THE LIMITATIONS OF ELECTRIC CARGO CYCLES – A LITERATURE REVIEW

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ABSTRACT

Purpose - The aim of this paper is to discern the knowledge from the literature by conducting a literature review to provide ECB users with insight into the limitation of ECBs that affect their penetration and the relationships among these limitations themselves and the advantages of ECCs; and secondly, to outline directions for further research.

Design/methodology/approach - During the systematic review process, a search protocol was developed after the initial snowball sampling process. Then keywords regarding cargo bikes are used to find the potential papers on Scopus. Afterwards, 42 scientific journals papers and 29 conference proceeding papers published in English were selected. Finally, 17 papers are excluded according to specific criteria by reviewing the contents of the selected papers.

Findings –Seven limitations of ECCs regarding payload capacity, battery range, riding speed, charging time, terrain adaptability, the possibility of defect/malfunction, and service monotony were identified from the literature. The interacting relationships among these limitations showed that the deterioration of one limitation can have negative impact on other limitations. More importantly, the improvement of one limitation may have negative impact on other limitation. In addition, the changes in both directions (improve/deteriorate) of the limitations can also overshadow some of the advantages of ECCs. Finally, research gaps and relevant further research directions were identified.

Originality/Value - The results of this paper provide insights with academic and practitioners. To our best knowledge, this study is the first paper to investigate the interacting mechanism among the limitation of ECBs themselves and the advantages of ECCs, which enriches the knowledge of ECCs in the existing relevant literature. From the practical perspective, the review paper provides stakeholders with a theoretical support for the understanding and decision-making on the adoption of ECCs, potentially reducing the concerns and reservations against the adoption of ECCs.

Practical implications - When deciding to introduce ECBs, logistics service providers (LSPs) are suggested to focus on the ECB's cargo capacity and battery mileage according to the specific service market. The above two parameters will not only affect the initial investment, and mid-term operation economy but also affect the later maintenance cost. At the same time, the LSP should adjust the above two parameters according to the terrain of the operating environment. In addition, optimising space-saving loading and packing operations are even more important than conventional transportation modes in urban logistics because the low use of vehicle capacity will reduce the effectiveness of last-mile logistics. It is also important to note that not all limitations of ECCs hold equal significance for ECC users. Hence, users must learn to differentiate which limitations to ignore and which limitations to address based on their specific circumstances.

INTRODUCTION

Electric cargo cycle (ECC) is treated as a promising alternative fleet to the conventional vans (Švadlenka et al., 2020) because of its lower environmental impact (Enthoven et al., 2020; Shahmohammadi et al., 2020), easy access to restricted zones, high efficiency in densely inhabited areas (Ramírez-Villamil et al., 2022), and savings regarding to parking, etc (Anderluh et al., 2017; Caggiani et al., 2020; Elbert and Friedrich, 2020). On the other hand, the adoption of ECCs is restricted by its vehicular limitations such as loading capacity, battery, and riding speed, etc (Thoma and Gruber, 2020). Before real application, a comprehensive understanding of the characters of ECCs is crucial. By linking each drawback together, the hidden interacting mechanism between each drawback is appear. In addition, exploring the potential impact of these drawbacks on the advantages of ECCs can also provide a deeper insight into the significance of each drawback. However, from

the literature, the drawbacks of ECCs are only briefly mentioned and the relationships between these drawbacks and their impacts on the advantages of ECCs are vague.
The aim of this paper is to discern the knowledge from the literature by conducting a literature review to provide ECC users with insight into the limitation of ECCs that affect their penetration. To our best knowledge, this study is the first paper to investigate the interacting mechanism among the limitations and the advantages of ECCs, which enriches the knowledge of ECCs on the existing relevant literature and provides stakeholders with theoretical support for the understanding and decision-making on the adoption of ECCs.
This paper is structured as follows: the objectives and the methodology; followed by the descriptive analysis of the data including the year, source, and region of the selected papers; together with the findings that include the identification of the interacting mechanism of ECCs' limitations and the potential impacts of these limitations on the advantages of ECCs; and finally, major research gaps and conclusions are proposed.

