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Sustainable Urban Freight for Energy-Efficient Smart Cities—Systematic Literature Review

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Abstract: Smart cities need energy-efficient and low-emission transportation for people and goods. Most studies focus on sustainable urban-transportation systems for passengers. Freight transportation in cities has increased significantly during the COVID-19 pandemic, leading to greenhouse gases emissions and negative externalities, such as traffic congestion. The purpose of this paper is to identify through a systematic literature review which innovations (hardware and software) applied by logistics service providers (LSPs) in sustainable urban freight (SUF) are suitable to support the transition to energy-efficient smart cities. We propose to classify the existing innovations in last-mile delivery for SUF into categories: (1) urban freight consolidation and/or trans-shipment; (2) the Consumer as a Service Provider (CaaSP); (3) choice of transportation modes. We introduce the concept of CaaSP as an innovative solution in last-mile delivery (LMD), where customers take over some transport operations with the use of smart technologies, and thus reduce the energy demand. We consider the modes of transportation, such as: drones, autonomous delivery robots, autonomous vehicles, cargo bikes (including e-cargo bikes, e-tricycles), electric vehicles (mainly vans), and combined passenger-and-cargo transportation rapid-transit systems. From the analyzed dataset, we find that energy-efficiency in smart cities can be improved by the consolidation of parcels in micro-depots, parcel lockers, and mobile depots. We analyze smart technologies (the Internet of things, big data, artificial intelligence, and digital twins), which enable energy efficiency by reducing the energy demand (fuel) of SUF, due to better operational planning and infrastructure sharing by logistics service providers. We propose a new IEE matrix as an actionable tool for the classification of innovations applied by LSPs in SUF, according to the level of their interconnectivity and energy efficiency. Additionally, this paper contributes to the theory by exploring possible future research directions for SUF in energy-efficient smart cities.

Keywords: city logistics; logistics service providers; energy efficiency; low-emissions transport; urban deliveries; Customer as a Service Provider (CaaSP)

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1. Introduction

1.1. Motivation—Importance of Sustainable Urban Freight in Smart Cities

The share of urban population is constantly increasing; in 2022 on average 57% of the total population live in cities [1]. In the European Union (EU), the share of the urban population has reached about 75%, whereas 82% of the total population of North America live in cities [2]. "Urban areas" consume between 60 and 80% of energy worldwide (mainly for electricity and transportation), and have a significant environmental impact with respect to greenhouse gases (GHGs) emissions [3,4].

The smart-city concept refers to an approach to urban management that focuses on the application of modern, environmentally friendly technologies (e.g., investments in renewable energy production) in urban areas [5,6]. At the European Union (EU) level, the definition of smart cities combines three crucial elements, such as transportation, information communications technology (ICT), and energy savings [7]. In smart cities, through the application of modern ICT and effective urban governance, energy management and transportation, the focus is placed on improving the sustainability and liveability of cities [8,9].

Smart cities are built on elements that aim to facilitate a better quality of life, such as [10–14]:

- Energy-efficient and easily accessible urban mobility.
- Infrastructure for environmental protection and the reduction of carbon dioxide (CO_2) emissions (e.g., smart building and smart living).
- Innovative technologies for sustainable-energy consumption.
- Interconnectivity (e.g., easy and affordable access to the broadband Internet).
- Intelligent urban services (for example, based on real-time sensor data).

Studies on smart cities are polarized in three dimensions, namely technology, people, and governance [15]. Academic discussion on the definition of smart cities highlights the need to combine intelligent technologies with strategic urban planning to ensure sustainable development, economic growth, and improved well-being in urban areas [16–19].

Transportation systems are vital for the sustainable development of cities [20]. Studies on sustainable transport in smart cities focus mainly on urban mobility (passenger transport) [21–23].

The current urban-freight systems are mainly based on fossil fuels. Urban freight creates 10–15% of the equivalent vehicle miles traveled in urban areas [24]. Urban freight contributes to more than 25% of CO2 emissions in a city [25], and therefore reducing its negative impact is crucial to the development of smart cities. Factors such as congestion, air pollution, and traffic accidents impact sustainability and post-pandemic recovery in cities [26–28].

The smart-city concept allows policy makers to fill in the gaps in the availability of urban data for decision making, by collecting and analyzing real-world data through the sensors, actuators, meters, and personal mobile devices [29]. Thus, the smart city can be characterized as instrumented, interconnected, and intelligent [30,31].

Disruptive ICT technologies are implemented to optimize urban freight (so-called smart logistics), but their impacts on smart cities and sustainability are understudied in the literature [32]. Smart logistics includes technology-enabled, flexible, extendable, and intelligent management of logistics processes, which is supported by auto-identification tags and sensors to capture real-time data about objects (e.g., vehicles, parcels)and the environment (e.g., urban infrastructure, traffic conditions, weather conditions), to enable real-time data sharing and the management of the urban logistics network [33,34].

Sustainable urban freight (SUF) is a process that encompasses the environmentally friendly and accessible collection and delivery of goods in urban areas. Furthermore, we investigate the link between SUF and the transition towards energy-efficient smart cities.

The energy and transportation systems in cities are interlinked [12,35,36] by applying ICT, smart meters and smart grids for flexible energy-demand management, electricity storage, and distributed energy production (fossil fuels and renewables) [37].

Most studies related to energy systems and transport in smart cities focus on urban mobility (passengers), and they rarely consider the movement of goods.

1.2. Aim and Originality of This Paper

The previous systematic literature reviews on sustainable urban freight (SUF) for smart cities included the classification of sustainability dimensions of transportations systems [38], extraneous and endogenous factors for the development of SUF transportation [39,40] and the assessment of ICTs for improving urban freight [41].

He and Haasis [40], through a systematic literature review (SLR,) have identified exogenous (urban development) and endogenous trends (innovations) that influence the transition from traditional freight to SUF in smart cities. They stated that exogenous trends, such as constant growth of urban population, and urban sprawl, result in extended range and increased frequency of urban deliveries. They lead to negative externalities (noise, congestion, and GHG emissions). Furthermore, urban development requires the extension of existing freight infrastructure/networks to meet the growing demand for last-mile deliveries (LMDs) [9,36].

Endogenous trends (the implementation of new technologies by logistics service providers), focus on reducing the negative externalities, and shift towards more environmentally friendly modes of transportation (for example, electric/hybrid delivery vehicles, cargo bikes/cars, delivery drones, and delivery robots). Furthermore, they reconfigure the network by using city micro-hubs, mobile depots, autonomous depots, parcel lockers, and public transit systems [22,37–39].

To the best of our knowledge, no previous studies have investigated the relationship between the innovative solutions for last-mile delivery in SUF, and their suitability for the transition to energy-efficient smart cities.

The purpose of this paper is to identify through a systematic literature review, which innovations (hardware and software) applied by LSPs in sustainable urban freight are suitable to support the transition to energy-efficient smart cities.

We search for answers to the following research questions:

- Q1: What innovations are companies (logistics service providers) applying in last-mile delivery (LMD) for sustainable urban freight (SUF) in energy-efficient smart cities?
- Q2: What smart technologies enable the use of LMD for SUF applications in energy-efficient smart cities?

Innovations in last-mile delivery (LMD) in SUF are emerging solutions, which are applied by companies for transportation and trans-shipment of goods in urban areas, with a focus on the reduction of related externalities.

In this paper, we build on the findings of studies on the application of innovation to develop sustainable urban freight by He and Hassis [39,40], and our previous work on the role of logistics service providers in increasing the sustainability of urban freight [42,43]. The originality of this research results from linking up the application of innovations (logistics solutions) by logistics service providers to enable sustainability (reduced CO_2 emissions) and energy efficiency. We propose a classification tool, the so-called IEE matrix (interconnectivity and energy efficiency) to assess the suitability of these solutions for energy-efficient smart cities.

The remainder of this paper includes the description of the research methodology in Section 2. The descriptive analysis of the dataset is presented in Section 3, followed by the content analysis in Section 4. The discussion of the results is described in Section 5. The final conclusions are stated in Section 6.

2. Materials and Methods

2.1. List of Abbreviations

All the abbreviations which are used in the text are shown in Table 1.

Table 1. Abbreviations.

Abbreviation	Definition
AI	Artificial Intelligence
B2C	Business-to-customer
CaaSP	Customer as a Service Provider
CO_2	Carbon dioxide
DTL	Distributed ledger technology (Blockchain)
DT	Digital twin
EU	European Union
GHGs	Greenhouse gases
GPS	Global Positioning System
ICT	Information communications technology
IoT	Internet of things
LMD	Last-mile delivery

Table 1. *Cont.*

Abbreviation	Definition
ILMD	Innovation in last-mile delivery
RFID	Radio-frequency identification
SUF	Sustainable urban freight

2.2. Research Methodology

In this study, the systematic literature review method is applied. The main stages of this research are presented in Figure 1. Studies on sustainable urban freight for energy-efficient smart cities are fragmented and transdisciplinary; they merge engineering (e.g., the design of new vehicles or transportation processes), social science (for example, the economy, management studies, and user behavior), and computer science and environmental science (for example, the reduction in greenhouse gas emissions). This divergence makes stating the research questions challenging. For that reason, an iterative process is chosen for the definition, clarification, and refinement of the research questions. First, the scoping studies are performed, as recommended by Tranfield et al. [44], to identify boundaries and define search criteria.

