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# Electric cargo cycles - A comprehensive review

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ABSTRACT

Electric cargo cycles (E-cargo cycles) have the potential to reduce the negative impacts of transportation systems, when utilised for the right application. There is a growing literature pertaining to them, especially for commercial transport. It is essential to have a comprehensive outlook of the prevailing literature to synthesise the existing knowledge base. Therefore, this work comprehensively consolidates the studies in the growing field of E-cargo cycles. The primary focus is on commercial transport. However, insights obtained from the very limited number of studies pertaining to private transport is also presented. Within commercial transport, the focus is on typology, penetration, impacts, and operational and policy requirements. The typology is developed based on (i) Trip type, (ii) Network configuration, and (iii) Fleet composition. The factors influencing the penetration of E-cargo cycles are identified and classified into six groups, namely (i) Operation, (ii) Vehicular, (iii) Infrastructural, (iv) Workforce, (v) Organisational, and (vi) Policy. Furthermore, the impacts of E-cargo cycles are categorised as (i) Economic, (ii) Environmental, (iii) Societal, (iv) Traffic and safety, (v) Operational, and (vi) Governance. Besides, factors that influence the impact on cost-of-using E-cargo cycles are found and grouped under (i) Customer, (ii) Operator, and (iii) Policy maker. To facilitate the selection of network configuration and fleet composition, when beginning to utilise E-cargo cycles, a simplified decision making scheme is provided. Policy requirements discussed in the pertinent literature are also described and categorised as (i) Regulatory, (ii) Incentive, (iii) Infrastructural, and (iv) Awareness creation. Finally, a typology is provided for private transport, along with a summary on penetration and impacts.

## 1. Introduction

Policy makers around the world are attempting to minimise environmental impacts in their cities and make cities more liveable. One of the major sectors of concern within this regard is Transportation. Urban transport accounts for 23% of greenhouse gas emissions in the EU (European Commission, 2016). Along with environmental footprint, planners are also concerned about congestion issues, and their economic implications. Every year, road congestion in Europe costs around 1% of GDP (Christidis and Rivas, 2012). Therefore, sustainable solutions are in need of the hour.

One of the possible strategies, conceived to reduce the negative effects of transportation systems, is the application of electric cargo cycles (E-cargo cycles) in both commercial and private transport. E-cargo cycles lie in between conventional cargo cycles and cars, in terms of cost, payload and range (Gruber et al., 2014), and enable both greater loads and larger distances than conventional cargo cycles, overcoming their common disadvantages, such as lower range, lower payload and driver fatigue (Transport for London, 2009). They are especially suitable in dense urban areas, for example city centres (Schliwa et al., 2015), allowing easy movement in narrow historic streets, where cars cannot travel. In several situations, cargo cycles are competitive to conventional motorised vehicles in terms of travel time (Gruber and Narayanan, 2019). Furthermore, they do not result in any local emissions.

There is a growing interest for E-cargo cycles around the world, especially as an alternative to cars and small delivery vans. In Germany alone, there are 60 manufacturers specialized in cargo cycles (Internationale Automobil-Ausstellung, 2019). Car manufacturers, like Volkswagen, have started conceptualising the development of new E-cargo cycles (Volkswagen, 2018). However, reservations exist when it comes to their application and their full potential is yet to be utilised. Policy makers and businesses are still uncertain about their suitability. One of the possibilities to reduce the reservations against them is to discern and assimilate the collective knowledge from the existing studies in the pertinent literature. Such a review of existing literature should cover a wide range of literature and make conclusions that are supported

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by the evidence cited, thereby providing value to the reader (van Wee and Banister, 2016). Hence, the main objective of this research is to comprehensively review the studies on E-cargo cycles, for various facets of their application, including but not limited to typology, penetration, impacts and policies required.

Although E-cargo cycles can be used for both private and commercial transport, the current literature concentrates more on the latter, and only a few studies are available for the former. Hence, this review predominantly focuses on the application of E-cargo cycles in commercial transport, although the studies related to private transport are also reviewed at the end. Furthermore, it is to be noted that the existing literature predominantly focuses on Europe, with few exceptions, focusing on other locations such as Austin, Portland, Seattle, Rio de Janeiro, São Paulo, Seoul and Singapore. The geographical areas of focus of the reviewed studies are shown in Fig. 1.

A few studies not specific to E-cargo cycles are included, since they are applicable to both electric and human-powered cargo cycles, or cycles in general. The documents reviewed in this research include journal papers, conference papers, policy papers and technical reports. A semi–structured approach is followed starting from collecting studies from Scopus, based on 4 keywords (*cargo cycle, cargo bike, electric cargo cycle, E-cargo cycle*), for the publication year range 1950–2021.[1] The automated python code developed to query the Scopus database is made available in an open source GitHub repository.[2] The obtained studies are screened based on their relevance and topics. Additional papers are obtained from the references of the screened papers.

According to the year of the reviewed studies, studies published until 2015 focus on demand and policy related aspects. From 2016, studies also concentrate on impacts (including costs and environmental aspects). From 2017, the following further topics have gained emphasis: typology and operational aspects (including network configuration), with a strong attention found for network configuration from the year 2019. The contributions of this research work are summarised as follows:

- Overview of E-cargo cycle typology. The typology presented can assist policy makers and businesses to obtain an overview of different types of systems that are being discussed in the pertinent literature and are possible to be deployed.
- Evaluation of their penetration and the influencing factors. A discussion on the penetration and the influencing factors supports in understanding the potential of E-cargo cycles.
- Categorisation of the impacts expected. Categorised impacts help relevant stakeholders to recognise the effects of introducing E-cargo cycles.
- Exploration of policy and operational requirements. The insights obtained on policy and operational requirements can guide policy makers and businesses, for a better planning of E-cargo cycle deployment.
- Identification of research gaps, which will be beneficial for future research.

This paper is structured as follows: an overview of the typology and relevant characteristics pertaining to commercial transport are presented (Section 2), followed by a discussion on penetration (Section 3). Then, the impacts of E-cargo cycles are consolidated (Section 4). Afterwards, operational framework and policy requirements are explored (Section 5). Subsequently, a section is included for the insights synthesised for the private transport (Section 6). Finally, major conclusions and research gaps are distilled (Section 7). Table A1 in the Appendix contains a brief description of studies examined in this review work.

[1] The search was completed in February 2021, thus included sources available in the database at that point.

[2] https://github.com/nsanthanakrishnan/Scopus-Query.

## 2. Typology and characteristics

The term "cargo cycle" comprises of a wide variety of adapted cycles, designed to carry heavy and bulky loads or passengers (e.g., children). Cargo cycles used to constitute a major portion of the urban traffic in 1920s and 1930s (Internationale Automobil-Ausstellung, 2019). They were a critical part of the business model of merchants, craftsmen and factories. The delivery bike, box bike (Bakfiets), butcher bike and deli bike used to be the common symbols of the working class (Mechanic - Bicycle Pro Shop, 2019). Many hungry families in Netherlands utilised cargo cycles during the winter famine in 1944 to pick up food from their farming relatives, and trikes were deployed to evacuate villages along the river Meuse and elsewhere (Kirkels, 2016). Decline in the use of cargo cycles during the late 1950s and the early 1960s could be attributed to the rise of pickup trucks and vans and increasing ownership of cars. A revival started taking place in 1980s in Denmark and Netherlands (Internationale Automobil-Ausstellung, 2019). In 1984, Lars Engstrom, a blacksmith, built a cargo cycle, which was a tricycle with two front wheels on either side of a large cargo box (Agency, 2019). Successful development of cargo cycles began in the early 2000s, which brought the cargo cycles to the 21st Century (Mechanic - Bicycle Pro Shop, 2019).

A natural progression with the advent of modern technologies is the emergence of E-cargo cycles. Today, a wide variety of E-cargo cycles are available in the market, with different battery range, load capacity and cargo box volume, and each variety has its own purpose. Today, E-cargo cycles are capable to transport 50–250 kg of cargo (with exceptions up to 500 kg), and have a battery range of up to 50–80 km (Lenz and Riehle, 2013; Schier et al., 2016). The available models can be broadly divided into bikes (bicycles), trikes (tricycles) and quads (quadricycles), based on the number of wheels. Four-wheeled cycles also exist, although they are not generally allowed to use the cycle lanes in many countries. Based on vehicle construction type, Gruber and Narayanan (2019) enlist five different E-cargo cycles, which are (i) delivery bike, (ii) long john bike, (iii) longtail bike, (iv) front load tricycle and (v) heavy-load tricycle (see Fig. 2). The study includes empirical data based on 18 different models of E-cargo cycles, which are consolidated into aforementioned five groups. E-cargo cycles can have electrical assist up to 25 kmph or 45 kmph (the latter is usually prohibited from being driven in cycle lanes). There are two systems of motor, namely hub-drive and mid-drive (Babboe, 2020). While the former is meant for frequent riding on even roads with an occasional inclination, the latter is meant for frequent riding on hilly roads with an inclination of more than 3%. There are E-cargo cycles with walk-assist mode, which would allow easy movement even when someone is not cycling, for example from a bicycle rack to a bicycle path (Babboe, 2020). Furthermore, some models have weather protection (e.g., Faxér et al., 2018). Nutzfahrräder (2020) provides a catalogue of different cargo cycles available all over the world.

To enable decision makers (public authorities and industrial managers who work towards the deployment of fleets) to have an overview of the different systems of E-cargo cycle application in commercial transport, a typology is presented in Fig. 3 with a focus on operational aspects. As shown in the figure, the different systems can be commonly categorised on the basis of trip type, network configuration and fleet composition.

