Optimising the Spatial and Digital Accessibility of Parcel Lockers: A Global Analysis of Adoption Dynamics

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Abstract. Research on Parcel Lockers (PLs) in last-mile delivery (LMD) has gained significant academic attention over the past decades. While spatial factors such as population density, transport infrastructure, and commercial proximity are well-explored in determining PL allocation, less attention has been given to digital aspects critical to their effective deployment. PLs are predominantly deployed in urban areas, with limited availability in suburban and rural regions. Existing studies have primarily examined their socio-economic benefits and freight optimization, yet research on strategic spatial allocation—particularly user accessibility—remains scarce and fragmented. This study aims to address this gap by conducting a mix-approach. Firstly, we conduct a literature review using Scopus, identifying 37 relevant research papers based on keyword searches (parcel AND locker AND digit OR techn* AND accessibility OR proximity OR location/spatial location**). Secondly, we identified the main challenges in urban, non-urban contexts regarding accessibility, proximity and digital use of PLs. Preliminary findings highlight two key challenges: the lack of research on PL deployment in non-urban areas and a widespread digital divide among potential users, emphasizing the need for targeted awareness campaigns to promote equitable adoption. The results provide a foundation for researchers, city planners, and logistics companies to develop context-specific strategies aimed at bridging socio-economic disparities, improving spatial accessibility in underserved areas, and enhancing digital literacy initiatives to support PL adoption.

Keywords: Parcel lockers · Accessibility · Digital and spatial planning · Last mile logistic · Sustainable mobility

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1 Introduction

In the early 2010s, the last-mile logistics sector underwent a profound transformation driven by several key factors, including the rapid growth of e-commerce, advances in digitalization, and changing consumer expectations for faster and more convenient delivery options. With the expansion of e-commerce, consumer expectations have changed, and logistics companies must face a crucial challenge: managing last-mile delivery (LMD) [1–3]. LMD efficiency is characterized by a series of challenges that logistics companies must face, and each has a direct impact on costs of deliveries, effectiveness and sustainability of this part of supply chain [4, 5]. In fact, LMD represents one of the most expensive phases of the entire logistics process [6]. Another critical issue is related, especially in large cities (so in urban context), to the presence of traffic, which represents a major obstacle to rapid deliveries. Congestion and difficulty in accessing certain areas (both urban and non-urban) make the final delivery phase complex and slow in operations, with the risk of generating delays and compromising the customer experience [7]. Consumers also demand increasingly faster delivery, often free or at low transfer cost. This expectation, fuelled by e-commerce enterprises (e.g., Amazon, Alibaba, etc.), has put significant pressure on logistics providers to optimize last-mile delivery operations [8].

This growth in LMD creates significant pressure on logistics companies, which must try to meet these demands without compromising the quality of service or increasing transfer costs too much. In addition, the final delivery phase has a significant environmental impact. Vehicle traffic contributes to CO_2 emissions, and the numerous trips required to deliver single packages to homes increase air pollution. Sustainability is now a priority for many companies, but finding environmentally friendly and, at the same time, economically sustainable solutions remain a major challenge [9].

To address the challenges of last mile delivery, many companies are adopting alternative delivery models (as parcel lockers, or pickup points among others), designed to respond more efficiently and flexibly to the needs of modern consumers. One of the most popular models is that of automatic lockers (APLs) and collection points known as click-and-collect (C&C). These LMD solutions allow customers to collect their packages at predefined locations, usually located in easily accessible points such as supermarkets, gas stations or shopping centres. The convenience of these solutions lies in the possibility for consumers to choose when to collect the package, avoiding waiting for the courier at the receiving point of their choice. On the business side, this model reduces the costs associated with home deliveries, especially in urban areas where traffic and logistical limitations can slow down the process. In addition, lockers reduce the number of failed delivery attempts, optimizing resources and improving operational efficiency [10, 11]. Other emerging solutions include those called collaborative and crowdsourced delivery, which sees the use of independent “couriers”, often ordinary people, who make deliveries on behalf of specific digital platforms [12, 13]. This model is particularly useful in urban areas, where the demand for fast deliveries is high and where managing a fixed company fleet would be more complex and expensive. Multimodal logistics and the use of micro-distribution hubs represent another interesting solution to improve the efficiency of urban deliveries.These alternative delivery models not only respond to the