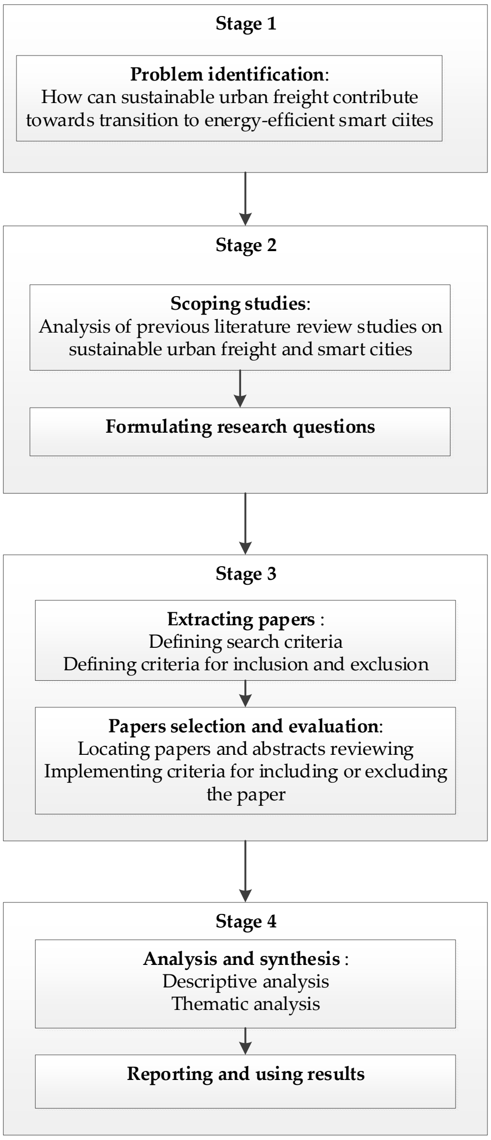

Figure 1. The overview of the research methodology.

During the scoping studies, we look at the recent systematic literature reviews on sustainable urban freight (SUF), and smart cities [40,45–47]. The scoping study allows us to identify the fact that SUF is investigated in the literature at the macro-level (city logistics), and at the micro-level context (last-mile delivery) [48].

The city logistics approach focuses on the relationship between stakeholder, infrastructures, and policies (e.g., urban development planning, environmental policies, etc.). The micro-level studies focus on the last-mile-delivery (LMD) management to the final customers. In this study, we present the micro-level perspective, but the links to the macro-level perspective are duly noted.

In this study, we examine the logistics innovations which have high potential for improving the energy efficiency of deliveries in urban areas, and are compatible with a smart city's characteristics (interconnectivity and intelligence).

Generally, urban freight is less energy-efficient (with a higher fuel consumption) than long-haul freight, due to frequent stops, a higher share of idle time per trip, multiple delivery points per trip, a higher frequency of deliveries, different drop-off times, and non-optimal rescheduling, due to the absence of recipients [49,50]. Logistics service providers apply logistics innovations to reduce the GHGs emissions and energy demand, which is needed to establish SUF.

Logistics innovation is defined here as a new solution applied to last-mile urban delivery (LMD) in order to improve the transportation and/or trans-shipment of goods, and to reduce the related environmental impact of LMD.

We chose a systematic literature review, as it allows us to "report as accurately as possible what is known and not known about the research questions stated in a study" [51]. Furthermore, a SLR involves stricter scientific rigor than a narrative literature review [44].

To provide reliability and comprehensibility for this study, a review protocol is designed (as presented in Figure 1), which includes elements as follows [44,52–54]:

- Research questions addressed by the study,
- The sample, which is the focus of the review,
- The search strategy for the identification of relevant studies.

2.2.1. Extracting Papers

The Scopus database is chosen for paper extraction,

The scoping studies allowed the definition of the search criteria, as shown in Table 2.

Table 2. Search criteria in Scopus database [55].

Category	Search Criteria
Keywords	Smart city, sustainable urban freight, sustainable last mile delivery
Search string	TITLE-ABS-KEY (smart AND cit *) AND TITLE-ABS-KEY (sustain * AND urban AND freight) OR TITLE-ABS-KEY (sustain * AND last AND mile AND deliver *)
Time range	2008–2022 *
Language	English
Type of documents	Journal, Conference Paper,
Authorship	Defined (author/-s name displayed)

* The search was performed in December 2022–January 2023, so some papers from 2022 might not be indexed yet.

Due to the relatively small number of papers on the SUF for smart cities (only 70 papers), we extracted the keyword "energy-efficient" manually from the content of the papers in the dataset.

The extraction of the papers was an integrative process (see Figure 2). First, we checked whether the papers fulfilled all the search criteria.

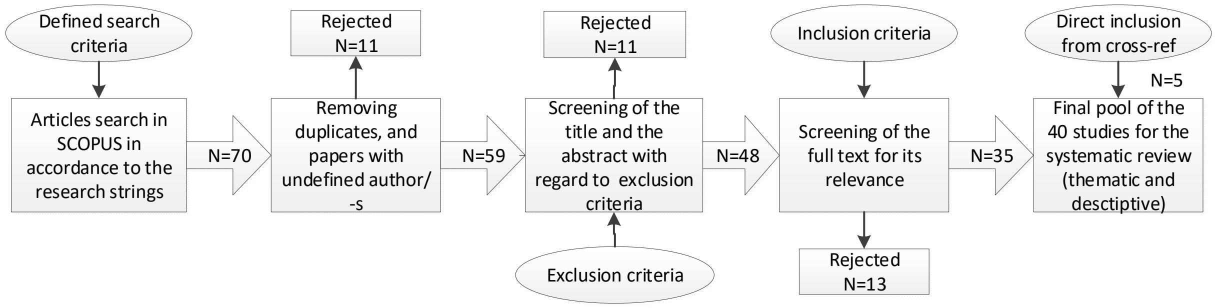

Figure 2. The overview of the process of papers selection and evaluation.

2.2.2. Inclusion and Exclusion Criteria

Out of the dataset of the extracted 70 papers, there were 2 duplicates and 9 records which contained some generic descriptions of conference proceedings, with no identified authorship. For these reasons, they were removed from the dataset.

Next, we screened the title and abstract in the set of remaining 59 papers. The exclusion criteria were applied during the screening process, as follows:

- Paper considers only policy making for SUF;
- Paper considers only endogenous factors for SUF (urban planning, urban development, etc.);
- Paper considers urban-mobility solutions only for passengers (not for goods).

After applying the exclusion criteria, we rejected an additional 11 papers from the dataset.

In the next step, the full texts were screened for compliance with the following inclusion criteria:

- Paper considers the movement of goods (urban integration of transport and/or last-mile delivery) in smart cities.
- Paper investigates a company (logistics service provider), or group of companies (supply chain);
- Paper gives an answer to at least one of the research questions.

In this step, an additional 13 papers were rejected, as they did not meet all the inclusion criteria. After reading the full text of the 35 papers, their references were analyzed. The potentially relevant studies were screened for exclusion and inclusion criteria. Finally, the additional five papers from cross-referencing, which met all the inclusion criteria, were added to the dataset for further investigation [39,55–58]. Detailed bibliometric and descriptive analysis was performed on a pool of 40 papers.

3. Descriptive Analysis

3.1. Distribution of Papers by Year and by Country

The search criteria in Scopus included the time frame of the last 15 years (2008–2022). However, after the search, it turned out that all obtained papers were published in 2015 or later. Furthermore, most articles were published between 2020 and2022, with the highest number in 2021 (13 articles). The review took place between December 2022 and January 2023, so it is important to note that some papers from 2022 may not have been indexed yet. The distribution of the articles according to years is shown in Figure 3.

The bibliometric analysis was supported by the software VOSviewer, in order to analyze and visualize the results, as recommended in previous literature review studies [59–61]. The default settings of the software were used [62]. The result is shown in Figure 4.

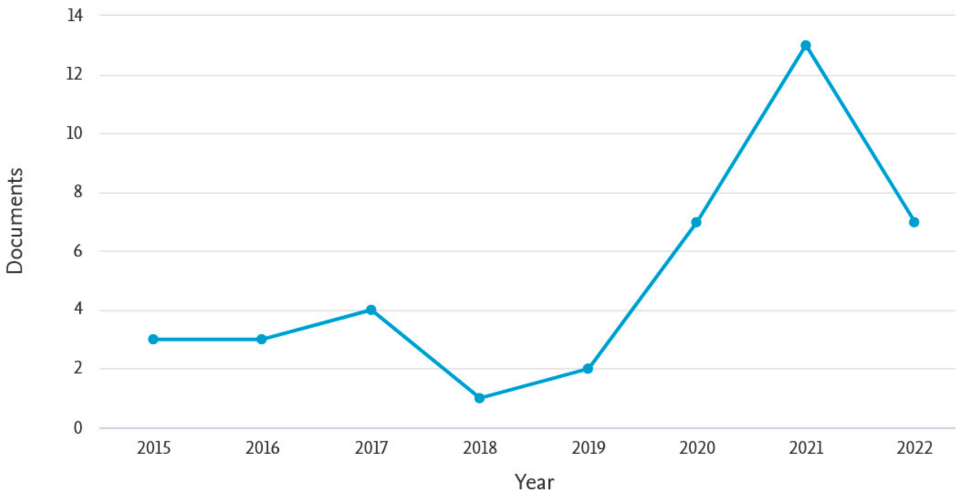

Figure 3. Distribution of papers by year (adopted from Scopus).

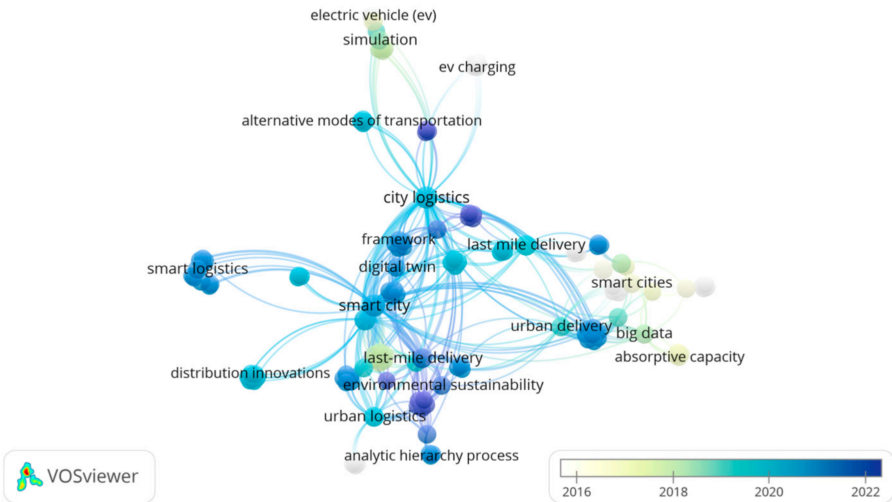

Figure 4. Evolution of the topics based on the keywords.