### 2.1. Trip type

Based on trip type, E-cargo cycle trips can be divided into service and delivery trips (Gruber and Narayanan, 2019; Wrighton and Reiter, 2016). Service trips refer to trips carried out by service providers and workmen travelling to customer's location, who have to carry some materials and tools to perform services (Rudolph and Gruber, 2017). Five among the six most relevant market segments identified by Rudolph and Gruber (2017) for commercial E-cargo cycle use fall under the

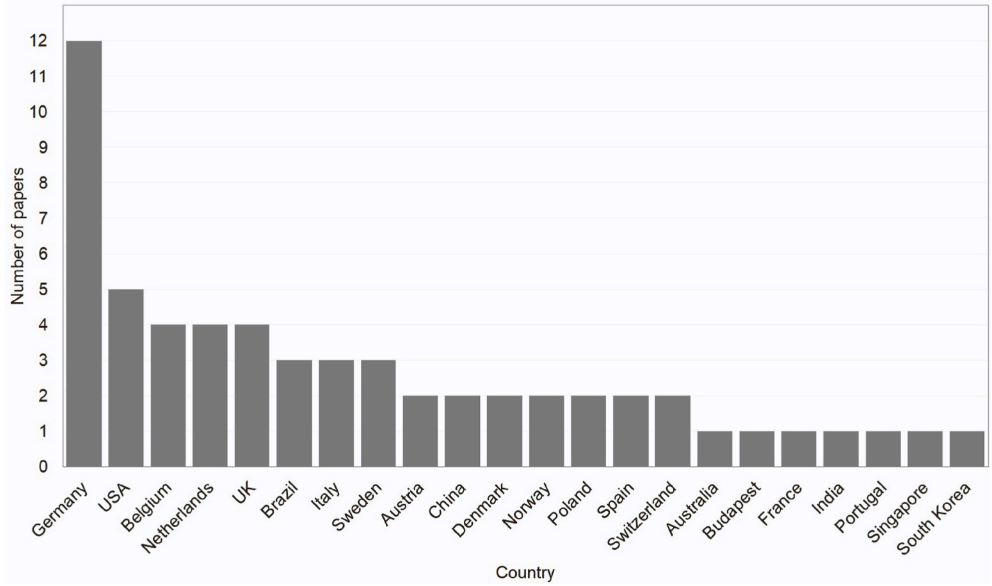


**Fig. 1.** Geographical areas of focus of the reviewed studies.

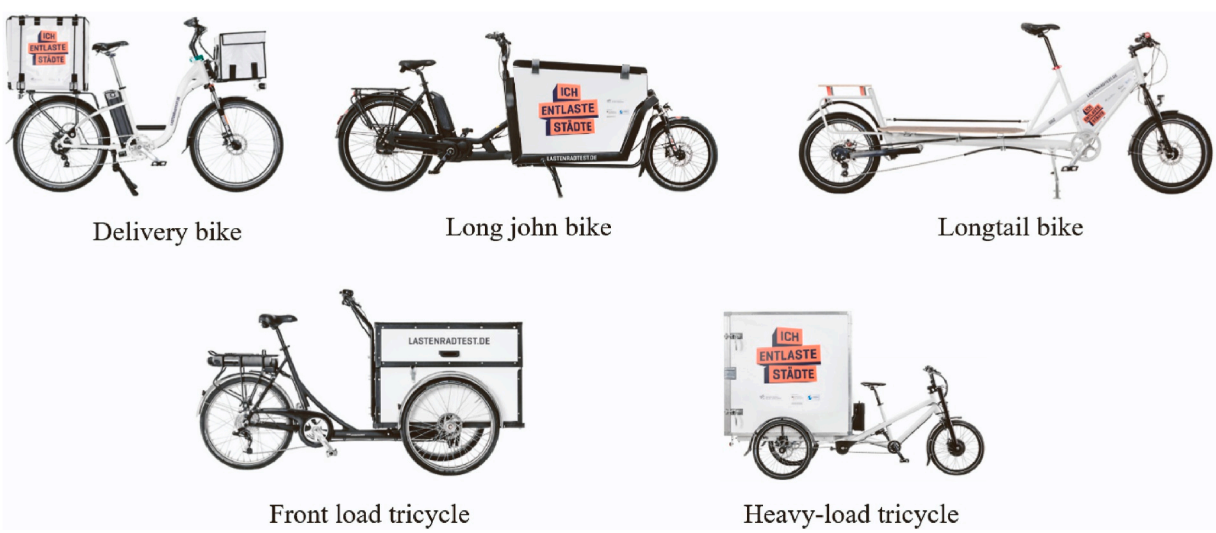


**Fig. 2.** Cargo cycles according to construction type (Gruber and Narayanan, 2019).

category of delivery trips. The five market segments are postal services, courier services, parcel services, home delivery services (e.g., restaurants and small retailers) and internal/on-site transport (transport activities within large company grounds). The sixth market segment is service trips. Travel between offices for meetings, during which there is a need to transfer goods (e.g., Faxér et al., 2018), could also be included under service trips.

### 2.2. Network configuration

With regards to network configuration, two variations can be observed, namely direct scheme (Faxér et al., 2018; Gruber and Kihm, 2016; Gruber and Narayanan, 2019; Lee et al., 2019; de Mello Bandeira et al., 2019; Moolenburgh et al., 2019; Narayanan et al., 2022; Nocerino et al., 2016; Nürnberg, 2019; Perboli and Rosano, 2019) and schemes with intermediate shifting (Arvidsson and Pazirandeh, 2017; Assmann et al., 2019, 2020; Athanassopoulos et al., 2016; Choubassi et al., 2016; Dalla Chiara et al., 2020; Enthoven et al., 2020; Hofmann et al., 2017; Leonardi et al., 2012; Tipagornwong and Figliozzi, 2014; Naumov and Starczewski, 2019; Marujo et al., 2018; Moolenburgh et al., 2019; Navarro et al., 2016; Niels et al., 2018; Nocerino et al., 2016; Ormond Junior et al., 2019a,b; Sardi and Bona, 2018; Verlinde et al., 2014). While transfer of parcels and packages to E-cargo cycles from other vehicles in a transshipment point occurs in the latter, delivery is carried out without transshipment in the former. Rudolph and Gruber (2017) state that the courier services (which are generally business-to-business deliveries with high value and strict time constraints) usually involve direct trips, while delivery using E-cargo cycles in parcel service segment requires application of a transshipment point. Service trips could also be included under the category of direct trips. Maes and Vanelslander (2012) mention direct trips carried out in advertisement sector, medical sector, administrative sector and legal industry as A-to-B trips.

With regards to the type of transshipment points used in schemes with intermediate shifting, Urban Consolidation Center (UCC; e.g., Leonardi et al., 2012), Micro-hub/Micro Consolidation Centre (MCC; e.g., Fikar et al., 2018) and Transit Point (TP; e.g., Marujo et al., 2018) are the different types found in the literature. An MCC is a small UCC for

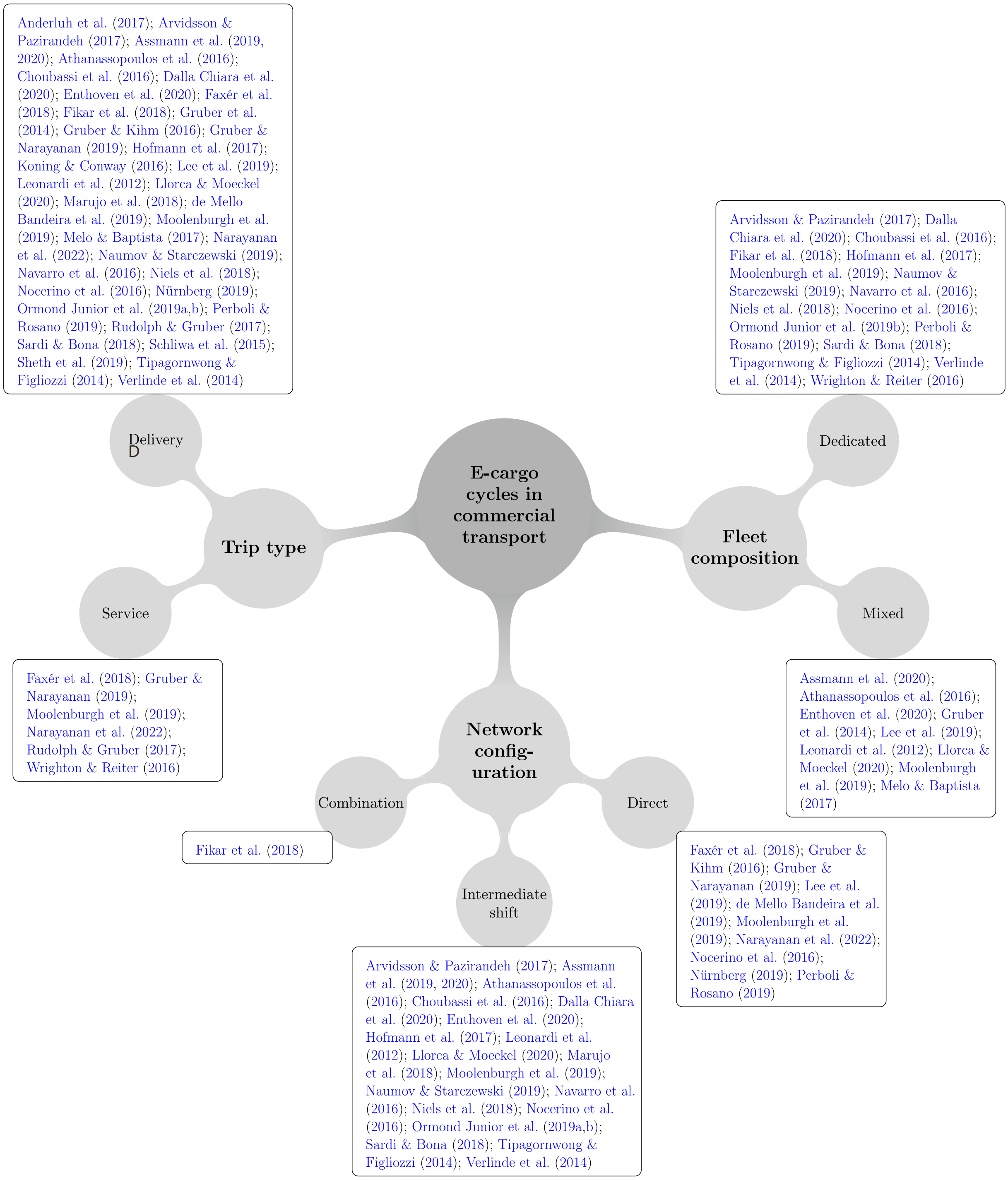


**Fig. 3.** Typology for e-cargo cycle usage in commercial transport and indicative references.

transferring and consolidating parcels, whose size can be equal to a container or smaller. Different operators could use an UCC or an MCC, and could share the same cargo cycle fleet for delivery from the transshipment point (Navarro et al., 2016; Ormond Junior et al., 2019a). In TPs (e.g., Athanassopoulos et al., 2016; Assmann et al., 2020), goods are not generally stored or consolidated and hence, is just a location (e.g., parking spaces) to transfer goods from other vehicles to E-cargo cycles. Therefore, temporal synchronisation (i.e., matching of arrival times, with a possibility for time windows) between the different vehicle fleets is required. Assmann et al. (2020) state two types of TPs, namely singular and cooperative TPs. In the former, a location is used by only one logistic provider, while several logistics providers use one location together in the latter. Although cooperative TPs are stationary, singular TPs can be stationary, semi-stationary or mobile.

