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Making last mile logistics models aware of customer choices, demand sustainability and data economy

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Abstract

By 2030, the rise of delivery vehicles in the ten most populated cities worldwide is expected to increase GHG emissions between 21% and 32%. This trend puts pressure on public and private stakeholders to take measures to improve the sustainability of last mile logistics in cities. The EU-project DECARBOMILE (DECARBOnize last MILE logistics) aims to develop interoperable and multimodal logistics solutions for decarbonized last mile delivery in urban contexts in the years 2022–2026. This study presents a new framework of last mile's cause-and-effect chain to identify potential sustainable logistics solutions, hence embracing customer centricity. The latter is beyond the scope of conventional logistics management and makes it difficult to manage the subsequent drivers of last mile logistics and supply chain disruption: demand patterns and data valorization. The sustainability framework first maps the last mile challenges against the PI-oriented transport system model. With its sustainable performance criterion, the framework provides a standardized approach to prioritize actions for addressing the challenges and measuring their target impacts accordingly. As a conclusion of this study, the approach: (1) provides a standardized method to identify use cases to decarbonize the last mile logistics in different contexts, (2) supports the development of a stakeholder-focused, effective decision support system that enables to define, analyze, and compare scenarios based on sustainability targets, and (3) fosters the design and deployment of sustainable last mile systems as well as their replicability.

Keywords Last mile logistics, Data economy awareness, Demand sustainability, Customer centric focus, System performance criteria, Physical internet, Decision making support, Conceptual system model

1 Introduction

Digitalization has forced retailers to provide a wider range of purchasing options for their customers, from single to multi- and omni-channel strategies. This results in countless last mile logistics options to deliver or return orders, regardless of their retailing strategy [1]. As customers continue to make an increasing number of their purchases online, deliveries destinations multiply beyond retail stores and involve new facilities and locations dedicated to processing additional steps of consumer deliveries [2]. Moreover, the shipments are becoming smaller and more numerous, putting pressure on last mile capacities [3, 4]. This is more visible in urban areas where the pressure to satisfy demands is high and will continue to increase [5]. Because of these changes, the number of delivery vehicles worldwide is expected to rise from 5.3 to 7.2 million by 2030 (+36%), with a subsequent increase in congestion from 53 to 64 average commute times per minute (+21%) and an increase in greenhouse gas (GHG)

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emissions from 19 to 23 MT (+21%) [4]. Hence, last mile logistics concerns major environmental and economic challenges for companies and cities [6].

Some companies and cities already consider last mile logistics as a major source of challenges and companies seek new last mile strategies to cope with customer trends striving for profits and sustainability [7–11]. Solving the challenges of last mile logistics is complex due to its multidisciplinary nature and the number of stakeholders involved. Several studies, including [12] and [13], highlight the importance of customer centricity for the provision of innovative solutions. This involves adopting "business strategies that emphasize placing customers at the center of all the organization's activities to understand and properly satisfy their needs" [14]. Incorporating the customer perspective can reveal hidden opportunities for business development meeting customers' demands while promoting practices that increase sustainability [15–17].The subsequent decision-making process for sustainable last mile logistics is more complex, and there are efforts to provide toolkits, that help to identify problems and map sustainability solutions with relevant Key Performance Indicators (KPIs) [18].

Additionally, the integration of information and communication technologies (ICTs) within the framework of the Physical Internet (PI) paradigm is pivotal for addressing such complexity inherent in modern logistics systems. The PI concept promotes a global logistics framework characterized by physical, digital, and operational interconnectivity, which is essential for enhancing sustainability and improving overall efficiency across societal, environmental, and economic dimensions [19–21]. By leveraging ICT, the PI facilitates seamless communication and coordination among various logistics stakeholders through the standardization of interfaces and protocols, the synchronization of modes and channels, and the modularization of containers [22, 23]. In addition, vertical and horizontal collaboration takes place, as the transport of the PI containers is carried out by different logistics service providers (LSP) [24, 25]. This collaborative approach is crucial for achieving a more sustainable logistics ecosystem, as it allows for shared resources and reduced redundancies in transportation and storage [26]).

Even if there are logistics models where demand from human activities drives the entire transport system [27], current approaches to last mile development still do not consider demand sustainability, overlooking that the logistics system will not be sustainable if demand is not sustainable. By not integrating demand drivers such as commerce digitization and the subsequent customer centricity, logistics models do not provide a link with the drivers of value chain disruption. Therefore, the subsequent role that capillary solutions play to redesign both, logistics and value chains, in the emerging scenario under the increase in sustainability requirements, is not considered.

This leads to the following gaps:

1. Qualitative toolkits, while holding the promise to help to explore complex issues, lack objective criteria to guide consistent decision-making. This allows for too much subjective interpretation, leading to potentially less effective or equitable decisions. Integrating objective criteria is needed to ensure that decisions are based on clear standards rather than personal biases.
2. The PI focus remains at the level of logistics systems planning and implementation without further looking at demand and the mutual influence between demand's and logistics services' sustainability.

This study aims to develop a new conceptual framework, by considering customer centricity in sustainable last mile planning, business modelling, implementation and operation. It embraces the core innovation of Theory of change (ToC), which gives a situation analysis, maps different types of outcomes with their interrelations and based on the desired outcomes, formulates relevant interventions [28]. The core objective of this paper is to create a tool that is directly derived from this conceptual framework. This tool is designed to showcase the cause-and-effect relationships between targets that arise from sustainability features and challenges in last mile logistics. By leveraging the insights provided by the conceptual framework, the tool also offers prioritization criteria to identify and implement the necessary actions to effectively address these challenges. Thus, the development of both the framework and the tool are closely linked, with the tool serving as a practical application of the theoretical insights gained from the framework.

This study is structured as follows: Section 2 provides the theoretical background regarding sustainable last mile logistics and presents the PI-enriched logistics model. Section 3 describes preliminary study that was conducted. Section 4 develops the conceptual framework, while Section 5 outlines the research methodology to apply this framework. Section 6 details the initial application of the framework in a case study conducted in Logroño. Section 7 discusses the findings from the previous sections and Section 8 presents the deriving conclusion including the contributions, limitations and further research.

2 Theoretical background

The new framework for designing sustainable last mile logistics systems is based on a literature review of current approaches to sustainability in urban logistics, along with a conceptual logistics model enriched with the principles of the PI.

2.1 Sustainability in last mile logistics

In the past few years, the importance of sustainability has increased. Many researchers have presented three main dimensions: environment, economy, and society, with relevant features and indicators when discussing sustainable development [29–31]. For conducting the literature review, a systematic approach was taken to ensure rigor, transparency, and reliability in the process. To do so, we have reviewed more than 50 articles (including journals, books, conferences, etc.) in the context of sustainability and last mile logistics.

2.2 Environmental features and indicators

This dimension focuses on the protection of biodiversity, the restriction of environmental capacity, and the conservation of natural resources [32]. By reviewing previous works in this area, it can be seen that experts introduce three main categories for environmental features: Regulations (e.g. Political Stability, Rule of Law, or Regulations) [33], Ecological and Livability (e.g. Solid waste, Air, Visual (aesthetic issues) and Noise pollution) [34] and System Efficiency (e.g., Ecosystem Preservation, Infrastructure Efficiency [31, 33]).