The analysis of the dominant keywords by years allowed us to identify the evaluation of topics that were most popular. The popular keywords were alternative modes of transport, electric vehicles, and how they are charged (early publications from 2015 to present). Furthermore, the keywords covered the technologies typical for smart cities, which aim for interconnectivity and intelligence in data analysis, such as digital twins, big data analysis, the Internet of things, and smart logistics (2019–2022). There were various keywords used to describe the movement of goods in urban areas: city logistics, last mile delivery (last-mile delivery), and urban delivery. In addition, several papers emerged that focus on the absorptive capacity of implemented innovations. The focus on environmental sustainability is strong in recent publications (2020–2022), and has been increasing. The detailed thematic analysis is presented in Section 4.

The distribution of papers by country (authors' affiliation) is presented in Figure 5. Most of the authors were employed by the Italian universities (11 papers). This is mainly due to the publication of the results of EU-funded projects, such as i-NEXT (Innovation for Green Energy and Exchange in Transportation); the SMILE Project (Smart Green Innovative Urban Logistics Models for Energy Efficient Mediterranean Cities), Opti-LOG (last-mile delivery with low-mission and zero-emission vehicles), C-LIEGE (Clean las- mile transport and logistics management for smart and efficient local governments in Europe), etc. The 12 countries with more than one paper in the analyzed pool are presented in Figure 5.

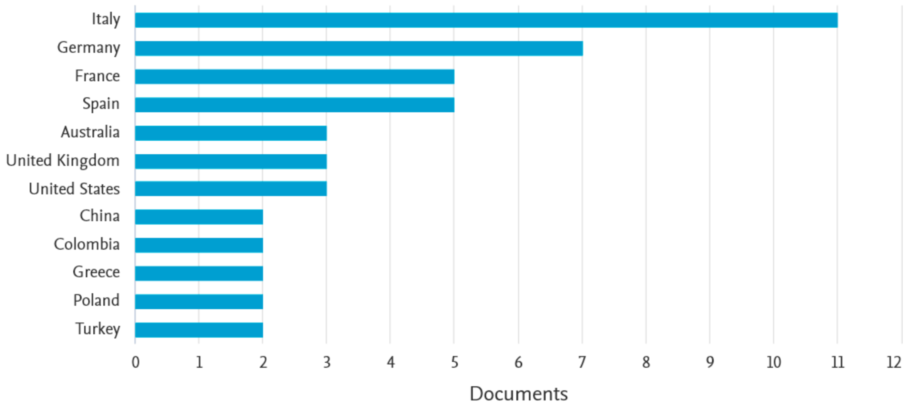

Figure 5. Distribution of papers by countries (top 12 countries).

3.2. Distribution of Paper Sources and Subject Areas

In the analyzed pool of papers, 65% of papers were published in journals, and 35% in peer-reviewed conference proceedings.

The sources of publications were very fragmented, and the analyzed 40 papers were published across 27 different outlets, with only six sources which published at least two papers each. The most popular outlet was *Sustainability* (journal), with six papers published there, followed by four papers in *The Transportation Research Procedia*; and three papers published in *Transportation Research part D: Transport and Environment*. *Advances in Intelligent Computing*, *Sustainable Cities and Society*, and *Proceedings of the IEEE International Conference on Smart City* attracted two papers each. The rest of the sources were mentioned only once in the analyzed dataset. The source distribution of papers is shown in Figure 6.

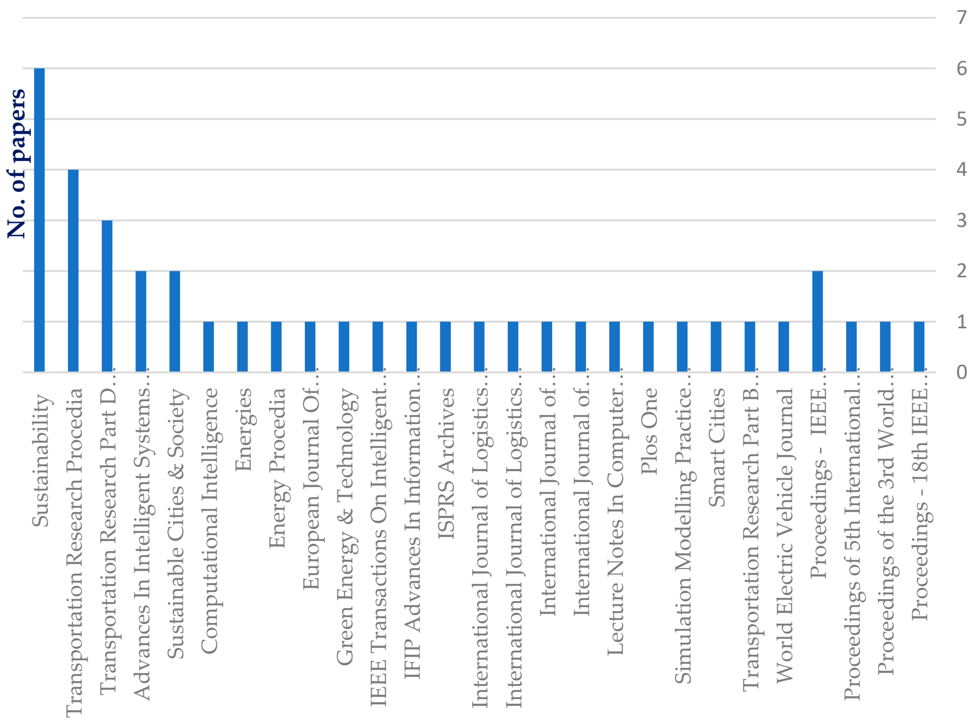

Figure 6. Distribution of papers by sources.

Sustainable-urban-freight (SUF) research for energy-efficient smart cities is fragmented and interdisciplinary (see Figure 7). In the dataset, the papers were predominantly classified as social sciences (21.6%), followed by engineering (19.6%) (e.g., topics related to the design of new vehicles, the location of logistics facilities and the routing of vehicles), and computer science (e.g., the configuration of IoT network, processing algorithms for big data and machine learning, and network security), and energy studies, both with 13.4% (e.g., models for energy consumption).

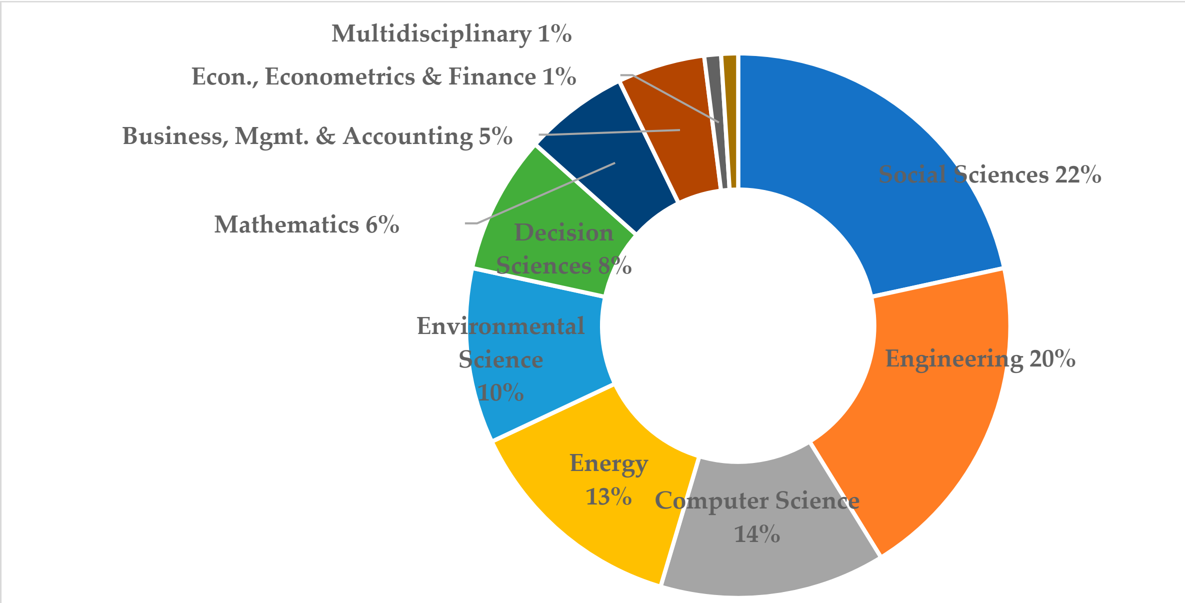

Figure 7. Distribution of papers by subject areas.

3.3. Distribution of Research Methods

In the dataset, qualitative and quantitative approaches were used to solve the problems in SUF for energy-efficient smart cities. The distribution of the research methods is shown in Figure 8. The dominant approach was mathematical modelling. Mathematical models are often applied in supply-chain research, as they are suitable for problem solving at strategic, tactical or operational levels, in transportation routing, distribution network design and optimization [63]. Mathematical modelling approaches in the analyzed studies included: mixed-integer/integer linear programming, nonlinear programming, multi-objective programming, multicriteria decision making, heuristic algorithms, metaheuristics, and hybrid models. The case study was the dominant approach among qualitative methods.

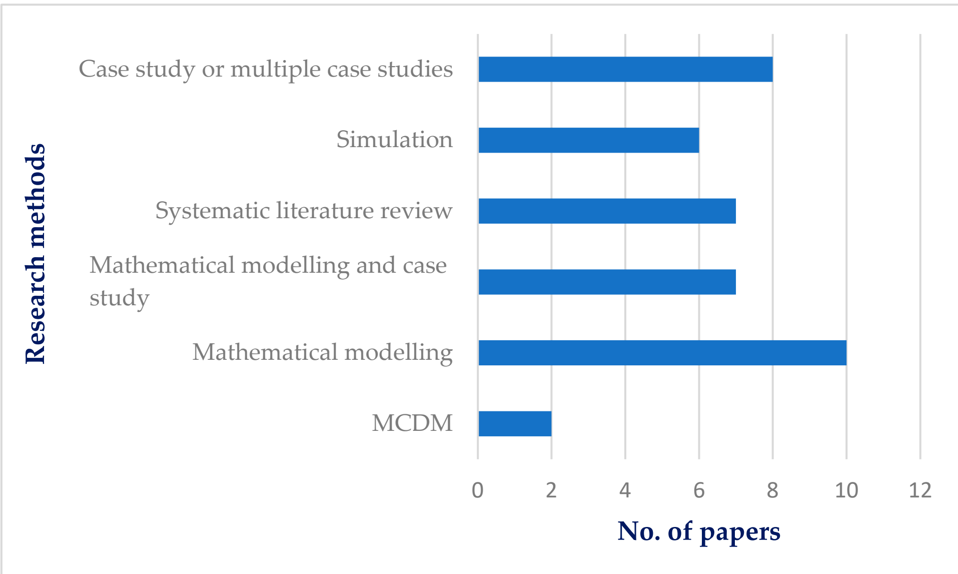

Figure 8. Distribution of papers by dominant research methods.