OBJECTIVE AND METHODOLOGY

Aligned with the established objective, this work tackles the following three questions:
RQ1: What are the main limitations of ECCs? – To comprehend the characteristics of an ECC, alongside its advantages, a distinct and profound understanding of its primary limitations is imperative.
RQ2: What are the relationships among these limitations – Once the drawbacks of ECCs have been identified, it becomes possible to ascertain the interacting mechanisms among these limitations.
RQ3: How the limitations of ECC undermine its advantages – In addition to the relationship between the disadvantages of ECCs, these disadvantages may also affect the advantages of ECCs.
To achieve the stated objective, a comprehensive review was undertaken through 3 steps: literature search – in which papers were selected and collected; literature analysis – where selected papers were reviewed; direction of further research – research gaps in the literature were identified and proposed.
Phase 1: literature search
1) Classification context – the focus of the analysis is on the limitations that affect its adoption.
2) Unit of analysis – single scientific paper published in scientific journals and conference proceedings. As the novelty of the topic, all the contribution from both black and grey literature are considered to ensure data comprehensiveness to the most extent.
3) Snowball sampling – at the beginning of the process, 9 papers are referred by research team members to get started. The information about the paper for snowball sampling are below:

Citation	Source	Country
(Taefi et al., 2015)	E-Mobility in Europe: Trends and Good Practice	Germany
(Rudolph and Gruber, 2017)	Research in Transportation Business & Management	Germany
(Gruber and Narayanan, 2019)	Transportation Research Record	Germany
(Mangiaracina et al., 2019)	International Journal of Physical Distribution & Logistics Management	Italy
(Thoma and Gruber, 2020)	Transportation Research Procedia	Germany
(Seidlová and Ledvinová, 2021)	Transport Means: proceedings of the international scientific conference	Czech Republic
(Narayanan and Antoniou, 2022)	Transport policy	Germany
(Pérez-Guzmán et al., 2022)	Transportation Research Part A	US
(Ramírez-Villamil et al., 2022)	Computational Logistics: 13th International Conference, ICCL 2022, Barcelona, Spain, September 21–23, 2022, Proceedings	Colombia

Table 1. Papers for snowball sampling

4) Search protocol – through forward and backward referencing, 10 key words of "cargo bike(s)", "cargo-bike(s)", "electric cargo bike(s)", "E-cargo bike(s)", "city logistics", "deliver(y/ies)", "freight(s)", and "last-mile" are selected and searched in the title, abstract, and the keywords, on the database Scopus.
5) Filter setting - Moreover, only articles published in English and in final stage were considered.
6) Exclusion criteria -15 papers (appendix table 1) are excluded according to the criteria below:

Criteria	**Citation**	**Criteria**	**Citation**
Vehicle design	Hogt et al., 2017	Share economy	Hess and Schubert, 2019
	Bogdanski et al., 2021		Perboli et al., 2022
	D'Hondt et al.,2022	Wrong vehicle type	Rajesh and Rajan, 2020
Mobility	Ehrhardt, 2016		Bieliński&Ważna, 2020
	Baum et al., 2019		Nascimento et al., 2020
	Serrano-Hernandez et al., 2021	Consolidation facility	Fikar&Gronalt, 2018
	Carradedo and Mostofi, 2022	Willingness-to-pay	Engelhardt, 2023
Land use	Schnieder et al., 2020	-	

Table 2. Exclusion criteria

7) Scope definition – together with the 9 papers for snowball sampling, 71 papers published from 2014 to 2023 relating to the application of electric cargo bikes in the field of urban logistics are selected out of 77 papers for further research.
Phase 2: literature analysis
Regarding the analysis method, the approaches employed in previous review papers (Mangiaracina et al., 2019; Bosona, 2020; Narayanan and Antoniou, 2022; Golinska-Dawson and Sethanan, 2023) were examined. The analysis in this study was conducted as follow: firstly, the main characteristics of papers including the year of publication, region/country, and the source title will be summarised first. Then, papers are analysed by content. The analysis process will be conducted by cross-checking among other authors to ensure the work is unbiased. By following this approach, it became feasible to fulfil the primary research objective. This involved elucidating the key topics behind each research question, providing insightful theoretical knowledge with stakeholders, and identifying research gaps that warrant further investigation in the future.
Phase 3: further research direction
Based on the findings obtained in the previous stage, gaps in the literature were identified. Specifically, shortcomings in existing contributions were delineated, and recommendations for future research endeavours were put forth.

DISCRIPTIVE ANALYSIS OF THE LITERATURE

In terms of the years of publication, from 2014 to 2019, cargo cycle deliveries had gained limited attention and interests from the academic and practical sections. The remaining 51 papers are published from 2019 to 2023. This may be due to the realisation of the noticeable advantage of ECCs from both academics and practitioners.

