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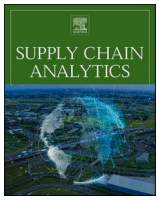

A systematic review of vehicle routing problems and models in multi-echelon distribution networks

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ABSTRACT

The vehicle routing problem (VRP) is a combinatorial optimization problem that determines optimal routes to enhance distribution efficiency. One of the most popular strategies in freight distribution is multi-echelon distribution. Multi-echelon distribution networks often apply to supply chain management, land transportation, the maritime industry, aviation, etc., and rely on VRP. This comprehensive review systematically analyses 382 papers retrieved through the Scopus database. We use a bibliometric and network analysis tool to complete a systematic literature mapping identifying key interrelationships and research clusters. The analysis depicts five main research clusters: green logistics and decision analysis, scheduling and inventory optimization, VRP for city logistics, mathematical modeling and optimization, and outbound logistics and customer service, identified based on author keywords of the systematically derived paper pool. Each cluster is provided with foundational knowledge, concepts, theories, and employed techniques. Finally, future studies are suggested to explore more comprehensive investigation in highly discussed domains like city logistics problems in e-commerce, vehicle routing problems for sustainable logistics, and technological advancement-based applications.

1. Introduction

The vehicle routing problem(VRP) is one of the most extensively researched problems in the field of operational research. It is primarily applied in the logistics and transport domains. The first attempt at theoretical research in the field of vehicle routing was started by [1] with the "truck dispatching problem". Later, the generated truck dispatching problem was generalized to the vehicle routing problem by [2] It is more than fifty years since these publications and there is an explosive growth in terms of research related to the problem. The basic VRP can be described as discrete quantities of commodities are to be delivered to n clients who are geographically dispersed around the central depot by m vehicles possessing an identical capacity, initially stationed at a central depot.

There are various difficulties that basic VRP poses as well as challenges in practical applications. Therefore, many variants of the basic VRP, with varied parameters resulting in a different structure from the basic VRP, have been suggested, along with numerous solution approaches (3). Various software tools, such as geographical information systems (GIS) and advanced planning & scheduling systems, have been created to address VRP variants.

At the very beginning, single-echelon scenarios were the only concern in many studies, but later studies focused on multi-echelon problems. Recently conducted review studies on VRPs by Mor, A. et al.[3] and Zhang H. et al. [4] explain the different extensions of basic VRP considering one level of distribution facilities such as single depot or multiple depots. However VRPs for multi echelon distribution networks particularly focus on multiple levels of distribution facilities, such as warehouses, depots, or satellites, which are more complex networks. Further, the applicability of multi echelon VRPs in real world scenarios is higher than the basic VRPs as it involves with more decisions. Therefore it is worth identifying the unique contribution of VRPs for multi echelon distribution networks, focus areas, and solution methods.

One of the most popular strategies used by transportation companies to cut costs is multi-echelon distribution. In multi-echelon distribution systems, intermediate points (warehouses, satellites, etc.) are involved

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between the source and delivery point [5]. Recently, N-echelon VRPs have received significant attention from researchers [6]. The most discussed problem is the two-echelon vehicle routing problem (2E-VRP). The first use of a two-echelon distribution system with an explicit minimization of the overall transportation costs has been discussed by Jacobsen et al. [7].

Supply chain and inventory problems are the key topics of the multi-echelon systems, and the two-echelon systems in particular [8,9]. They deal with the flow of goods based on the information flows, eventually resulting in monetary flows [10]. Numerous commercial sectors, including express delivery services, distribution of groceries and supermarket goods, distribution of spare parts, home delivery services, and distribution of newspapers and magazines have widely adopted two-echelon distribution networks [11]. Freight distribution and VRPs have played a major role in the past, not only in supply chain planning but also in fields like maritime, aviation, etc. Smilowitz et al. [12] addressed the routing of deferred items and ground vehicles using the "deferred item and vehicle routing problem". It is an attractive cost-saving choice approach for package delivery companies to offer several service levels; using the extra space on aircraft for delayed package shipping. Kisialiou et al. [13] discussed the problem of tactical supply vessel planning arising in upstream offshore petroleum logistics. Further, Ozkan [14]developed a model to solve distance-constrained multi-based multi-unmanned aerial vehicles(UAV)- routing problems to mitigate forest fires using UAVs.

In our search for related literature, we found that VRP applications in multi-echelon networks in the discussed fields are still expanding. However, we verified the need for a systematic literature review with a more specific discussion on VRP in multi-echelon networks. The systematic review is a method to focus on a specific topic comprehensively and to evaluate the state of knowledge [15]. It helps to identify the gaps in the current understanding of the field. Further, it will guide future research directions by highlighting methodological concerns in research studies. Therefore, the paper aims to review the applications of VRP in multi-echelon networks in the context of fields such as chain management, land transport, aviation, maritime, etc.

The structure of this paper is as follows. Firstly, we review quantitative and formal modeling papers to narrow down the specific area. We develop a keyword structure that gives a relevant paper pool for the study. We present the systematic literature review which demonstrates a scientific, structured process to mitigate biases in the selection process. In Section 2 of this paper, we discuss these research methodologies and the tools used along with used keyword structure and some statistics. Secondly, we used a bibliometric and network analysis tool, VOSViewer, to work with the retrieved dataset. Thirdly, the literature mapping and data clustering results of the retrieved dataset help us to identify specific research streams. These streams have been considered as clusters and have been described with foundational knowledge, concepts, theories, and employed techniques. Therefore, in Section 3, we present results and discussion along with our bibliometric analysis and network analysis. We conclude the paper with a discussion of findings and potential research directions.

2. Material and methods

Systematic reviews have significantly contributed to evidence-based practices, with the development of their process, and meta-analysis during the past decade [16]. Systematic literature reviews require an iterative process to define appropriate keywords, search the literature, and to complete the analysis [17]. Systematic reviews are different from traditional reviews since they follow a scientific, transparent, and replicable process that reduces the selection pool of literature[18]. Further, systematic reviews reduce biasness in selecting literature and allow to summarize them objectively [19]. The following steps were made for the search protocol. These steps are influenced by Fahimnia et al., [20] who adopted a five-step methodology for data collection and evaluation.

2.1. Database selection and defining the keywords

The study used the Scopus[1] database to choose the articles with the keywords identified in Table 2. We defined a three-level keyword structure that expects to filter only the multi-echelon VRP studies in defined areas. Table 1 shows the keyword structure where level 1 defines the search context vehicle routing problem, level 2 focuses on specified areas that are the focus of this study, and level 3 narrows down the search term to network-level/echelon.