3.4. Distribution of Keywords

The studies on sustainable urban freight for energy-efficient smart cities are fragmented, and at a relatively early stage of development (appearing mainly after 2015). The analysis of the main keywords was carried out in VOSviewer. The results are shown in Figure 9.

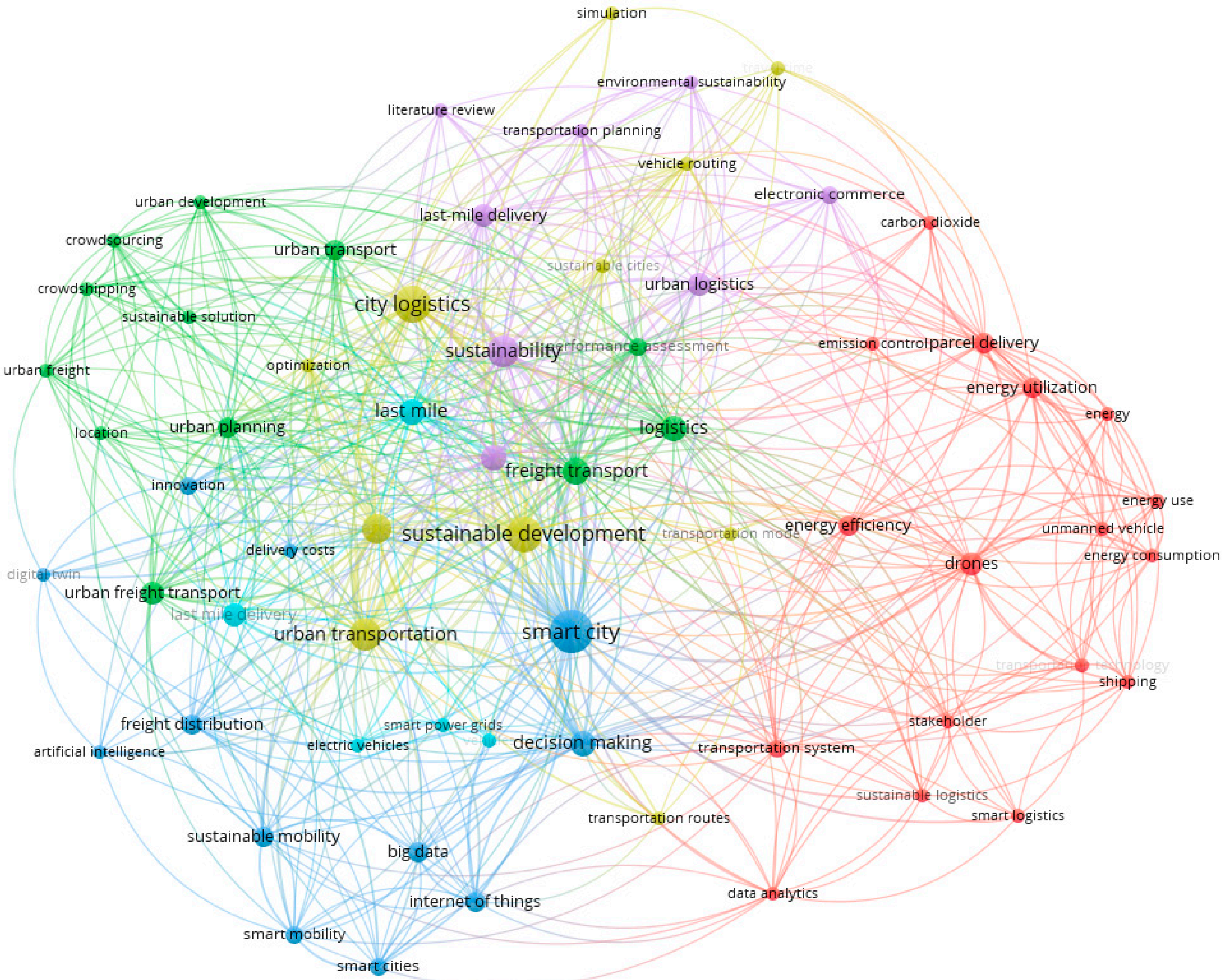

Figure 9. Most-occurring keywords (at least 2 times) and the co-occurrence among the identified publications.

The further analysis included the co-occurrence of the keywords (482 were both indexed keywords and the author's keyword). The minimum co-occurrence was defined as value = 2, in order to provide some visibility of results. A collection of 65 keywords was obtained, which were divided into six dominant clusters using the method of correlation strength. The content of each cluster is presented in Table 3.

Out of 482 keywords (both those defined by the authors and indexed keywords), only 65 occurred at least 5 times in the dataset. This is evidence of the fragmentation of research topics and the early stages of the development of research, as dominant terms have not yet been established.

Table 3. Clustering of keywords based on results from VOSviewer.

Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6
carbon dioxide data analytics drones emission control energy consumption energy energy efficiency energy use energy utilization parcel delivery shipping smart logistics stakeholder sustainable logistics transportation system transportation technology unmanned vehicle	Crowd-shipping Crowd-sourcing freight transport location logistics performance assessment sustainable solution urban development urban freight urban freight transport urban planning urban transport	artificial intelligence big data decision making delivery cost digital twin innovation freight distribution internet of things smart cities smart city smart mobility sustainable mobility	city logistics freight transportation optimization simulation vehicle routing sustainable cities sustainable development transportation mode transportation routes travel time urban transportation	electronic commerce environmental sustainability last-mile delivery literature review sustainability traffic congestion transportation planning urban logistics	electric vehicles last mile last mile delivery smart power grids vehicles

The findings of the bibliographic analysis show that:

- In the six identified clusters, there are some duplications of similar keywords, because of the lack of well-established terminology in this area, which is typical for the early stage of research in a domain.
- Many keywords refer to activities at macro-level, such as urban planning, urban development, environmental sustainability, transportation system, city logistics, smart city/smart cities, sustainable logistics, and smart logistics.
- There is a very limited number of keywords (e.g., drones, electric vehicles, IoT, digital twins) that represent SUF innovations for smart cities at the micro level (suitable for implementation by logistics service providers).
- Keywords that pertain to the analysis of SUF for operationalization of energy-efficient smart cities at the micro-level (related to the management of last-mile delivery) are very limited.

An in-depth thematic analysis of the papers on sustainable urban freight for energy-efficient smart cities is discussed in the next section.

4. Thematic Results

Urban freight can be organized into a one-tier structure with direct last-mile delivery to the final customers, from a distribution center (mainly for small and medium-sized cities) or into a more complex system with trans-shipment depots (a two-tier system of last-mile deliveries) in large cities and megacities [40,64].

Searching for the answer to the research question Q1, we identified the logistics innovations (software and hardware) which companies (in particular LSPs) apply to provide sustainable urban freight in smart cities.

From the macroscopic perspective, the innovative solutions for the SUF in energy-efficient smart cities are classified here into three categories, namely:

- Urban freight consolidation and trans-shipment for last-mile delivery;
- Choice of mode of transportation for last-mile delivery;
- Consumer as a Service Provider (CaaSP) in last-mile deliveries.

Those solutions need to meet the smart city's characteristics, namely interconnectivity and intelligence. Thus, they require enabling ICT smart technologies to trigger their full energy-efficiency potential (RQ2). The summary of the thematic analysis is shown in Figure 10.

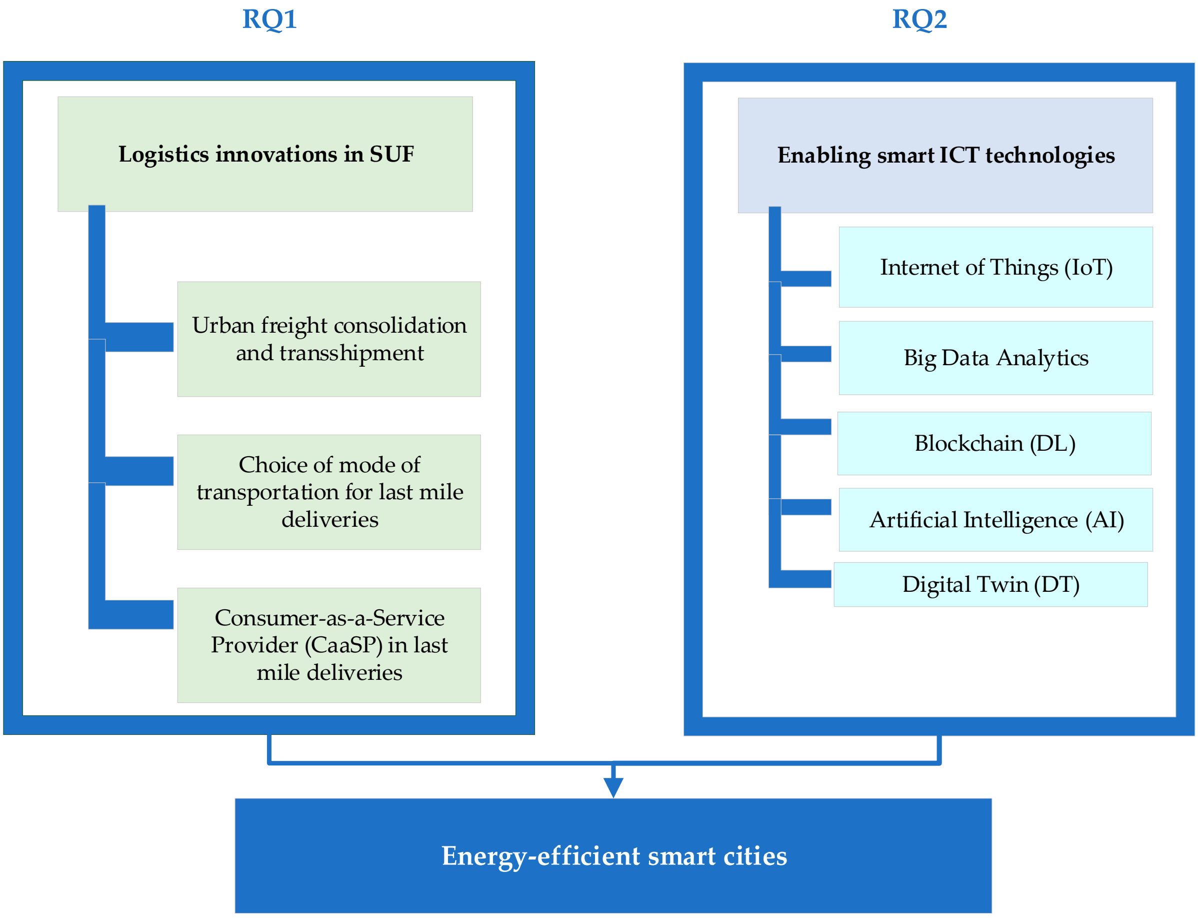

Figure 10. The summary of the thematic analysis of the dataset—macroscopic view.