2.3 Societal features and indicators

This dimension refers to "social justice, equal opportunity, and protection from social disadvantages for the supply of goods and services, emphasizing the possibility of future generations and equity among classes" [32]. It can be categorized into two main levels: Human being and Community [35–37]. At the human being level, societal features and indicators focus on individual well-being and personal working conditions. These include: types of work benefits (insurances, vacation), working conditions (work schedule, salary) and working harmony (type of employee and salary) [37]. Providing secure and safe services in accordance with accepted procedures of quality has become important [38], as well as satisfaction and opportunity which are awarded for performance above minimum requirements [39]. These aspects are crucial for human beings because they directly impact individual quality of life, job satisfaction, and the ability to perform work safely and effectively. The focus of this level is on the immediate environment surrounding of the individual, including their interactions within the workplace and the benefits they receive for their work. On the community level, societal features and indicators shift from individual well-being to the broader context in which people live and interact. Key features at this level include: the density of urban development and safety as people sense an attachment to and pride of the place [40], accessibility and equity of the service level in an area (homogenous or heterogenous), and concordance. This includes demand dependency on available capillary services [41], and public infrastructure. This is linked to restrictions in urban areas [42] due to geographical difficulties, historic centers, population density, narrow streets, strict regulations, and limitations of spaces and facilities for fast loading and unloading [43]. At the human being level working conditions focus on the individual, while at the community level, they relate more to the built environment. For example, how well the community is equipped with necessary infrastructure impacts the overall quality of life and can either support or hinder the working conditions of the population. This includes factors like the availability of safe and efficient public services, and stress linked to the physical environment in which these services are delivered.

2.4 Economical features and indicators

The economic dimension refers to the goal of enhancing quality of life over the long term by creating a competitive economic system [32]. It contributes to the creation of added value and financial viability by confronting it to the associated costs (profitability) [16, 40] and looks at the potential optimization to increase the efficiency of resources used (productivity) [44, 45]. Likewise, it considers other features: quality of services, measuring resources [46] in relation to the service level, the level of synergies to achieve a target level [47], the compatibility of the demand with other demand requests requiring similar functionalities [17], and the volume of innovations introduced into the system and used [48, 49].

2.5 Urban transport system model and physical internet

For assessing the potential contribution of the later presented framework to last mile logistics modeling we analyze a state-of-the-art Conceptual System Model of Transport and Traffic, the potential influences of the PI on it, and the scope that it covers.

The system model used in this study is a further development of the conceptual model for transportation first introduced by [50] with a market-oriented focus along with the systems model of land use, accessibility, transport and traffic by [51] with a planning perspective. [50] isntroduced three variables: transportation system, activity system and flows that influence each other. This model can be used to describe the overall system performance and its changes. A change in one variable also leads to a

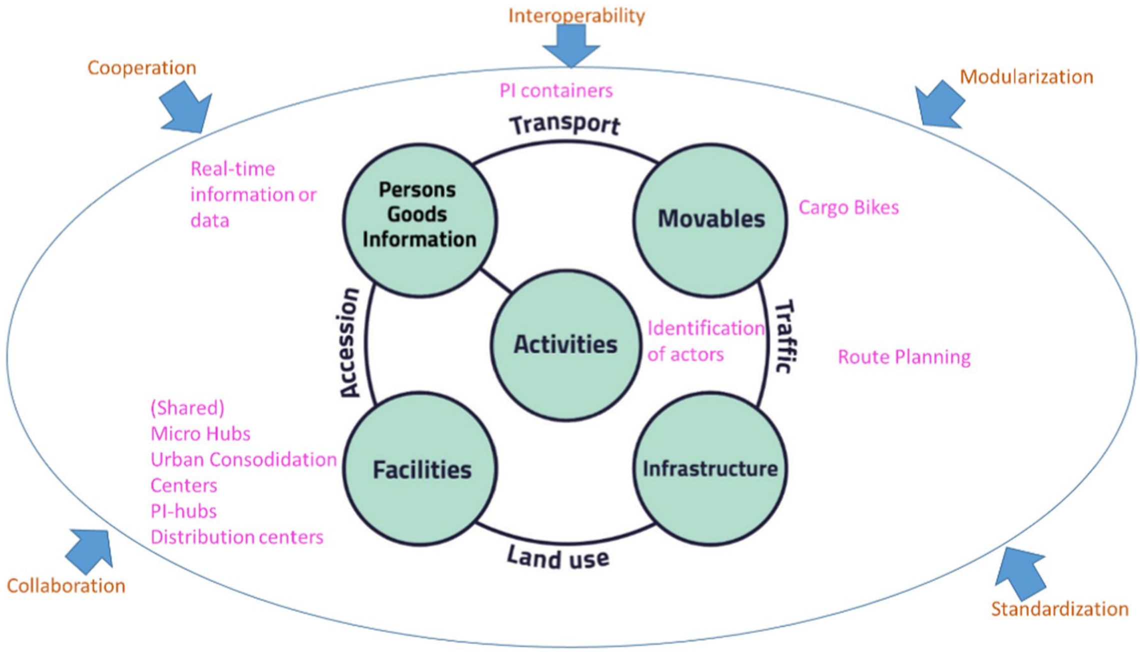

Fig. 1 PI-enriched (orange) and changes of elements (pink) of the Conceptual System model of Transport and Traffic (Own illustration based on [27])

change in the others. [51] enriches this model with more planning aspects. For this purpose, the elements of the transport system Persons and Goods, Vehicles and Vessels, Infrastructure and Facilities are represented as a system. The elements are connected by the relations Transport, Traffic, Land Use and Accessibility. The Activities are driving the system, but according to [51] they are not strictly a part of the model. [27] develops the Conceptual System Model of Transport and Traffic further. This model includes the flow of information and the planning and implementation of all human activities, which are the fundamental part of the model, as they trigger the demand for transportation and drive the entire transport system. Fig. 1 shows the model with the influences of the PI shown in orange and the observed changes of the elements in pink. The PI concept can help to identify the actors involved along with the innovations to make urban logistics more sustainable, even as customer demand for (urban) logistics increases [24, 27]).

The conceptual system model is independent of a specific transport and space system. The objects of flow are Persons, Goods and Information. The availability of accurate real-time information or data (e.g., on the current traffic situation or access restrictions) can optimize route planning and, for example, increase the efficiency and reliability as well as the sustainability of urban logistics operations [52]. Flows are not possible without Transport, whereby people, goods and information change their address from A to B. The PI-concept encourages the implementation of consolidation or cooperation in transport [26] and has an impact on the nodes and infrastructure usage [27]. The vertical and horizontal collaboration takes place, as the transport of the PI containers is carried out by different LSP and the transshipment and (intermediate) storage takes place in shared facilities (distribution centers, logistics hubs, PI-hubs) [10, 24, 25]. Movables (vehicles and vessels) carry out this transport on the corresponding infrastructure. The PI concept has an impact on the usage of transport capacity of the movables (e.g., cargo bike instead of van) and vice versa. The interaction between the two elements is the Traffic resulting from physical movement. By choosing alternative transport systems (e.g., water instead of road) or alternative movables (e.g., cargo bikes instead of vans), the PI could reduce the environmental impact by traffic density in cities and thus reduce the negative impacts of traffic. Within the framework of the PI concept, the modular loading units (PI containers) independently find their way through the logistics system, whereby modularization and standardization ensure the required level of interoperability between the logistics nodes for achieving collaboration. The modularity of the transport equipment increases the importance of the information flow [24, 25]. The location of the Facilities with their address and the physical transport infrastructure are represented by Land use. The facilities as a fixed or temporary structure are immovable for a specific time and are the nodes of the transport system. The PI concept envisages the use of additional (small) facilities such as micro hubs or urban consolidation centers in cities, resulting in an increase of land use, that needs to be considered in transport planning [24]). The relation Accession represents the possibility to leave point A and to arrive at point B at certain times and the general accessibility of the facilities with various means of transport. Accession is influenced by potential regulations as well as the necessary number of tours for the transport [27].