2.2. Initial search results

The initial keyword structure resulted in 742 papers. The keywords in Table 2 were used in the Scopus database with the use of acceptance criteria "title, abstract, keywords" to collate the articles. We limited our search to papers written in English. We also limited the search to journal articles excluding conference papers, book series, books, and magazine articles in line with previous systematic reviews [21]. This reduced the initial dataset to 474 papers which constituted the primary literature pool for the literature analysis.

2.3. Classification scheme

We excluded the duplicate articles from the dataset before analysis. Then the results from Scopus were categorized based on type, publication year, author name, subject area, document type, keywords, source, publication stage, affiliation, funding sponsors, country/territory, source type, and language of papers. The search results were examined to check for irrelevant subject areas to narrow down the results further. After assessing the subject areas, it was identified that they were suitable, and the papers mostly covered the focus area. In this database, the papers could be listed in more than one subject area due to their identified contribution by Scopus. The irrelevant search results in Scopus were excluded after a thorough search result analysis. The final results of 382 papers were downloaded using the Comma Separated Values (CSV) file for further analysis. Table 3 illustrates the procedure that was used to collect and refine the literature pool.

2.4. Data analysis approach

Data analysis was conducted in two parts: bibliometric analysis and network analysis. We used VOSviewer for the bibliometric analysis and network analysis. We choose this tool because it creates networks based on different relations and they support to reveal evolution or impact of the scientific literature. Similarly, VOSviewer extract and visualize important keywords from the literature helping to identify main con-

Table 1
Fahimnia et al. five-step methodology for data collection & evaluation.

Step 1	Defining the appropriate search terms
Step 2	Initial search results
Step 3	Refinement of search results
Step 4	Initial data statistics
Step 5	Data analysis

[1] Scopus database managed by Elsevier Publishing is an outstanding source of vehicle routing problem peer-reviewed articles. Scopus is the largest abstract and citation database for peer-reviewed academic literature within the fields of science, technology, medicine, social sciences, and arts and humanities. Scopus covers more than 25,000 peer-reviewed journals, making it more comprehensive than the Web-of-Science database which includes only ISI indexed journals.

Table 2
The proposed three-level keyword structure.

Level 1		vrp OR "vehicle routing problem" OR "vehicle routing"
	AND	
Level 2		"logistic*" OR freight OR cargo OR haul OR consignment OR shipment OR "supply chain" OR "land transport" OR "air transport" OR aviation OR airline OR airport OR "maritime transport" OR shipping OR "shipping line" OR seaport OR rail OR "unmanned aerial vehicle*" OR drone*
	AND	
Level 3		"echelon" OR "single-echelon" OR "two-echelon" OR 2e* OR "three echelon*" OR "tri-echelon" OR "n-echelon" OR "multi* echelon" OR "multi-echelon" OR tier OR "multi-tier*" OR "multiple tier*" OR "intermediate depot*" OR "multi mediate depot" OR level* OR "multi-level"

Table 3
Procedure used to collect and refine the literature pool.

Steps of the process	Number of Papers
1. Searching papers on Scopus using primary keyword structure	1761
2. Narrowing down the pool based on focus area	742
3. Narrowing down the pool to peer-reviewed journal papers indexed on Scopus	474
4. Narrowing down to papers in English	457
5. Using exclusion keywords to filter out irrelevant publications	421
6. Assessing individual papers independently and reaching consensus on the final pool of papers	382

cepts, or trends within literature. Additionally it supports to query and download data from various sources like Scopus, Web of Science, Crossref etc.

Further, Microsoft Excel was used as a support tool for bibliometric analysis. We used VOSviewer to analyze bibliometric networks, publications, authors, journals, countries, and organizations [21]. Additionally, there were five types of bibliometric mapping analysis in VOSviewer: co-occurrence of keywords, citation, named as coauthor, bibliographic coupling, and co-citation [22]. VOSviewer analyzed the keywords using text mining techniques to analyze the content of titles, keywords, and abstracts. Therefore previously mentioned CSV file was imported to VOSviewer and selected the option to create co-occurrence of keywords.This network shows which keywords are frequently used by other publications. We used the clustering algorithm of VOSviewer to group the publications into clusters based on their co-occurences patterns. Each cluster represents a subtopic or specific research stream in the literature. Further, we built up clusters that consisted of closely associated articles using VOSviewer. VOSviewer mapping technique was used to visualize the network, that assigns a size and position to each keyword based on its co-occurrence relations and number of occurences. The final map shows the most relevant and influential keywords in the literature pool.

3. Results and findings

3.1. Bibliometric analysis

This section presents the bibliometric analysis consisting of initial author and affiliation statistics. VOSviewer was used for the initial bibliometric and statistical analysis with the support of Microsoft Excel.

Over the past decades, the applications in VRP have increased rapidly [23]. As previously mentioned, 386 journal papers were shortlisted for this analysis. The distribution of papers based on year is shown in Fig. 1. According to Fig. 1, we observed an increasing interest in the studies related to multi-echelon networks with VRP. Only sixteen papers were published between 1985 and 2006. Between 2006 and 2023, there was an increase in the number of publications. The most significant increase occurred between 2017 and 2023. In 2023, 40 papers were published within this topic. This increase is due to the wide expansion of solution methodologies for multi-echelon VRP and also its relevancy in this domain.

We conducted the analysis based on the contribution of the authors of the studies, using bibliometric analysis. Table 4 shows the number of published articles by key contributing authors in this research domain. The author Young Wang of Chongqing Jiaotong University, China has made the highest contribution with 12 publications in this specific domain. Reza Tavakkoli-Moghaddam from the University of Tehran, Iran has contributed 10 journal articles. The third place on the list is taken by Haizhong Wang from the Oregon State University, the United States with a contribution of nine publications. Yao Liu, Maozeng Xu, and Hongqi Li from China were other top contributors.

Fig. 2 shows the distribution of studies based on the country of

Table 4
Key contributing authors.