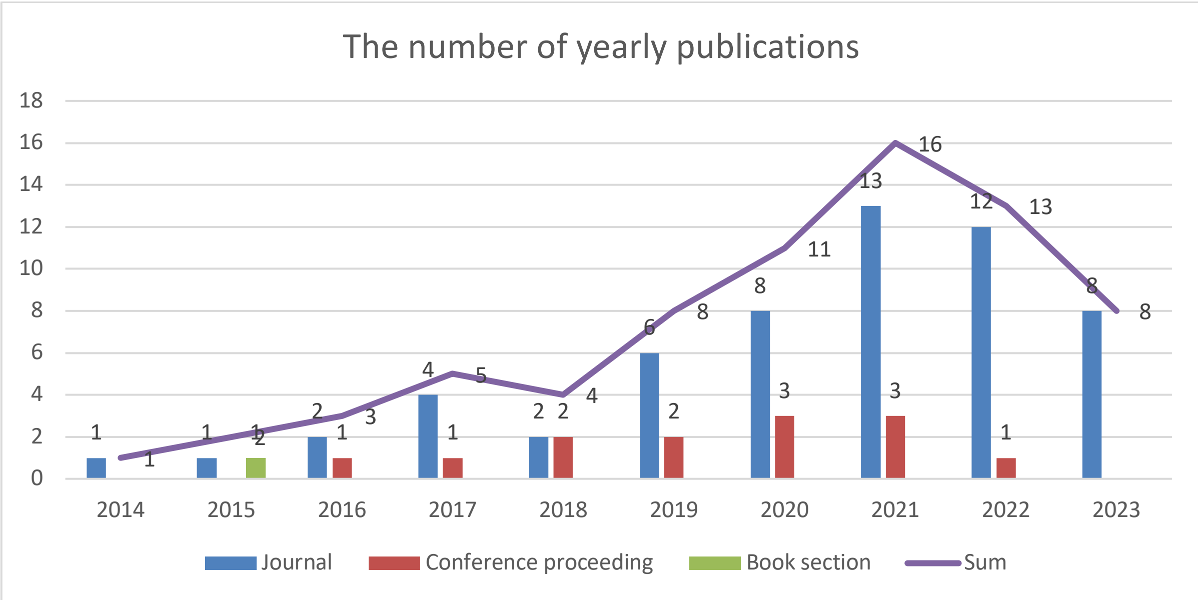

Figure 1: The number of papers published yearly categorised by different resource type.

In terms of the countries (Figure 2), this topic was mostly developed in Germany (21). This may because most of the top logistics companies in the world such as DHL, DB Schenker, UPS, and FedEx are from these two countries. Also, these logistics companies are inspired by and leading the trend of green logistics with enough resources to trial new logistics concepts. In addition, Germany has highly developed infrastructures, high-tech warehouses and the most developed logistics network that is ahead of most European countries. The second largest contribution to this topic is by Poland (7), Italy (7), and US (5). The rest of countries have less contributions than 5.

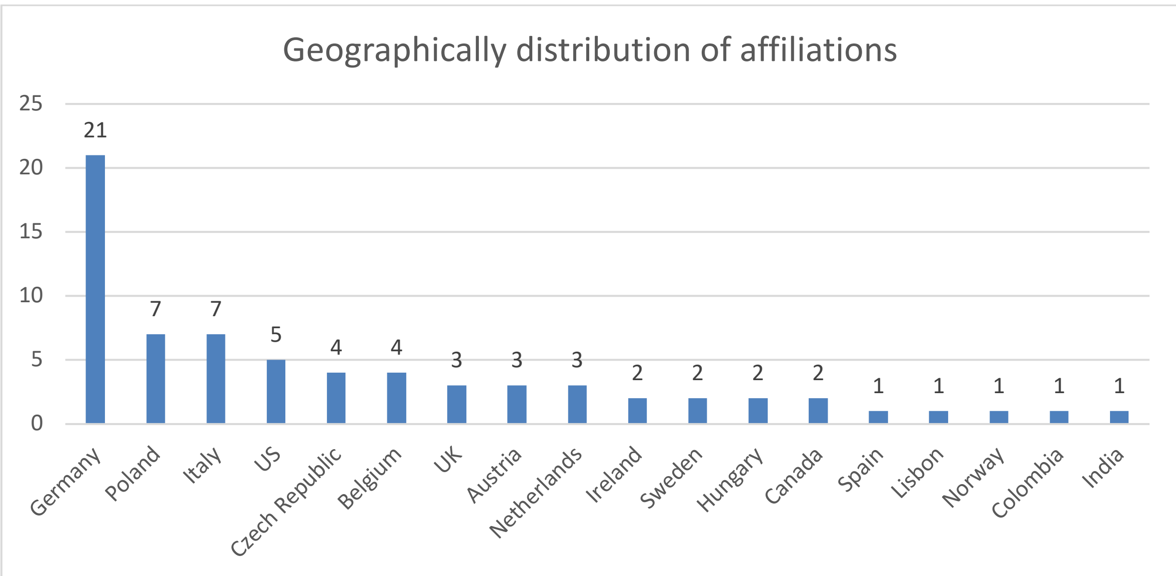

Figure 2: Number of papers published in different countries

In terms of the sources of the selected papers (Table 3), more than half of the journal papers (31/57) were published in journals pertaining to the field of transportation, followed by energy and sustainability (14), operations (4), logistics (4), and others (4).