The model is suitable for both transport and traffic in general and for last mile logistics in particular. In last mile logistics, the goods are often parcels, fresh food or building materials, carried by smaller vehicles such as cargo bikes or vans, all of which move within the limited space of the inner-city infrastructure. Additional facilities such as urban consolidation centres, micro-hubs or smart lockers are often necessary for last mile logistics and can be represented in the model too. Hence, it enables to represent logistics processes that can be linked to the subsequent KPIs, identifying the different elements involved in the sequence of relations. Likewise, it enables to map where the different challenges of last mile logistics operate, and how they interfere with the ensemble of elements and relations. Hence, the impacts on last mile dynamics can be assessed along with subsequent actions. For example, it can be checked whether the main contribution to emissions is the type of vehicles or the location of facilities to prioritise actions and relevant investments and adaptations in operations [27].

But even if the logistics models consider Activities triggered by demand that drive the entire transport system, their focus remains at the level of demand planning and implementation without further looking at its sustainability. That means that current models are missing a key input for a full assessment of sustainability, including the drivers of customer choices such as incentives based on data monetization. Despite a steady growth of literature on last mile logistics sustainability over the past years [16, 29, 31], the current body of knowledge does not include those drivers in the models to make up a prioritization criteria for holistic decision-making.

3 Preliminary study

Given the information found in the literature study about potential features for sustainable last mile logistics, the authors conducted a preliminary study to reduce the number of features and indicators in last mile logistics sustainability. This process of participant observation within last mile logistics practices has been carried out in Spain, Belgium, United Kingdom and France. It led to identifying a set of key features for the sustainable performance of last mile practices, and to test them on field in Guadalajara's Metropolitan Area (GMA) [53]. The study included different stakeholder groups and has been performed from September 2018 to April 2023. The goal of these works was to validate the potential of collaboration and cycle-logistics to reconfigure last mile urban systems towards sustainability.

Moreover, the authors worked with public authorities, LSPs, businesses, and their customers. This collaboration showed that addressing both supply and demand aspects leads to a more holistic and sustainable approach to last mile delivery in cities, improving urban logistics performance in the tested pilots compared to the baseline [53]. It also helps to identify and validate a set of key features of the sustainable performance of last mile practices, that stakeholders can target to guide their transformation towards more sustainable set ups. Table 1 shows the features, identified in the preliminary study, which are categorized in the three sustainability dimensions (social, environmental, and economic) consistent with the literature review. The economic features in terms of offer are productivity and profitability, the social ones are working conditions and safety, and the environmental one is systemic viability, which includes air quality, regulations, resource consumption and economic externalities. In terms of demand, the economic features are the economic nature and operational compatibility of goods, the social ones are the sales' dependence on capillarity and customers geography, and the environmental one is also the systemic viability.

The output of this preliminary study provides a structured baseline for the subsequent phases of the research, facilitating a focused and evidence-based approach to bridging the identified gaps. This ensures that the future steps in the study can build on solid empirical

Table 1 Sustainable Features identified (Own illustration)

Sustainable features and indicators		
	Dimensions	**Features**
Offer	Environmental	Systemic viability
	Social	Safety
		Working conditions
	Economic	Profit
		Productivity
Demand	Environmental	Systemic viability
	Social	Customers geography
		Sale's capillarity dependence
	Economic	Operational compatibility
		Economic nature

foundations, ultimately leading to the successful deployment of sustainable last mile logistics solutions.

4 Conceptual framework

To address the gaps associated with last mile urban systems towards sustainability, this study develops a conceptual framework that leverages the principles of the ToC to enhance the sustainability of last mile urban systems. These principles provide a robust methodological foundation for analyzing the current situation, mapping out ideal targets and intermediate outcomes, understanding their interconnections and settling objectives. It hence outlines the causal pathways through which desired outcomes can be achieved, which leads to formulate relevant interventions providing the enabling outputs to reach the objectives. Urban logistics, particularly the last mile delivery part, is increasingly audited for its environmental and economic impacts. The ToC offers a systematic approach to understanding and addressing these challenges by providing a structured methodology for planning, implementing, and evaluating interventions aimed at achieving specific outcomes [16, 17].

The developed conceptual framework involves several key components as demonstrates in Fig. 2. The framework begins with a thorough situation analysis, where key stakeholders—such as LSP, local governments, retailers, and consumers—are identified and their roles in the last mile logistics ecosystem are mapped out [12]. This step involves assessing the current state of last mile logistics, focusing on KPIs such as profits, air quality, customer and employees' engagement. By doing so, the analysis highlights specific challenges that hinder the sustainability of current logistics systems and the desired situation.

Following the situation analysis, the framework focuses on mapping stakeholders' intermediate objectives that enable them with added values while contributing to achieve the system targets. They include short-term, intermediate, and long-term effects, showcasing their interrelations [54, 55]. This mapping helps stakeholders to identify the relevant outcomes achieving their objectives, and how they influence one another and contribute to the systems' overarching sustainability. Outcomes include reducing carbon emissions, minimizing waste, and increasing the rate of renewable energy sources in last mile logistics, all contributing to reduce environmental bills and pressure over all stakeholders. Additionally, companies may seek to improve economic efficiency by optimizing costs and delivery routes, thereby reducing overall operational expenses. Likewise, public administrations may focus on improving accessibility to goods and services, ensuring fair labor practices, and settle more efficient and less intrusive logistics operations, all of them contributing to enhance the quality of life for urban residents.

Based on such desired outcomes identified through the mapping process, relevant interventions can be formulated. These interventions should be evidence-based and provide tailored outputs (key results) to address the specific challenges identified in the situation analysis [56]. To prioritize those actions, the framework integrates