Author	Number of Published Articles
1. Wang Y.	12
2. Tavakkoli-moghaddam R.	10
3. Wang H.	9
4. Liu Y.	8
5. Xu M.	7
6. Li H.	6

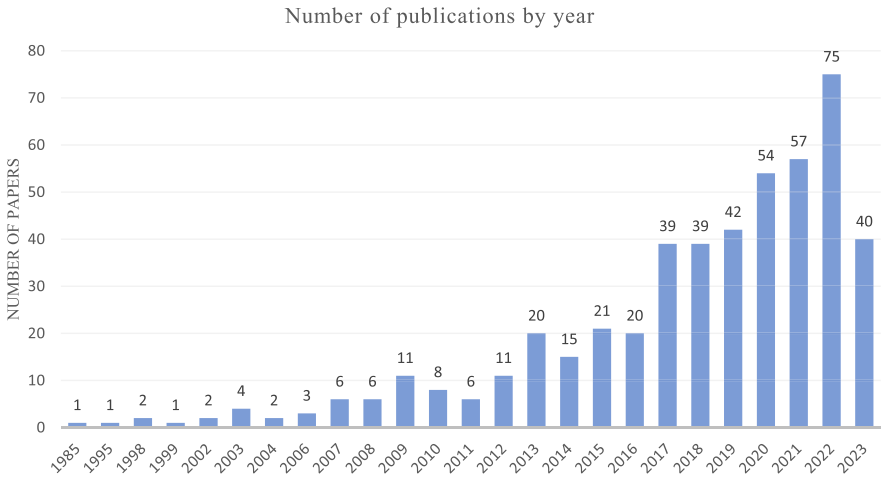

Fig. 1. Paper distribution based on year of publication.

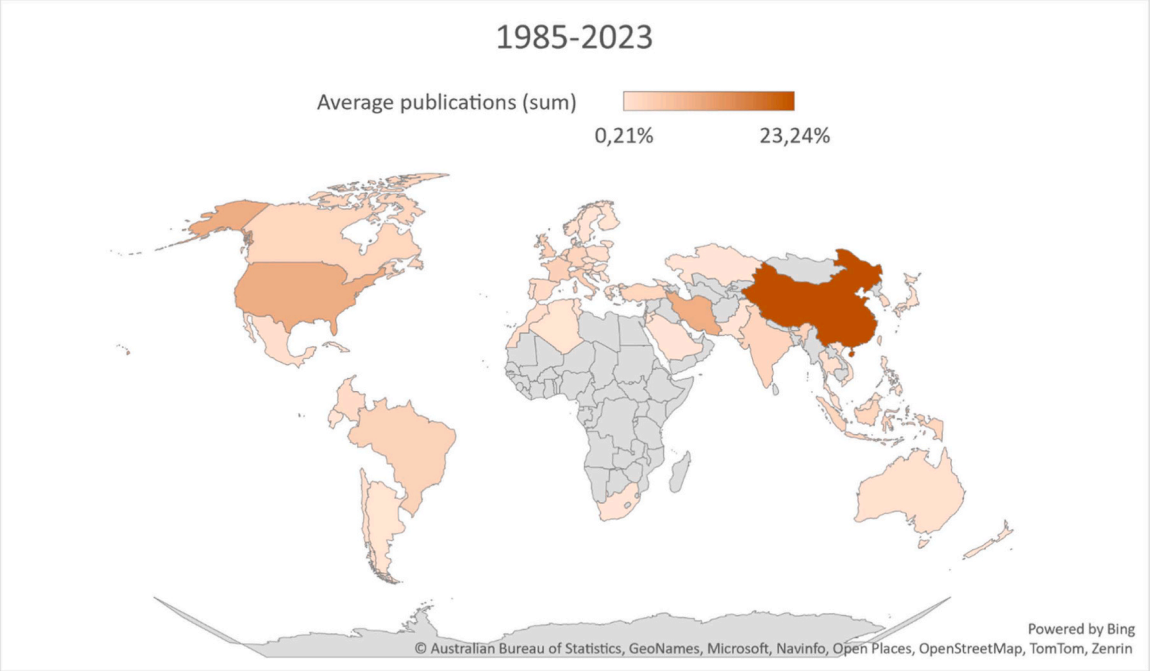

Fig. 2. Paper distribution based on the country of publication.

affiliation of the authors. China is the country with the highest number of articles on VRP in the multi-echelon network. The United States assumes second place and Iran takes third place, contributing 12.5 % and 7.8 % of the papers, respectively. Authors based in Canada and Italy have contributed to this specific area by taking the fourth and fifth places.

Table 5 represents the publication outlets representing the paper pool. Most articles have been published in *Computers and Industrial Engineering* journal while *Computers and Operations Research* is in second place. *European Journal of Operational Research* is in third place. *Transportation Research Part E: Logistics and Transportation Review* and *International Journal of Production Economics* have taken fourth and fifth places, respectively.

3.2. Network analysis

We performed the clustering and analysis using author keywords that were produced in selected papers. Fig. 3 was created using the keywords of the papers. Waltman et al. [22] discussed a unified approach to help to avoid inconsistencies between the results produced by mapping and clustering techniques.

3.2.1. Cluster 1: green logistics and decision analysis

This cluster represents the logistics systems that contribute to mitigating environmental degradation with the support of decision analysis methods. This cluster represents the green logistics applications with the support of decision analysis methods. In the decision-making process of logistics services, it is required to address environmental concerns while strengthening customer satisfaction.

Introduction to the pollution routing problem was the first overview of green logistics in 2011 [24]. Then research studies focused on the green vehicle routing problem (GVRP) with the objectives of minimizing fuel, emission costs etc. The foci shifted over the years from 2011 to controlling the source of pollution, optimizing routes, and reducing total costs of green routing. In 2016, Xiao and Konak [25] studied a logistics system that took into account product delivery and pickup, which tried to reduce the greenhouse gases released by automobiles. The literature on green logistics has risen significantly within the past few years mainly because of the environmental impacts.

Green logistics are beneficial to reduce logistics costs and lead to improved sustainability performances. Therefore, green logistics and green transportation have emerged as popular topics among researchers in supply chain management [26]. Additionally, studies have considered decision analysis methods to distribute remanufactured or repaired products with concerns about emission levels of the system.

One of the significant applications is the distribution of products that are repairable or reusable. Therefore, the studies have developed single-objective or multi-objective non-linear programming models focusing on the GVRP [27]

This GVRP is another new branch in the models, considering the sustainable logistics context. Studies have evaluated three echelon supply chains, analyzing the distribution chain linked to food products from farm to the final customer using GVRP [28]. Some instances consider both social and environmental sustainability in logistics distribution, optimized through decision analysis methods. Granillo-Macías [29] conducted an analysis based on a case study in Mexico to optimize the distribution and delivery of school breakfast using mathematical models to minimize the total cost of the distribution network logistics, considering environmental and social sustainability factors.