Type & sum	**Journal**	**Num**
Transportation 31	Transportation Research Procedia	7
	European transport research review	4
	Research in Transportation Business & Management	4

	Transportation research part A: policy and practice	3
	Case studies on transport policy	2
	Transportation Research Interdisciplinary Perspectives	2
	EUROPEAN TRANSPORT/TRASPORTI EUROPEI	1
	International Journal of Sustainable Transportation	1
	Journal of Transport Geography	1
	Journal of Transportation Engineering, Part A: Systems	1
	Transportation research record	1
	Transport policy	1
	Transportation Research Part C: Emerging Technologies	1
	IEEE Transactions on Fuzzy Systems	1
	Transportation Science	1
Energy/ Sustainability 14	Energies	7
	Sustainability	4
	Renewable and Sustainable Energy Reviews	1
	Environmental science & technology	1
	Energy Research & Social Science	1
Operations 4	Computers & Operations Research	2
	Central European Journal of Operations Research	1
	European Journal of Operational Research	1
Logistics 4	International Journal of Logistics Research and Applications	1
	International Journal of Physical Distribution & Logistics Management	1
	Logistics Journal: Proceedings	1
	Logistics Research	1
Others 4	Applied sciences	2
	Procedia CIRP	1
	IEEE Access	1
Total	Total	57

Table 3. Journal paper source

FINDINGS

The limitations of ECCs

Limitation 1: Payload capacity

The payload capacity of ECCs indicates both the capacity in weight and in volume. The weight capacity varies depending on different vehicle configurations (Table 4). For example, the weight capacity for cargo bikes, trailers, trikes, and quad ranges from 24-300kg, 32kg-60kg, 100-600kg, and 150-300kg respectively. Also, the threshold weight capacity of cargo trikes and quads is higher than that of cargo bikes, but the weight capacity of different vehicle types overlaps to some extent.

Type	Load (kg)	Citation	Type	Load (kg)	Citation
Bike	50	(Perboli and Rosano, 2019)	Bike	300	(Temporelli et al., 2022)
	70	(Johnson and Chaniotakis, 2021)		50-75	(Nürnberg, 2019)
	80	(Caggiani et al., 2021)		50-100	(Vasiutina et al., 2022)
	100	(Fikar et al., 2018)		50-120	(Naumov and Pawluś, 2021)
	100	(Sárdi and Bóna, 2018)		150-300	(Choi et al., 2021)
	100	(Bayliss et al., 2023)	Trike	250	(Clausen et al., 2016)
	120	(Schünemann et al., 2022)		272	(Sheth et al., 2019)
	125	(Sheth et al., 2019)		500	(Nürnberg, 2019)

	150	(Naumov, 2021)		500	(Naumov and Pawluś, 2021)
	180	(Hofmann et al., 2017)	Quad	150	(Dybdalen and Ryeng, 2022)
	250	(Fraselle et al., 2021)		300	(Aiello et al., 2021)
	300	(Taefi et al., 2015)	-		

Table 4: Payload capacity of ECCs in weight

For the volume capacity (Table 5), both the cubic meter of the storage chamber and the number of package (pkg) the chamber can store are used to indicate volume capacities. The cargo bikes' capacity varies from 1000L-1750L (16-50 parcels). The volume capacity of one type of cargo trike and cargo quad is 2500L and 1000L respectively. For the bike type, 40 pkgs of volume capacity is mostly mentioned. Similar to weight capacity, the volume capacity does not show an obvious increase with the increased number of wheels.

Type	Result	Citation	Type	Result	Citation
Bike	245L	(Sárdi and Bóna, 2021)	Bike	40 pkgs	(Sheth et al., 2019)
	1000L	(Hofmann et al., 2017)		40 pkgs	(Assmann et al., 2020)
	1000L	(Bayliss et al., 2023)		40 pkgs	(Büttgen et al., 2021)
	1750L	(Temporelli et al., 2022)		40 pkgs	(Kania et al., 2022)
	16 pkgs	(Anderluh et al., 2017)		40-50 pkgs	(Niels et al., 2018)
	20 pkgs	(Llorca and Moeckel, 2020)	Trike	2500L	(Clausen et al., 2016)
	20 pkgs	(Llorca and Moeckel, 2021)	Quad	1000L	(Aiello et al., 2021)