growing demand for fast and efficient deliveries but also represent a turning point for sustainability. By adopting innovative technologies and a more flexible approach to delivery management, companies are helping to make last mile delivery more sustainable, efficient and closer to the expectations of an increasingly aware and demanding consumer. The purpose of this article is to provide a qualitative analysis of Parcel Lockers in terms of accessibility, proximity, and user-friendliness as digital access points for customers in LMD. To achieve this, authors first conducted a literature review based on the findings of [14–16], expanding the research with an in-depth analysis of PLs in non-urban contexts, comparing them with urban areas to understand differences in usage and the underlying reasons, then investigate the spatial accessible-digital divide, offering an interpretation of equity in LMD among e-commerce users. The methodology is structured in two main phases. After the literature review phase, authors conducted a content analysis of the papers selected and in the second part of this paper authors compared the results of LR to examine the territorial and digital aspects regarding the PL localization across different countries. The three key research questions are:

– RQ1: What are the main findings from studies on spatial location for the use of parcel lockers (e.g., user accessibility, proximity to lockers)?
– RQ2: What are the main differences between urban and non-urban context in PL system?
– RQ3: Is the digital divide (e.g., eco-friendly acceptance of PLs) more significant than spatial allocation in influencing adoption?

1.1 Aim and Scope on the Study

The paper has three main objectives. Firstly, it aims to identify the key spatial and digital characteristics influencing consumer behaviour toward parcel lockers. Secondly, it seeks to understand how these factors can enhance the benefits of PLs, particularly in the context of last-mile delivery and rural area dynamics, as discussed by [15, 16].

Finally, the study classifies findings based on their relevance to accessibility challenges, digital adoption strategies, and spatial optimization methods, while also assessing proposed solutions for improving PL accessibility. Unlike previous studies, the novelty of this research is to provide a detailed focus on the territorial aspects of PL systems, integrating socio-economic factors already identified in the literature with the behavioural insights from [16] to give an overview of digital divide among customers.

RQ1 addresses the first part of the literature review, while RQ2 and RQ3 are explored through both content analysis and case study comparisons that highlight spatial and digital factors, investigating how accessibility varies across different countries, cities, and lesser-known characteristics of PLs in LMD, particularly through multi-territorial comparisons.

Sustainability in last-mile logistics through parcel lockers (PLs) depends on urban density, placement strategies, and retrieval behaviour. RQ2 explores how urban and non-urban settings influence environmental benefits, while RQ3 assesses whether technological barriers outweigh spatial factors in adoption. Research highlights that PL efficiency varies significantly by location, with urban areas benefiting the most.

Transit-based PLs reduce vehicle kilometres travelled (VKT) and emissions. In London, Berlin, Singapore, and Paris, PLs cut VKT by up to 53%, integrating with metro

stations and commercial hubs to enable trip-chaining and reduce dedicated trips [17, 18]. In Singapore, lockers near bus stops increased demand by 7% [19], while London's dense network shifted deliveries from homes, reducing congestion [18]. These findings highlight the fact that urban spatial allocation maximizes sustainability benefits.

However, suburban and exurban PLs often fail to deliver similar environmental gains. In cities like Brisbane, Milan, and Los Angeles, over 40% of consumers drive to retrieve parcels, offsetting emissions savings [11, 20]. Retail-based lockers further reinforce car dependency, while cities with limited public transport, such as Rome and Sydney, see consumers favouring home delivery over traveling more than 2 km to a locker [21]. Thus, while urban PLs promote sustainability, lower-density areas face behavioural and spatial challenges that reduce environmental benefits.