Environmental sustainability has been discussed as largely related to the logistics operations and has utilized numerous decision analysis methods. A heuristic approach based on mixed integer linear programming (MILP) models was developed to compute the efficient frontier of

Table 5
Publication outlets that published papers.

Journal	Number of studies
Computers and Industrial Engineering	21
Computers and Operations Research	19
European Journal of Operational Research	18
Transportation Research Part E: Logistics and Transportation Review	12
International Journal of Production Economics	11
Expert Systems with Applications	10
International Journal of Production Research	10
Journal of Cleaner Production	10
Transportation Science	10

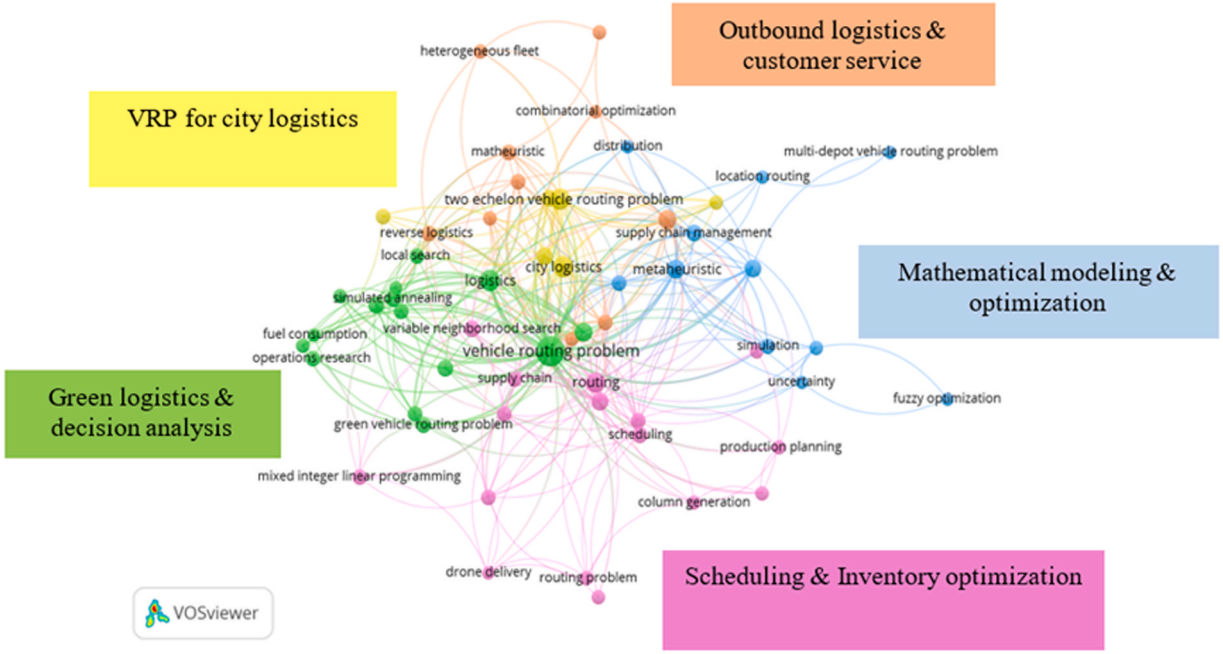

Fig. 3. Network Visualization.

the proposed problems. Studies have discussed problems to minimize fuel consumption in freight distribution so as to reduce gas emissions. Similarly, a new mathematical model for the calculation of greenhouse gas emissions, and a new green capacitated location routing problem model considering fuel consumption minimization, have been proposed by Toro et al. [30]. Furthermore, a study has assessed the implementation of an electric fleet of vehicles for the distribution of goods to convenience stores operating in Bogotá, Colombia to reduce environmental impacts while maintaining a level of service [31]. The satisfactory-green vehicle routing problem is a new branch that has considered environmental pollution and customer satisfaction in developing MILP models [32]. Additionally, Bakeshloo M. et al.[33] have prepared an effective decision-making dashboard that evaluates appropriate routes, the best-mixed fleet, vehicle speed, and idle time. Another branch can be identified as the green open location routing problem (G-OLRP). Real world applications have solved the problem by suggesting a new, bi-objective vehicle routing problem that combines open location routing problem with the growing requirement to reduce fuel usage and minimize environmental effects [34] and also formulated VRP with time windows to optimize freight distribution in an urban landscape while using renewable energy.

The food supply chain is known as one of the major sources of environmental disruptions due to high consumption of resources, negative effects on transportation, toxic effects on ecosystems and humans, and emissions of greenhouse gases, etc. [35]. Similarly, in perishable supply chains, novel and robust mixed-integer linear programming models have been developed, considering environmental concerns, fuel consumption, and urban traffic conditions [36]. Studies have focused on minimizing carbon emission in cold chain logistics companies while collaborating to deliver cold chain commodities with the models like the joint distribution-green vehicle routing problem [37] Further, significant attention has been given to improving the retail chain distribution networks [38]. Additionally, distribution network sustainability in food retail supply chains has been considered while using new frameworks like the split delivery-vehicle routing problem [35].

Cluster 1: "Green Logistics and Decision Analysis" mainly studies the contribution that is made to reduce environmental degradation in logistics activities and the use of decision analysis methods. Green vehicle routing problems, green capacitated location routing problems, satisfactory green vehicle routing problems, green open location routing problems, joint distribution green vehicle routing problems, and split delivery vehicle routing problems are some of the key models that have been considered in these studies. The food supply chain has been identified as one of the sources of environmental disruptions, and researchers have made efforts to limit greenhouse gas emissions, carbon emissions, fuel consumption, and urban traffic congestions through decision analysis models.

3.2.2. *Cluster 2: scheduling and inventory optimization*

Scheduling an integrated supply chain at the operational level is critical. The routing of vehicles in a distribution network and the scheduling decisions made by the manufacturer are interrelated concerns. An integrated framework for decision-making will support the company in streamlining its operations, improving its service quality, and enhancing customer satisfaction [39]. The purpose of scheduling the phases in an integrated manner is to optimize short- and mid-term decisions in the supply chain to achieve a balance between economic objectives such as cost reduction and profit maximization [40]

In literature, production scheduling and vehicle routing are two well-discussed problems. Production and distribution scheduling problems, and proposed metaheuristic algorithms, have been evaluated and integrated as solution approaches [39]. Studies have focused on supply chain scheduling problems that aimed to minimize fuel costs, carbon emissions, customer dissatisfaction, and multiple time windows [41].