Table 5: Payload capacity of ECCs in volume

Although ECCs have a noticeable advantage regarding their small size, which enables them to park on narrow streets without causing traffic jam(Seeck and Engelhardt, 2021) and to manoeuvre in historical city centres (Ledvinová and Seidlová, 2019; Castillo et al., 2022), this advantage also become one of the major drawbacks of limited payload capacity (Seidlová and Ledvinová, 2020; Naumov and Pawluś, 2021). Compared to conventional vans/trucks, payload capacity of ECCs only account for 15%-20% that of conventional vans (Kania et al., 2022), so that the size and weight of goods to be delivered compared to the payload capacity become a crucial factor for the cargo cycles operations (Giglio et al., 2021). Although some electric cargo bikes' capacity is comparable with the capacity of light commercial vehicles (Naumov, 2021), optimising space-saving loading and packing operations are even more important than conventional transportation modes in urban logistics (Naumov and Pawluś, 2021), because the low use of vehicle capacity will reduce the effectiveness of last-mile logistics (Bosona, 2020). When customers are widely dispersed (Boysen et al., 2023), limited load capacity becomes a significant barrier to implement the bike distribution system, forcing the bikes to be stored closer to final customers (Dalla Chiara et al., 2023) with high population density (Himstedt and Meisel, 2023) to avoid rendering the routing inefficient (Arnold et al., 2018).

Limitation 2: Battery range

From the literature (Table 6), the battery range for electric cargo bikes ranges from 19-100km, while only one study states that the range for an electric cargo trike is 20km. The battery range currently aimed at by most manufacturers is between 50 and 100 km (Schier et al., 2016), while 90% of delivery tours travelled by ECCs are up to 75km (Gruber et al., 2014). However, short range is still a limitation of ECCs (Naumov and Starczewski, 2019) as the achievable battery range depends on many factors such as battery size, the number of stops, payload, degree of acceleration, riding style, and topography and weather (Schier et al., 2016; Schünemann et al., 2022). With limited battery range, ECCs have to plan their route considering the requirement to maintain a charge battery (Sherriff et al., 2023), and can only serve a relatively small area on a single charge (Naumov and Pawluś, 2021) and its adoption will be affected by this (Fraselle et al., 2021; Giglio et al., 2021).

Type	Range	Year	Citation
Bike	100km	2015	(Taefi et al., 2015)
	100km	2017	(Fikar et al., 2018)
	90km	2018	(Sárdi and Bóna, 2018)
	19-40km	2019	(Sheth et al., 2019)
	90km	2021	(Sárdi and Bóna, 2021)
	80km	2021	(Büttgen et al., 2021)
	100km	2021	(Naumov and Pawluś, 2021)
	20km	2022	(Kania et al., 2022)
	25-30km	2022	(Schünemann et al., 2022)
	60km	2022	(Temporelli et al., 2022)
Trike	20km	2016	(Clausen et al., 2016)

Table 6: Battery range of different types of ECCs

Limitation 3: Riding speed
Cargo bikes are not a comprehensive solution for delivery companies due to their restricted speed capabilities on larger roads (Şahin and Yaman, 2022). The average speed of ECCs ranges from 10 to 24km/h in the literature (Table 7). Although there is no regulation restricting the volume, weight and the type of the payloads a ECC can carry, the maximum riding speed and power are limited up to 25km/h and 1000W respectively (Gonzalez-Calderon et al., 2022)(Gonzalez-Calderon et al., 2022). The deployment of cargo bikes can worsen speed and increase delay times (Assmann et al., 2020).

Average speed	Citation
10km/h	(Aiello et al., 2021)
12km/h	(Arnold et al., 2018)
15km/h	(Sárdi and Bóna, 2018; Dybdalen and Ryeng, 2022)
20km/h	(Llorca and Moeckel, 2021)
24km/h	(Bosona, 2020; Llorca and Moeckel, 2021)

Table 7: Average riding speed of ECCs

Limitation 4: Charging time
The recharging time is also a substantial limitation of ECCs (Aiello et al., 2021). According to Melo and Baptista (2017), Sheth et al. (2019) and Malik et al. (2023), a depleted battery requires 4 to 8 hours to be fully charged.
Limitation 5: Terrain adaptability
In some hilly area, ECC faces the inability in climbing steep slopes (Sheth et al., 2019; Bosona, 2020).
Limitation 6: The possibility of defect/Malfunction
ECCs will suffer from insufficient quality of cargo cycles' components (Rudolph and Gruber, 2017; Vasiutina et al., 2021) due to some of the built-in components are designed originally for recreational riding so that cannot withstand the additional payload (Nürnberg, 2019). In addition, the high load on ECCs will shorten their lifetime as well (Pérez-Guzmán et al., 2022).
Limitation 7: Service monotony
The variety of packages ECCs can transport and which supply chain they can be part of will be restricted (Dybdalen and Ryeng, 2022). For example, the small payload restricts cargo bikes purely to courier work such as documents and small dimension parcels (Schliwa et al., 2015; Nürnberg, 2019), which constitute the majority of the B2C deliveries (Rai et al., 2019). Additionally, extremely heavy packages are not suitable for cycle deliveries either (Rajendran and Harper, 2021).