In rural areas, sustainability potential declines further due to low adoption, sparse infrastructure, and long retrieval distances. Studies in South Africa, Vietnam, and France show that lockers over 5 km from residential areas see low usage, with users preferring home delivery [22, 23]. In Vietnam, fewer than 20% of surveyed users engage with PLs due to digital barriers and weak connectivity [24]. These findings support RQ3, as digital exclusion compounds spatial limitations, restricting sustainability impacts.

To address inefficiencies, alternative models like mobile parcel lockers (MPLs) and micro-consolidation centres (MCCs) have emerged. France and China have seen AI-driven MCCs cut freight emissions by up to 30%, demonstrating the benefits of flexible logistics solutions. Technological innovations further support sustainable PL networks. Solar-powered lockers in rural European and African regions provide energy-efficient alternatives, while bike-friendly PL locations in Amsterdam and Copenhagen improve multimodal access. AI-driven delivery clustering has also reduced emissions by 15–20% in pilot projects [25, 26]. These advancements highlight how digital optimization mitigates spatial constraints, reinforcing RQ3 by enhancing sustainability through technology. This paper is organised as follows: after Sect. 1 show a general introduction and state of art; Section 2 describes the methodology; Section 3 presents the key findings and Sect. 4 shows the discussion and a comparison with other studies to reduce the gaps on this part of the literature, and to provide directions for future studies. The last sect. 5 draws general conclusions and further research suggestions.

2 Methodology

The present research employs a two-phase methodology (Fig. 1). The first phase consists of a literature review, based on the studies of [14, 16] to assess the state of the art on parcel lockers and their accessibility, with a particular focus on geographical disparities and the digital divide.

The second phase of the study includes both a comparative case study analysis and a qualitative investigation of key factors influencing spatial accessibility, proximity, and digital accessibility of parcel lockers. This phase also considers the role of the proximity and spatial distribution of PLs in various urban settings, considering pioneer studies on land-use as [27, 28].

The analysis also examines the role of technology in enabling more sustainable and efficient last-mile delivery solutions [29, 30]. Additionally, the second part of the

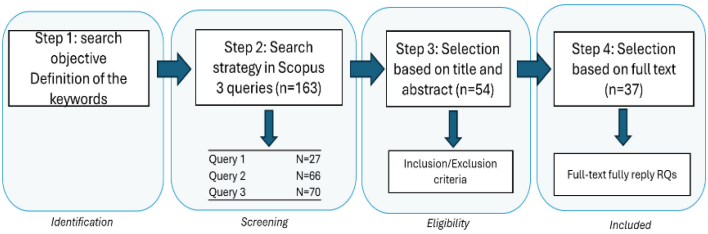

Fig. 1. Literature review process. Elaboration of authors based on [13–19].

research includes a comparative analysis of case studies to understand how accessibility influences the choice of PLs and how technology serves as an eco-friendly solution. The literature review methodology is structured into four key aspects based on [31]: defining objectives and search criteria, screening and selecting articles, assessing eligibility, and identifying full-text articles for content analysis. The literature review protocol is described in Table 1.

Table 1. Literature review protocol. Elaboration of authors.

Publication type	Journal and conference papers
Article language	English
Database	Scopus
Timeline of publication studies	Studies published between 2000 and the first quarter of 2025
Search fields	Title, keywords, and abstract
Utilised keywords	parcel AND locker AND accessibility OR digital OR techn* OR spatial AND location OR accessibility OR proximity
Data analysis	Content-based analysis grounded on the previous studies approach

The inclusion criteria are:

- Studies related to parcel lockers, accessibility, digital technology, proximity, and spatial location.
- Papers published in peer-reviewed journals or reputable academic sources following the Table 1 protocol.
- Articles that address territorial and digital perspectives in the context of parcel locker adoption.
- Empirical or theoretical studies providing quantitative or qualitative insights into accessibility and digital inclusion.
- Research discussing last-mile delivery, urban logistics, and digital infrastructure for parcel locker adoption.