Maes and Vanelslander (2012) suggest a city hub-and-spoke model, wherein a small storage space is utilised for package swapping. Such a model falls under the category of intermediate shifting. A mobile depot operation is studied in Arvidsson and Pazirandeh (2017). The idea is to utilise an existing transport network within a city. In Arvidsson and Pazirandeh (2017), a freight bus serves as the mobile depot with the use of E-cargo bikes for the last mile deliveries. This type of operation also falls under the category of intermediate shifting. Trips involving only the usage of existing facilities of the logistics companies such as regional terminals and depots (without a transshipment point introduced in between) are not considered as trips with intermediate shifting, but rather as direct trips. It is possible to combine direct trips and intermediate shifting. For example, in Fikar et al. (2018), an optimisation algorithm is utilised for the decision between direct trip and delivery through intermediate shifting. Hofmann et al. (2017) use the term 'Direct urban distribution scheme' for a system involving direct trips. They also mention two other distribution schemes, single-level and two-level urban distribution schemes, which could be included under the category of intermediate shifting. The former involve Depot-UCC, Depot-MCC and Depot-TP schemes, while the latter involve Depot-UCC-MCC and Depot-UCC-TP schemes. Depots are production sites or distribution centres or warehouses of single or multiple enterprises, generally located outside the urban area.

Apart from the above discussed schemes, novel approaches, such as intermodal combinations with busses (e.g., Arvidsson and Pazirandeh, 2017) and trains (e.g., Sutton, 2020) are also seen in the literature.

### 2.3. Fleet composition

Concerning fleet composition, an operator or a service provider may rely solely on E-cargo cycles, which can be called dedicated E-cargo cycle fleet (Arvidsson and Pazirandeh, 2017; Dalla Chiara et al., 2020; Choubassi et al., 2016; Fikar et al., 2018; Moolenburgh et al., 2019; Tipagornwong and Figliozzi, 2014) On the other hand, E-cargo cycles can also be used along with other modes, such as cars and vans. Such a fleet can be called mixed fleet (Assmann et al., 2020; Athanassopoulos et al., 2016; Enthoven et al., 2020; Gruber et al., 2014; Lee et al., 2019; Leonardi et al., 2012; Moolenburgh et al., 2019; Melo and Baptista, 2017). The indicative references for fleet composition in Fig. 3 are based on whether the analysis results are pertaining to a mixed fleet or only E-cargo cycles. Furthermore, in the case of intermediate shifting, fleet composition is considered for the trips from the transshipment point to the delivery point (or vice versa for pick-up trips, i.e., from the pick-up point to the transshipment point), since conventional motorised vehicles (vans and trucks) are predominantly used for the transport to the transshipment point (or from the transshipment point for pick-up trips). In case of mixed fleets, Maes and Vanelslander (2012) suggest to use E-cargo cycles for time sensitive deliveries, and other types of vehicles for the rest of the deliveries. This suggestion is based on the fact that cycles suffer less from road congestion issues, especially in the presence of dedicated cycle lanes. The multiple case studies analysed in Moolenburgh et al. (2019) show that E-cargo cycle fleets can be in-house or external.

For readers who are interested in the business model of the companies operating in E-cycle logistics, Ribeiro et al. (2015) present the business model overview of nine different companies from six different countries, operating in the field of application of E-cycles (both normal and cargo cycles). They present product related (key partners, activities, and resources), customer related (customer relationship, customer segments, and communication and sales channels) and finance related aspects (cost structure and revenue streams), along with value proposition.

## 3. Penetration and influencing factors

Benefits and impacts of E-cargo cycles depend on their substitution potential (in terms of usage possibilities). Furthermore, although there could be potential for their use, their real utilisation depends on several factors. Therefore, this section examines the existing literature to ascertain the penetration potential of E-cargo cycles, along with the identification of influencing factors. For a summary of the studies considered in this section, the reader is referred to Table A1 available in the Appendix.

### 3.1. Substitution potential

Based on a review of pertinent literature and a survey of experts, Lenz and Riehle (2013) conclude that a quarter of freight transport in a city centre could be carried out using (cargo) cycles. Furthermore, they conclude that it is possible for at least 30% of the existing operators to readily integrate cargo cycles into their fleet. For direct courier trips (see Section 2 for the definition of direct trips), 66%–83% of the deliveries could be made using E-cargo cycles (Gruber et al., 2013). This conclusion is based on the consideration of the distance of the trips, along with the weight and volume of the goods carried. Comparing the cycle freight between 2001 and 2014, Koning and Conway (2016) have observed that cycle freight accounted for more than 1107 total kilometres per day (tkm/day) in 2014 (compared to 103 tkm/day in 2001) in Paris. 63% of this 1107 tkm/day is associated with E-cargo cycles. Based on an analysis of an area with a linear distance of 2 km in Porto (Portugal), Melo and Baptista (2017) conclude that 10% of conventional vans can be replaced with E-cargo cycles, without changing the overall network efficiency.

Although it is unrealistic to state that E-cargo cycles can be utilised for every commercial trip, as shown in Table 1, the pertinent literature suggests that a significant share of commercial trips can be carried out using E-cargo cycles. Besides, the literature usually concentrates on delivery trips, and the substitution potential could be higher, when service trips are also taken into account.

Gruber et al. (2013) and Gruber and Kihm (2016) state that E-cargo cycles can substitute car and conventional cycle trips. Specifically, 42%–68% of the courier trips carried out using cars could be served using E-cargo cycles. Koning and Conway (2016) conclude that (cargo) cycles mainly substitute motorised two-wheelers and vans, and only a very small-scale replacement of trucks is found. Therefore, truck deliveries are less suitable for substitution by E-cargo cycles, while car and van trips are better suited.

### 3.2. Influencing factors

The factors that influence the penetration of E-cargo cycles (both purchase and willingness-to-use) are identified and categorised in this section, with a focus on decision makers, as well as city policy makers, who wish to foster the growth of E-cargo cycles. As shown in Fig. 4, 26 different factors can be found from the pertinent literature. These factors are grouped into 6 categories, namely (i) Operational, (ii) Vehicular, (iii) Infrastructural, (iv) Workforce, (v) Organisational, and (vi) Policy-related. In Sections 3.2.1 - 3.2.6, the individual factors are explained together with their impact on the penetration of E-cargo cycles.

#### 3.2.1. Operational

A common conclusion found in the pertinent literature is that E-cargo cycles are suited for areas with high density of population and

**Table 1**
Summary on the substitution potential for commercial trips.

| Study | Effect | Remark(s) |
|---|---|---|
| Gruber et al. (2013) | 66%–83% | Direct courier deliveries |
| Lenz and Riehle (2013) | 25% | Freight transport at city centre |
| Koning and Conway (2016) | 63% | Actual penetration among cycle freight (168 tons/day; 1107 tkm/day) |
| Wrighton and Reiter (2016) | 17% | Car trips (commercial trips: one-third, private trips: two-thirds) |
| Melo and Baptista (2017) | 10% | Freight transport in areas with maximum linear distance of 2 km |

Note:
- Studies are sorted by year and then alphabetically on authors.
- Koning and Conway (2016) use real-world use data and therefore, the study implicitly reflects labour availability. However, other studies base their conclusions on parameters such as cargo payload and volume and the (un)availability of adequate labour force is not considered.
- Readers are referred to Table A1 in the Appendix for a description of the studies included in this table.

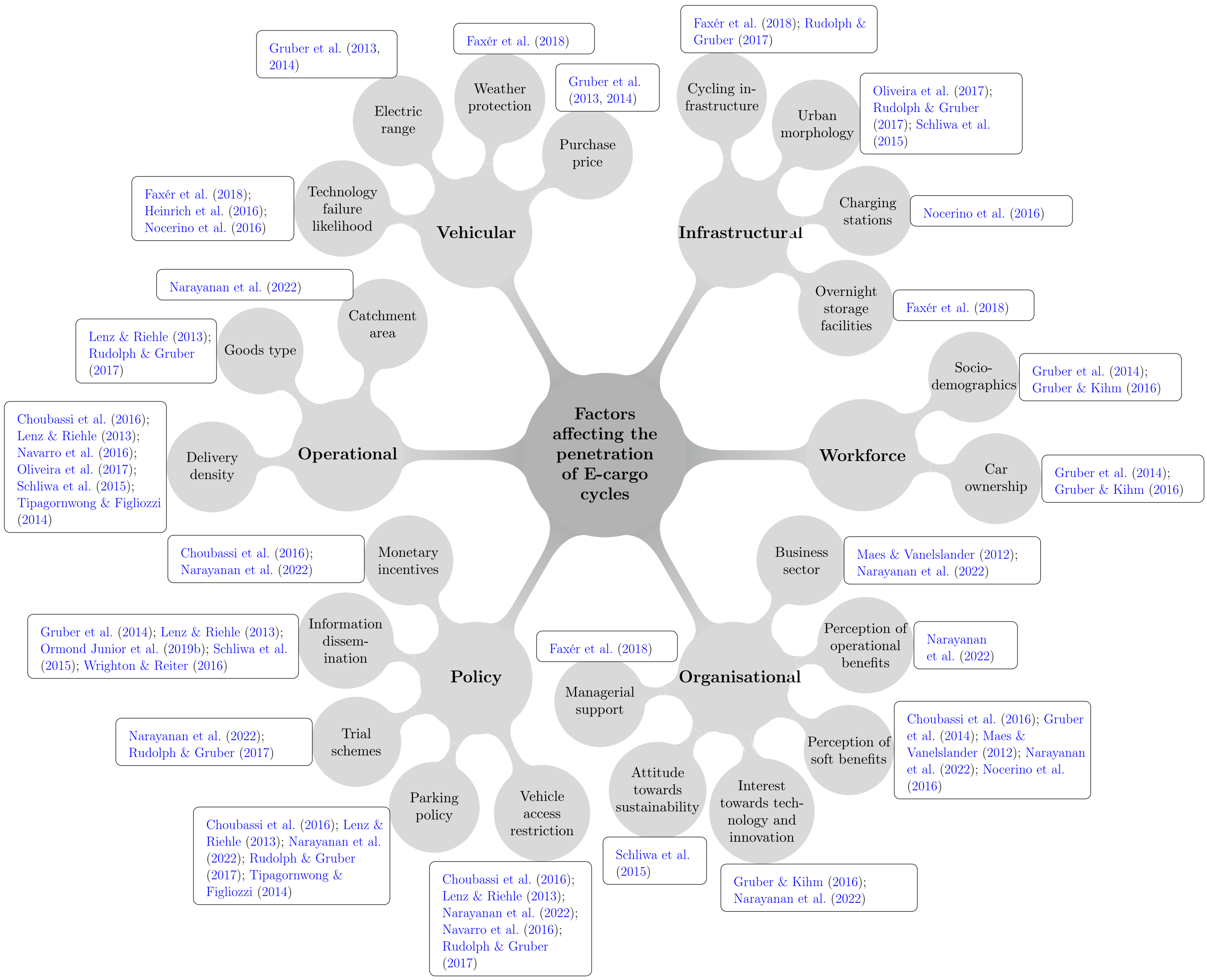


**Fig. 4.** Classification of the factors influencing the penetration (purchase and willingness-to-use) of E-cargo cycles and indicative references.