The relationship among limitations of ECCs

The relationships between limitations of ECCs are shown in the figure below:

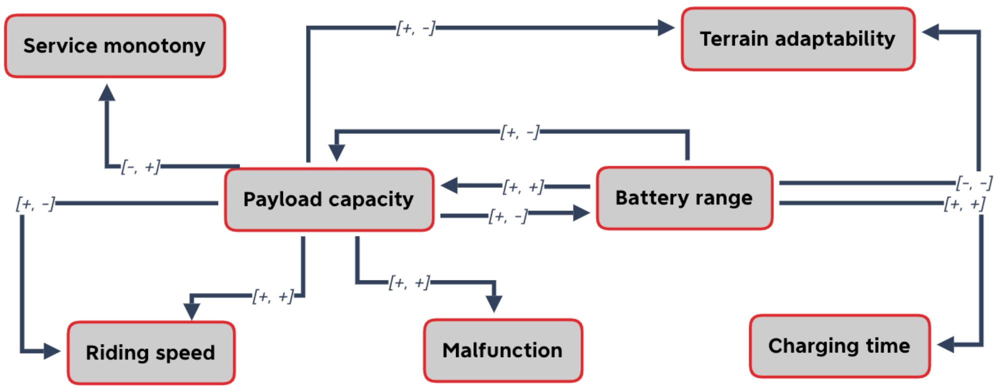

Figure 3. The relationship among limitations of ECCs that affect their adoption

The limitation of payload capacity of ECCs become one of the most important factors due to its various impacts on other limitations. ECCs have limited capabilities in terms of the payload weight and volume in turn restricted the variety of packages they can transport and the supply chain they can be part of (Dybdalen and Ryeng, 2022), which deteriorate the limitation of service monotony. However, the impacts of increasing payloads in weight are also worth to mention. For instance, due to the power limitation (250W) of ECCs (Aiello et al., 2021), the acceleration and top speed are highly dependent on vehicle payload (Naumov and Pawluś, 2021). ECCs tend to move slower due to the weight being carried (Lachapelle et al., 2021; Ceccato and Gastaldi, 2023). In some situations, loading more than three-quarters of the available loading capacity will substantially slow down the riding speed (Gruber and Narayanan, 2019). On the other hand, the impact of payload on riding speed can be totally different when ECCs riding on downhills where the components of weight along the slope will be turned into power, so that the speed of ECC will gain a lot when going downhill (Dybdalen and Ryeng, 2022). Besides that, the achievable battery range will be significantly affected by payload. More specific, the energy consumption of the powertrain can double from 0.783kWh for the empty payload to 1.447kWh for the full payload (Fraselle et al., 2021). In addition, the exceed payload in weight can also decrease the terrain adaptability of ECCs; due to the fact that slopes become difficult to climb if the cargo bike is heavily loaded (Rudolph and Gruber, 2017). The last main impact of exceed payload in weight is high possibility of malfunction. Some built-in components of ECCs are originally designed for recreational riding and may not be robust enough to withstand the additional payload (Nürnberg, 2019; Pérez-Guzmán et al., 2022).

The second most crucial limitation of ECC is battery range. The maximum payload in weight during operation will be restricted by the battery range (Gruber and Kihm, 2016; Melo and Baptista, 2017; Aiello et al., 2021). In addition, as the battery range will be constrained when operating in topographically moved areas (Choi et al., 2021), the limited battery range will negative affect the abilities in operating in hilly terrains. On the other hands, the battery range is not the bigger the better. Although increasing the battery capacity allows for longer delivery routes, it also reduces the available payload due to the battery's weight occupancy, therefore reducing the number of serviceable clients (Aiello et al., 2021). Additionally, it is common knowledge that a larger battery capacity corresponds to a longer charging time. This observation can be easily confirmed by referring to the information provided on the official websites of ECC powertrain manufacturers such as BOSCH, YAMAHA, SHIMANO, etc.

Among all the identified limitations of ECC, payload and battery range have the same effect on certain variables. On the other hand, they are also a pair of mutually restraining variables – an increase in one leads to a decrease in the other. In addition, the payload capacity and battery range are the most impactful and interconnected. In other words, the other five limitations are all related to either the payload capacity, battery range, or both, while there is no identified connection among these five limitations except for their relationship to the payload capacity and battery range. Among the two most influential and interrelated limitations, the payload capacity stands out as the primary factor affecting all other limitations, except for charging time. Compared to payload capacity, although the battery range connects lower number of limitations including payload capacity, charging time, and terrain adaptability, it can affect the payload capacity bidirectionally. The payload capacity can also be capable to achieve this, impacting riding speed bidirectionally, instead of battery range. Both the payload and battery range can affect the terrain adaptability of ECCs, when an overloaded ECC equipped with insufficient battery capacity, the terrain adaptability suffer the most. Lastly, the total design weight of the vehicle is not only determined by the cargo capacity but also affected by the battery size: the larger the battery capacity, the heavier the self-weight.