The bibliographic research was conducted using the academic database “Scopus”, ensuring a comprehensive collection of relevant scientific contributions. Search strings

were constructed to capture key themes related to parcel lockers, accessibility, digital technology, proximity, and spatial location. The following queries were used:

- Query 1: parcel AND locker AND accessibility OR digital OR techn* OR spatial AND location identified 27 articles, of which 25 were initially accepted, with two being excluded for not addressing accessibility, proximity, or digital access.
- Query 2: parcel AND locker* AND accessibility OR digital OR techn* OR accessibility retrieved 66 articles, with 45 being initially accepted. After removing 21 duplicates and excluding 3 articles for irrelevance and 17 for not addressing key themes, 25 remained for abstract review.
- Query 3: parcel AND locker* AND accessibility OR digital OR techn* OR proximity resulted in 70 articles, with 5 initially accepted, 65 duplicates, and one irrelevant paper removed. After abstract screening, four papers were retained, and one was selected for full-text review.

2.1 Screening and Selection of Articles

A multi-phase review process was used to refine the dataset. Firstly, authors analysed paper selection based on Title and Abstract (n = 163). Duplicate records were first removed, followed by an abstract-based evaluation to ensure relevance. The final step was to read the full text of the records to exclude articles that lacked a territorial and digital perspective. At the end of the selection process, the sample was reduced from n = 163 to 54 papers. Ultimately, these 54 articles were reviewed at the full-text level, and 37 were selected dealing with our research question (RQ1, RQ2, RQ3).

2.2 Content Analysis and Case Study Comparison

The 37 selected articles underwent a structured content analysis to extract key insights, with a particular focus on the geographical distribution of parcel lockers and digital literacy barriers. The reviewed studies employ a diverse range of methodologies, including case studies, surveys, GIS-based spatial analysis, and policy evaluations, spanning different geographical contexts. Key themes explored include urban vs. non-urban disparities, technological barriers, and strategies for optimizing accessibility. Section 4 presents a comparative analysis of spatial disparities across countries, focusing on accessibility constraints, user preferences, and the role of digital tools in addressing logistical and environmental challenges. The present research also explores how smart technologies, and sustainable practices enhance PL systems, identifying potential improvements in urban and non-urban contexts. This structured approach ensures a comprehensive and balanced representation of studies addressing accessibility challenges, digital inclusion, and socio-economic barriers to PL adoption, particularly in underserved areas. The findings contribute to identifying best practices for improving last-mile delivery efficiency while promoting equitable access to parcel locker services.

3 Key findings

This section presents findings from the literature review and context analysis on PLs in urban and non-urban areas, highlighting their role as micro-consolidation centres in transforming last-mile delivery. Results indicate that PLs and MCCs reduce doorstep

deliveries, optimize routes, and lower vehicle trips, contributing to reduced congestion and emissions.

Prior studies confirm these benefits, including fewer failed deliveries [21], improved route efficiency [18], and integration with workplace and transit-adjacent hubs [19, 32]. Additionally, PLs indirectly support environmental sustainability through delivery consolidation [17, 20, 25]. The literature reveals regional variations in PL adoption, addressing key research questions:

– Spatial Accessibility (RQ1): PL adoption is highest in transit hubs, retail centres, and commercial areas [21], while low-density [22] regions face accessibility challenges, requiring alternative placement strategies [26].
– Urban vs. Non-Urban Differences (RQ2): Urban areas benefit from dense PL networks supporting multimodal last-mile solutions, whereas non-urban areas rely on car-dependent retrieval models due to limited infrastructure [27, 33, 34].
– Digital Barriers (RQ3): Digital literacy, smartphone penetration, and internet access significantly impact PL adoption, particularly in rural and lower-income areas [10, 11, 14].

While efficiency and logistics optimization drive PL adoption, sustainability benefits are often secondary, arising from delivery consolidation and reduced failed attempts [35, 36]. The next sections categorize findings by accessibility constraints, digital adoption strategies, and spatial optimization, comparing regional approaches to PL implementation. Urban areas leverage proximity-based strategies, while technological and socioeconomic barriers remain key challenges in less connected regions.