commercial activity (a proxy for delivery density) (Choubassi et al., 2016; Navarro et al., 2016; Niels et al., 2018; Oliveira et al., 2017; Schliwa et al., 2015). Therefore, E-cargo cycles are more preferred for CBDs and historical centres (Choubassi et al., 2016; Oliveira et al., 2017). In Lenz and Riehle (2013), the maximum distance travelled per delivery (using cargo cycles), as reported by the companies that participated in the study, ranges from 4 km to 50 km, with majority less than 20 km. A daily range of 80 km–120 km is observed.

Narayanan et al. (2022) have found that E-cargo cycles are not preferred by organisations with a larger catchment area of commercial trips. A decrease in probability to purchase E-cargo cycles is observed with higher catchment areas. Regarding goods type, Lenz and Riehle (2013) state that E-cargo cycles are more suitable to deliver small volumes, and not heavy goods. Hence, E-cargo cycles are found to predominantly replace cars and light commercial vehicles. Nevertheless, a positive trend for E-cargo cycles is observed in the freight market. Shipment sizes are becoming smaller, with increased demand for smaller delivery time windows and same-day delivery, making E-cargo cycles more pertinent (Rudolph and Gruber, 2017).

### 3.2.2. *Vehicular*

Technical deficits have a substantial impact on the user acceptance of E-cargo cycles (Heinrich et al., 2016). Weak motors and technical malfunctions of engines and batteries can have a negative impact on the penetration of E-cargo cycles (Faxér et al., 2018; Nocerino et al., 2016). Early adopters are considered as innovation drivers, motivating manufacturers to bring adequate cargo bike models to the market, and thus, lowering technology failure likelihood (Heinrich et al., 2016). Faxér et al. (2018) state that a different manoeuvre of the gear than on a regular cycle is required, and hence, it takes some practice to change gears. This could be seen as a problem at early stages, especially at ramps.

Purchase price and electric range are also important factors (Gruber et al., 2014; Gruber and Kihm, 2016). Longer electric range can be an advantage for driving comfort. However, there exists a trade-off between electric range and purchase price, since batteries constitute a significant portion of the purchase price. Furthermore, availability of weather protection is seen as beneficial to encourage E-cargo cycle use (Faxér et al., 2018).

### 3.2.3. *Infrastructural*

Better cycling infrastructure is required to support the penetration of E-cargo cycles (Faxér et al., 2018; Rudolph and Gruber, 2017). Eight out of ten survey respondents in Faxér et al. (2018) convey that they are not comfortable to share the road with cars, i.e., dedicated cycle lanes are required. Furthermore, E-cargo cycles are wider than normal cycles.

Hence, (comparatively) wider cycle lanes are required to make users feel safer. Apart from cycle lanes, adequate parking facilities are also a necessity. In addition, implementation of shortcuts for cycles can also support E-cargo cycle penetration (Narayanan et al., 2022).

Concerning urban morphology, E-cargo cycles are more viable in urban areas with narrow streets (Schliwa et al., 2015) and historical buildings (Oliveira et al., 2017). However, presence of steeper gradients can be an issue (Rudolph and Gruber, 2017). Similarly, lack of over-night storage facilities is a barrier to the penetration of E-cargo cycles (Faxér et al., 2018). In addition, lack of adequate charging stations is also perceived to be a barrier (Nocerino et al., 2016). Narayanan et al. (2022), based on a nation-wide trial scheme in Germany, point out that the users may require a battery range of up to 200 km, while the battery capacity of E-cargo cycles range between 50 km and 80 km. Furthermore, the users are hesitant to charge the vehicle in their private space and expect charging spots in business or public spaces. Although it is possible to carry additional batteries, the willingness to do so is still unclear.

#### 3.2.4. Workforce

Increasing age and income, as well as lower education level, are found to negatively influence the willingness-to-use E-cargo cycles by messengers (freelancers who are contracted on a commission basis to pickup and deliver items by using their own vehicles, usually cycles, cars or vans) (Gruber et al., 2014; Gruber and Kihm, 2016). Similarly, car ownership negatively influences the willingness-to-use. On the other hand, male messengers are found to be more likely to use E-cargo cycles, compared to female messengers. Therefore, in case of deliveries through freelance messengers, the penetration of E-cargo cycles is significantly influenced by the characteristics of the messengers.

#### 3.2.5. Organisational

Beginning with the favourable business sectors, E-cargo cycles are suitable for administrative sphere (delivery of letters and small parcels under time pressure), legal industry, advertisement sector, medical sector (e.g., hospitals and pharmacists working together to collect prescriptions from and deliver to elderly people), sandwich bars and flower shops (Maes and Vanelslander, 2012). Similarly, in Narayanan et al. (2022), a higher likelihood of purchase is observed for organisations belonging to the following sectors: (A) Electricity, gas, steam and air conditioning supply; (B) Water supply, sewerage, waste management and remediation activities; (C) Wholesale and retail trade, repair of motor vehicles and motorcycles; (D) Transportation and storage; (E) Accommodation and food service activities; (F) Information and communication; (G) Financial and insurance activities; (H) Real estate activities; and (I) Arts, entertainment and recreation. Their finding is based on the purchase decision of the participating organisations in a trial scheme in Germany. The business sector of the participating organisations is identified using the classification of economic activities provided by Statistisches Bundesamt (2008). For the list of organisations participated in the trial scheme, the reader is referred to Ich entlaste Städte (2020).

Organisations that perceive higher operational benefits, such as accessibility, flexible parking and travel time reliability, are more likely to purchase E-cargo cycles. Likewise, the perception of soft benefits, such as better image, higher enjoyment, improved employees' health and the possibility to achieve corporate environment goals, also plays a significant role in the purchase decision (Maes and Vanelslander, 2012; Choubassi et al., 2016; Nocerino et al., 2016; Narayanan et al., 2022). Usage of E-cargo cycles can draw attention of people on streets (Gruber et al., 2014), and can be more appealing to customers and the general public (Choubassi et al., 2016; Moolenburgh et al., 2019). During unloading, cyclists face fewer issues with the people around, when compared to truck drivers (Moolenburgh et al., 2019). In addition, E-cargo cycles provide a unique selling point (young and healthy people carrying out sustainable deliveries) (Maes and Vanelslander, 2012). Furthermore, Narayanan et al. (2022) conclude that campaigns promoting the soft benefits of E-cargo cycles, along with purchase subsidies, will positively influence the purchase.

Interest in vehicle technology is found to be an important factor for commercial use of E-cargo cycles (Gruber and Kihm, 2016). Their analysis is based on a survey of messengers involved in courier deliveries. However, based on a survey of potential users from different business sectors, Narayanan et al. (2022) found that the interest in technology and innovation does not significantly influence the actual purchase decision, although the purchase intention is significantly influenced. Attitude towards sustainability also plays a major role for the penetration of E-cargo cycles. In Schliwa et al. (2015), based on interviews, the rationale to start business by ten cycle logistics companies in five different UK cities is found to be the sustainable ethics and the interest to contribute to a more liveable city. Finally, strong organisational and managerial support is a necessity for the penetration of E-cargo cycles (Faxér et al., 2018). Based on a pilot project (Faxér et al., 2018), found out that the introduction of E-cargo cycles can affect workplace dynamics. Therefore, there can be a delay in the planning phase, during which the delivery process and schedule have to be adapted to the E-cargo cycle. During the actual delivery phase (execution phase), a change in the fundamental behaviour of drivers is required, since they would have been using cars or vans for years.

#### 3.2.6. Policy

One of the major factors that influences the shift from conventional vehicles to E-cargo cycles is the implementation of vehicle access restrictions (Choubassi et al., 2016; Lenz and Riehle, 2013; Narayanan et al., 2022; Navarro et al., 2016). Choubassi et al. (2016) conclude that the assignment of no-truck zones within CBD plays a major role in the shift to E-cargo cycles. Narayanan et al. (2022) found that the actual purchase decision of E-cargo cycles is influenced by the deterioration of conditions for conventional vehicles, such as vehicle access restrictions. Similarly, Lenz & Riehle (2013) state that the pricing of city centre streets for conventional motorised vehicles can support the penetration of E-cargo cycles.

Parking policy for conventional motorised vehicles also plays a significant role in the shift to E-cargo cycles. Higher parking fines for conventional modes support the penetration of E-cargo cycles (Choubassi et al., 2016; Lenz and Riehle, 2013). Similarly, parking restrictions are also beneficial (Tipagornwong and Figliozzi, 2014). Apart from vehicle access restrictions and parking policy, trial schemes also result in a positive impact. Narayanan et al. (2022) conclude that the trial schemes are effective in reducing the negative reservations towards cargo cycles and increasing their purchase.

The lack of perception of E-cargo cycles as a suitable mode is a major barrier towards their penetration Lenz and Riehle (2013); Schliwa et al. (2015). A deficit of information regarding E-cargo cycles is observed, and a positive relationship is found between E-cargo cycle use and the perception of existing information as sufficient (Gruber et al., 2014). In addition, owners of small businesses are averse to shift from cars to E-cargo cycles, since they feel that such a shift can be considered as a sign of commercial failure (Wrighton and Reiter, 2016). Although the negative perceptions are decreasing in recent times, awareness campaigns are still a necessity to stimulate positive perceptions. Similarly, provision of monetary incentives is also required (Choubassi et al., 2016). A more detailed discussion on the policy requirements is included in Section 5.2.