4.1. Logistics Innovations in SUF in Energy-Efficient Smart Cities

From the dataset, information was extracted about innovations in LMD that companies apply to develop SUF, and which support energy efficiency at the micro-level in smart cities (RQ1).

Innovations in last-mile delivery (LMDs) can be divided into those aimed at transporting goods (transportation methods), and those that enable goods to be consolidated, sorted and stored for short periods of time, to optimize transport activities. The development of sustainable urban freight for energy-efficient smart cities requires a combination of transportation and trans-shipment solutions.

Correia et al. [53] highlight the need to involve stakeholders in the process of developing SUF for smart cities. To overcome the lack of tools enabling the efficient organization of deliveries and the storage of goods in real time, we thus consider also innovations which aim at increased customer involvement.

Table 4 summarizes the innovations for last-mile delivery (LMD) applied by companies for the development of sustainable urban freight in energy-efficient smart cities. The required level of interconnectivity to obtain energy efficiency is assessed as:

- Low—It is energy-efficient, even without the support of smart technologies.
- Medium—it is energy-efficient with some support from smart technologies.
- High—it is energy efficient only with the support of smart technologies.

Table 4. Innovations for LMD applied by LSPs for the development of SUF in energy-efficient smart cities.

Category	Innovations in LMD for SUF	Energy Efficiency	Papers	Intelligence *	Interconnectivity *
LMD consolidation and/or trans-shipment in SUF	Mobile depots	Lower energy demand in shared infrastructure	[39,40,55,65,66]	+	++
	Parcel lockers	Lower energy demand—reduced no. of trips	[67–69]	++	++
	Micro-depots	Lower energy demand in shared infrastructure	[65,70–72]	++	++
Consumer as a service provider (CaaSP) in SUF	Crowd-shipping	Lower energy demand—reduced distance travelled per parcel	[65,67,73]	++	+++
	Self-collection	Lower energy demand—reduced no. of trips	[69,74]	+	++
Mode of transportation for LMD in SUF	Drones	Energy demand strongly depends on weather and urban conditions	[40,56,75,76]	+++	+++
	Autonomous delivery robots	Lower energy demand, alternative energy sources	[39,40,77]	+++	+++
	Autonomous vehicles	Lower energy demand, alternative energy sources	[39,40,58,78]	+++	+++
	Cargo bikes (including e-cargo bikes, e-tricycles)	Lower energy demand, alternative energy sources	[69–71,79,80]	++	++
	Electric vehicles	Lower energy demand, alternative energy sources	[57,76,78,81,82]	++	++
	Combined passenger and cargo transport, rapid transit systems	Lower energy demand, reduced no. of trips	[83,84]	+++	+++

* low +, medium ++, high +++.

The main innovations for last-mile delivery (LMD) in sustainable urban freight (SUF) are analyzed in the next subsection (a microscopic perspective).

4.1.1. LMD Consolidation and/or Trans-Shipment for SUF

The micro-depot is a facility located in the city center (or at close proximity), which is used by logistics service providers (LSPs) for loading, unloading, sorting, and short-time storage of parcels for the purpose of LMD. The micro-depot usually refers to the containers which are placed in the city centers by LSPs for consolidation of LMD with low-emission city freighters. The main benefits of the consolidation of urban freight in a city center are the proximity to the final customers, the opportunity to use sustainable vehicles, the improvement in the ease of loading/unloading in the city, and integration into innovative business models [65,66].

The studies on the application of the micro-depots focus mainly on the optimization of their location, vehicle routing while reducing the emissions, and infrastructure sharing between operators (LSPs). Fontaine et al. [68] analyze the importance of consolidation in sustainable urban freight. They investigate single- or two-echelon systems with micro-depots and city freighters (low-emission and low-load-capacity modes of transportation). They propose a novel approach to strategic network design for LSPs, which enables the choice of city freighters (for example, cargo bikes or e-cargo bikes) in shared service regions of different providers (so-called pooling). Novotna et al. [70] study the multi-criteria decision-making problem of location for the postal network operators that allows consolidated deliveries to final customers using cargo bikes. The location problem of small consolidation centers (the mini-depot) is also analyzed by Mpogas et al. [72], with the usage of flexible and environmentally friendly vehicles for LMD.

Research shows that LMD consolidation run by a single operator is not financially viable in the long run. For this reason, the sharing of infrastructure among different operators is a promising solution. Rosenberg et al. [65], introduce a new concept of "Shared Micro-depot for Urban pickup and Delivery (S.M.U.D.)". They consider the sustainability impact of alternative solutions such as mobile depots (trailers) for improving the economic viability of such projects, while respecting the need to reduce the environmental impact. Sharing micro-depots among different LSPs can realize the benefits of consolidation, especially shared-infrastructure costs and reduced trips (combining packages from different LSPsat one time), thus reducing fuel consumption, greenhouse gas emissions, and congestion.

The main limitations for expanding the shared model in LMD are the need for standardization of software and hardware, the safety of date and parcels (e.g., damage of goods on a shared trip, public acceptance, and the participation of all stakeholders (e.g., local administration, LPS, and customers).

A mobile depot is most commonly a vehicle with a trailer, which is fitted for unloading and loading equipment, warehousing facilities, and administrative space [66]. The problems of the economic viability of mobile depots are similar to those presented above for mini-depots. The benefits of mobile depots result from the flexibility of their location (they can be moved on a daily basis, if needed). Studies on mobile depots are limited in the analyzed dataset, despite the examples of pilot implementations in different European cities (e.g., Brussels). This topic deserves more attention in the literature.

Parcel lockers are a common business practice, as they are a convenient method of LMD in the business-to-customer setting (B2C). Final customers can pick up a package whenever it is convenient for them. Studies from the analyzed dataset focus on environmental sustainability. Researchers mainly analyze the impact of reduced trips by LSPs (avoiding multiple attempts to deliver, due to the absence of a recipient) and the reduction in GHG emissions [65,68,69]. Leyer et al. [69], introduce the concept of reducing last-mile delivery in the urban-food supply chain, by implementing a network of refrigerated parcel lockers for e-groceries. In the proposed model, customers could take over the delivery service themselves, or food packages are delivered to them by cargo bikes. The reduced energy demand results from using the combination of the location-routing problem and the vehicle-routing problem to find the optimal location for parcel lockers, and the best routes for vans. This optimization approach is applied in the case of Hannover (Germany), and results in a reduced environmental impact in comparison to the conventional delivery of online-ordered groceries.

Studies on the application of parcel lockers highlight the critical role of customer self-pickup in improving the sustainability of LMDs. Therefore, the next section will focus on this research direction.

4.1.2. Consumer as a Service Provider (CaaSP) in LMD for SUF

We name here the concept of engaging customers in last-mile delivery as CaaSP (Customer as a Service Provider). CaaSP is defined as an LMD innovation, where the customer takes over part of the shipping business with the help of smart technology, reducing the distance traveled per package by the LSP. This approach can be implemented through crowdfunding or by the self-collection of parcels (e.g., e-grocery). Smart lockers are investigated, together with self-collecting [78] (the case of Athens), in order to identify the benefits of sustainable urban freight in smart cities. Engaging customers reduces travel times, traffic and emissions.

Crowd-shipping [70] is an emerging approach to delivering parcels in urban areas that is commercially attractive and environmentally friendly, as additional new trips are not required. This LMD innovation has high potential for the sustainable movements of goods in smart cities, as it utilizes the unexploited resources of individuals instead of commercial vehicles, and benefits from real data, due to the interconnectivity and intelligence of applied supporting IT technologies. Ghaderi et al. [67,73], investigate a more sustainable LMD of parcels that uses smart-city technologies such as the Physical Internet (IoT) and a dedicated crowd-shipping platform. They propose an optimization algorithm to analyze real data from crowd-shippers for successful parcel collection and the optimization of the location of parcel lockers (as trans-shipment nodes) at key points, to increase the chance of successful delivery. Crowd-shippers and customers are also potential providers of real-time data from their mobile devices (crowd-sourcing) for better planning of LMD for logistics service providers. It should be noted that the security and privacy of data protection are important challenges [65,67,73]. This topic deserves more attention in the literature.

4.1.3. Mode of Transportation for LMD in SUF

The choice of the most sustainable mode of transportation is a common research problem in the analyzed dataset. Serrano-Hernandez et al. [76] propose a multi-criteria framework (economic, environmental, and social criteria) using the AHP method for the choice between electric vans and trucks, cargo bicycles and tricycles (conventional and electric engines), and drones.

