realm of internal material handling, particularly in the increasingly widespread adoption of electric forklifts (Copetti et al., 2023).

The momentum generated by Industry 4.0 paradigms is equally significant. Through automation and system interconnection, certain technologies gain an edge over those still reliant on human intervention (Sun et al., 2022). Consequently, there is a growing interest in comparing different technologies to identify the most promising ones for various process activities, such as logistics. In the literature, several studies delve into the benefits of both vehicles through economic and environmental analyses. Baldisseri et al. (2022) assess the feasibility of integrating a truck-drone delivery system from both an economic and environmental perspective. Similarly, Stefanini and Vignali (2022) compare the use of forklifts with automated guided vehicles for internal logistics activities. However, to the best of the authors' knowledge, the is a dearth of comprehensive studies, including reviews, examining the applications of forklifts and drones in logistic activities and their sustainable practices. Similarly, there is a lack of bibliometric reviews on these topics, and no study has attempted so far to provide a comparative analysis of the different bibliometric results obtained when exploring sustainable logistic applications of forklifts and drones, respectively. Nonetheless, understanding the existing literature on the sustainable logistic applications of drones and forklifts and comparing the respective results could be highly

valuable for two reasons. First, it could help to reorganize the research conducted in these fields (i.e., forklifts and drones' applications), thereby identifying key contributions and the most prolific authors, journals, and countries investigating logistic applications and sustainable practices. Secondly, it could aid in identifying current and future research trends in the two analyzed domains, allowing to highlight differences and commonalities, and providing a solid foundation for novel studies in both areas. To address this gap, this paper presents a comparative analysis of the results of two bibliometric reviews, each performed following a Systematic Literature Network Analysis – SLNA. The reviews focus on: (i) the application of forklifts for sustainable logistic practices, and (ii) the application of drones for sustainable logistic practices. The choice to employ SLNA arises from its suitability as a bibliometric methodology, standing out among other methods such as systematic literature review, critical review, and meta-analysis. SLNA facilitates a comprehensive representation, both quantitatively and qualitatively, of the intellectual structure of current and emerging trends within a research topic identified from a broad and general sample of articles (Donthu et al., 2021). When comparing the two bibliometric reviews, each of these reviews will address two research questions referring to its domain:

(RQ1) What are the most productive and influential countries, journals, authors, and contributions in the literature on forklifts/drones for sustainable logistic applications?

(RQ2) What are the main themes and research streams driving research on forklifts/drones for sustainable logistic applications?

By comparing the results of the two bibliometric reviews, this paper will aim to achieve three objectives. First, to identify the existing literature on the two analyzed domains, understanding the main similarities and differences in the sustainable application of forklifts and drones within logistic practices. Secondly, to explore the top-contributing countries, journals, and authors in both fields (along with their main contributions) by analyzing the number of publications and citations. Finally, to analyze past and current research themes related to forklifts and drones' sustainable logistic applications by examining authors' keywords and their co-occurrence. In achieving these objectives, this study aims to contribute to the literature by producing relevant outcomes on similarities, differences, and promising technology gaps for sustainable logistics through bibliometric comparison of key research on forklifts' and drones' logistic applications. Specifically, the first outcome of this study will be descriptive metrics on the retrieved research documents, providing an overview of the current body of knowledge. Moreover, another contribution of this paper will be to lay the groundwork for future research activities in the analyzed domains, providing researchers with comparative results on forklifts and drones useful to identify potential literature gaps.

The remainder of this paper is as follows: Section 2 provides a description of the materials collected through the SLNA and outlines the methodology followed to conduct the bibliometric reviews. Section 3 shows the results of the bibliometric reviews and their comparisons. Finally, Section 4 provides concluding remarks.

2. METHODOLOGY

Within this study, a bibliometric analysis was conducted to compare the state-of-the-art use of drones and forklifts in logistics activities and their sustainable practices following the approach described in Cantini et al. (2022). As a first step, the most relevant keywords were identified to achieve the research objective based on the most pertinent bibliometric studies in the field of sustainable logistics and green warehousing (Bartolini et al., 20219, Fahimnia et al., 2015). These keywords were classified, as shown in Table 1, into three semantic areas: logistics processes (Semantic Area 1), sustainable analysis (Semantic Area 2), and movement equipment (Semantic Area 3).