The impacts of identified shortcomings on ECCs' advantages

Based on the literature, it is evident that out of the seven limitations identified in the previous section, only four of them have the potential to weaken the advantages of ECCs (Figure 4). It is also important to note that the advantages mentioned below are not exhaustive. There are additional benefits associated with ECCs, but they haven't been found being related to any of the limitations identified in last section.

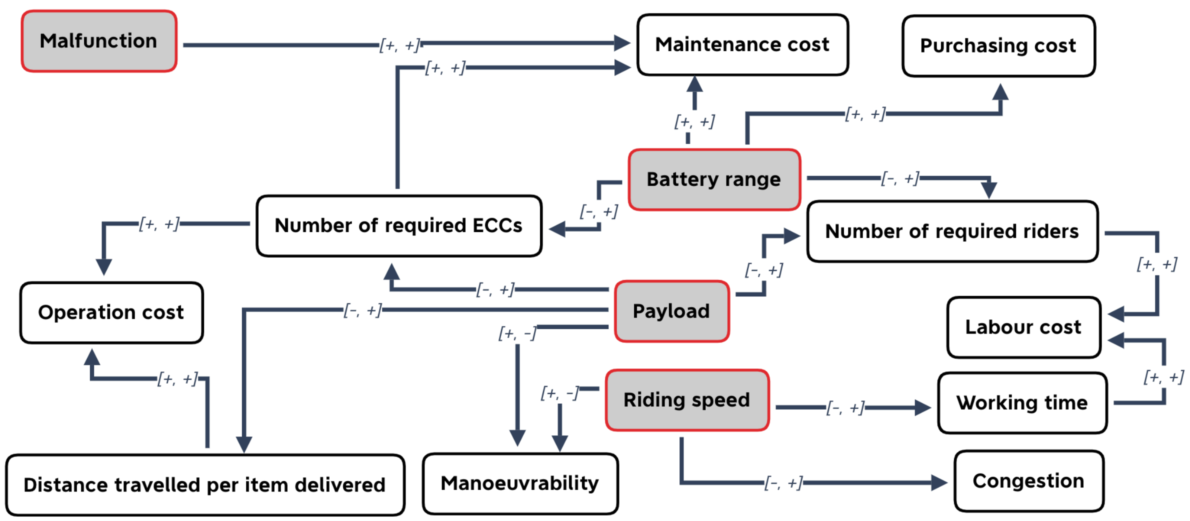

Figure 4. The relationship between the limitations and advantages of ECCs

Affected advantage 1: Low operation cost (Rajendran and Harper, 2021)

Both the limited payload capacity and battery range necessitate a higher number of ECCs (Clausen et al., 2016), which significantly increase the running cost in the initial stage. In addition to the higher number of ECCs, limited payload capacity can also result in excessive delivery traffic in city centres (Boysen et al., 2023) and the increased number of required tours (Hofmann et al., 2017), consequently further increases the distance travelled per item delivered (Arvidsson and Pazirandeh, 2017; Assmann et al., 2020).

Affected advantage 2: Low labour wage (Saha et al., 2022)

While the limited payload capacity, limited battery range, and low riding speed can all potentially compromise the advantage of ECCs in terms of low salary, it is important to recognize that they affect this aspect in different ways. The wage costs are determined by both the duration of a delivery tour and the number of personnel required (Kania et al., 2022). Due to the low riding speed, there is an expected increase in travel time, thus working time (Arnold et al., 2018; Bayliss et al., 2023). In addition, either of the limited payload capacity and battery range can also force the logistics companies hiring more riders to deliver the goods (Clausen et al., 2016; Arvidsson and Pazirandeh, 2017).

Affected advantage 3: Low maintenance cost (Taefi et al., 2015)

No matter how big the battery capacity is, the battery needs to be replaced when reaching the charging cyclical lifetime (500-1000 charging cycles) (Sheth et al., 2019; Schünemann et al., 2022). From the above, when choosing battery capacity, not only the initial investment, but also the later maintenance cost should be considered. In addition to

battery range, the increase in the required number of ECCs and frequent malfunction of ECCs due to its defect can also increase the maintenance cost considerably.
Affected advantage 4: Low purchasing cost (Ramírez-Villamil et al., 2022)
The battery is a costly component of ECCs and is directly linked to the purchasing price (Gruber et al., 2014). As the battery capacity increases, its cost also rises, consequently leading to an overall increase in the purchasing price of ECCs.
Affected advantage 5: Manoeuvrability (Enthoven et al., 2020)
Designing for maximum payload could lead to the increase in braking distance and turning radius (Rudolph and Gruber, 2017), thus compromising the manoeuvrability of ECCs (Moolenburgh et al., 2020). The increase in riding speed can also scarify the manoeuvrability by increasing the braking distance, especially riding on downhill terrains (Dybdalen and Ryeng, 2022).
Affected advantage 6: Traffic benefits (Sárdi and Bóna, 2021)
Regardless of the cause, the slow riding speed of ECCs contributes to traffic congestion (Seidlová and Ledvinová, 2021), resulting in longer delays (Melo and Baptista, 2017).