Besides the aforementioned factors, another barrier to E-cargo cycle penetration is the weather condition (Choubassi et al., 2016; Rudolph and Gruber, 2017). Nevertheless, Narayanan et al. (2022) found out that organisations, who test E-cargo cycles during winter season, are more probable to purchase them due to a reduction in negative reservations. Furthermore, it is to be noted that current cargo cycle models usually have a closure at the top, thus protecting the goods from damage and reducing weather related risks.

## 4. Impacts

E-cargo cycles can impact cities and people in different ways. In this section, the impacts discussed in the literature pertaining to the commercial transport are identified. A classification of the relevant studies is provided, as presented in Fig. 5. A discussion on each identified impact is included in the following paragraphs. Where applicable, the results of this discussion are presented in a tabular form. Most of the studies reviewed use empirical data from pilot projects and carry out statistical analyses or utilise analytical methods to ascertain the impacts. Only a few studies (e.g., Dalla Chiara et al., 2020; Fikar et al., 2018; Hofmann et al., 2017; Melo and Baptista, 2017) use simulation systems. Application of optimisation algorithms is also seen in the literature (e.g., Anderluh et al., 2017; Cortés-Murcia et al., 2019; Enthoven et al., 2020; Niels et al., 2018; Tipagornwong and Figliozzi, 2014). A brief description of the modelling approaches, assumptions and place of analysis of all the studies examined in this section is presented in Table A1, which is available in the Appendix.

Since the studies examined usually base their analysis on different assumptions, scenarios and methods, it is not appropriate to directly compare the results without taking the context into account. However, an examination of the direction of impact and the range of values that can be expected is beneficial, and this is the objective of this section.

### 4.1. Economic

When compared to conventional motorised vehicles, many E-cargo cycle models are cheaper to purchase (Lenz and Riehle, 2013; Leonardi et al., 2012; Ormond Junior et al., 2019b), although expensive E-cargo cycles are available today. Fuel cost savings are also significant, along with lower maintenance cost (Choubassi et al., 2016). Based on empirical data, Ormond Junior et al. (2019b) point out the economic benefits of the implementation of new distribution strategies that utilise E-cargo cycles. Besides, managers, employees, and customers interviewed in their study (conducted in São Paulo), recognise mostly the environmental benefits of E-cargo cycles, and not the economic benefits. Therefore, in some cities, there may be a need to better disseminate the economic benefits of utilising E-cargo cycles.

There could be an increase in cost in the short term, in cases where intermediate shifting is a necessity (e.g., Verlinde et al., 2014). The main reason for this is the additional infrastructure costs incurred during the restructuring of the delivery system. Another reason for increase in cost is the application of E-cargo cycles for isolated pilots, thus resulting in lesser efficiency (Athanassopoulos et al., 2016). Similarly, offering very short delivery times, and therefore less options to consolidate goods in the intermediate shifting facility, could also result in an increase in cost (Fikar et al., 2018). Nevertheless, the cost could be decreased over time, with proper planning and an improvement in efficiency of operations. Thus, the majority of the studies reviewed (summary shown in Table 2) conclude a reduction in cost (Arvidsson and Pazirandeh, 2017;

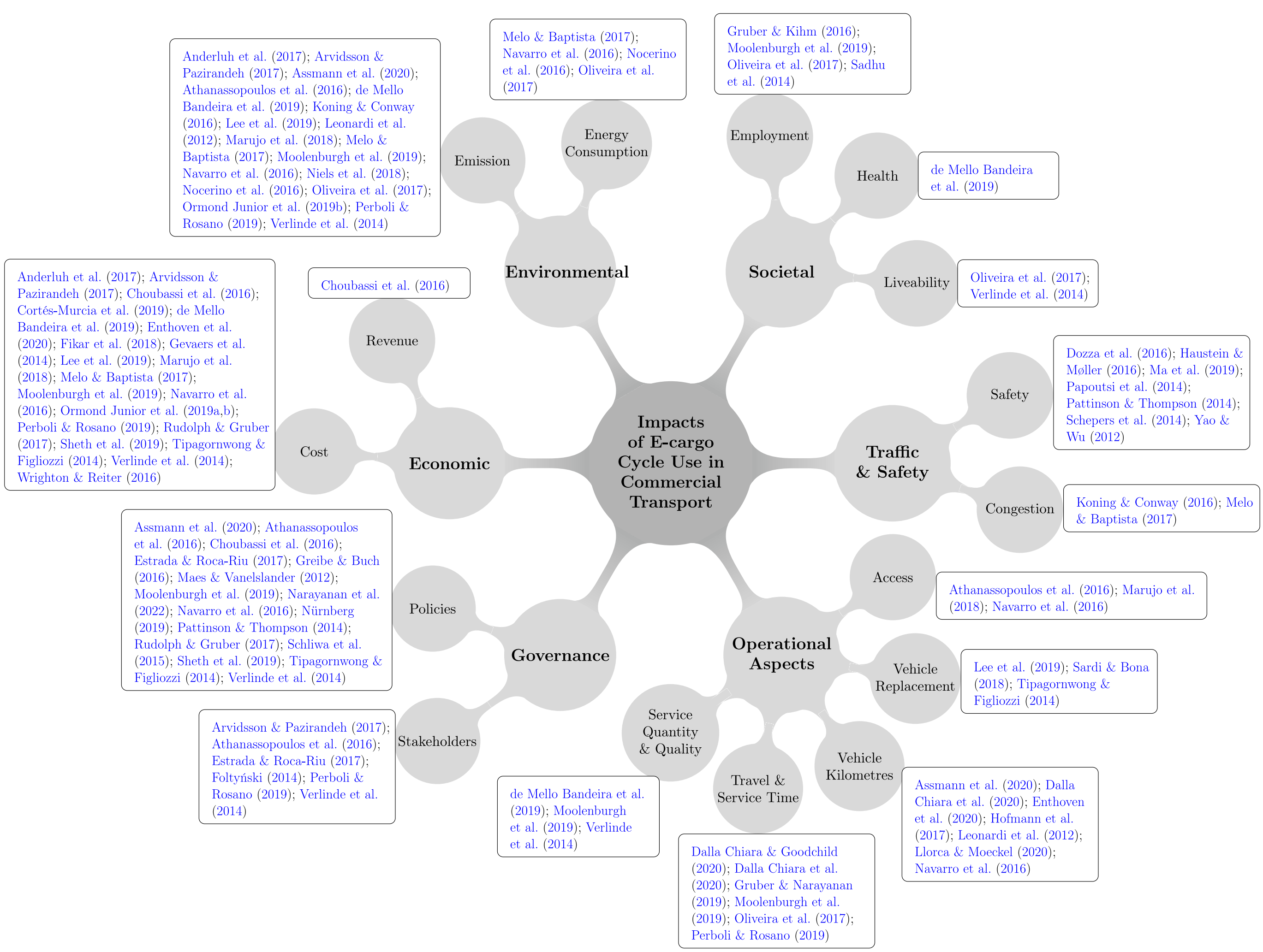


**Fig. 5.** Classification of the impacts of E-cargo cycle use in commercial transport and indicative references.

**Table 2**
Summary of the Economic–related impacts.

| Variable | Study | Effect |
|---|---|---|
| Cost | Verlinde et al. (2014) | +100% in the short term |
| | Athanassopoulos et al. (2016) | (−), without storage container |
| | | (+), with storage container (Application location is different from that of the above) |
| | Choubassi et al. (2016) | (−), with proper consolidation center and cycling infrastructure in the city |
| | Navarro et al. (2016) | (−) |
| | Wrighton and Reiter (2016) | up to −45% (€1.6/parcel delivered for electric cargo cycles and €2.91/parcel delivered for motorised vehicles) |
| | Arvidsson and Pazirandeh (2017) | (−), when the utilisation rate of the maximum weight and volume of the freight bus is above 25% |
| | Rudolph and Gruber (2017) | -€0.27/km (€0.08/km for E-cargo cycles and €0.35/km for cars), for an annual mileage of 10,000 km |
| | Melo and Baptista (2017) | (−) |
| | Fikar et al. (2018) | (+), because of short delivery times |
| | Marujo et al. (2018) | (−), when the average delivery drop size is low |
| | Lee et al. (2019) | −5.7% to −26.9% |
| | de Mello Bandeira et al. (2019) | −27.9% |
| | Moolenburgh et al. (2019) | −7% to −60% |
| | Ormond Junior et al. (2019a) | (−) |
| | Ormond Junior et al. (2019b) | −31%, with new distribution strategies |
| | Sheth et al. (2019) | (−), for low delivery volumes, close proximity to the distribution center and high density areas |
| | Enthoven et al. (2020) | (−), with the application of covering locations |
| Revenue | Choubassi et al. (2016) | (+) |

Note: Studies are sorted by year and then alphabetically on authors per each category; (+) indicates increase in the value of the respective variable and (−) indicates decrease in the value of the respective variable; Readers are referred to Table A1 in the Appendix for a description of the studies included in this table.

Choubassi et al., 2016; Cortés-Murcia et al., 2019; Enthoven et al., 2020; Lee et al., 2019; Marujo et al., 2018; de Mello Bandeira et al., 2019; Melo and Baptista, 2017; Moolenburgh et al., 2019; Navarro et al., 2016; Ormond Junior et al., 2019a; Rudolph and Gruber, 2017; Sheth et al., 2019; Wrighton and Reiter, 2016).

Although several studies conclude a reduction in cost, the change in cost is certainly influenced by a number of factors. The factors that are examined in the pertinent literature include demand density, drop size, fleet ownership, intermediate shifting type, distance between delivery locations and intermediate shifting point, utilisation rate of the intermediate shifting point, presence of covering locations, cycling infrastructure quality and service time. Based on the stakeholder who has the major influence, these factors are grouped into three categories, namely (i) Customer, (ii) Operator, and (iii) Policy maker, as shown in Fig. 6.