Investigating perishable food supply chains, the operational coordination of production scheduling and vehicle routing with time windows has been studied by Ma et al. [42]. A nonlinear mathematical model was built for this purpose. Similarly, Vahdani et al. [43] discussed integrating important operational decisions in production scheduling in perishable products and VRP to achieve customer satisfaction. A study has explicitly discussed vehicle routing decisions for the delivery process, focusing on integrated production-distribution operational level scheduling problems [44].

This cluster focuses on inventory optimization and scheduling in the context of suppliers catering to the customers' demands by using a fleet of vehicles for delivery while minimizing the total cost of the system. Additionally, studies have focused on the stochastic inventory routing

problem at a single central supplier shipping to multiple customers in a specified time horizon [45]. It has used optimization methods, including metaheuristic algorithm, to solve location-inventory-routing models [46]. Further, contributions were made to evaluate how inventory optimization aims to offer a satisfactory performance by achieving inventory levels according to a planned covering level [47]. Vendor-managed inventory systems raise the concern of inventory routing problem (IRP). IRP is a combination of VRP and inventory management. Li et al.,[48] studied the IRP, considering time consumption that fetches lead time to replenishment. In such a scenario, the lead time for the replenishment of inventory depends upon the routing decisions taken by the vendor. These decisions effects on each other are tightly connected.

Cluster 2: "Scheduling and Inventory Optimization" mainly focuses on the contribution of inventory optimization and scheduling problems within the context of targeting customer demand using a fleet of vehicles for delivery. The purposes of the studies mainly focus on improving service quality, and customer satisfaction, optimizing mid-term and long-term decisions, minimizing fuel costs, minimizing emissions, and offering satisfactory performance.

3.2.3. Cluster 3: VRP for city logistics

Cluster 3 focuses on VRP applications used in city logistics. Most recent literature addresses quantitative modeling and sustainability problems. Most of the distribution companies have used multi-echelon logistics systems to deliver to the customers in densely populated city areas. Furthermore, studies have focused on concepts like multi-echelon distribution networks and the use of environmentally friendly vehicles to reduce the negative impacts caused by urban transportation activities.

The introduction of the concept of the 2E-VRP to the literature has attracted the attention of many researchers within the context of urban freight transportation [49]. In city logistics, the studies have focused on delivery and pickup problems. The mixed integer programming models have been used to formulate especially 2E-VRP with simultaneous pickup and delivery constraints [50]. The use of electric vehicles by logistics and e-commerce companies for freight distribution has increased due to lower emissions, comparably low noise, etc. There are the drawbacks of electric vehicles leading to difficulties in managing logistics activities with aspects like enroute charging necessity. To mitigate those difficulties, two echelon-electric VRP with the option of battery-swapping stations has been proposed by Jie et al. [51] as one of the first studies in this context. Also, later studies have focused on the electric vehicle routing problem (EVRP) with charging batteries without swapping them [52].

In city logistics, the collection of recyclable waste is one of the major concerns, especially in densely populated areas. One of the most difficult processes in all solid waste management is the collection and transportation process [53]. Recent studies have suggested reverse logistics networks with a mixed fleet of electric vehicles to collect recyclable waste [54]. Further, wet waste management and solid waste management are serious concerns in recent years in urbanized cities which use VRP models with financial, environmental, and social objectives [55]. Additionally, researchers have used approaches like simheuristic for rich versions of the waste collection problem considering the cost savings and the cooperation of governments [56].

Table 4 demonstrates the different types of freight distribution in the city logistics context within this cluster. The rise of e-commerce and the need for faster delivery to the customers have encouraged optimizing the distribution networks. Therefore, optimization methods like heuristics, metaheuristics and simulation have commonly been used to obtain VRP solutions. Also, it was identified that intermediate facilities have contributed massively to freight distribution to make the processes smooth and fast. Also significantly, last mile delivery problems have applied for households and industrial purposes.

In city logistics, there are numerous paths for future research in VRP. The discounts or bonus for delivery options in terms of revenue generation is an emerging scope that has to integrate in applications of VRP [57]. Also, technological advancements have been discussed to optimize E-VRP with detailed energy consumption simultaneously with road characteristics and interaction with other vehicles on the road [58], and to combine with autonomous vehicles. Further, the Table 6 provides a summary of the papers of the cluster given city freight distribution. We have included the type of freight distribution, optimization method and the type of dataset used for the problem to provide an overview on the VRP problems in city freight distribution.

Cluster 3: "VRP for City Logistics" discusses the numerous implications of logistics activities. The two-echelon vehicle routing problem has been suggested in most studies as a common approach for solving distribution network issues. Further, electric vehicle usage has been considered, merging EVRP applications. Another main focus is on recyclable waste and solid waste management utilizing different VRP approaches. The freight distribution types in city logistics and respective VRP types and optimization methods have been categorized in this cluster.

3.2.4. Cluster 4: mathematical modeling and optimization

The growing interest in more general, intelligent methods leads researchers to experiment with heuristic methods. When exact methods aren't suitable for the application, practitioners turn to heuristics, which are "rule of thumb" methods for tackling optimization problems [59].

In recent years, the heuristic method has been used as a popular optimization method with numerous additions. The intermediate facilities in distribution systems are one of the main contributors to a smooth operation in distribution networks. Therefore, to optimize such networks, methods such as three-phase heuristic coupling a genetic algorithm, local search and integer programming. [60], a three-phase heuristic solution approach where population-based metaheuristics and integer programs [61] have used. The use of recharging stations especially for electric vehicles is a new research direction in freight distribution to minimize operational costs. This special application has been investigated with the use of construction heuristics and improvement heuristics to optimize two-echelon vehicle routing problems with recharge stations [62]. In logistics and transportation, uncertainty is frequently involved where vehicle routing problems play a major role. With the concerns over uncertainty, an efficient heuristic based on an adaptive large neighborhood search has been used to solve in a robust VRP with time windows [63]. A new class of VRPs introduced by Derigs & Pullmann, [64] is multi-depot, multi-trip VRP with order incompatibilities that combine several synchronization constraints. This model also used the heuristic concept of concurrent neighborhood search.