Drones provide an interesting alternative to road transportation in smart cities. Drones benefit from built-in intelligence, which also allows autonomous deliveries. Despite the growing interest in drones for LMD, real-life application by LSPs are still relatively rare [56,75]. Theoretical studies consider the usage of real-time data, for example, weather conditions [75], and the topography of the urban area. Zhang et al. [56] analyzed the key energy-consumption models of drones for urban freight purposes with respect to distance travelled, speed, cargo weight, drone weight (and battery weight), drone delivery flight profile, and weather conditions. They conclude that there are discrepancies between current drone energy-consumption models, and that additional empirical research is needed. The energy consumption is strongly dependent on the weather conditions (mainly wind). Kirschstein [78] compares the energy consumption and related GHG emissions of urban freight delivery (parcels) by drones, conventional vehicles (diesel trucks), and electric vehicles, which serve customers from the same urban depot. Their results show that the drone-based parcel delivery system can be less energy efficient in urban conditions than in other systems. Electric trucks are the most energy efficient. In the scenarios analyzed, conventional diesel trucks consumed about 40–50% more energy than electric vehicles in low- and medium-traffic conditions (for the same radius and traffic conditions).

However, promising, the application of drones also raises the question of social acceptance for drone-based deliveries in crowded historical city centers, due to privacy issues [76]. Furthermore, the issue related to energy consumption needs to be further investigated.

Autonomous delivery robots (for sidewalks) are being tested in practice by Amazon, FedEx, and other logistics service providers, but their presence in theoretical studies is very limited. Figliozzi [77] investigates the efficiency of autonomous drones, and sidewalk and road delivery robots for last mile delivery, taking into account their energy consumption and CO2 emissions. He presents a comparison of the CO_2 emissions of the autonomous vehicles with an electric vehicle (e-van) and a conventional combustion-engine vehicle. He calculates that autonomous vehicles have the potential to reduce energy consumption and related CO_2 emissions when replacing internal-combustion vehicles (delivery vans). In many of the analyzed cases the autonomous vehicles were more energy-efficient than the e-vans. Furthermore, the source of the energy is important for an exact calculation of the related emissions. The operational simplicity and robustness are among the main concerns when testing the application of mobile robots for different scenarios and use cases. Delivery robots are being considered as a feasible solution for LMD in the next 5–10 years. The main challenges are their ability to dynamically rearrange behavior in response to unpredicted external events using IoT devices, when achieving an acceptable operating cost [77].

Bucchiarone et al. [58] propose the concept of autonomous vehicle as a service for the urban movement of people and goods (the so-called autonomous shuttle-as-a-service). They consider the delivery of goods in city centers, together with the smart transportation of people using the same vehicle, in order to reduce emissions and congestion. They highlight the challenges of the application of sensors, AI and blockchain technologies for routing, tracking, and certifying the sustainability and safety of transportation while preserving data privacy.

In the analyzed dataset, cargo bikes (and e-cargo bikes) are the most popular mode of transportation in two-tier sustainable urban freight, especially for small parcels. The main reason for this is their cost and energy-efficiency, and potential for reducing CO_2 emissions, compared to traditional freight vehicles (mainly vans). The main research problem was planning the network for cargo bikes, as they have limited load capacity and range [71,79]. The application of cargo bikes aims to reduce the equivalent carbon dioxide (CO_2e) emissions as those of conventional vans [79]. Studies also report a higher energy efficiency than that of electric vehicles, thanks to the fact that the cargo bike engine stops as soon as the driver stops cycling [71]. The energy efficiency can be obtained also by the application of electric tricycles and urban consolidation centers for LMD pilot projects in Barcelona and Valencia (Spain) [80]. The results of these pilot projects show significant savings in energy (fuel) consumption and a reduction in CO_2 emissions. The authors estimate that with full-scale implementation, 2 tons of CO_2 per year could be saved. The tricycles, combined with micro-depots, allowed for the optimization of routing and shortening of the distance travelled per parcel, as tricycles did not need to make detours in the traffic-restricted zones in the city centers. The main challenges in upscaling the proposed solution was its economic viability, as to obtain the acceptable operating cost a cooperation between different LSPs proved crucial. Furthermore, the sharing of resources among different logistics service providers, and pooling, is investigated [82,83].

Electric vehicles (mainly vans) are a preferred mode of transportation in the historic city center, where low CO_2 emissions are required [81]. The benefits of their application results from reduced energy demand compared to traditional combustion engines (diesel) [40,78]. However, questions are raised about the source of electrical energy in the grid, as the share of renewable energy in the total energy production is country-dependent. Dispenza et al. [84] presented a pilot project (located in Sicily) for a microgrid with solar energy (input), and hydrogen and electricity (as output) for electric, hydrogen and hybrid vehicles. They considered self-production in order to satisfy the demand for sustainable urban transportation of persons and goods. The proposed solution applied a photovoltaic (PV) plant, with a battery energy storage system (BESS) to offset the uncertainty of solar renewable energy. Solar energy (PV and stored in BESS) supplied an electrolyzer compressor (hydrogen production) and recharge infrastructures for the vehicles (EV, FCEV and FCHEV) developed in this project. For the purpose of sustainable urban freight, an electric freight van is proposed, with a payload of EUR 2 pallets. Self-production and self-consumption of energy are managed by a dedicated ICT, which optimizes the supply and demand for hydrogen when a solar source is available. The proposed solution is interesting, but the question of its scalability needs to be raised.

The emerging research area is the shared urban infrastructure for the joint transport of passengers and freight [40,82]. Fatnassi et al. [82] investigated the shared on-demand freight rapid-transit system and the rapid-passenger transit. They proposed a mathematical model for the routing problem for electric vehicles with limited battery capacity when satisfying the number of transportation requests that arrive on a periodic basis while minimizing the empty movements of a fleet. Andaloro et al. [57] proposed a new concept of modular electric vehicles, with upper bodies for both passenger transportation and sustainable urban freight. They took into account the lowest ratio between total weight and load capacity, range of autonomy, recharge times, and cost in terms of batteries and recharge system technologies.

The cooperation among logistics service providers supports the energy efficiency of SUF. Bresciani et al. [85]. focus on the behavioral dimension in sustainable urban freight for reducing carbon emissions and increasing energy efficiency. They consider the platform dedicated to LSPs for the reservation of loading/unloading when using IoT sensors to determine in real-time the presence of a vehicle. The proposed solution offered benefits in the form of improved load factors and shorter routes, 'an *optimal assignment of goods to vehicles based on weight, volume, delivery restrictions, and destination*'. They propose a system of incentives for companies and individual users to benefit from "green behavior". The collaborative approach with the strong participation of private and public entities and individual users is identified as a key driver to achieve energy efficiency. Ref. [86] also investigated energy efficiency and reduced energy demand in sustainable urban freight using a cooperative approach between public and private stakeholders, through the prism of a '*new set of integrated solutions and demand-orientated 'push and pull' measures*'. The results of the pilot implementation in seven cities in Poland, the UK, Bulgaria, Germany and Malta provided a broad spectrum of tools that could be implemented by local authorities (city transport managers), and LSPs.

4.2. Smart Technologies Which Enable the Application of ILMDs for SUF in Energy-Efficient Smart Cities

Smart technology is ICT infrastructure for real-time data for a decision-making purpose [87–89]. The main characteristic of the smart city is interconnectivity (or connectivity), which allows the collection and analysis of the real-time data through system information and provides relevant information for smart decision-making by stakeholders [38]. Shee et al. [32] state that '*technology-enabled smart logistics has an immediate positive effect on the smart city environment, which in turn has positive impacts on social and economic performance*'.

This section focuses on the answer to the research question Q2. We analyze how smart technologies which are typical of smart cities can unlock the energy efficiency potential of LMD innovations in sustainable urban freight transport.

Table 5 analyzes the application of disruptive smart technologies to sustainable urban freight to support energy-efficient smart cities.

Table 5. Smart city technologies for sustainable urban freight and energy-efficiency.

Smart Technology	Area of Application in SUF	Enabled Innovations in LMD for SUF	Research
Internet of Things (IoT) (Wireless sensors and actuators, RFID tags)	Real-time positioning/locating of vehicles, traffic monitoring, dynamic routing, real-time tracking and tracing of parcels/goods, monitoring driver's fatigue, cargo condition monitoring, environmental scanning	Mobile depots Parcel lockers Micro-depots Crowd-shipping Autonomous delivery robots Various modes of transportation for SUF	[32,41,61,67,73,85,88–90]
Big Data Analytics	Autonomous reporting, e.g., for environmental purpose	Autonomous vehicles Electric vehicles Micro-depots Crowd-shipping	[32,41,91–95]
Blockchain (DTL)	Tracking cargo and certifying users while preserving privacy; monitoring and verifying GHG emission levels in LMD	Autonomous vehicles Micro-depots Crowd-shipping Mobile depots Parcel lockers	[41,58,61]
Artificial Intelligence (AI)	Advanced machine-learning techniques for identification of mobility patterns and optimization of transport services	Various modes of transportation for SUF	[41,58]
Digital Twin (DT)	LMD network mapping and visualizing, freight-parking management in LMD	Various modes of transportation for SUF	[96]

The smart technologies for ILMD enable vehicle-to-infrastructure or vehicle-to-vehicle communication, autonomous LMD management, smart contracts and infrastructure sharing [61].

Sustainable urban freight telematics enable real-time vehicle tracking, tracing of vehicles and parcels, navigation and scheduled delivery windows, whilst aiming for economic and environmental sustainability (reducing energy consumption and noise and reducing pollution). Chen et al. [88] propose the application of the Internet of things (IoT) for dynamic mobility management and the optimization of sustainable urban freight (because it benefits from reduced congestion). Comi et al. [90] develop an integrated approach to planning loading and unloading operations and modeling transport demand for restricted traffic zones in Rome. The proposed tool allows for real-time booking and monitoring, and is integrated into the data from freight-routing applications via the Internet of things. Shee et al. [32] implement the TOE (technological, organizational, and environmental) framework to investigate the impact of the application of smart technologies by companies in urban freight to improve the sustainability of smart cities. They test, by using structural modeling, the hypotheses about the importance of smart technology characteristics and companies' capabilities to implement smart technologies, to enable the development of more sustainable smart cities. They conclude that IoT technologies, which are used by LSPs (e.g., in-cabin cameras, fleet telematics, wireless sensors, RFID tags, GPS for tracking and tracing vehicles, and driver behavior) help to increase the visibility of logistics flows and the safety of urban-freight operations in smart cities. Furthermore, smart technologies reduce the risk of late delivery, due to traffic conditions (congestion, accidents, and weather conditions). IoT devices support meeting regulatory requirements (e.g., urban green spaces, speed limits, loading zones, and delivery windows). Real-time collection and sharing of data allow the lowering of the environmental impact due to reduced fuel consumption and related GHG emissions. IoT devices play a major role in capturing, storing, and transferring data for business intelligence (big data analytics) [93].