Examining the influence of the factors, an increase in demand density is found to decrease costs (Choubassi et al., 2016; Sheth et al., 2019). However, E-cargo cycles become inefficient as the drop size (volume per delivery) increases (Marujo et al., 2018; Sheth et al., 2019). With regards to operator related factors, there are mixed results on the effect of personnel costs (wage per hour per person). Choubassi et al. (2016), Llorca and Moeckel (2020), Sheth et al. (2019) and Tipagornwong and Figliozzi (2014) use same wages from labour statistics for E-cargo cycle riders and conventional vehicle drivers, because of wage standardisation. However, Anderluh et al. (2017), Moolenburgh et al. (2019) and Nocerino et al. (2016) use a reduced cost, since riders do not require the skills of drivers. Thus, the impact of personnel cost is dependent upon the local labour laws. With respect to fleet ownership, it is beneficial to integrate E-cargo cycles with the existing fleet system (i.e., internal fleet), rather than outsourcing the deliveries of the smaller packages in city centres to an external E-cargo cycle operator (Perboli and Rosano, 2019). Concerning the type of intermediate shifting, the results from Anderluh et al. (2017) show that transit points (for which temporal synchronisation between two different vehicle fleets is required) are associated with higher cost than a satellite facility (e.g., consolidation centres; for which temporal synchronisation is not required), when the cost of storage in the satellite facility is ignored (the reader is referred to Section 2.2 for information on intermediate shifting and its types). Hence, operators can decide between the two intermediate shifting systems based on the comparison of the cost of temporal synchronisation to the cost of the storage facility. In addition to the type of intermediate shifting, the location of the shifting point (i.e., the distance between the shifting point and the delivery locations) influences the cost. The lower the distance, the lower is the cost (Choubassi et al., 2016; Sheth et al., 2019). Furthermore, the utilisation rate of the intermediate shifting facility (in terms of maximum weight and volume) also affects costs. For example, Arvidsson and Pazirandeh (2017) conclude that there is a reduction in costs due to E-cargo cycles, only when the utilisation rate is above 25%. Similarly, in Verlinde et al. (2014), the operators state that costs could be reduced by utilising the full capacity of the shifting facility. Finally, introduction of covering locations (e.g., parcel lockers located in a common place from where customers can pick up goods themselves) can reduce costs (Enthoven et al., 2020). Concerning factors related to the policy makers, Choubassi et al. (2016) conclude that the economic benefit of using the E-cargo cycles is improved with the presence of dedicated right-of-way for the cycles (i.e., exclusive cycling lanes). A related factor is the service time, which includes travel and parking cruising time. Based on case studies from Netherlands, Moolenburgh et al. (2019) found out a reduction in service time due to the use of E-cargo cycles, along with a decrease in cost per mile. Tipagornwong and Figliozzi (2014) describe that the per mile cost is sensitive to the travel speed. An interlinked factor with the service time is the service quantity (deliveries per hour). A reduction in cost is associated with an increase in service quantity (de Mello Bandeira et al., 2019).

### 4.2. Environmental

The most discussed benefit of E-cargo cycles is the positive environmental impacts. The energy consumption of E-cargo cycles range from 9 to 18 Wh/km (Koning and Conway, 2016; Nocerino et al., 2016; Ormond Junior et al., 2019b; Sardi and Bona, 2018; Tipagornwong and Figliozzi, 2014), while an E-van may consume 200 Wh/km (Nocerino et al., 2016), a E-truck may 800 Wh/km (Sardi and Bona, 2018), and a traditional van greater than 800 Wh/km (Ormond Junior et al., 2019b). As shown in Table 3, the pertinent literature points towards a reduction in energy consumption (e.g., Melo and Baptista, 2017; Navarro et al., 2016; Oliveira et al., 2017) and $CO_2$ (e.g., Lee et al., 2019; Marujo et al., 2018; Melo and Baptista, 2017; Nocerino et al., 2016; Verlinde et al., 2014) and overall emissions (CO2e) (e.g., Leonardi et al., 2012; de Mello Bandeira et al., 2019; Ormond Junior et al., 2019b. The literature predominantly talks about the reduction in $CO_2$ emission, and depending up on the analysed scenario, a range of values could be expected for the same, as shown in Fig. 7. Although it appears that the replacement of conventional vans is more probable to result in a higher emission

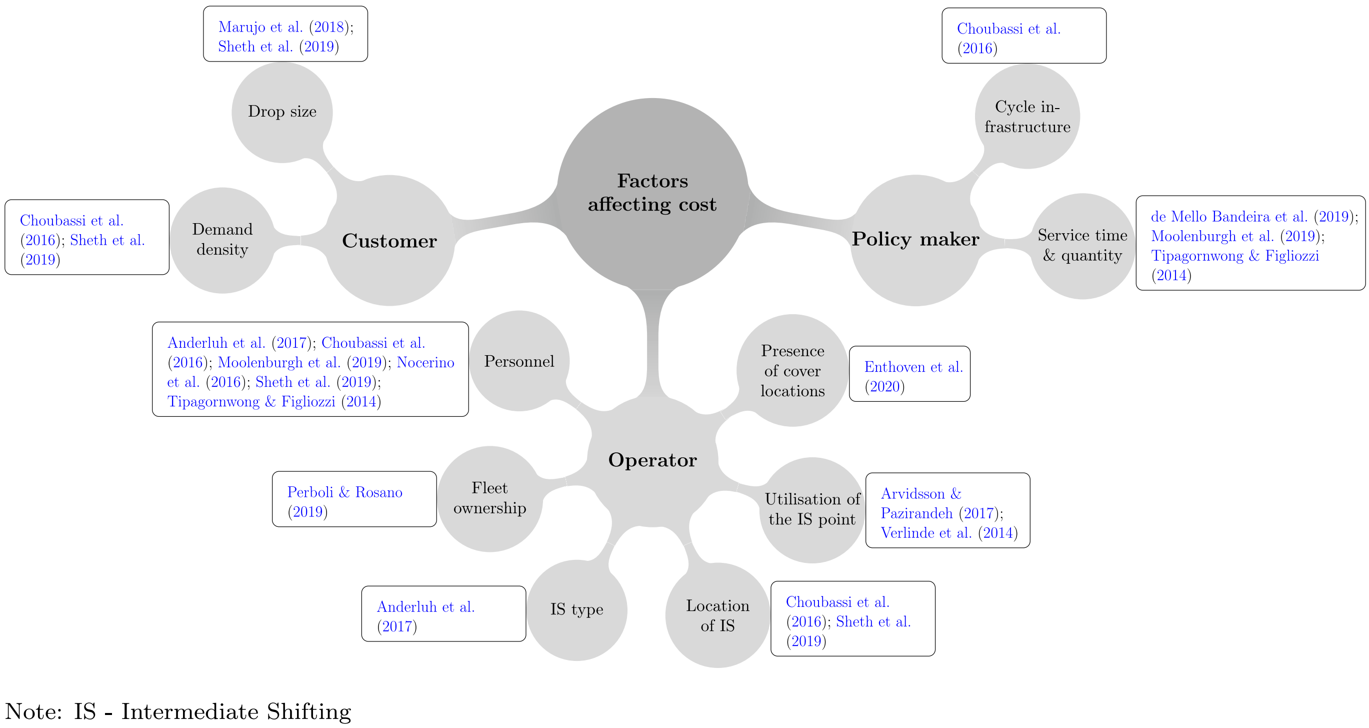


**Fig. 6.** Classification of the factors affecting the cost of using E-cargo cycles in commercial transport and indicative references.
Note: IS - Intermediate Shifting.

reduction, given the low number of data points (≤5 data points per vehicle type), it is not plausible to make a certain conclusion.

Mixed results are found for $NO_x$, $SO_2$ and $PM_{10}$ emissions, the reason being the energy source for electricity generation. While renewable energy sources can result in positive impacts, usage of non-renewable sources can result in negative impacts (Athanassopoulos et al., 2016; Ormond Junior et al., 2019b). The impact on emissions depends upon the vehicle type utilised to transport goods to the intermediate shifting point (Assmann et al., 2020). For example, trucks can have a strong influence on the GHG emissions, while vans have strong influence on air quality ($PM_{10}$). Trucks have better consolidation potential than vans. Hence, when efficiently utilised along with E-cargo cycles, trucks can result in better reduction of GHG emissions than vans. However, the $PM_{10}$ emission factor for trucks is ten times higher than the one for vans. This higher emission factor neutralises the consolidation effect, thereby resulting in negative impacts.

### *4.3. Societal*

An increase in employment opportunity is generally stated in the pertinent literature because of E-cargo cycle use. Especially, socially disadvantaged people could have the possibility of employment

**Table 3**
Summary of the Environmental–related impacts.

| Variable | Study | Effect |
|---|---|---|
| Energy Consumption | Navarro et al. (2016) | (−) |
| | Nocerino et al. (2016) | (−), energy costs saved around €0.15/km |
| | Oliveira et al. (2017) | (−) |
| | Melo and Baptista (2017) | (−), even for the scenarios with worst traffic performance |
| Emissions | Leonardi et al. (2012) | CO2e: −55%/parcel delivered |
| | Verlinde et al. (2014) | $CO_2$: −24%; $NO_x$: +48%; $SO_2$: −24%; $PM_{2.5}$: −59%; $PM_{10}$: −22% |
| | Athanassopoulos et al. (2016) | $CO_2$: (−); CO: (−); $NO_x$: (−); $SO_2$: (+); $PM_{10}$: (+), without storage container<br>(+), with storage container (Application location is different from that of the above) |
| | Koning and Conway (2016) | $CO_2$: −1.7 tons/day |
| | Navarro et al. (2016) | $CO_2$: −2 tons/year |
| | Nocerino et al. (2016) | $CO_2$: −1.8 to −5.3 kg/day |
| | Anderluh et al. (2017) | (−) |
| | Arvidsson and Pazirandeh (2017) | $CO_2$: up to −80% |
| | Oliveira et al. (2017) | (−) |
| | Melo and Baptista (2017) | $CO_2$: −73% |
| | Marujo et al. (2018) | $CO_2$: −52%; CO: −19%; $NO_x$: −58%; NMHC: −20%; PM: −49% |
| | Niels et al. (2018) | $CO_2$: −7.5 tons/year |
| | Lee et al. (2019) | $CO_2$: −10% |
| | de Mello Bandeira et al. (2019) | CO2e: −23.37 kg/month |
| | Moolenburgh et al. (2019) | $CO_2$: −80% |
| | Ormond Junior et al. (2019b) | CO2e: −97% per year |
| | Assmann et al. (2020) | $CO_2$: +16% to −66%; |

Note: Studies are sorted by year and then alphabetically on authors per each category; (+) indicates increase and (−) indicates decrease; NMHC: Non-Methane HydroCarbons; CO2e: $CO_2$ equivalent; Readers are referred to Table A1 in the Appendix for a description of the studies included in this table.