The metaheuristic solution approach is another optimization method that has been used in recent studies and in many industries. Genetic algorithm is proven to be a powerful metaheuristic for a problem that has sub-optimal solutions, but also feasible solutions can easily be found (59). In home healthcare logistics, R. Liu et al. [65] considered a special VRP with simultaneous delivery and pickup time windows and proposed a genetic algorithm and a tabu search method for a solution approach. Freight transportation is one of the leading causes of traffic congestion, pollution, and safety in the context of city logistics. In order to reduce environmental impact and increase service level in city freight distribution, flexible metaheuristic algorithm has been used in studies [66]. Also, the metaheuristic method has been used in industries like oil and gas to optimize the routing of resources to multiple remote sites. Therefore, the application of metaheuristic profiling as a monitoring tool that helps to develop balanced algorithms combining metaheuristics was studied by Wood [67]. Further, studies have addressed a logistics problem in a hospital complex by introducing a two-level VRP using metaheuristic methods [68]. Similarly, a study demonstrated a novel simulation-based model for the VRP of a three-echelon blood sample supply chain, that serves as a decision support tool for optimizing resource utilization and service quality in healthcare systems

Table 6
Papers in the cluster about city freight distribution.

Type of Freight Distribution	Type of VRP	Optimization Method			Data sets used	Authors
		Heuristic	Metaheuristic	Simulation		
E-commerce - General Parcel Delivery	VRP with delivery options	×			Synethetic data and Randomly generated instances	(Tilk et al., 2021), (Dumez et al., 2021)
	2E-VRP	×			two well-known 2E-LRP datasets from literature	(V. F. Yu et al., 2021a)
				×	18 artificial test instances and real world data	(Anderluh et al., 2020)
			×		2E-CVRP datasets from literature	(K. Wang et al., 2017)
	Multi-Depot VRP	×			Benchmark instances from literature	(Schneider & Löffler, 2017)
E commerce - Grocery Delivery	VRPTW			×	Real world data	(Leyerer et al., 2020)
	Capacitated Two-Echelon Vehicle Routing Problem with Time Windows (C2E-VRPTW)		×		Real world data (parcel delivery company)	(Nolz et al., 2020c)
Freight Distribution with Intermediate Facilities	VRPTW	×			Real world data, data sets from literature	(Musolino et al., 2019a), (K. Wang et al., 2017)
				×	Historical or simulation data	(Crainic et al., 2015)
	2E-VRP	×			Real world data., data from literature	(Anderluh et al., 2017),(Mancini, 2013), (Hemmelmayr et al., 2012), (Huang et al., 2017)
			×		Simulation dataset	(Breunig et al., 2019b),(Breunig et al., 2016)
	Two echelon capacitated VRP (2ECVRP)	×			Data from literature	(Jie et al., 2019b), (Perboli et al.,2009)
			×		Data from literature	(K. Wang et al., 2017)
Last Mile Delivery for Households	2E-VRP	×			Data from literature	(Huang et al., 2018),(Enthoven et al., 2020)
			×		Real world data	(Groß et al., 2020)
				×	Simulation dataset	(Letnik et al., 2020)
	2ECVRP	×			Real world data	(Mühlbauer & Fontaine, 2021)
Last Mile Delivery for Industrial Purposes	Electric VRP with time windows			×	Real world data	(Napoli et al., 2021b)

[69]. Further, the metaheuristic approach has been used to model the newspaper production and distribution problems as an open vehicle routing problem with time windows and zoning constraints, and shows the efficiency of the current methodology [70]. Similarly, [71] proposed a simulation-based optimization approach for the two-echelon vehicle routing problem with stochastic demands.

In this cluster, fuzzy optimization and robust optimization can be recognized as sub-areas of optimization modeling. Furthermore, these two strategies for resolving uncertainty can be proposed as formulations of the selective vehicle routing problem under uncertainty. It is encouraged, in real-life scenarios that include uncertain conditions, like milk collection problems, to optimize using fuzzy optimization models [72]. In significant cases, such as disaster management relief operations, the optimization models in Fuzzy Selective VRP can be utilized [73] The first attempt to introduce an integrated model for cross docking systems designs under fuzzy environment was done by Mousavi et al. [74]. Additionally, in sustainable supply chains, conditions such as multi-product multi-site multi-distribution multi-customer is addressed using fuzzy non-linear programming models due to the uncertain conditions [75].

Robust optimization has been considered to lead the solution and be immune to possible variations in uncertain parameters. The logistics companies that deliver products to retailers in congested urban areas have addressed VRP with time windows and multiple deliverymen using a static robust optimization approach [76]. In relief logistics planning, the dynamic and complex nature of the disaster relief chain would be optimized with these robust optimization models [77].

Cluster 4: “Mathematical Modeling and Optimization” discusses the solution approaches that have been adopted in the studies. The heuristic, metaheuristic, and simulation approaches are mainly considered, while exact methods are less in practice. Furthermore, fuzzy optimization and robust optimization have been identified as the main sub-areas of optimization modeling.

3.2.5. *Cluster 5: outbound logistics and customer service*

This cluster mainly discusses the outbound logistics processes, including reverse logistics, cross-docking, and customer service functions. The major decisions at the operational level of outbound logistics and customer service are vehicle routing and scheduling, truck scheduling at cross docks, dock door assignment, etc. VRP of reverse logistics is complex since the characteristics of uncertain demand, long recovery period, and connectivity of multiple nodes to one node compared with forwarding logistics [78].

Transporting recyclable wastes is a customer service that has financial, environmental, and resource implications. The importance of the recycling network is studied. A heterogeneous fleet of electric vehicle routing problem with time windows for a two-echelon recycling network was analyzed with the concerns of factors mentioned by Cao et al. [79]. Also, a new mathematical formulation was identified, using methods and techniques to optimize the logistical echelons of the wastepaper recycling system [80].

In reverse logistics, remanufacturing difficulties relate to a situation in which original products are disseminated, and subsequently, secondhand products are gathered from customers to be repaired and resold in a different market at a reduced price. It is evident that studies have focused on the mentioned fact and have developed programming models to solve VRP applications, including original and remanufactured products [81]. Additionally, manufacturing organizations are concerned about implementing environmentally efficient supply chains while maximizing their profit. With that purpose and to efficiently handle reverse logistics operations, Kumar et al. [82] developed a forward-reverse logistics model based on the optimum routing of

vehicles.

Cross-docking is a valuable concept that many businesses utilize to manage product movement. It allows products to be transshipped from suppliers to buyers [83]. According to the literature, the economic aspect of cross-docking has been studied while identifying whether enhances the quality of customer service and customer satisfaction. Therefore, Baniamerian et al.[84] considered customer satisfaction in developing a VRP and scheduling problem with cross-docking and time windows in a three-echelon supply chain. Since return process management has become an essential concept in numerous industries, studies have expanded the value of cross-docking with reverse logistics [83]. Gunawan A. et al. [85]developed a vehicle routing problem with cross-docking to minimize the costs of product movements in a four-level supply chain network.