Table 1. Keywords semantic area classification

Semantic Area 1	Semantic Area 2	Semantic Area 3
warehous*, inventory manag*, material handling, *logistic*	sustainab* assessment, sustainab* evaluation, sustainab* estimation, economic assessment, economic evaluation, economic estimation, energy efficiency, energy assessment, energy evaluation, energy consumption, energy reduction, energy estimation, energy saving*, energy transition*, emission assessment, emission evaluation, emission reduction, emission estimation, carbon emission, carbon assessment, carbon evaluation, carbon consumption, carbon reduction, carbon estimation	forklift* , fork lift*
		drone, drones, unmanned aerial vehicle*, quadricopter*, multirotor*, multicopter*

Since the aim of the study is to compare the usage of forklifts and drones within logistics processes from the same perspectives, two search strings were identified. Both search strings share the keywords and the logical representation of the

first and second semantic areas, while differing in the third. Within each search string, logical OR operators were used to connect keywords within each semantic area, and the AND operator to link different semantic areas. Additionally, quotation marks were used to identify the precise sequence of words within, and the asterisk operator (*) to include all words sharing a common stem but differing in their prefixes or suffixes.

The search was conducted in the Scopus research database within the fields of title, abstract, and keywords. Scopus was selected as the single database for the SLNA for two main reasons. Firstly, the most commonly used software for bibliometric analysis relies on specific metadata rules tailored to different databases (e.g., Scopus, Web of Science, Pubmed), limiting the choice to single research databases. Secondly, the selection of Scopus was motivated by its extensive coverage of journals in subject areas such as management, engineering, and environmental sciences (Ahi and Searcy, 2015), which encompass publications relevant to the comparison of the two technologies. Following the research methodology, a total of 93 manuscripts were identified for the forklift search and 141 for the drone search. These two samples were then included for analyses on the temporal trend of the number of publications, average number of citations, and geographic distribution. Furthermore, analyses were conducted on the keywords, their relationships, and clustering. The analysis of the results was performed using Microsoft Excel, VOSviewer software, and the Bibliometrix package in RStudio.

3. RESULTS AND DISCUSSION

The first database related to forklifts shows a composition of documents mostly attributed to articles (46 out of 93, 49%) and conference papers (41 out of 93, 44%) over a time span ranging from 1976 to 2024, with an annual growth rate of 2.32%. On the other hand, drone-related research has a higher composition of articles (87 out of 141, 62%) compared to conference papers (42 out of 141, 30%). The reference period is much narrower and more recent, spanning from 2015 to 2024. Despite the shorter time window, the number of publications on drones is more current and shows significant growth with an annual growth rate of 27.65%. From the perspective of average citations per article, research on forklifts has a value of 9.5, while that of drones is 11.6.

Figure 1 illustrates the temporal trend of the number of publications and the average number of citations for both research queries. As shown, the production has increased for both topics. However, regarding forklift research, it is spread over several years and does not have a well-defined peak, while drone research is concentrated over a few years with a significant peak in 2023. This interest may be stimulated by the COVID-19 phenomenon and how drones have been increasingly investigated for emergency situations. A similar pattern is observed for the average number of citations, concentrated in the short period from 2017 to 2019.
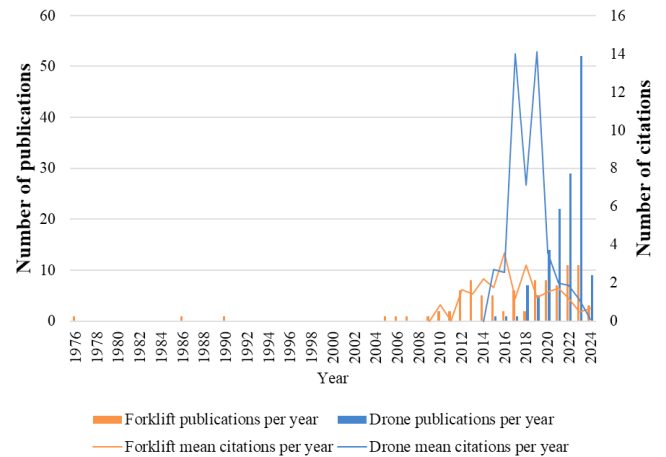

Figure 1. Publication and citation trend of forklift and drone manuscripts.

Regarding the sources, the forklift research extends to 72 sources, while that of drones extends to 98 sources. For drones, the journal with the highest number of publications is "Sustainability" (8 publications), a result that could be related to the potential of drones to enhance the sustainability of business processes. Following in terms of the number of drone publications are the journals "Drones", "Energies", and "IEEE Access" each with 5 publications, respectively. On the other hand, in the case of forklifts, the most relevant journal is "Energies" (5 publications), followed by "Automation in Construction" (4 publications).