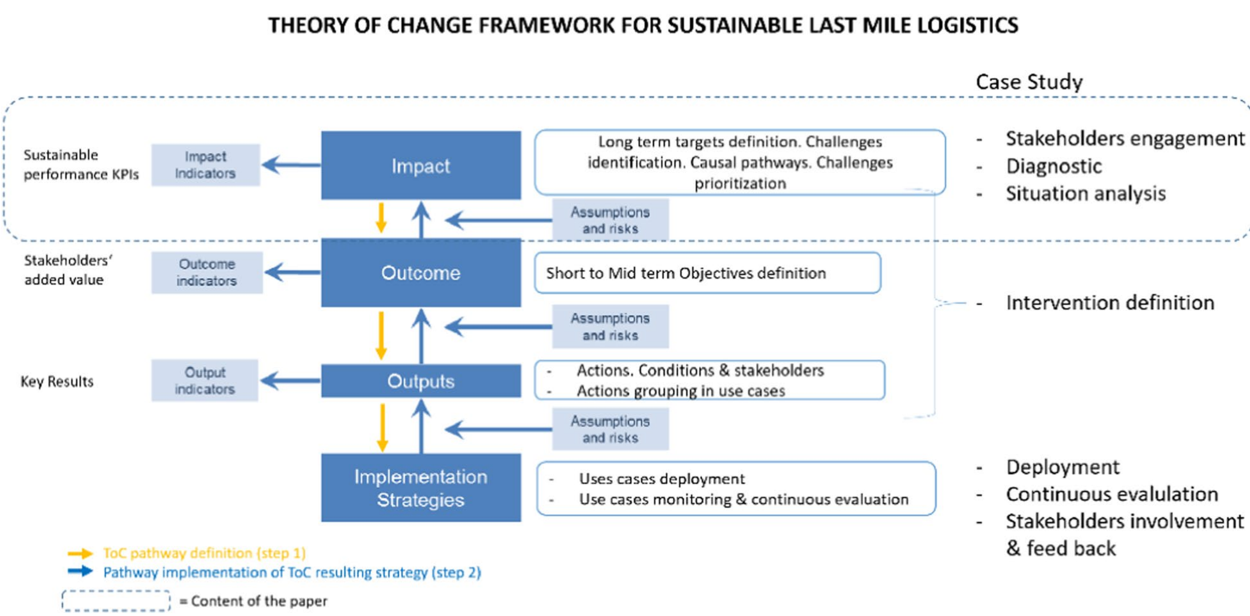

Fig. 2 Conceptual framework designed to address the transformation of current last mile systems to embrace sustainability, with a ToC logic. (Own illustration)

the functional, cause-and-effect logic central to the ToC. This involves identifying and ranking the interdependencies between various components of the logistics system, determining where interventions can be most effective. Specific interventions leading to key results can be then formulated to address the identified challenges, such as the implementation of smart routing technologies, the adoption of low-emission vehicles, and the development of urban consolidation centers. The framework also lays the groundwork for continuous monitoring and evaluation, ensuring that the impacts of these interventions are tracked and adjusted as necessary to achieve the desired outcomes. By clearly defining the actions to be taken, the required conditions for success, and the stakeholders involved, this framework provides a comprehensive approach to define an implementation strategy for achieving the change pursued and advancing towards the sustainability of last mile logistics in urban areas [57].

There are several outcomes from this framework. First, it extends the literature review to identify the sustainability indicators linked to each feature, including those related to data exploitation. Second, it extends the assessment of the sustainability of the components of the last mile system by introducing the PI-enriched logistics model. This has provided a tool to assess the sustainability of last mile performance in cities. It highlights the interdependencies between challenges, the sustainability targets they impact, and the components involved. This assessment forms the core of the study and is a key contribution to completing the envisioned ToC framework for sustainable last mile logistics.

5 Applied methodology

The Horizon Europe project DECARBOMILE, aims to test and validate different approaches to decarbonize last mile logistics in four Living labs (LL) in (Nantes (France), Logroño (Spain), Istanbul (Türkiye) and Hamburg (Germany), defining and implementing several use cases in each of them in the span of four years, between September 2022 and August 2026. In line with the objective of advancing last mile sustainability in urban areas, the ToC framework has been developed to provide the steps to define action plans and to prioritize them into use cases as Fig. 3 illustrates.

As a first step, the relevant challenges have been identified in each LL by local stakeholders (e.g. Local authorities & decision-makers, Logistics and Transport companies, business and consumers, Universities and Researchers) in a set of workshops between February and March 2023. Workshop tools, activities and the agenda were wrapped up into guidelines, including an e-mail template for inviting external stakeholders, a draft of attendance list and the reporting template to document the workshop results. Additional templates were provided for the different workshop activities. They were split in two rounds for data collection. During the first-round, participants listed their last mile needs and challenges on repositionable notes and placed them in different categories: environmental, social, technological, economical. Within the second round, a joint discussion led to rank the identified topics from high to low relevance to identify the most pressing needs and challenges.

This collection of challenges is at the base of the ToC framework, which aims to map and prioritize the challenges collected for identifying and implementing targeted actions. Prioritizing requires a holistic approach considering the whole spectrum of last mile logistics stakeholders to uncover nuanced behaviours and practices that influence last mile systems sustainability, and their interdependence. Therefore, in a second step the framework combines the last mile practices sustainability features (cf Section 3) with the PI-enriched conceptual system model of transport and traffic (cf. Section 2.5) to map the challenges' impacts on the sustainability of urban last mile, showcasing their causal pathways.

Local partners of each LL were asked to map each challenge of their relevant lists with offer and demand sustainability features by marking the boxes of Table 2 below [58].

In this step, the challenges are also mapped against the PI-enriched Conceptual System Model of transport and traffic (cf. Section 2.5), by marking whether a challenge affects the component of the logistic model (x) or not (blank) (Table 3).

This leads to identifying the challenges that affect more elements and relations of the urban logistics system and how transversal they are. Furthermore, it shows through which components of the logistics system each challenge affects the sustainability of the overall system, and which of its specific features. Likewise, the tool shows the dependencies between the challenges, so they can be prioritized in a third step of analysis, based on this mapping of challenges, impacts and causal links.

A similar approach has already been used by other authors to conduct studies in the field of sustainability. [59] employed participant observation as part of a mixed methods approach to study the integration and reporting of Sustainable Development Goals (SDGs) in higher education. This methodology allowed for a comprehensive understanding of the challenges and innovations in sustainability practices within the university setting. [60] introduced a workshop method for early sustainable product development that utilizes back casting from sustainability principles to create a vision, assess the current state, and derive strategies. It enables us to map

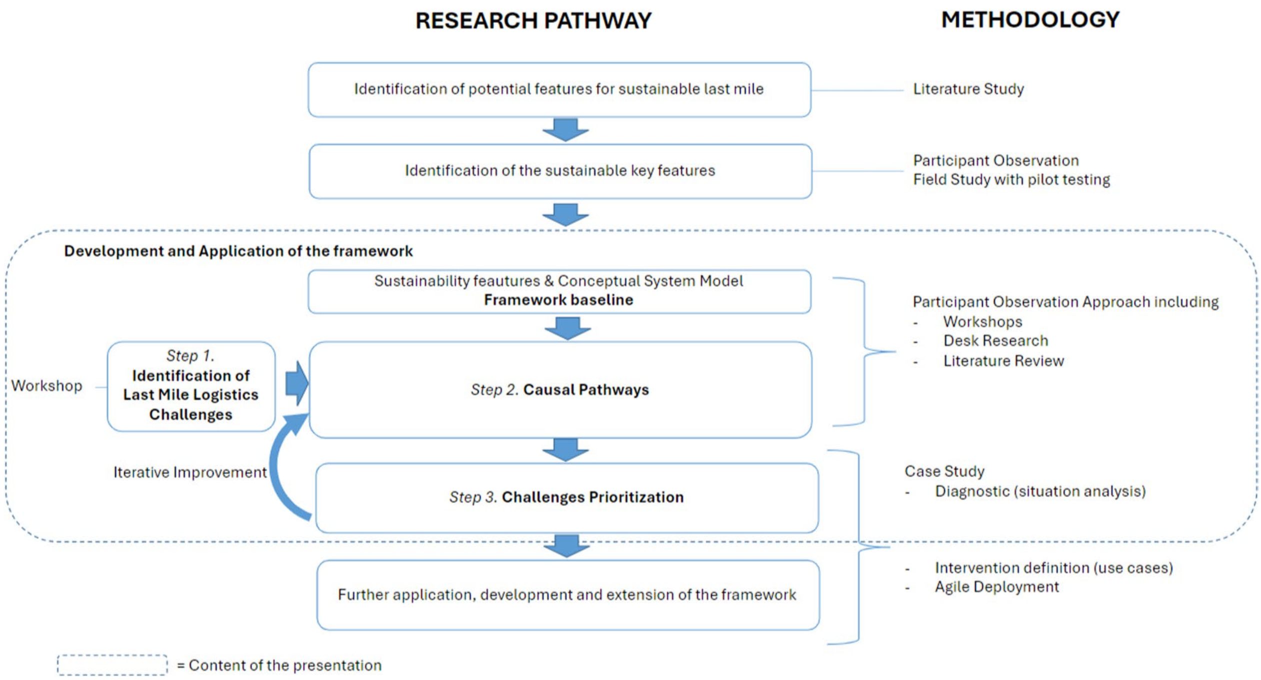

Fig. 3 Methodology pursued for the content of the paper overall applied development of the framework, and boundaries of the research pathway presented on this paper (Own illustration)

sustainability challenges and opportunities at a conceptual level, settling the baseline for defining use cases.