Further, it is evident that studies have focused on the increase of delivery speed and customer satisfaction, and the income satisfaction of crowd-shippers. As an example, Lan et al. [86]developed an extension of a two-echelon city dispatching model with mobile satellites solved by a multi-directional evolutionary algorithm. Further studies have considered significant improvements in its routing plans, with a lower number of vehicles and a higher rate of orders delivered to the customer within the prescribed time window, especially in studies like Pena et al. [87] which examined a real-world application of a food company's distribution center. Furthermore, Wang & Wen [88] studied a low-carbon vehicle routing problem derived from a real, cold chain logistics network, and the results suggested that customer satisfaction is a critical influencer for companies to plan multi-echelon vehicle routing problem strategies. A new mathematical model was introduced under the name satisfactory-green vehicle routing problem that considered cost, pollution, and especially customer satisfaction specifically [89].

Cluster 5: "Outbound Logistics and Customer Service" discusses reverse logistics applications that concern environmentally friendly supply chains while catering to customer needs. The cross-docking concept is also debated within the cluster that emphasizes customer services. Further, the chapter elaborates on the importance of customer satisfaction and extensions of VRP.

4. Discussion of the results and future research directions

In this section, we further examine the potential areas for future research that have been discussed in the literature. It highlights the evolving nature of the domain, with a focus on city logistics, sustainable logistics, and new technological advancements. In order to foresee upcoming issues in urban logistics, it is crucial for us to identify the trends that have a significant impact on city logistics. The emergence of the topics such as emergency logistics networks related to the Covid-19 pandemic and the use of blockchain technology for optimization are notable trends. The growing e-commerce market has sparked research into robot delivery models, with technology companies and traditional logistics providers both exploring this innovative approach. Fig. 4

The trending keywords that appear more than 10 times can be listed as logistics, heuristics methods, metaheuristics, genetic algorithm, tabu search, supply chain management, reverse logistics, time window, city logistics, two-echelon vehicle routing problem, and electric vehicles.

One of the main trending topics is city logistics problems due to the high growth in e-commerce that increases freight distribution activities [90]. Mainly governments and logistics providers have made significant efforts to ease traffic congestion to enhance the quality of life. Therefore, freight distribution has been utilized through smaller and eco-friendly, electric vehicles for serving customers [91]. Further, these problems mainly have to deal with intermediate points where the multi-echelon routing problem comes into play. New business models, such as attended home delivery, same-day delivery, and mobility-on demand have been identified in logistics services over the past decade. These models have integrated with demand management and vehicle routing optimization, and studies have rapidly emerged in this domain [92].

The vehicle routing problem for sustainable logistics has emerged in recent years as a trending research area. Models to reduce greenhouse gas emissions [93], optimize sustainable food distribution & delivery [94] sustainable pickup and delivery focusing on CO_2 emissions [95],

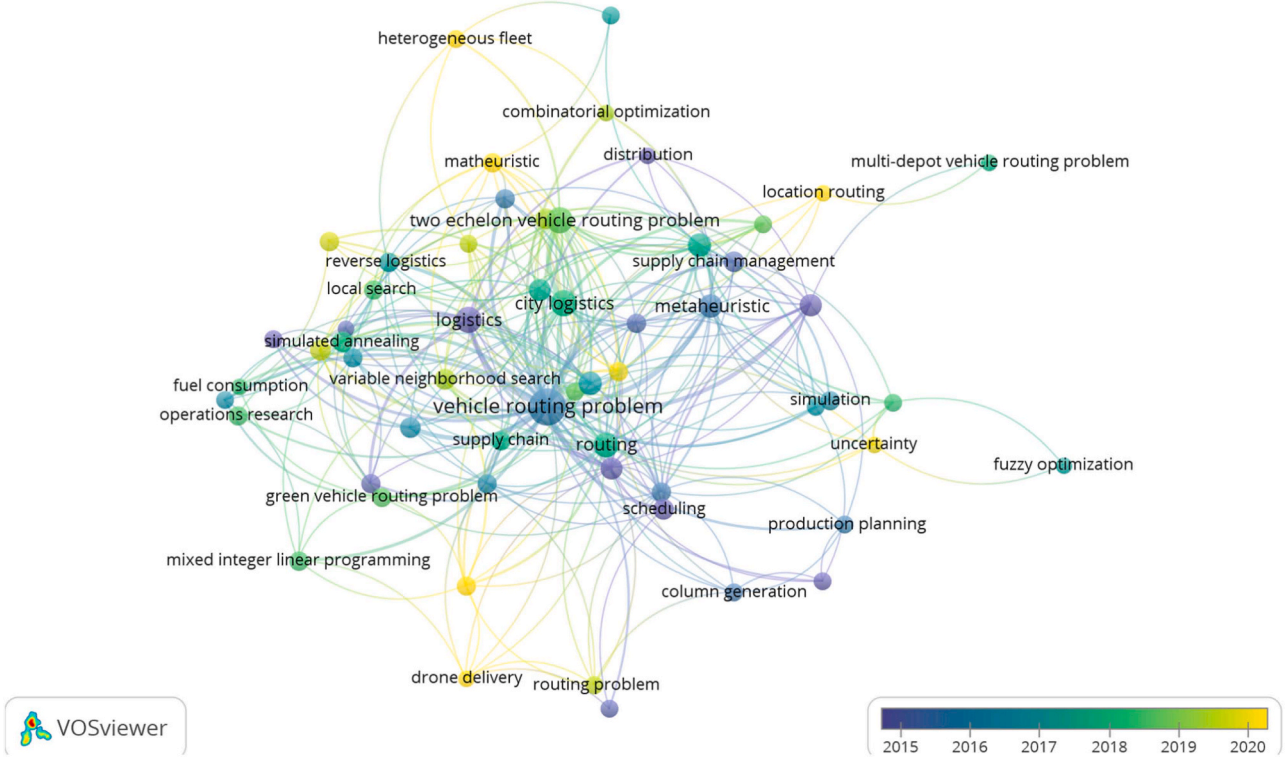

Fig. 4. Evolution & future research directions.

optimizing liquefied natural gas (LNG) distribution for energy sustainability [96], evaluating green policies within logistics companies [97], sustainable logistics model for the distribution of online orders [98], and planning of city logistics through sustainability goals [99] can be identified as the key focuses of sustainable logistics.