4 Comparative Analysis

This section examines territorial contexts in detail, whereas the previous one focused on the studies. A comparative analysis of regional contexts highlights the varying factors that influence PL adoption across urban, suburban, and rural environments, revealing the impact of infrastructure, digital accessibility, and logistics planning. RQ1 investigates spatial accessibility and transport integration, highlighting the role of proximity in usage frequency. RQ2 compares urban and non-urban contexts, while RQ3 assesses the impact of the digital divide and smart technologies on PL adoption. The analysis identifies structural, digital, and logistical barriers, proposing strategies and solutions to improve PL accessibility across diverse territorial contexts. The adoption and effectiveness of parcel lockers and micro-consolidation centres vary significantly across regions, shaped by infrastructure investments, transport integration, digital accessibility, and user behaviour. Findings of reviewed papers reveal that regional disparities are strongly linked to transport systems, urban planning, and digital inclusion policies, which ultimately influence last-mile delivery efficiency and sustainability outcomes (Table 2). A key contrast emerges between Europe and Asia, which prioritize transit-integrated lockers, and North America and Australia, where PLs are predominantly located in car-centric retail hubs. Germany, the UK, and Singapore have successfully embedded PLs within public transport networks, significantly increasing user accessibility and reducing VKT and congestion [19, 37]. Singapore's model, for instance, has improved

PL adoption rates by 7% by integrating lockers into metro and bus stations, allowing users to retrieve parcels during daily commutes [24]. Meanwhile, France and Germany are leading in sustainability-driven solutions, including solar-powered lockers and GIS-based MCCs, which have been shown to reduce freight emissions by up to 30% through optimized delivery routes [18, 25, 38]. In contrast, the US and Australia have developed car-dependent locker networks, where over 40% of consumers drive to pick up parcels, limiting accessibility for non-drivers and offsetting sustainability benefits [11, 20]. Retail-based PL placements in shopping malls and large commercial centres further reinforce this car dependency, making PL systems less effective in reducing emissions compared to transit-based alternatives. Although some urban transit-integrated lockers exist in major US metropolitan areas, these remain underutilized due to a lack of policy incentives for workplace-based and multimodal locker networks [21]. In emerging markets such as South Africa, Eastern Europe, and Latin America, rural PL accessibility remains a significant challenge due to long retrieval distances (5+ km in some regions), limited digital infrastructure, and low literacy rates [22, 34, 39]. Vietnam, for example, still relies heavily on home deliveries, as PL networks remain underdeveloped outside of major cities [23]. Some countries have tested mobile parcel lockers (MPLs) and community-based retrieval hubs, but scalability remains limited without public-private partnerships to support infrastructure expansion [40].

Table 2. Main overview of PLs aspects by region. Elaboration of authors.

Region	Key findings	Accessibility & Proximity	Digital Access	Environmental sustainability	Policy & Research aspects	References
Europe (Germany, UK, France, Italy)	Transit-integrated lockers in urban areas improve accessibility, but suburban and rural adoption remains uneven. Car dependency reduces sustainability benefits.	Well-integrated in urban transit hubs but less coverage in suburban zones.	Strong app-based tracking; elderly and low-tech users face digital barriers.	Transit-integrated lockers reduce CO_2 emissions by up to 53% (Gutenschwager et al., 2024). Car-based retrieval limits net savings.	Expand suburban transit-based locker networks and integrate bike-friendly access to reduce car dependency. Improve digital literacy initiatives for non-tech users.	[18, 37, 38]
North America (USA, Canada)	Lockers are primarily placed in retail locations, limiting accessibility for non-drivers. Transit-integrated PLs are underutilized.	Low transit integration; high car dependency increases accessibility gaps.	Significant digital access divide, particularly for low-income and elderly populations.	Car-based locker retrieval generates 60% more CO_2 emissions than transit-based systems (Leung et al., 2023). Urban MCCs have reduced emissions by 30% in some pilot projects.	Expand workplace-based and transit-integrated lockers in major metro areas. Introduce financial incentives for sustainable PL adoption.	[11, 20, 21]

(*continued*)

Table 2. (*continued*)