Both research topics involve a significant number of countries worldwide based on authors' affiliations, as shown in Figure 2. The forklift research covers 29 countries, while the drone research covers 45 countries. In both cases, China has the highest number of publications (68 publications for forklifts and 186 for drones). Other notable countries for both research topics include the USA (35 publications for forklifts and 43 for drones) and Italy (55 publications for forklifts and 37 for drones). Finland stands out for the recent period with a productive period between 2011 and 2015 regarding forklift research (42 publications), while Greece shows growth starting from 2022 for drone research (34 publications).
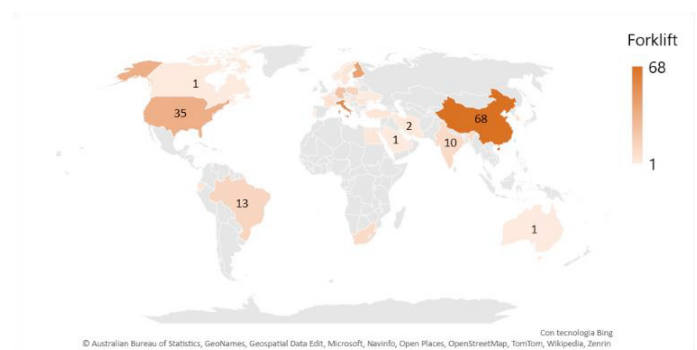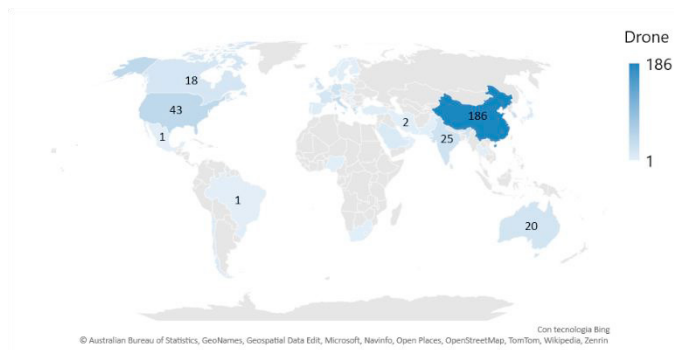
Figure 2. Geographical distribution for forklift (orange) and drone (blue) research.

To fully address RQ1, the most productive and influential authors were analyzed for both research topics, considering the number of publications and citations. Figures 3 and 4 depict the annual production of authors concerning the use of forklifts and drones within logistic processes, respectively. Within these graphs, only the top 10 most relevant authors for each research are included. In these graphs, the size of the circles represents the number of annual publications, while the color intensity represents the number of citations.
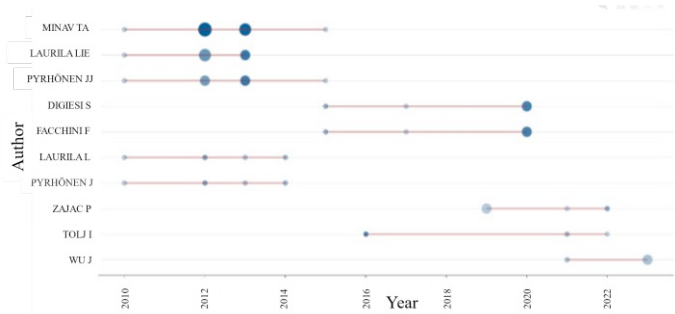

Figure 3. Authors' yearly production on forklift research.

For the research on forklifts, the investigation appears to be continuous and carried out by research groups across three consecutive time intervals. In the first time interval, between 2010 and 2015, the most productive authors with the highest number of citations are present. Among these, the most influential author is Minav T.A. with 9 publications and 298 citations.
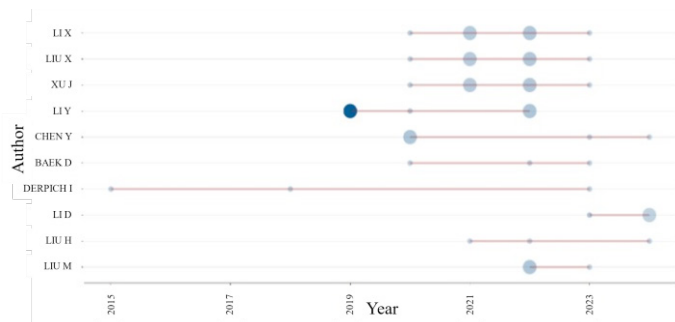

Figure 4. Authors' yearly production on drone research.