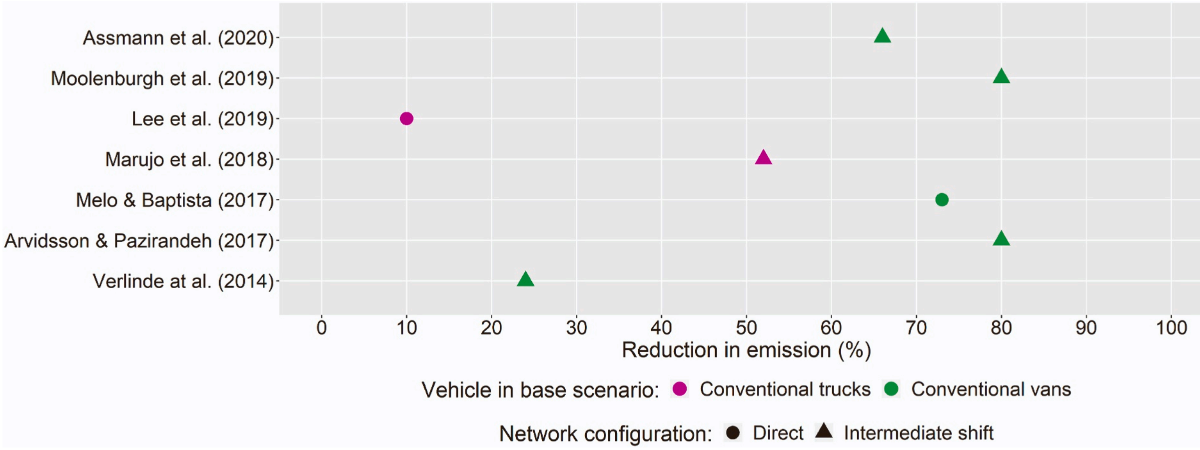


**Fig. 7.** Maximum reduction in $CO_2$ emission.

(Moolenburgh et al., 2019). Sadhu et al. (2014) conclude that cargo cycles can contribute to a decrease in unemployment. Their conclusion is based on a study of intracity freight transport in Delhi (India). Due to flexible working conditions and low entry barriers, a cycle messenger job is a viable option for students (Gruber and Kihm, 2016). The possible generation of new jobs is also pointed out by Oliveira et al. (2017). Therefore, on the one hand, new employment opportunities are created, while, on the other hand, the issues of an operator can be reduced. For example, if there is a shortage of drivers, and operators are looking out for alternatives (Moolenburgh et al., 2019). Application of cargo cycles, for which personnel with driving license and other qualifications (e.g., for driving vans) are not required, can be a potential solution.

Oliveira et al. (2017) state that the quality of life of the population in cities could improve. Based on a survey, Verlinde et al. (2014) conclude that a positive impact on the visual and physical nuisance caused by freight traffic is observed, due to the use of cargo cycles. Citizens experience a more pleasant neighbourhood. Thus, application of cargo cycles can improve liveability in cities. Concerning the health of employees, a lower heart rate level is observed during E-cargo cycle use in de Mello Bandeira et al. (2019).

### 4.4. Traffic & safety

Examining the growth and the impacts of deliveries using cycles in Paris, Koning and Conway (2016) found a reduction in congestion caused by deliveries. Within the deliveries carried out using cycles, E-cargo cycles constitute 63% of the total kilometres of delivery, and the reduction in congestion is due to the decreased use of vans. However, in case of mixed traffic conditions (i.e., E-cargo cycles sharing the same lanes with other modes) and for a penetration of more than 10%, Melo and Baptista (2017) found that traffic conditions worsened due to the lower speeds of the cycles (up to 84% longer delays). On the other hand, as shown in Table 4, there are positive impacts for a penetration rate of less than 10%. This shows that, in case of mixed traffic, there exists a critical threshold for the penetration of E-cargo cycles, above which the positive impacts may reduce and may even lead to negative impacts.

With regards to safety, Pattinson and Thompson (2014) state that large delivery vehicles pose safety issues in Australia and cycling is currently restrained, because of the poor road design and the absence of best practice freight vehicle standards. In many Australian cities, cyclists and motorised vehicle users have to share the same road space. Therefore, application of E-cargo cycles to replace conventional delivery vehicles, together with infrastructure improvements, could mitigate the safety issues, and at the same time may support mode shift to cycling for private trips. On the other hand, based on the literature related to E-bikes, cycles with E-assist are generally ridden faster (Dozza et al., 2016; Schepers et al., 2014). Hence, there could be increased safety risks (Dozza et al., 2016; Haustein and Møller, 2016; Ma et al., 2019; Papoutsi et al., 2014; Schepers et al., 2014; Yao and Wu, 2012). 29% of the 685 survey participants in Haustein and Møller (2016) state that the accidents involving E-bikes might not have taken place, if conventional cycles were used. A deeper look into the pertinent literature shows the following to be the main reasons for accidents: (i) underestimation of the speed of the electric cycles by other road users (Haustein and Møller, 2016), (ii) errors and aggressive behaviours (Yao and Wu, 2012), (iii) illegal occupation of motor vehicle lanes and red-light running (Ma et al., 2019). In addition, males are more prone to accidents (Papoutsi et al., 2014; Schepers et al., 2014; Yao and Wu, 2012), while individuals with driver's license are less likely to cause accidents (Yao and Wu, 2012). Furthermore, crashes occur mainly in curves and while overtaking, and is also dependent on the average speed difference between conventional and electric cycle users (which differs between countries, e.g., 1–3 kmph in European countries, while 7 kmph in China) (Schepers et al., 2014).

### 4.5. Operational aspects

Starting with access, E-cargo cycles enable access to places that are

**Table 4**
Summary of the traffic–related impacts.

| Variable | Study | Effect |
|---|---|---|
| Congestion | Koning and Conway (2016) | (−) |
| | Melo and Baptista (2017) | (−), for penetration ≤10% |
| | | (+), for penetration > 10%; under mixed traffic condition |
| Safety | Yao and Wu (2012) | (−), because of error and aggressive behaviour of the riders of electric cycle |
| | Pattinson and Thompson (2014) | (+), due to the reduction in accidents caused by conventional delivery vehicles |
| | Schepers et al. (2014) | (−), given the faster speeds of electric cycles, when compared to conventional cycles |
| | Dozza et al. (2016) | (−), given the faster speeds of electric cycles, when compared to conventional cycles |
| | Haustein and Møller (2016) | (−), since the speed of the electric cycles are underestimated by other road users |
| | Ma et al. (2019) | (−), illegal occupation of motor vehicle lanes and red-light running |

Note: Studies are sorted by year; (+) indicates increase and (−) indicates decrease; The studies on safety are mostly from E-bike literature, and they have been included, since they are also relevant for the E-cargo cycles. Readers are referred to Table A1 in the Appendix for a description of the studies included in this table.

restricted for conventional motorised vehicles (Athanassopoulos et al., 2016; Marujo et al., 2018; Navarro et al., 2016). The access to the restricted areas can lead to new business opportunities in additional areas.

#### 4.5.1. Vehicle replacement

Although there are E-cargo cycles with a payload capacity of up to 500 kg, not every commercial user purchases a cycle with high payload capacity. Also, in certain situations, even a payload capacity of 500 kg is not sufficient. Therefore, a vehicle replacement value (which represents the number of E-cargo cycles required to replace one conventional motorised vehicle) of more than one is expected (e.g., Lee et al., 2019; Tipagornwong and Figliozzi, 2014), i.e., multiple E-cargo cycles may be required to replace one conventional vehicle. However, when efficiently utilised in combination with the conventional vehicles (i.e., optimally replacing only a certain number of conventional vehicles with E-cargo cycles), there could be a reduction in the total fleet size (e.g., Sardi and Bona, 2018). In such a case, a vehicle replacement value of less than one is obtained. It should be noted that the replacement value is not based on the carrying capacity of the vehicles, but rather the true weight distribution of the commercial trips. Furthermore, even in case where the vehicle replacement value is more than one, a reduction in cost (compared to the existing scenario with only convention vehicles) is still possible, provided the replacement is done optimally. For example, the results from Lee et al. (2019) suggest a replacement ratio of 1.5, resulting in a reduction of cost (refer Table 2).

**Table 5**
Summary of the impacts on operational aspects.

| Variable | Study | Effect |
|---|---|---|
| Vehicle replacement | Tipagornwong and Figliozzi (2014) | 1 to 2 to replace a van |
| | Sardi and Bona (2018) | 0.5 to 1.3 to replace a truck |
| | Lee et al. (2019) | 1.5 to replace a truck |
| VKT | Leonardi et al. (2012) | −20%/parcel |
| | Navarro et al. (2016) | (−) |
| | Hofmann et al. (2017) | −15% to - 27% |
| | Assmann et al. (2020) | (−), when truck used along with electric cargo cycle<br>(+), when van used along with electric cargo cycle |
| | Dalla Chiara et al. (2020) | up to −75% |
| | Llorca and Moeckel (2020) | (−), when the demand density is at least 100 parcels/$km^2$ |
| Travel time | Gruber and Narayanan (2019) | −5 min to +40 min for a distance of up to 20 km; Without the consideration of possible extra time for cars (e.g., time for parking & walking to the exact destination). |
| Service time | Oliveira et al. (2017) | (−)% |
| | Moolenburgh et al. (2019) | −30% |
| | Perboli and Rosano (2019) | (−) |
| | Dalla Chiara et al. (2020) | up to −40% |
| Service quantity | Athanassopoulos et al. (2016) | +11% to +14% (number of deliveries per day) |
| | Lee et al. (2019) | Same, when 6 trucks (out of 35) were replaced with 9 E-cargo cycles |
| | de Mello Bandeira et al. (2019) | +26% (number of deliveries per hour) |
| Service level | Verlinde et al. (2014) | (−); however, no complaint from the customers about the service quality |
| | Moolenburgh et al. (2019) | (+) |

Note: Studies are sorted by year and then alphabetically on authors per each category; (+) indicates increase and (−) indicates decrease; Readers are referred to Table A1 in the Appendix for a description of the studies included in this table.