Region	Key findings	Accessibility & Proximity	Digital Access	Environmental sustainability	Policy & Research aspects	References
Asia (Singapore, Vietnam, China)	Singapore and China lead in smart locker adoption with strong transit integration. Vietnam lags due to infrastructure gaps and uneven PL distribution.	Singapore's PLs at transit hubs increased adoption by 7% (Tsai et al., 2024). Vietnam faces major accessibility gaps outside of urban centres.	High smartphone penetration in urban areas; rural regions struggle with digital infrastructure.	Urban PLs reduce last-mile emissions through AI-based route optimization. Vietnam still relies on home deliveries, increasing emissions.	Expand public-private partnerships to fund PL networks in developing regions. Improve rural infrastructure and smartphone adoption strategies.	[19, 23, 24]
Emerging Markets (South Africa, Eastern Europe, Latin America)	Sparse locker availability in rural areas discourages adoption. Mobile lockers (MPLs) are being tested but lack large-scale implementation.	Long retrieval distances (often 5+ km in rural zones) significantly reduce adoption rates.	Limited digital literacy and weak internet access in rural areas create adoption barriers.	Solar-powered lockers are being piloted in South Africa and Eastern Europe, but uptake remains slow. Transport integration is a major limitation.	Prioritize mobile locker deployment in remote areas. Improve public-private funding to expand PL infrastructure in underserved communities.	[22, 25, 39]

A detailed analysis of individual countries reveals distinctive challenges and best practices. Table 3 provides a breakdown of specific factors shaping PL adoption in key markets.

Table 3. City-Specific insights on parcel locker adoption. Elaboration of authors.

Cities	Accessibility & Proximity	Digital Access	Environmental Sustainability	Key Gaps
Berlin, London, Paris, Milan	Well-integrated transit-based lockers in metro and rail stations improve first- and last-mile efficiency. Suburban areas remain underserved.	Strong mobile integration and app-based tracking, but elderly users face authentication barriers.	Transit-integrated lockers reduce CO_2 emissions by up to 53%, but suburban car-retrieval limits full benefits.	Expansion needed in suburban and low-income areas. Digital inclusion for elderly and non-tech users remains a challenge.

(*continued*)

Table 3. (*continued*)

Cities	Accessibility & Proximity	Digital Access	Environmental Sustainability	Key Gaps
New York, Toronto, Los Angeles, Chicago	Retail-based lockers dominate, reducing walkability. Some transit lockers exist (NYC, Toronto) but remain underutilized.	Significant digital divide—low-income and elderly users struggle with app-based authentication.	Car-based locker retrieval results in 60% higher CO_2 emissions compared to transit-integrated models.	Limited adoption of workplace- and transit-integrated lockers. Lack of policies promoting sustainability incentives for PL expansion.
Singapore, Shanghai, Ho Chi Minh City	Singapore's lockers near metro/bus stations increased adoption by 7%. Shanghai has a dense smart locker network, but Ho Chi Minh City lacks infrastructure.	High smartphone penetration aids adoption in urban areas. Rural communities face connectivity and authentication barriers.	Singapore's PL system optimizes last-mile logistics, lowering emissions. Vietnam relies on home delivery, increasing transport inefficiencies.	Infrastructure gaps in Vietnam's urban areas. Lack of government investment in expanding PL coverage.
Johannesburg, Warsaw, São Paulo, Mexico City	Sparse locker availability and long travel distances (>5 km) reduce adoption rates in peri-urban areas. City centres have uneven PL coverage.	Weak internet access and digital literacy create major adoption barriers. SMS-based PIN codes and RFID authentication are being tested.	Solar-powered lockers are being piloted but lack large-scale deployment.	Lack of regulatory frameworks for PL expansion. Transport integration remains weak, limiting sustainability benefits.