Conversely, the results of the drone research show a different trend, with increasing interest observed in recent years. As depicted in Figure 4, a significant portion of relevant authors

is concentrated between the time interval of 2020 and 2022. The only distinction is noted for author Derpich I., who has contributed to drone utilization within logistics since 2015. Among the relevant authors, the most impactful contribution comes from Li Y. with a total of 328 citations across 5 articles. However, the most productive authors are Li X., Liu X., and Xu J., all with a total of 6 publications.

To address RQ2, we analyzed the main themes related to the sustainable logistic applications of forklifts and drones by examining their co-occurrence using VOSviewer (van Eck and Waltman, 2010). The analyses were conducted with a minimum threshold of 4 keywords, and an appropriate thesaurus was utilized for accuracy. The results are presented in Fig. 5 and Fig. 6 for forklifts and drones, respectively. In these figures, the size of the dots indicates the frequency of occurrence of each keyword, while the connections between dots represent co-occurrences. Additionally, different colors are used to distinguish between clusters, which may correspond to distinct topics.
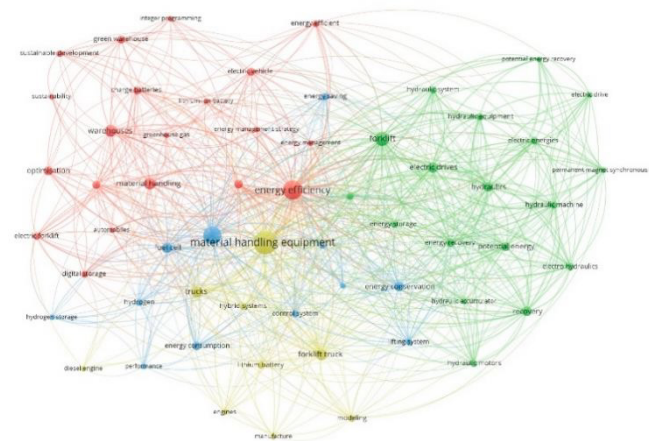

Figure 5. Keywords' co-occurrence network of forklifts application in sustainable logistic research.

Based on the colors and keywords of Fig. 5, four main research themes were identified with VOSviewer. Within the red cluster, the majority of keywords pertain to the theme of electric forklift optimization. In the green cluster, keywords relate to hydraulic systems and energy recovery. The yellow cluster contains keywords regarding motor typology and control, particularly diesel engines and hybrid drives. Finally, the blue cluster encompasses keywords conceptually less interconnected, with main themes revolving around energy consumption evaluation, hydrogen, and construction.
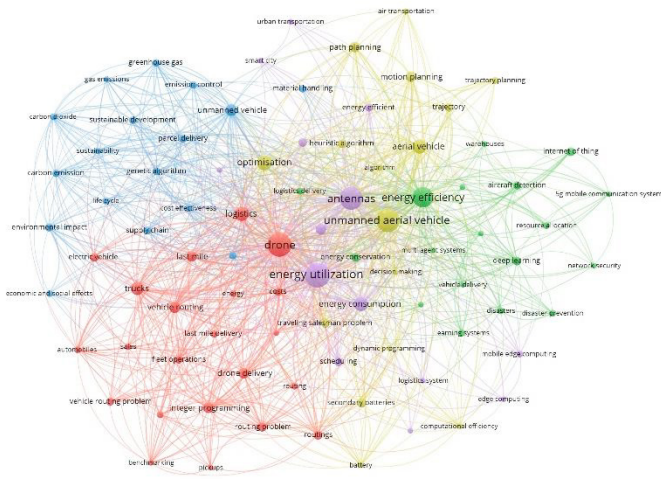
Figure 6. Keywords' co-occurrence network of drones application in sustainable logistic research.

Similarly, based on the colors and keywords of Fig. 6, five main research themes were identified. The red cluster identifies keywords primarily corresponding to process activities regarding themes of drone last-mile delivery and routing. The green cluster identifies keywords more related to Internet of Things (IoT) technologies and deep learning for energy-efficient drones. The blue cluster, on the other hand, predominantly addresses impact typology, with keywords mainly concerning economic and emission evaluation. The yellow cluster, also related to processes involving drones, delves into the primary reference parameters with themes of path and trajectory planning. Lastly, the violet cluster encompasses themes regarding the use of drones in urban environments.