RESEARCH GAPS AND FUTURE DIRECTIONS

The literature on the adoption of ECCs in logistics contexts is still growing. However, several research gaps deserve further study. Firstly, in addition to vehicle-related barriers, other factors from environmental (Dybdalen and Ryeng, 2022), infrastructural (Llorca and Moeckel, 2021; Rajendran and Harper, 2021), and regulation perspectives (Rudolph and Gruber, 2017; Seidlová and Ledvinová, 2020) can also affect the adoption of ECCs. And the relationship between different factors belonging to different aspects is still not clear. Therefore, there is a need to conduct a further review regarding a comprehensive framework of the factors affecting the adoption of ECCs and their relationships with each other. By doing this, potential ECCs users can have a more comprehensive understanding of the feasibility of adopting ECCs depending on their specific situation.
Besides understanding the fundamentals of ECC, it is crucial to investigate the well-being of riders and the operational risks faced by logistics companies when considering the implementation of ECC. These factors play a significant role in influencing the intentions of both riders and logistics companies to embrace ECC (Thoma and Gruber, 2020; Narayanan et al., 2022). Hence, it is essential to identify the specific elements that contribute to the welfare of riders and the operational risks encountered by logistics companies, as well as the factors that impact these elements.
Afterward, in terms of the battery range, although some of the literature mentioned that ECCs can travel 50-100km depending on a single charged battery(Schier et al., 2016), there is seldom information about whether this battery range is a nominated battery range or an achievable battery range. This piece of information is crucial as the achievable battery range is largely affected by the external environment and usage scenarios (Schünemann et al., 2022). In addition, despite a few studies has briefly mentioned that the advancement of battery and charging technology, such as fast charging can facilitate the successful implementation of ECCs (Gruber et al., 2014), there is currently a lack of research on the potential impact of utilizing these technologies in conjunction with ECCs to tackle the issue of limited battery range. Consequently, further research is essential to assess the impact of different factors in different cases on the achievable battery range and the feasibility of implementing battery swapping or fast charging technology for ECCs.

CONCLUSIONS

In the process of this review, the literature relating to electric cargo cycles in logistics fields has been explored and synthesized. Throughout this review, we summarized the impact of each limitation of ECCs on both the limitations themselves and the advantages of ECCs. This provides logistics service providers with a theoretical support for decision-making, deployment, and application, which enables LSPs to have a better understanding and clear judgement on the adoption of ECCs. Since not all limitations of ECCs are likely equally important for ECC users, they must learn to differentiate which limitation of ignore and which limitation to address depending on their specific circumstances. Finally, gaps in the literature were illuminated, followed by further research directions identified throughout our review process. In developing the future research agenda, this review establishes a foundation for further exploring the integration of ECC with external environment, people, and novel technology to be empirically evaluated by researchers and consequently provide insights to practitioners with broader scope.

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APPENDIX

Title	1st author	Year

Sustainable mobility for Berlin - Green.Smart.Digital.	Ehrhardt F.	2016
Designing light electric vehicles for urban freight transport	Hogt R.	2017
Agent-based simulation of restaurant deliveries facilitating cargo-bikes and urban consolidation	Fikar C.	2018
Functional perceptions, barriers, and demographics concerning e-cargo bike sharing in Switzerland	Hess A.-K.	2019
State of the art - Automated micro-vehicles for urban logistics	Baum L.	2019
Characterization and analysis of the economic viability of cycle logistics transport in Brazil	Nascimento COL.	2020
Review and development of a land consumption evaluation method based on the time-area concept of last mile delivery using real delivery trip data	Schnieder M.	2020
Sustainable performance of cargo bikes to improve the delivery time using traffic simulation model	Ben Rajesh P.	2020
Electric scooter sharing and bike sharing user behaviour and characteristics	Bieliński T.	2020
The Urban Freight Distribution in Medium Size Cities: Descriptive Data Taken from Pamplona (Spain) and Angers (France)	Serrano-Hernandez A.	2021
Development of a General Specification Sheet for Heavy-Duty Cargo Bikes	Bogdanski R.	2021
A Simulation-Optimization Approach for the Management of the On-Demand Parcel Delivery in Sharing Economy	Perboli G.	2022
Development of An Electric Tricycle for Service Companies and Last-mile Parcel Delivery	D’Hondt J.	2022
Electric cargo bikes in urban areas: A new mobility option for private transportation	Carracedo D.	2022
Who is willing-to-pay for sustainable last mile innovations?	Engelhardt M.	2023

Appendix table 1. Excluded papers