6 Case study

6.1 Study area

A first case study to define the action plan to apply in use cases based on the ToC framework was conducted in Logroño's LL. Over the last 10 years, the city's appearance and form have been considerably altered around a lively and commercial old town through changes in land use patterns and new developments. Furthermore, the city's location on the major road provides easy access to jobs, education, shopping, and commercial services.

6.2 Results of the case study

The workshop in Logroño collected 29 main challenges for last mile sustainability in the city. The subsequent analysis of the challenges per component of the logistics model shows the interdependencies between them, to rank them and set priorities. The prioritization shows which challenges should be tackled first, acting on which elements and relations of the logistics model, according to how much pressure they put on the performance of the system.

Table 4 shows the concentration of affectations to each performance aspect per component of the conceptual logistics model of the system (Dark Red: very high to Dark Green: very little) based on the number of challenges. The table also shows the Level of Affectation of each component of the model as the ratio between the total number of challenges that it induces across the different areas of the performance and the maximum possible. The results in Table 4 show that Productivity and Profitability are the most affected aspects of the performance by challenges along with the Systemic Viability of demand. They are mostly challenged through Transport, Goods, Persons and Information, and Activities, with the relevant Movables and Accession right after and Facilities slightly behind.

In this sense, Table 5 allows us to address the specific challenges affecting the system in detail. For instance, in Logroño, only three challenges are impacting almost every category on the performance of both sides, OFFER and DEMAND, and almost all components of the logistics model (8 out of 10): City clusters to consolidate last mile, Scarcity for logistics spaces in the center and Data enabled decisions. After those challenges, the most frequent challenges affecting the logistics model (7/10) are: Keep local retail in the economic loop, Last mile delivery & shop supply and Adapt built infrastructure: cycle, charging, hubs, lockers. However, out of all the challenges affecting the Elements and Relations of the logistics model, two have the most impacts on the sustainability features of city's last mile performance: Improve cargo-bikes quality, accessibility, maintenance and Awareness.

Table 2 Sustainable performance assessment of the challenges (exemplary) (Own illustration)

Sustainable Performance Assessment										
CHALLENGE	OFFER					DEMAND				
	ECO		SOC		ENV	ECO		SOC		ENV
	productivity	profit	working conditions	safety	systemic viability	economic nature	operational compatibility	sale's capillarity dependence	customers geography	systemic viability
Shortage of space for new facilities	x	x			x		x	x	x	x

Although they involved components of the logistics model carrying less pressure (level of affectation).

Last but not least, the results show the ranking of challenges according to the overall pressure that it induces to city's last mile logistics, considering its interdependences: how many times challenges appear simultaneously in different parts of the logistics system. For example, the first challenge "City clusters to consolidate last mile" appears in 5 out of the 7 red zones (see Table 5) of the logistics system, in 18/22 of the orange, in 11/17 of the yellow, and in 14/26 of the light green zones, and in 7/16 dark green zones. Whereas the second one "Scarcity for logistics spaces in the center" appears in all the zones except in the dark green zone. Based on the ranking, the first challenge should be considered first, and the actions defined to address it would contribute to address more effectively the whole system.

By doing so, the results show to what extent the challenges affect several aspects of the sustainable performance of the system and to what extent they affect different elements and interactions in the urban logistics model. Based on this assessment, the challenges can be prioritized for addressing them orderly, according to their impact on performance, and their interdependences: addressing one could unblock addressing others or require coping first with another so that the two challenges should be considered together, with the resulting action requirements and expected results. Later, this information can help to identify who should be involved and the subsequent dynamics it may enable to trigger.

7 Discussion

The findings of this study provide critical insights into the potential for transforming last mile logistics systems towards sustainability, through both empirical and

Table 3 Logistics model and challenges (exemplary) (Own illustration)

Logistics Model ASSESSMENT									
CHALLENGE	ELEMENTS					RELATIONS / INTERACTIONS			
	Goods, Persons, Information	Movables	Infrastructure	Facilities	Activities	Transport	Traffic	Land Use	Accession
Shortage of space for new facilities	x	x			x		x	x	x

Table 4 Number of challenges related to each part of logistics model and Performance (Own illustration)

PERFORMANCE			LOGISTICS MODEL								
			ELEMENTS					RELATIONS / INTERACTIONS			
			Goods, Persons, Information	Movables	Infrastructure	Facilities	Activities	Transport	Traffic	Land Use	Accession
OFFER	ECO	Productivity	20	16	1	15	19	21	7	6	17
		Profitability	21	19	1	17	22	23	9	8	19
	SOC	Working conditions	8	8	0	7	9	8	2	2	6
		Safety	9	11	0	10	11	10	3	2	8
	ENV	Systemic viability	17	16	1	13	17	18	7	6	14
DEMAND	ECO	Economic nature	7	6	0	5	8	9	2	2	6
		Operational compatibility	18	12	1	13	16	18	6	7	14
	SOC	Sale's capillarity dependence	15	13	1	12	14	17	8	7	13
		Customers geography	15	11	1	10	12	16	6	5	13
	ENV	Systemic viability	21	18	1	16	21	21	9	8	17
Total			151	130	7	118	149	161	59	53	127
Level of Affectation			66%	65%	70%	66%	65%	70%	66%	66%	67%

conceptual approaches. The study successfully identifies and categorizes key features and indicators of sustainable last mile practices, offering a comprehensive foundation for stakeholders seeking to improve their logistical systems. This approach resonates with the broader principles outlined by [61], particularly the emphasis on integrating various dimensions of sustainability in operational planning.

Moreover, the engagement of diverse stakeholder groups—including public authorities, LSPs, businesses, and customers—emerges as a key strength of this study. This collaborative approach led to the identification of challenges to critical features of sustainable last mile logistics, such as profitability, systemic viability, and operational compatibility, which are in line with the three dimensions of sustainability: economic, environmental, and social. By addressing both supply and demand-side factors, the research highlights a holistic methodology for tackling urban logistical challenges. These findings are supported by similar works in urban logistics, which emphasize the importance of collaboration among key actors to optimize sustainability outcomes [12, 16].

For example, in the Logroño case study, the challenge of city clusters for last mile consolidation has the greatest impact, primarily affecting infrastructure. Although infrastructure is the only element of the logistics model directly impacted by this challenge, it carries the highest level of influence (70%). Addressing this will require specialized expertise to assess and implement appropriate measures. Challenges that require similar actions can be grouped together, providing the basis for defining use cases that incorporate the relevant components of the logistics model, guided by their interdependencies.