Other emerging solutions highlighted in this research paper include collaborative and crowdsourced delivery models, where independent couriers—often ordinary individuals—deliver parcels on behalf of digital platforms, as stated by [12, 13]. This approach, widely adopted by companies like Amazon Flex and Uber Eats, is gaining traction in last-mile logistics as an alternative to traditional courier networks. In urban settings, crowdsourced delivery optimizes route efficiency by leveraging gig economy workers and real-time demand allocation, reducing idle trips and increasing parcel delivery speed. However, in non-urban areas, its scalability is limited by lower delivery density and the reliance on private vehicle transport, which can offset sustainability benefits. Integrating crowdsourced delivery with PLs and MCCs could enhance flexibility, particularly

in underserved areas, by enabling decentralized pick-up and drop-off points, reducing last-mile inefficiencies, and complementing fixed locker infrastructures [16, 17].

5 Conclusions

The successful integration of parcel lockers and MCCs into last-mile logistics provides critical lessons for policy development and urban planning. Findings from Germany, the UK, and Singapore demonstrate that transit-integrated lockers significantly improve accessibility while reducing congestion and emissions. Singapore's strategy of collocating PLs within transport hubs has increased retrieval rates by 7% compared to non-integrated networks, reflecting a strong preference for trip-chained parcel collection [24]. Similarly, France's implementation of solar-powered lockers and AI-driven MCCs has optimized urban parcel drop-offs, reducing freight-related emissions by over 30% in some cities [18, 25]. While European cities effectively integrate PLs into public transit infrastructure, suburban and rural adoption remains uneven. Urban accessibility is enhanced by dense PL networks, particularly in metro stations, rail hubs, and commercial districts, where transit-based lockers reduce CO_2 emissions by up to 53% [17]. However, suburban PL placement is far less extensive, with most networks concentrated in major metropolitan areas. France and Germany, for instance, have expanded suburban locker availability, but car-dependent retrieval remains prevalent in lower-density zones [41], limiting the full sustainability benefits of transit-based lockers [37]. In rural areas, PL accessibility is severely constrained by lower population density and longer retrieval distances, typically exceeding 5 km in many regions of Europe [2, 3, 22, 39]. As a result, rural consumers are more likely to rely on home deliveries, reducing the environmental impact of PL networks. MCCs in suburban and exurban locations could enhance accessibility by consolidating deliveries closer to rural drop-off points, yet scalability remains limited without public-private infrastructure investments. Pilot projects in France and Spain suggest that MCC-supported rural PL networks can reduce last-mile emissions by 20–25% while increasing user adoption in peri-urban zones [25]. While MCCs are increasingly recognized as a sustainability-driven solution, their quantifiable impact on PL adoption and last-mile delivery efficiency remains an area for further analysis. In France and the Netherlands, MCCs have been integrated into last-mile logistics hubs, supporting parcel lockers by consolidating shipments before distribution to high-demand locker locations. In Paris, an AI-optimized MCC network has improved PL replenishment rates by 18%, reducing stockouts and failed deliveries, thereby increasing overall consumer adoption [42]. Additionally, studies from Germany and Belgium indicate that MCC-enabled PL networks can reduce total last-mile freight mileage by 25–30%, particularly when combined with electric cargo bikes for final deliveries [37]. This multimodal approach not only improves urban delivery efficiency but also enhances environmental sustainability, particularly in cities with strong regulatory support for low-emission logistics solutions [43]. Despite successful urban implementations, MCCs have yet to reach their full potential in suburban and rural areas. Policy frameworks should focus on expanding MCC networks to support PL deployments outside city centres, ensuring that lower-density regions benefit from sustainable last-mile logistics solutions. Public-private partnerships could play a key role in funding MCC expansion, particularly in