The challenges of implementing IoT for last-mile delivery arise from issues with privacy and security, with respect to gathering, storing, and analyzing data [61]. According to Schatzinger and Lim [91] "*leveraging big data and IoT is considered to be a key data sharing with their competitors*".

Some authors argue that this challenge might be overcome by more efficient involvement of policy makers, by sharing data on urban freight and offering tools which encourage companies to share and standardize their data [41,90].

SUF solutions, such as the sharing of infrastructure, electric vehicles, and autonomous vehicles, are especially attractive areas of integration for IoT and big data, as the obstacles of data availability and accessibility can be overcome by the application of sensors, actuators and mobile devices.

Big data analytics (big data) refers to "a holistic approach to manage, process and analyze the 5 Vs (volume, velocity, variety, veracity, and value) in order to create actionable insights for sustained value delivery, measuring performance and establishing competitive advantages." [95]. In the area of sustainable urban freight in smart cities, big data is collected by real-time tracking of vehicles (e.g., GPS), mobile devices from the logistics network, and transactional data of LSPs (IoT devices). The data is then applied to modeling and analysis of SUF operations (big data analytics). Large data sets enable resource pooling and capacity sharing among different stakeholders (in particular, LSPs) [92]. The challenge is the acceptance of the big data solution by LSPs, which are concerned about the breach of sensitive data.

The availability of standardized historical and real-time large data sets is a prerequisite for the application of machine learning (AI) in the sustainable urban freight in energy-efficient smart cities. Lindawati et al. [93,94] present an example of such a solution, namely, a platform to improve energy efficiency by consolidating deliveries, thus reducing the number of vehicles and increasing their load factor. The platform allows for anonymizing data coming from stakeholders, bundling their demand for LMD, offering the auction mechanism and routing engine. The challenges of data sharing, ownership, data cleaning, and compliance with standards are crucial to upscale the big data application in sustainable urban freight in smart cities [93].

The ICT solution that researchers have foreseen to solve the trust and data sharing problem is blockchain (DTL-distributed ledger technology). DTL refers to a consecutive list of time-stamped records, which are related to using cryptography, and the obtained distributed-asset database is available to the partners in the LMD network. The application of blockchain to sustainable urban freight is in its infancy. The interesting application area is the certification of CO2 emissions along the LMD network, as DTL allows data sharing between partners in the LMD network with greater trust and the automatic generation of smart contracts [41,58,61].

An interesting potential for improving data availability for machine learning is crowd-sourcing, as mobile devices can be used for data provision for LMD planning purposes. Mrazovic et al. [97] analyze the availability of designated loading areas with real-time occupancy information of check-in in designated loading areas using a crowd-sourcing mobile application (in Barcelona). The proposed mobile solution allows for reducing costs (no hardware-based investments in sensors) and enhancing information availability (e.g., the license-number plate of a vehicle in the parking). Information on real-time availability forecasting supports route planning and better managing of urban freight infrastructures and operations, as well as improving fuel consumption (energy demand is lower, due to less idle time and the elimination of unnecessary cruising for a parking space).

The digital twin is 'a virtual representation of entities and processes in the real world, synchronized at a specified frequency and fidelity' [98]. Real-time information about the utilization of freight parking spaces is critical for LMD efficiency, as commercial vehicles may spend a great deal of their time cruising for parking. This situation results in increased fuel consumption and related GHG emissions. Liu et al. [96] propose the application of a digital twin for Smart City Logistics Parking (SCLP) to obtain information from the urban infrastructure that is necessary for the management of cargo parking. They identified crucial sources of information on the real-time condition of the infrastructure, dynamic traffic, destination information, and occupancy of logistics facilities. They proposed that DTs serve as counterparts to other physical objects, providing the required information about real-time status. The digital twin is an interesting option in the framework of smart logistics (or Logistics 4.0), but its applications in the SUF in smart cities are very limited. This research topic would merit from more interest from academia

Smart technologies support energy efficiency in smart cities by the reduction in the energy (fuel) in sustainable urban freight, due to better planning of deliveries and infrastructure sharing (e.g., they benefit from the reduced number of trips, due to a better load factor of vehicles). Improvement in energy efficiency is, however, not the core interest of the studies in the analyzed dataset. Future research that contributes to filling in this research gap would be beneficial.

5. Discussion

5.1. Potential for Improving Energy Efficiency by SUF in Smart Cities

The aim of this systematic literature review was to identify LMD solutions which are applied in sustainable urban freight, and to support the transition towards energy-efficient smart cities.

In the dataset, the articles were published in 2015 or later, which could be linked to the adoption of the Paris Agreement [99] and the growing interest of local governments and companies in the fight against climate change and global warming. The majority of the analyzed papers deal with the reduction of GHG emissions (in particular, CO_2 and NO_x). These findings are consistent with the related work of Mucowska [60].

The sustainable urban freight for smart cities is shaped by external trends. They include: urbanization, the rapid growth of e-commerce during COVID-19, multichannel distribution, pressure for on-demand deliveries, deficiencies in urban planning for logistics operations (lack of loading and unloading space in city centers), high cost of delivery per parcel (inefficient use of modes of transportation), the introduction of traffic-restricted zones in city centers, pressure to lower energy demand, and GHG emissions [38,43,66,100].

LMD innovations support the smooth and energy-efficient flow of goods in sustainable urban freight. They support the trans-shipment, consolidation of parcels and transportation of goods in the last-mile deliveries to final customers. They contribute to energy efficiency at the micro level (logistics service providers). Their application to smart cities requires interconnectivity (and intelligence), which is provided by smart technologies.

In response to the research question RQ1, we identify and classify LMD innovations that are applied by logistics service providers (LSPs). These solutions must meet requirements for increased energy efficiency (compared to conventional urban road freight) and be suitable for interconnection with smart city devices.

First, we analyze the solutions for trans-shipment and consolidation in LMD. Micro-depots, parcel lockers, or mobile depots support the smart mobility, sustainability, and liveability of smart cities. The micro-depots are in line with the characteristics of a smart city, and help to reduce the energy demand of vehicles in LMD. Studies focus on the location of urban consolidation facilities to reduce their environmental impact (shorten travel distance) and to allow connectivity with the existing infrastructure for environmentally friendly modes of transportation such as cargo/parcel transportation (e.g., bike lines for cargo bikes), charging stations for electric vehicles, or access to a suitable fly path for drones. In addition, mini-depots and parcel lockers have the potential to use crowd-funding (reducing the number of journeys and reducing energy demand).

The main challenges are related to the economic viability of small consolidation centers. The infrastructure sharing for improving the performance of logistics service providers (by improving the load factor of vehicles, lowering the distance travelled per parcel, lowering the delivery cost per parcel, etc.), is a relatively new research string, with high potential.

The micro-depots and parcel lockers are facilitators of the application of more energy-efficient modes of transportations for LMD, for example, electric van and e-cargo bikes for last-mile delivery, and the integration of customers into the delivery processes [69].

The choice of the mode of transportation is a common research topic in this dataset for SLR. Related studies on the decarbonization of urban freight predominantly propose a shift towards electric/hybrid vehicles [100–102], or the application of alternative modes of transportation, for example, cargo bikes/tricycles [103], and drones [104,105].

The modes of transportation which are analyzed in the context of SUF and which support interconnectivity (a key characteristic of a smart city) and energy efficiency are drones, autonomous delivery robots, autonomous vehicles, cargo bikes (including e-cargo bikes and e-tricycles), electric vehicles (mainly vans), and combined passenger and cargo transport or/and shared rapid-transit systems. Most articles on urban consolidation centers apply more than one mode of transportation. Cargo bikes and e-cargo bikes are the most popular among all modes of transportation, and this is consistent with the findings of a related work, an SLR by He and Hassis [39]. Cargo bikes and e-cargo bikes are implemented in all analyzed cases, as the most environmentally friendly (lowest CO_2 emissions) and with the highest energy efficiency compared to traditional vans and electric vehicles [71,79].

The topic of energy efficiency is present in the papers, but the focus is placed mainly on lowering the energy demand of urban freight vehicles by reducing fuel consumption. The topic of the smart power grid occurred in the bibliometric analysis only in cluster 6, in relation with electric vehicles and LMD, but it was discussed in depth only in the work of Andaloro et al. [90] with regard to flexible energy demand management, electricity storage, and distributed energy production (fossil and renewable).

In the context of sustainable urban mobility (the transport of passengers), the studies on energy efficiency are more advanced. For example, synergies between energy efficiency and mobility in smart cities are investigated from the angle of the participation of users (e.g., electric vehicles and smart homes), and optimization methods to reduce electricity peaks and related greenhouse gases [106–109]. Electromobility is studied from the perspective of energy demand management and vehicle storage capacity (V2G vehicle to grid) [105,110].

Studies on SUF consider the potential of LMD infrastructure (especially vehicles) for energy production and storage only marginally. There is a research gap in this regard. Additionally, the studies on renewable energy in SUF are not sufficiently represented. Only two papers consider solar energy [57,111], and other renewables are not discussed at all. This research gap deserves more attention.

5.2. Assessment of the Innovations in LMD for SUF for Energy-Efficient Smart Cities

For the assessment of innovations in LMD for sustainable urban freight, we propose a new tool, called the IEE matrix (interconnectivity and energy-efficiency matrix). We focus on the potential of innovative solutions in LMD (from Table 4) to support the transition to energy-efficient smart cities. The logic of the tool is simple (Figure 11). We use the traffic light analogy. Thus, the solutions with the highest potential are in the green field (high energy efficiency and high interconnectivity). Solutions with medium potential are colored yellow. The least-preferred solutions are in the red field.