The DECARBOMILE framework's approach to sustainability aligns with earlier studies, particularly in its emphasis on standardized performance criteria to guide decision-making. This is further supported by [18], which developed a toolkit for mapping sustainability solutions in urban logistics. Our study expands on this by not only offering a solution-mapping framework based on subjective criteria but also introducing a structured method for prioritizing these solutions based on their impact on sustainability. This prioritization approach is essential for effective decision-making in sustainable logistics.

[56] highlighted the importance of evidence-based, outcome-driven frameworks in driving sustainable logistics transformations, a principle we embraced by integrating the ToC with empirical data from stakeholder workshops. This ensured our interventions were grounded in real-world contexts and adaptable across various urban

Table 5 Prioritization of challenges according to its affectation and interdependences (Own illustration)

Challenge	Offer	Demand	Performance	Elements	Relations	Logistics Model	Total	Affectation rank	Interdependence				
City clusters to consolidate last mile	3	4	7	4	4	8	15	36.78	5	18	11	14	7
Scarcity for logistics spaces in the center	3	4	7	4	4	8	15	36.42	7	21	13	14	0
Data enabled decisions	2	4	6	4	4	8	14	31.78	6	17	13	12	0
Enable sustainable data treatment	3	5	8	3	3	6	14	31.17	7	18	9	12	1
Adapt built infrastructure: cycle, charging, hubs, lockers	3	5	8	4	2	6	14	31.12	7	18	9	12	1
Ensure quality standards	4	3	7	3	3	6	13	27.84	5	14	10	11	2
Keep local retail in the economic loop	2	4	6	3	4	7	13	27.22	7	14	8	12	0
Adapt vehicles	4	3	7	4	2	6	13	27.19	7	17	9	8	0
Providers' cooperation	4	3	7	4	2	6	13	27.19	4	18	17	2	0
Ensure traceability	4	2	6	4	3	7	13	27.15	7	13	7	12	z
Improve cargo-bikes quality, accessibility, maintenance	5	5	10	3	1	4	14	25.96	5	15	10	9	0
Scarcity of staff	5	3	8	3	2	5	13	25.93	7	15	10	7	0
Regulations to control urban distribution	5	2	7	3	2	5	12	22.90	2	9	7	13	4
Interoperate	3	4	7	3	2	5	12	22.64	7	17	10	0	0
Confidentiality policy	4	4	8	2	2	4	12	20.73	7	14	6	4	0
Awareness	5	5	10	1	2	3	13	20.16	5	10	8	7	0
Cluster customers	2	5	7	2	2	4	11	18.05	7	11	5	4	0
Companies trust, professionalization, leadership	5	2	7	2	2	4	11	18.05	7	7	3	10	0
Improve urban transport	5	4	9	2	1	3	12	17.40	5	10	4	7	0
Integrate real-time information devices	2	3	5	2	3	5	10	16.65	4	11	5	5	0
Transition to green mobility	5	3	8	2	1	3	11	16.04	3	10	8	3	0
Manage service liability	4	1	5	4	1	5	10	15.74	4	10	3	7	0
Ensure compliance with regulations	4	4	8	2	1	3	11	15.73	2	4	6	9	3
Keep last mile costs competitive	2	2	4	4	2	6	10	15.26	4	12	7	0	0
Last mile delivery & shop supply	2	2	4	4	2	6	10	15.23	7	10	2	4	0
Change consumption culture / habits	3	2	5	2	2	4	9	12.71	7	10	2	0	0
Think beyond costs	3	1	4	4	0	4	8	10.44	2	5	4	5	0
Subsidize chose low emissions options	2	1	3	2	0	2	5	3.89	2	4	0	0	0
km 0 tax	2	4	6	1	0	1	7	3.28	1	4	0	0	0

settings. Few studies have rigorously applied the ToC framework in last mile logistics, filling a gap in the literature, as argued by [5, 31], who emphasized the need for objective metrics to assess logistics sustainability.

By providing a method for prioritizing actions based on their environmental impact, the current study contributes to this ongoing discourse, offering a practical tool for stakeholders aiming to decarbonize last mile logistics. Additionally, the study resonates with the findings of [9], who explored the benefits of urban consolidation centers and alternative delivery modes, such as cargo bikes, in reducing the carbon footprint of last mile logistics. The incorporation of these strategies within the DECARBOMILE framework underscores the importance of adopting innovative solutions that can be tailored to the specific needs of different urban environments.

8 Conclusion and further steps

This study validates and extends the existing literature on sustainable last mile logistics by offering a structured, stakeholder-driven approach to identifying and implementing sustainability solutions in last mile logistics. By integrating the ToC and an enriched PI-logistics model, this research presents a comprehensive framework to guide future studies and practical implementations in this field. Through comparison with previous studies, this research highlights the critical importance of collaborative, context-specific solutions in achieving sustainable urban logistics. The framework presented offers a new perspective for transforming last mile logistics systems, addressing the fundamental gaps identified in this paper: lack of objective criteria and limited focus on demand. The approach is based on clear, measurable targets concerning the expected performance and value-added outcomes, supported by a holistic assessment of local challenges. This assessment maps out the various sustainability dimensions of the logistics system, identifies their interdependencies, and suggests ways to address them, settling priorities.

A key contribution of this study is its focus on the mutual influence between the sustainability of logistics demand and the sustainability of logistics offer. Current logistics models often overlook this interaction. By introducing the concept of “demand sustainability” and its associated challenges, the new framework addresses one of the main gaps identified in previous research. This approach centers on customer centric logistics, which is at the core of last mile logistics disruption. It considers the role of data in the decisions made by all key stakeholders—customers, LSPs, and companies utilizing disruptive business models based on data-enriched value propositions. This creates a crucial link between the logistics and supply chains and the broader value chain. Therefore, the framework seeks to enable stakeholders to more effectively navigate the transformation toward sustainable last mile systems, considering a wide range of factors that influence decision-making.

The tool presented in this study systematizes how to showcase the causal pathway between specific challenges and sustainability targets, laying the groundwork for replicating this approach to decarbonize last mile logistics. It also addresses a second key gap in sustainable logistics decision-making: the lack of objective criteria. The tool enables a qualitative and quantitative assessment that ranks challenges according to how they impact the overall sustainability performance of logistics systems and their core components. This prioritization, informed by a functional logic that includes interdependencies between components, sets the stage for developing effective, targeted actions. These actions can then be implemented with the involvement of relevant stakeholders, whether they are impacted by the challenges or act as enablers of change.

For each challenge, the next step is formulating specific objectives for the various stakeholders involved. These objectives must reflect the added value that each stakeholder gains from addressing the challenges, focusing on the specific components of the logistics model that are impacted. Once the objectives are defined, corresponding actions can be identified, along with success metrics to monitor the progress. This approach proposes to use Objectives and Key Results (OKRs), which set aspirational goals that drive teams and individuals toward meaningful change. By clearly defining objectives and aligning actions, stakeholders can address challenges in a more organized and effective manner.

Beyond data literacy, another main limitation of this study is the scope of application, limited to a single living lab. Ongoing application in the rest of DECARBOMILE’s living labs is expected to show the sensibility of results to the location. Another limitation is the current level of automatization of the assessment process, that the project aims to address by developing a digital twin decision support system for the definition and prioritization of use cases that foster the implementation of sustainable last mile systems in cities.