To better address RQ2, a Thematic Map of keywords was constructed using Bibliometrix (Cobo et al, 2011). This map facilitates the classification of keyword groups into four quadrants based on their degree of development (density) and relevance (centrality). In the upper right quadrant, highly evolved and research-significant topics, termed motor themes, are identified. Highly specific themes with limited associations are situated in the upper left-hand side, referred to as niche themes. Emerging or declining topics, indicative of underdevelopment, are positioned in the lower left quadrant. Finally, the lower right-hand quadrant encompasses keyword groups pertinent to the search but approached in a general manner, recognized as basic themes. The results are presented in Fig. 7. Regarding forklifts (Fig. 7a), niche themes include automated guided vehicles, acquisition of 3D data, and accident treatment (pink, 8 keywords and 17 occurrences). Electric drives and hydraulics emerged as motor themes (orange, 53 keywords and 212 occurrences), aligning with the VOSviewer analysis which also highlights electric batteries as a relevant theme. Hydrogen and hybrid are depicted as basic themes (brown, 7 keywords and 20 occurrences), consistent with the VOSviewer results. For drones (Fig. 7b), budget control and autonomous vehicles have been identified as basic themes (brown, 2 keywords and 5 occurrences). Aircraft detection and energy power utilization (orange, 11 keywords and 29 occurrences) are categorized as niche themes. Accident

prevention (blue, 6 keywords and 14 occurrences) is identified as a main theme but denoted as an emerging or declining theme. In comparison to VOSviewer, there is no mention of IoT or deep learning.
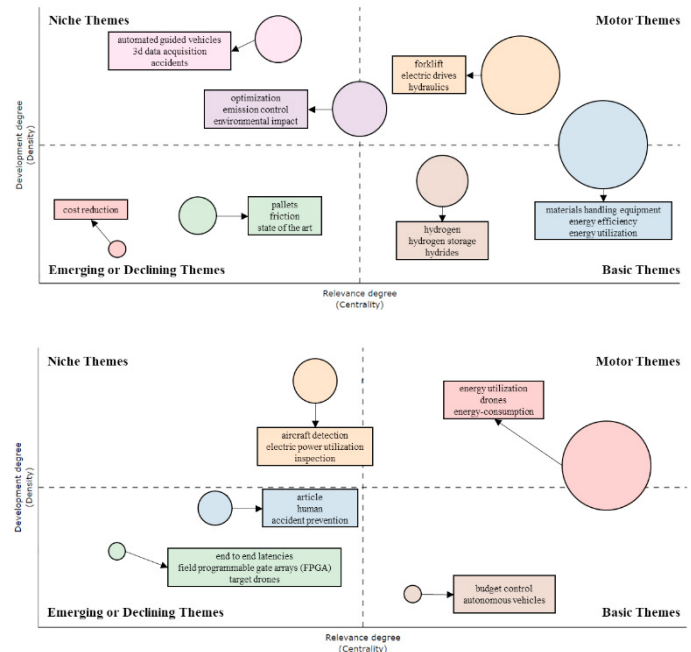

Figure 7. Thematic map of author's keywords for forklift (a) and drone (b) research.

4. CONCLUSIONS

This paper delves into the existing literature on drones and forklifts within the realm of sustainable logistics. Firstly, it examines the most productive and influential countries, journals, and authors by analyzing document numbers and citations. Subsequently, it identifies pertinent topics through keyword co-occurrence analysis using two distinct tools: VOSviewer and Bibliometrix. The findings reveal that drones represent a relatively newer field compared to forklifts, evidenced by a higher number of recent documents. Concerning forklifts, various themes are explored such as electric forklift optimization and the adoption of alternative fuel-based forklifts. Conversely, the drone sector is more associated with IoT and the adoption of artificial intelligence, particularly deep learning. Notably, significant efforts are directed towards the sustainability of last-mile deliveries and path planning, with a specific focus on the social dimension of sustainability through accident prevention studies.

From a theoretical standpoint, this study investigates the most relevant themes concerning drone and forklift sustainability evaluation and provides insights on the most prolific countries in these domains. From a practical perspective, warehouse managers and practitioners can utilize this research to identify areas for improvement and highlight unmet needs in investigation. However, this research has its limitations. The study confines the comparison to two main technologies relevant to logistic processes. Nevertheless, other technologies (e.g., automated guided vehicles, electric trucks, electric bikes, etc.) could be integrated into the comparison to better delve into thematic evolutions and research trends. Moreover, the

selection of specific keywords may influence the results, and exploring different search strings could yield varying outcomes. For instance, the comparison primarily focuses on the application of technologies from an economic and environmental perspective, while social phenomena are overlooked. A future development could be to investigate, under the umbrella of the triple bottom line sustainability objectives, the impact of technology application on economic, environmental, and social sustainability. Additionally, a more in-depth bibliographic analysis could provide further insights into the most relevant documents. Furthermore, the utilization of only one database limits the scope of the study, suggesting the inclusion of additional databases like Web of Science to expand the findings considering the limitations of commonly used bibliometric analysis software.

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