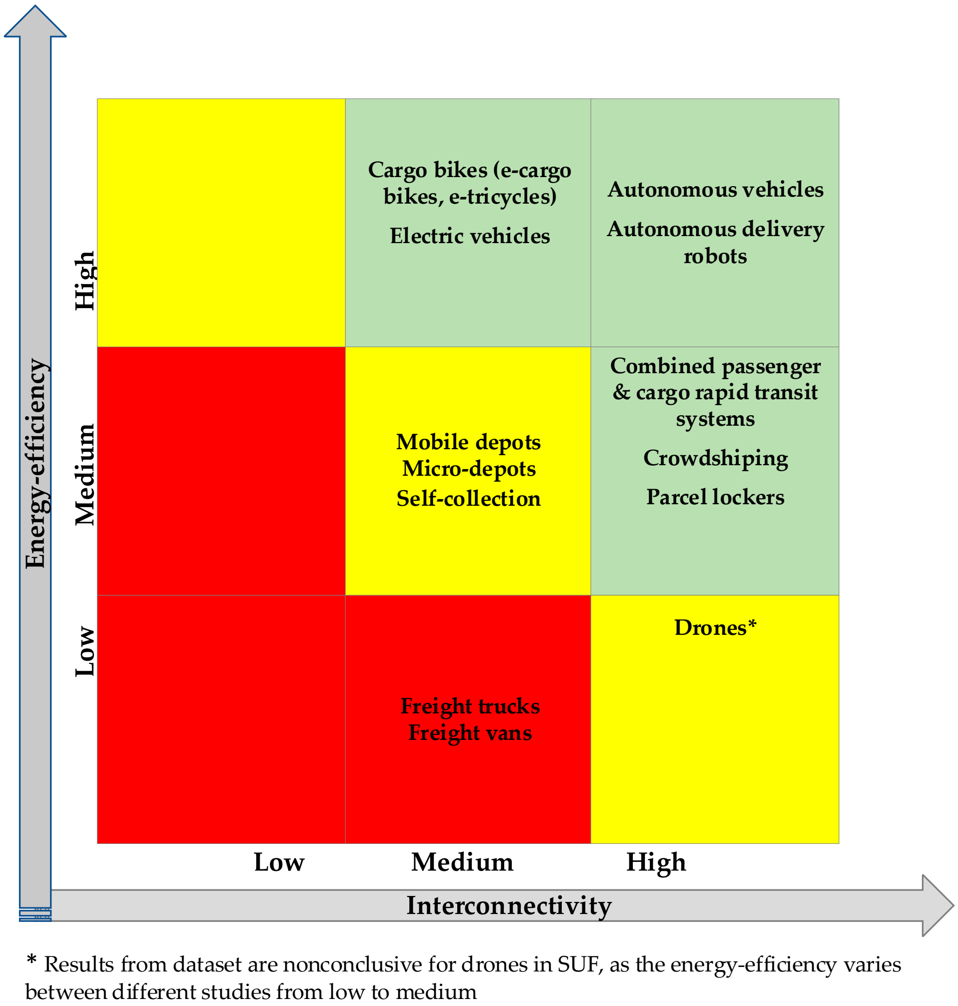

Figure 11. IEE matrix.

The base scenario for comparison is traditional urban freight with conventional vehicles and direct delivery to customer from a depot outside the city center (so-called one-tier LMD).

The classification rules for the energy efficiency potential are as follows:

- High—reduced energy demand compared to the traditional urban freight (e.g., electric vehicles, cargo bikes). Medium—reduced energy demand in comparison to the traditional urban freight appears under certain favorable conditions (e.g., good weather).

- Low—reduced energy demand compared to traditional urban freight could appear only with the enabling of smart technologies (e.g., conventional van routing supported by IoT devices).

The second dimension in the IEE matrix is interconnectivity, which we assess using the classification rules, as indicated in the last column of Table 4.

5.3. Recommendation for Future Research Directions

This paper contributes to the theory by exploring possible future research directions for SUF in energy-efficient smart cities. The analyzed research area is relatively new (in the dataset the papers were published after 2015) and very fragmented. During our scoping study and SLR, we noticed that review articles on smart cities marginalized sustainable urban freight, focusing primarily on policy development, urban development and urban mobility (for passengers). The current EU policies, for example the European Green Deal [112], include the decarbonization of transportation, a reduction in the dependence on fossil fuels and an improvement in energy efficiency. For example, emissions from trucks should be reduced by 50% by 2030. The application of innovations (hardware and software) by logistics service providers in last-mile delivery is an efficient solution for promoting the sustainable urban freight system [40].

For this reason, in this research, our aim is to investigate the innovation use in sustainable urban freight by LPSs, as this allows for the reduction in greenhouse gas emissions (or the carbon footprint) and related energy demand. However, for some of the innovative SUF solutions, the reduced energy demand and higher energy efficiency can be achieved only under certain circumstances (e.g., with the application of smart technologies). For this reason, there is a need to follow up on the topics which are under-represented in the dataset. The following research areas would merit more attention from academia:

- LMD consolidation and/or trans-shipment in SUF: Models and methods for the planning and optimization of operations in mobile depots and mini-depots, with a focus on energy efficiency and infrastructure sharing. The economic viability is crucial for scaling up LMD consolidations and trans-shipment, and costing models for infrastructure sharing (among LSPs) in SUF are needed.
- Consumer as a service provider (CaaSP) in SUF: solutions for increasing the usage of crowd-shipping data in planning and optimizing the vehicle routing for LPSs to reduce the energy-demand and number of trips.
- Mode of transportation for LMD in SUF: Energy-efficiency models for drones are often highly theoretical, and related results are often contradictory, so multiple real-life case studies are needed. The operational simplicity and robustness of mobile robots in SUF will be tested for different scenarios and use cases. Autonomous vehicles for SUF require further research into the challenges of sensor, artificial intelligence, and blockchain technologies in routing, tracking, and authenticating the sustainability and safety of transportation while preserving data privacy. Upscaling of the use of electric vehicles will be investigated, with a focus on the application of the self-production and self-consumption of energy in smart cities (V2G vehicle to grid and V2V vehicle to vehicle). New models are needed for optimizing the operation of electric vehicles with limited battery capacity, while meeting the number of transport requests and minimizing fleet emptying.
- Smart technologies for SUF: Smart technologies support energy efficiency in smart cities by the reduction in energy (fuel) in the sustainable urban freight, due to better planning of deliveries and infrastructure sharing (e.g., they benefit from the reduced number of trips, due to a better load factor of vehicles). Improvement in energy efficiency is, however, not in the core interest of the studies in the analysis dataset. Future research that contributes to filling this research gap would be beneficial. Large data sets especially, enable resource pooling and capacity sharing among different stakeholders (LSPs). The challenge is the acceptance of the big data solution by LSPs, which are concerned about the breach of sensitive data. The challenges of data sharing,

ownership, data cleansing and compliance with standards are critical in advancing big data applications in sustainable urban freight for smart cities. The digital twin is an interesting option in the framework of smart logistics (or Logistics 4.0), but its applications to the SUF in smart cities are very limited. This research topic will attract more interest from the academic community.

6. Conclusions

The aim of this paper is to identify, through a systematic literature review (SLR), which innovations (hardware and software) applied by LSPs in sustainable urban freight support the transition to energy-efficient smart cities. Through SLR, we provide the answer to the research question RQ1, and identify relevant innovations in last-mile delivery (LMD). Then, we analyze (RQ2) the smart technologies, which enable the application of the innovation to LMD in a sustainable and energy-efficient way.

The main findings of this study are as follows:

- There is a lack of well-established terminology in sustainable urban freight for energy-efficient cities, which is typical of the early stages of research in a domain.
- Topics important for an actionable approach to energy-efficient last-mile deliveries, namely trans-shipments/consolidation of parcels, are not reflected in keywords clusters, and would merit more attention in future research
- The topics of smart grids and renewable energy have not been sufficiently investigated in the case of sustainable urban freight. Thus, there is a gap with regard to research on flexible energy demand and storage management for the purpose of LMD in smart cities.

The contributions of these studies are:

- Classifying the innovative solutions for sustainable urban freight in smart cities into three categories: (1) urban freight consolidation and/or trans-shipment in LMD; (2) the consumer as a service provider (CaaSP); and (3) LMD transportation mode.

  Related research gaps are also defined through SLR.
- Identifying the smart technologies which enable sustainable and energy-efficient urban freight in smart cities. They are the Internet of things; big data, artificial intelligence, blockchain, and digital twin. Smart technologies support the energy efficiency related to the LMD in smart cities by a reduction in the energy demand (fuel) in sustainable urban freight, due to better planning of LMD and the sharing of infrastructure (e.g., the benefits from the reduced number of trips, due to a better load factor of vehicles).
- Exploring possible future research directions for SUF in energy-efficient smart cities.
- The proposal of a new tool, the so-called IEE matrix, which allows for an actionable classification of solutions in the area of sustainable urban freight, with respect to their level of interconnectivity and energy efficiency.

Managerial implications arise from identifying solutions that fit the characteristics of smart cities and promote energy efficiency at the micro level (especially LMDs managed by LSPs). The proposed IEE matrix is easy to use and actionable. The IEE matrix is a tool for qualitative assessment, so its applicability does not depend on the size of the dataset. Furthermore, the classification rules that are defined for the IEE allow for the expansion of the portfolio of innovative logistics solutions at any time. Thus, this paper contributes to the theory and practice.

The limitation of this study results from a relatively small dataset and the early stage of the development of this research area. Not enough research has been carried out so far in the analyzed area. To overcome this limitation, we include in the scoping research and in the discussion on the results, recent literature reviews, which deal with the broader topics related to smart cities, urban freight, and sustainability. In our studies, we not only aggregate the existing published papers, but also identify the key research needs. We have triangulated our findings with related systematic literature reviews, published in 2020–2022 (for example, [45]).

The further research will focus on the validation of the findings from SLR with the empirical studies with logistics service providers, in order to design the actionable decision-making framework which supports at the micro-level the transition towards energy-efficient smart cities.

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