Abbreviations

DECARBOMILE	Decarbonize last mile logistics
ECO	Economic
ENV	Environmental
GHG	Greenhouse gas
GMA	Guadalajara’s Metropolitan Area
ICT	Information and communication technologies
KPI	Key Performance Indicators
LL	Living lab
LSP	Logistics service providers
OKR	Objectives and key results

PI	Physical Internet
SDG	Sustainable Development Goals
SOC	Social
ToC	Theory of change

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Author contributions
Katharina Beck: She developed the theoretical framework and presented the challenges in the Physical Internet, provided some insights in results and conclusion. She contributed to the final version of the manuscript and wrote the paper with input from all authors.
Mohammad Mahdi Zarei: He developed the theoretical framework and designed the model in last mile logistics sustainability, provided some insights in results and conclusion. He contributed to the final version of the manuscript and wrote the paper with input from all authors.
Heike Flämig: She influenced the research (especially with the conceptual system model) and helped shape the research concept. She provided critical feedback, discussed the results and commented on the manuscript.
Isabella Hauswald: She led the deployment and systematization of the engagement with local stakeholders in the different locations of the project DECARBOMILE.
Isabel Froes: She conceived the 'conceptual-practical' contribution to articulating local stakeholders.
Amalia Giannakopoulou: She supported the follow up of the deployment and the systematization of stakeholders engagement.
Javi Esquillor: He conceived of the presented idea and designed and directed the project. Also, he verified the analytical methods and encouraged other authors to investigate Last mile logistics sustainability and Physical internet and supervised the findings of this work.

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Declarations

Competing interest
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References

1. Zarei, M. M., Agudo-Peregrina, Á. F., & Ponce-Cueto, E. (2020). Choosing the delivery and return method in purchases: the effect of situational factors in omni-channel contexts. *Economic Research-Ekonomska Istraživanja, 33*(1), 2120–2137.
2. Urquhart, R., Newing, A., Hood, N., & Heppenstall, A. (2022). Last-mile capacity constraints in online grocery fulfilment in great Britain. *Journal of Theoretical and Applied Electronic Commerce Research, 17*(2), 636–651.
3. Ishfaq, R., Defee, C. C., Gibson, B. J., & Raja, U. (2016). Realignment of the physical distribution process in omni-channel fulfillment. *International Journal of Physical Distribution & Logistics Management, 46*(6/7), 543–561.
4. Yau, A., Law, C., Cornelsen, L., Adams, J., Boyland, E., Burgoine, T., De Vocht, F., White, M., & Cummins, S. (2023). Association between household online grocery delivery service use and food and drink purchase behavior in England: cross-sectional analysis. *JMIR Public Health and Surveillance, 9*, e41540.
5. Silva, V., Amaral, A., & Fontes, T. (2023). Towards sustainable last-mile logistics: a decision-making model for complex urban contexts. *Sustainable Cities and Society, 96*, 104665.
6. Shaklab, E., Karapetyan, A., Sharma, A., Mebrahtu, M., Basri, M., Nagy, M., Khonji, M., & Dias, J. (2023). Towards autonomous and safe last-mile deliveries with AI-augmented self-driving delivery robots (Version 1). arXiv.
7. Anand, N., Yang, M., Van Duin, J. H. R., & Tavasszy, L. (2012). GenCLOn: an ontology for city logistics. *Expert Systems with Applications, 39*(15), 11944–11960.
8. Brusselaers, N., & Mommens, K. (2022). The effects of a water-bound construction consolidation centre on off-site transport performance: the case of the Brussels-capital region. *Case Studies on Transport Policy, 10*(4), 2092–2101.
9. Demir, E., Syntetos, A., & Van Woensel, T. (2022). Last mile logistics: research trends and needs. *IMA Journal of Management Mathematics, 33*(4), 549–561.
10. Edouard, A., Sallez, Y., Fortineau, V., Lamouri, S., & Berger, A. (2021). Survey on a Set of Features for New Urban Warehouse Management Inspired by Industry 4.0 and the Physical Internet. In T. Borangiu, D. Trentesaux, P. Leitão, O. Cardin, & S. Lamouri (Eds.), *Service oriented, holonic and multi-agent manufacturing systems for industry of the future*. Springer International Publishing.
11. Ranieri, L., Digiesi, S., Silvestri, B., & Roccotelli, M. (2018). A review of last mile logistics innovations in an externalities cost reduction vision. *Sustainability, 10*(3), 782.
12. Buldeo Rai, H., Mommens, K., Verlinde, S., & Macharis, C. (2019). How does consumers' omnichannel shopping behaviour translate into travel and transport impacts? Case-study of a footwear retailer in Belgium. *Sustainability, 11*(9), 2534.
13. Dablanc, L., & Browne, M. (2020). Introduction to special section on logistics sprawl. *Journal of Transport Geography, 88*, 102390.
14. Pardo-Jaramillo, S., Muñoz-Villamizar, A., Osuna, I., & Roncancio, R. (2020). Mapping research on customer centricity and sustainable organizations. *Sustainability, 12*(19), 7908.
15. Nogueira, M., Silva, B., & Gomes, S. (2023). The impact of customer-centric sustainability on brand relationships. *Sustainability, 15*(16), 12212.
16. Viu-Roig, M., & Alvarez-Palau, E. J. (2020). The impact of e-commerce-related last-mile logistics on cities: a systematic literature review. *Sustainability, 12*(16), 6492.
17. Wang, H., Dong, J., Niu, B., & Xin, X. (2023). Could shipment consolidation jointly improve the economic and environmental sustainability of a maritime service supply chain? *International Journal of Logistics Research and Applications*. https://doi.org/10.1080/13675567.2023.2167958
18. Novelog. (2023). https://www.novelogtool.imet.gr/Novelog-Tools/Toolkit
19. Cichocki, M., Montreuil, B., V Barenji, A., & Landschuetzer, C. (2023). Physical internet based hyperconnected logistics platform enabling heavy-duty machinery sharing in the composting industry: a simulation-based scenario investigation.
20. Colin, J.-Y., Mathieu, H., & Nakechbandi, M. (2016). A proposal for an open logistics interconnection reference model for a Physical Internet. In: 2016 3rd International Conference on Logistics Operations Management (GOL), 1–6.
21. Treiblmaier, H., Mirkovski, K., Lowry, P. B., & Zacharia, Z. G. (2020). The physical internet as a new supply chain paradigm: a systematic literature review and a comprehensive framework. *The International Journal of Logistics Management, 31*(2), 239–287.
22. Ballot, E. (2019). The Physical Internet. In H. Zijm, M. Klumpp, A. Regattieri, & S. Heragu (Eds.), *Operations, Logistics and Supply Chain Management* (pp. 719–734). Springer International Publishing.