The studies have focused on emergency logistics networks with the COVID-19 pandemic, and new variants of the VRP have been introduced, such as the two-echelon emergency vehicle routing problem with time window assignment [100]. Furthermore, concerns were raised about the perishable supply chain due to the global outbreak of the coronavirus. Therefore, studies were focused on optimizing vehicle routing and distribution to reduce the risks of demand and supply uncertainty, and reinforce distribution-related choices by optimizing overall network costs and supplier reliability at the same time[101].

The trending keywords for the past decade were further evaluated. The most prominent keywords were selected for this evaluation and the percentage of papers that the keywords are included in is shown in Fig. 5. Accordingly, city logistics is a popular keyword that has been discussed throughout the past years. Green VRP & carbon emission are considered in literature during the past five years. E-commerce is a highly discussed topic in studies in the 2018 – 2020 period. The growing interest in the circular economy is proven in the distribution of publications since 2020.

Further, studies on technological advancements and based applications can identify growing interest in recent years. Studies related to the use of electric vehicles have been an emerging topic during the past decade. Some recent studies discussed the implementation of blockchain technology. The solutions retrieved from the blockchain-enabled fleet-sharing methods to optimize drone operations [102] integration of construction sites' resource allocation problems, and logistics businesses' vehicle routing problems [103] are solved using blockchain techniques. Van-based robot last-mile pickup and delivery systems in urban settings [104], the use of smaller-sized electric vehicles [105], drone delivery within city limits [106] and synchronized trucks and drones for package delivery [107] are some novel directions that have been researched recently.

5. Conclusion

Research studies on applications in vehicle routing problems for multi-echelon distribution networks have increased recently. We have used bibliometric and network analysis tools to analyze literature related to the discussed topic quantitatively. We examined the evolution of this research area and identified emerging trends.

Firstly, we identified the contribution of the researchers in the field and different countries that have contributed to the domain. This information can be beneficial for scholars and students who are interested in conducting research in this domain with researchers at various universities. Then we identified five clusters that summarized the analysis of author keywords. These are green logistics and decision analysis, scheduling and inventory optimization, VRP for city logistics, mathematical modeling and optimization, and outbound logistics and customer service.

This study has highlighted an eminent topic in cluster 1: "Green Logistics and Decision Analysis", which represents the emerging trend in this domain focused on the environmental crisis and therefore sustainable developments and distributions. Further, green VRP has gained attention because of concerns about social and environmental sustainability in logistics distribution. Environmental sustainability has been explored in relation to logistics operations and has used a variety of decision analysis approaches.

Cluster 2: "Scheduling and Inventory Optimization" is another study area concerned with establishing a balance between economic objectives like cost reduction and profit maximization, and the stages of the supply chain which are scheduled in an integrated way with the goal of optimizing short- and mid-term choices. It simply discusses the ways of minimizing costs in an efficient scheduling and inventory optimization methods.

The highly discussed topics in the focused scope are city logistics problems due to the high growth in e-commerce, vehicle routing problems for sustainable logistics, and technological advancements and based applications. Therefore, cluster 3: "VRP for City Logistics" is an emerging domain that requires research to solve in challenges with freight transportation and logistics in urban and metropolitan regions.

Next, we identified another significant domain as cluster 4: "Mathematical Modeling and Optimization" which consists of theoretical research. This cluster provides fundamentally interesting study areas for the researchers, and studies are combinatorial complex in nature. It was identified how exact methods, heuristic, metaheuristic, and simulation approaches, are considered in practice, and also fuzzy optimization and robust optimization are identified as the main sub-areas of optimization modeling.

Finally, cluster 5: "Outbound Logistics and Customer Service" is another research direction with complex real-world problems which require new approaches to finding solutions. The outbound logistics processes, such as reverse logistics, cross-docking, and customer service

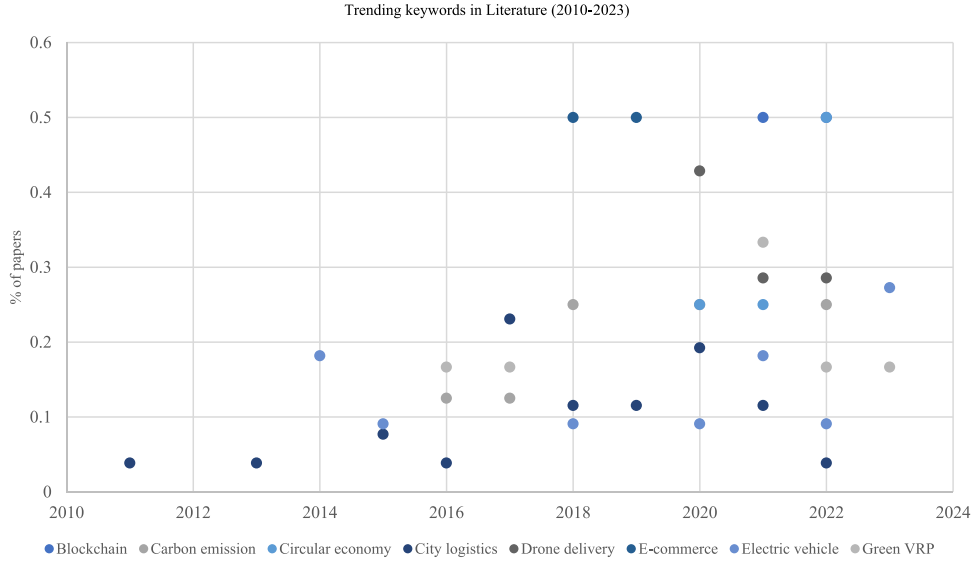

Fig. 5. Trending keywords in literature (2010–2023).

functions, are commonly addressed with different approaches for solutions. Additionally, to lessen the negative effects generated by distribution and transportation operations, studies have concentrated on ideas like multi-echelon distribution networks and the use of vehicle routing problems.

CRediT authorship contribution statement

Amila Thibbotuwawa: Writing – review & editing, Validation, Supervision, Resources, Investigation. **Mahekha Dahanayaka:** Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation. **Peter Nielsen:** Writing – original draft, Validation, Formal analysis, Data curation, Conceptualization. **Deniz Kenan Kilic:** Writing – review & editing, Visualization, Software, Formal analysis. **H. Niles Perera:** Writing – review & editing, Supervision, Investigation, Formal analysis.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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