regions where last-mile emissions remain high due to car-reliant delivery models. Future research and pilot programs should further explore how MCCs can improve PL adoption rates in underserved areas, bridging the gap between urban efficiency and rural accessibility. Beyond country-specific analyses, broader research contributions provide valuable insights into PL accessibility, digital adoption, and sustainability. Studies show that PLs located within 300–500 m of residential and commercial areas significantly increase adoption, while retrieval distances exceeding 5 km discourage use, particularly in low-density regions [21, 23, 33, 34]. Alternative placement models, such as MPLs and community-based drop-off points, are being explored in regions where permanent infrastructure is not feasible [40]. On the digital front, smartphone penetration has enhanced PL adoption in urban regions, but the digital divide remains a significant barrier in suburban and rural areas. Studies confirm that app-based authentication and mobile tracking are widely used in high-income urban areas, whereas older adults and low-tech users in rural regions struggle with digital accessibility [38, 39]. Some research suggests that hybrid authentication models—such as SMS-based PIN codes, RFID scanning, and biometric verification—can help bridge the digital divide and expand PL accessibility [42, 44]. Sustainability remains a key challenge, as AI-based route optimization and MCCs have shown potential to reduce emissions by over 50% in some cities [17, 18]. However, these benefits are highly location-dependent. Transit-based lockers demonstrate significant CO_2 reductions, while car-dependent models in suburban and peri-urban areas offset these gains [11]. This reinforces the need for integrated urban policies that align transport planning with LMD solutions. The present research provides actionable insights for urban planners, policymakers, and logistics companies to enhance last-mile delivery efficiency and sustainability. Urban planners can prioritize transit-integrated parcel locker (PL) networks by collocating lockers in metro stations, bus terminals, and mixed-use developments, reducing congestion, vehicle kilometres travelled (VKT), and emissions [19, 37]. Additionally, ensuring equitable PL distribution in suburban and low-income areas can improve accessibility. For policymakers, financial incentives for solar-powered lockers, bike-accessible retrieval points, and micro-consolidation centres can support sustainable logistics [33]. Digital inclusion initiatives, such as SMS-based authentication and public awareness campaigns, can bridge adoption gaps [42]. For logistics companies, investing in AI-driven route optimization, geospatial analytics, and mobile parcel lockers enhances efficiency and supports multimodal last-mile solutions. A combined approach integrating PLs, MCCs, and MPLs can ensure scalable, sustainable LMD strategies across diverse urban and non-urban contexts. Future research should explore the relationship between urban planning, transport networks, and last-mile logistics, examining how zoning laws, mixed-use developments, and MCC placement impact efficiency. Understanding how consumer behaviour, economic factors, and delivery preferences shape PL adoption is also essential, particularly in addressing barriers faced by low-income and underserved communities.

Comparative studies on emerging logistics solutions, such as mobile parcel lockers (MPLs), drone deliveries, and AI-driven logistics, could provide insights into their scalability, cost-effectiveness, and sustainability across urban and rural settings. Additionally, research should focus on equity in logistics, ensuring that PL accessibility is expanded beyond high-density urban areas to suburban and rural regions where digital

infrastructure and transport connectivity remain limited. Policy-driven interventions and inclusive urban planning strategies will be key to bridging accessibility gaps and promoting sustainable, fair, and efficient last-mile logistics solutions. The present research analyses PL adoption and LMD strategies, focusing on spatial accessibility (RQ1), urban vs. non-urban differences (RQ2), and the impact of the digital divide (RQ3). This review of 37 studies, including real-world case studies, aims to highlight regional disparities shaped by transport integration, digital accessibility, and sustainability factors. Findings show that Europe and Asia prioritize transit-integrated PLs. In contrast, North America and Australia's car-dependent networks limit accessibility and offset sustainability benefits. Emerging markets struggle with infrastructure and digital barriers, with rural retrieval distances exceeding 5 km discouraging adoption. The study identifies gaps in suburban and rural PL deployment, emphasizing the need for public-private partnerships, multimodal integration, and digital inclusion policies. Future research should focus on AI-driven logistics, micro-consolidation centres and mobile parcel lockers to enhance efficiency and sustainability. Understanding consumer behaviour and long-term policy impacts will be crucial for scalable last-mile solutions that balance spatial efficiency and digital equity. If, on the one hand, it is therefore essential to know and investigate the needs of demand, and therefore implement actions that can improve knowledge of travel habits and the use of collection points, on the other hand, in terms of infrastructure and services, it is desirable to implement technologies but also a combined passenger and freight approach, especially in areas with low transport demand. Therefore, the implementation of more technologies but also DRT systems could be a viable solution for improving the movement of people and goods in the aforementioned areas by supplementing or replacing PL deployment.

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