23. Montreuil, B., Meller, R. D., & Ballot, E. (2013). Physical Internet Foundations. In T. Borangiu, A. Thomas, & D. Trentesaux (Eds.), *Service Orientation in Holonic and Multi Agent Manufacturing and Robotics*. Springer, Berlin Heidelberg.
24. Kubek, D., & Więcek, P. (2019). An integrated multi-layer decision-making framework in the physical internet concept for the city logistics. *Transportation Research Procedia, 39*, 221–230.
25. Maslarić, M., Nikoličić, S., & Mirčetić, D. (2016). Logistics response to the industry 4.0: the physical internet. *Open Engineering*. https://doi.org/10.1515/eng-2016-0073
26. Crainic, T. G., & Montreuil, B. (2016). Physical internet enabled hyperconnected city logistics. *Transportation Research Procedia, 12*, 383–398.
27. Flämig, H., Hertel, C., & Sjöstedt, L. (2002). Multimodal transport: An integrated element for last-milesolutions. In: Proceedings of the International Congress on Freight Transport Automation and Multimodality: organizational and Technological Innovations, Delft.
28. Awwad, M., Shekhar, A., & Sundaranarayanan Iyer, A. (2018). Sustainable last-mile logistics operation in the era of E-commerce.
29. Cano, J. A., Londoño-Pineda, A., & Rodas, C. (2022). sustainable logistics for e-commerce: a literature review and bibliometric analysis. *Sustainability, 14*(19), 12247.
30. Rashidzadeh, E., Hadji Molana, S. M., Soltani, R., & Hafezalkotob, A. (2021). Assessing the sustainability of using drone technology for last-mile delivery in a blood supply chain. *Journal of Modelling in Management, 16*(4), 1376–1402.
31. Silva, V., Amaral, A., & Fontes, T. (2023). Sustainable urban last-mile logistics: a systematic literature review. *Sustainability, 15*(3), 2285.
32. Han, S., & Kwon, Y. (2019). Awareness and attitude of college students majoring in landscape architecture towards the sustainable development. *Sustainability, 11*(19), 5464.
33. Toumi, O., Le Gallo, J., & Ben Rejeb, J. (2017). Assessment of Latin American sustainability. *Renewable and Sustainable Energy Reviews, 78*, 878–885.
34. Zanella, A., Camanho, A. S., & Dias, T. G. (2015). The assessment of cities' livability integrating human wellbeing and environmental impact. *Annals of Operations Research, 226*(1), 695–726.
35. Booth, R. (2017). Couriers on Britain's shopping addiction: 'Customers don't care as long as it's cheap'. The Guardian. https://www.theguardian.com/business/2017/may/30/couriers-britains-shopping-addiction-online-low-pay
36. Ducarme, D., & Agrell, P. J. (2019). *Sustainable solutions for 'last mile'deliveries in the parcel industry: A qualitative analysis using insights from third-party logistics service providers and public mobility experts*. Université Catholique de Louvain, Louvain.
37. Shishiteva, P. (2017). Is parcel delivery becoming more sustainable. A comparison between delivery companies and traditional couriers.
38. Sułkowski, Ł., Kolasińska-Morawska, K., Brzozowska, M., Morawski, P., & Schroeder, T. (2022). Last mile logistics innovations in the courier-express-parcel sector due to the COVID-19 pandemic. *Sustainability, 14*(13), 8207.
39. Abdul-Rahman, H., Wang, C., Wood, L. C., & Ebrahimi, M. (2016). Integrating and ranking sustainability criteria for housing. *Proceedings of the Institution of Civil Engineers - Engineering Sustainability, 169*(1), 3–30.
40. Garus, A., Alonso, B., Raposo, M. A., Grosso, M., Krause, J., Mourtzouchou, A., & Ciuffo, B. (2022). Last-mile delivery by automated droids. Sustainability assessment on a real-world case study. *Sustainable Cities and Society, 79*, 103728.
41. Wagenhals, S., Garner, W., Duckers, L., & Kuhn, K. (2014). Sustainability index with integrated indicator dependencies. *Business, Management and Education, 12*(1), 15–29.
42. Bosona, T. (2020). Urban freight last mile logistics—challenges and opportunities to improve sustainability: a literature review. *Sustainability, 12*(21), 8769.
43. Perboli, G., & Rosano, M. (2019). Parcel delivery in urban areas: opportunities and threats for the mix of traditional and green business models. *Transportation Research Part C: Emerging Technologies, 99*, 19–36.
44. Gonzalez, J. N., Garrido, L., & Vassallo, J. M. (2023). Exploring stakeholders' perspectives to improve the sustainability of last mile logistics for e-commerce in urban areas. *Research in Transportation Business & Management, 49*, 101005.
45. Spicka, J., Hlavsa, T., Soukupova, K., & Stolbova, M. (2019). Approaches to estimation the farm-level economic viability and sustainability in agriculture: a literature review. *Agricultural Economics (Zemědělská Ekonomika), 65*(6), 289–297.
46. Iliemena-Ifeanyi, R., Uche, E., & Agu, S. (2021). Corporate resources and socio-economic sustainability of firms in Nigeria in the post Covid-19 pandemic era.
47. Halme, M., Jasch, C., & Scharp, M. (2004). Sustainable homeservices? Toward household services that enhance ecological, social and economic sustainability. *Ecological Economics, 51*(1–2), 125–138.
48. Krstić, M., Tadić, S., Kovač, M., Roso, V., & Zečević, S. (2021). A novel hybrid MCDM model for the evaluation of sustainable last mile solutions. *Mathematical Problems in Engineering, 2021*, 1–17.
49. Wang, C.-N., Nguyen, N.-A.-T., Dang, T.-T., & Hsu, H.-P. (2021). Evaluating sustainable last-mile delivery (LMD) in B2C E-commerce using two-stage fuzzy MCDM approach: a case study from Vietnam. *IEEE Access, 9*, 146050–146067.
50. Manheim, M., & Lang, A. S. (1979). The challenge of transportation systems analysis. Manheim, M. Fundamentals of Transportation Systems Analysis, 10–59.
51. Sjöstedt, L. (1996). A Theoretical Framework—From an Applied Engineering Perspective. Mobility, Transport and Traffic in the Perspective of Growth, Competitiveness, Employment, Paris, France, 71–79.
52. Elbert, R., Friedrich, C., Boltze, M., & Pfohl, H.-C. (2020). Urban freight transportation systems: current trends and prospects for the future. *Urban freight transportation systems* (pp. 265–276). Elsevier. https://doi.org/10.1016/B978-0-12-817362-6.00015-X
53. Esquillor, J., Flores, L., Escribano, P., & Larriba, E. (2023). Simulación y Politaje de Logística sustentable en la Última Milla. https://t.ly/lwf8U
54. Novotná, M., Švadlenka, L., Jovčić, S., & Simić, V. (2022). Micro-hub location selection for sustainable last-mile delivery. *PLoS ONE, 17*(7), e0270926.
55. Ut-Tha, V. (2023). Pioneering eco-cart: carbon reduction solutions for Thai online shoppers. *Management & Marketing, 18*(4), 515–536.
56. Rosenberg, L. N., Balouka, N., Herer, Y. T., Dani, E., Gasparin, P., Dobers, K., Rüdiger, D., Pättiniemi, P., Portheine, P., & Van Uden, S. (2021). Introducing the shared micro-depot network for last-mile logistics. *Sustainability, 13*(4), 2067.
57. Clark, H., & Taplin, D. (2012). *Theory of change basics: A primer on theory of change*. Actknowledge.
58. Beck, K., & Esquillor, J. (2023). Enabling the PI to solve multi-layered problems of the Last Mile Logistics.
59. Hansen, B., Stiling, P., & Uy, W. F. (2021). Innovations and challenges in SDG integration and reporting in higher education: a case study from the University of South Florida. *International Journal of Sustainability in Higher Education, 22*(5), 1002–1021.
60. Schulte, J., & Hallstedt, S. I. (2018). Workshop method for early sustainable product development. 2751–2762.
61. Reyes-Rubiano, L., Serrano-Hernandez, A., Montoya-Torres, J. R., & Faulin, J. (2021). The sustainability dimensions in intelligent urban transportation: a paradigm for smart cities. *Sustainability, 13*(19), 10653.