#### 4.5.2. Vehicle kilometres travelled (VKT)

When E-cargo cycles are utilised for the right applications, there could be a decrease in total VKT, as can be observed in Table 5. A major reason for this is the access restrictions for the conventional vehicles. While in several cases conventional motorised vehicles have to detour due to access restrictions, E-cargo cycles can drive directly (Navarro et al., 2016). Also, the presence of shortcuts available to cargo cycle users (Gruber and Narayanan, 2019) can reduce the total VKT. In addition, Dalla Chiara et al. (2020) observe that there is a greater reduction in VKT as the demand density increases from 25 deliveries/$km^2$ to about 150 deliveries/km.[2] The reduction in VKT reaches up to 75%, and also the total operating time reduces up to 40%. Beyond 150 deliveries/km,[2] the reduction in VKT stabilises. In some cases, use of trucks can result in better consolidation. Hence, trucks may result in VKT savings, while vans may not (e.g., Assmann et al., 2020). It should be noted that all the studies related to VKT, which are presented in Table 5, include intermediate shifting. The major reason for the use of intermediate shifting is the inadequate load carrying capacity of cargo cycles for certain situations. In the low-cost parcel sectors, the carrying capacity of E-cargo cycles is naturally inadequate for a large-scale substitution of conventional vehicles, and hence, use of intermediate shifting is a necessity. However, for a large share of other commercial trips (especially service trips), the carrying capacity of E-cargo cycles is adequate. For example, Gruber et al. (2014) conclude that around 85% of the goods transported by car couriers in Germany could have been feasibly transported by cargo cycles, i.e., without the need for intermediate shifting. Even in cases where E-cargo cycles may increase total VKT, application of covering locations (e.g., parcel lockers located in a common place from where customers can pick up goods themselves) can reduce total VKT. For example, Enthoven et al. (2020) conclude a 60% reduction in distance driven by cargo cycles. In case of such an application, it is desirable to serve customers in the same location by either one of the methods, i.e., either cargo cycle or parcel lockers (covering location). Furthermore, the potential reduction in total VKT is high, when the customers are open to both options, as this results in better possibilities to jointly optimise the delivery service.

#### 4.5.3. Travel and service time

E-cargo cycles can be competitive to conventional motorised vehicles in terms of travel time in several situations. For example, E-cargo cycles are found to be faster than car under certain conditions (Gruber and Narayanan, 2019), even without the consideration of possible extra time for cars (such as time for parking and walking to the exact destination location after parking). From the study, the factors influencing the difference in travel time between cargo cycles and cars are: trip distance, time of the trip (e.g., morning peak), cargo cycle vehicle type, availability of shortcuts for cycles, change in elevation between origin and destination, and car ownership in the city of operation. Concerning service time (operation time including the travel time), the pertinent literature suggests a reduction (Dalla Chiara et al., 2020; Moolenburgh et al., 2019; Oliveira et al., 2017; Perboli and Rosano, 2019). Moolenburgh et al. (2019) found a 30% decrease in round-trip time, mainly due to the presence of shorter routes for cycles. The study states that cycle routes are on average 15%–20% shorter than car routes. Apart from shortcuts, parking cruising time for cars influences the reduction in total trip times. On average, parking cruising time is 2.3 min per trip, and contributes to 28% of the total trip time (Dalla Chiara and Goodchild, 2020). In a subsequent study, Dalla Chiara et al. (2020) conclude a reduction in total operating time of up to 40%, when E-cargo cycles are used. A factor that majorly influences this reduction is the parking dwell time (include parking cruising time and the time spent walking to a delivery destination) savings associated with E-cargo cycle use.

#### 4.5.4. Service quantity and quality

Improvement in service time could lead to an increase in quantity delivered. For example, a 26% increase in the productivity is observed in de Mello Bandeira et al. (2019), resulting in an increase in the number of postal deliveries per hour from 31 to 39 in a high density neighbourhood of Rio de Janeiro. Similarly, Athanassopoulos et al. (2016) also report a productivity improvement of 11%–14%, based on pilots conducted by UPS in Hamburg. On the other hand, Lee et al. (2019), based on an analysis of a courier service in Seoul, conclude that the productivity was maintained when 6 trucks were replaced by 9 E-cargo cycles. Focusing on the quality of service, based on a survey, Moolenburgh et al. (2019) conclude an improvement in customer satisfaction (unfortunately, a deeper explanation of this result is not provided in the study for more exploration). However, Verlinde et al. (2014) conclude a slight drop in service level (punctuality) due to the additional time required for intermediate shifting. Nevertheless, there is no complaint from the customers about the quality of service. It is to be noted that the study is based on a demonstration project and in a real situation, the service level could be improved by adjusting the operations over time.

### 4.6. Governance

Within this section, stakeholder related aspects are discussed, while general policy related aspects will be separately dealt in Section 5.2. Looking into the stakeholder related aspects, introduction of E-cargo cycles has an effect on workplace dynamics (Faxér et al., 2018). For example, planning a new vehicle to an existing delivery schedule is challenging. Furthermore, riding E-cargo cycles require a different manoeuvre of the gear, when compared to regular cycles. Within this regard, pilot tests and training programmes are beneficial and this involves interaction with new stakeholders. A system involving intermediate shifting could involve complex interactions between multiple stakeholders. Foltyński (2014) states that partnerships with local stakeholders (e.g., local businesses and administration) are very important. For example, finding reasonable locations for intermediate shifting might require a close co-operation with public authorities (Athanassopoulos et al., 2016). Results from Verlinde et al. (2014) show that the objectives of the public and policy makers, such as improved liveability in the city, are better addressed by the utilisation of E-cargo cycles, while it may appear that the operators are not adequately benefited, unless policies such as internalisation of the external costs are implemented. Implementation of congestion pricing and introduction of tolls could be beneficial in this regard.

Based on a round-table discussion between operators, local authorities, transport union, consultants, vehicle manufacturers, ICT solution providers, researchers and citizens, Arvidsson and Pazirandeh (2017) state that the issues, such as risk and reward sharing and turf protection dynamics, related to the coordination between multiple stakeholders (involved in the case of intermediate shifting) are considered as significant barriers. Therefore, the interrelation and interplay between the multiple actors is crucial. All these point towards the necessity of interaction and collaboration between public, operators and policy makers to support the wide spread use of E-cargo cycles.

## 5. Operational framework and policy requirements

### 5.1. Operational framework

#### 5.1.1. Planning considerations

E-cargo cycles can optimise specific nodes of a supply chain, and cannot completely replace every existing mode (Sheth et al., 2019). It is a solution alongside other solutions (Moolenburgh et al., 2019). One of the concerns with regards to the use of E-cargo cycles is their load capacity. Nocerino et al. (2016), based on pilot results, conclude that a suitable selection of E-cargo cycle models can ensure adequate load capacity without any performance loss. A supporting conclusion is also found in Gruber et al. (2013), wherein the payload capacity of cargo cycles is stated to be sufficient by bike and car messengers. Nevertheless, the load capacities of the different vehicles in the fleet must be reflected in the planning and control systems (Moolenburgh et al., 2019). Better clustering of deliveries (e.g., geographically based on routes suitable for E-cargo cycles) using planning software could be helpful. Finally, sufficient E-cargo cycle fleet size is required to ensure timely deliveries (Fikar et al., 2018).

#### 5.1.2. Intermediate shifting points - necessity, location and necessity for sharing

For delivery trips, an intermediate shifting point (a location where shifting of a shipment from a larger mode such as vans to an E-cargo cycle occurs), within or at the boundary of the delivery catchment area, may be a necessity (Leonardi et al., 2012; Moolenburgh et al., 2019), although not for every case, e.g., direct trips (see Section 2). Where necessary, the type of shifting point and its location play a major role. For example, transit points, where no consolidation is carried out, are beneficial for areas with a traditional retail sector (Marujo et al., 2018). Consolidation is beneficial in reducing shipment delays, only when there is a substantial demand, since there is a possibility to pick-up multiple consolidated shipments (Fikar et al., 2018). Otherwise, the additional loading and unloading operations can have a negative effect. In case of an external company maintaining the intermediate shifting points, they must be maintained by a neutral company, who does not compete with the delivery operators, to avoid undue advantage and conflicts (Navarro et al., 2016). Choosing an optimal location for intermediate shifting calls for specific models for simulation. In view of this, Naumov and Starczewski (2019) formulated an optimisation model for locating the intermediate shifting points. The model is coded in Python and allows to simulate and choose the best location among the set of possible locations. In a subsequent study, Naumov (2021) demonstrated the model for a real-world case in Krakow (Poland), concluding that the model is capable of choosing an optimal location with lower total ton-kilometres for E-cargo cycle trips. In reality, the optimal solution for locating an intermediate shifting point may not be a practical one (e.g., because of narrow streets and urban policies). Nevertheless, Niels et al. (2018) conclude that a feasible application of E-cargo cycles is possible even for a less than optimal location. However, it should be noted that finding a practical location is also difficult. A practical location must be well-connected to the main access roads and close to the delivery zone (Navarro et al., 2016). With regards to consolidation centres, locating them at the periphery of the delivery zone can result in a high utilisation rate (Fikar et al., 2018). Furthermore, they should be hidden from the general public as much as possible to avoid visual nuisance to the neighbours. However, it is to be noted that the longer the distance between the delivery and the shifting point, the less suitable is the use of E-cargo cycles (Moolenburgh et al., 2019).

In case an external company is maintaining the intermediate shifting points, it is desirable to mix parcels from different delivery companies in one cycle (Schliwa et al., 2015). Otherwise, efficiency is reduced and cost is increased. However, in reality, mixing is something not permitted by the operators, usually due to scepticism and mistrust. A possible solution to overcome this barrier and prevent errors in delivery is to implement real-time tracking. Similarly, with the advent of ICT, it is possible to develop advanced software systems that can improve the efficiency of operations. For example, Rytle, with the help of an IT company in India, has developed a machine-to-machine communication system, which allows E-cargo cycle couriers to identify the package that has to be picked up next using smart glasses (Internationale Automobil-Ausstellung, 2019).

#### 5.1.3. Financial considerations

Basing the business model on a subsidised system is not preferable as it may become harder to sustain the business in the long term (Navarro et al., 2016). Also, the maintenance of E-cargo cycles is influenced by the weather conditions, and it is required to have a good insight into all the costs involved (Moolenburgh et al., 2019). If there is no viable plan at an

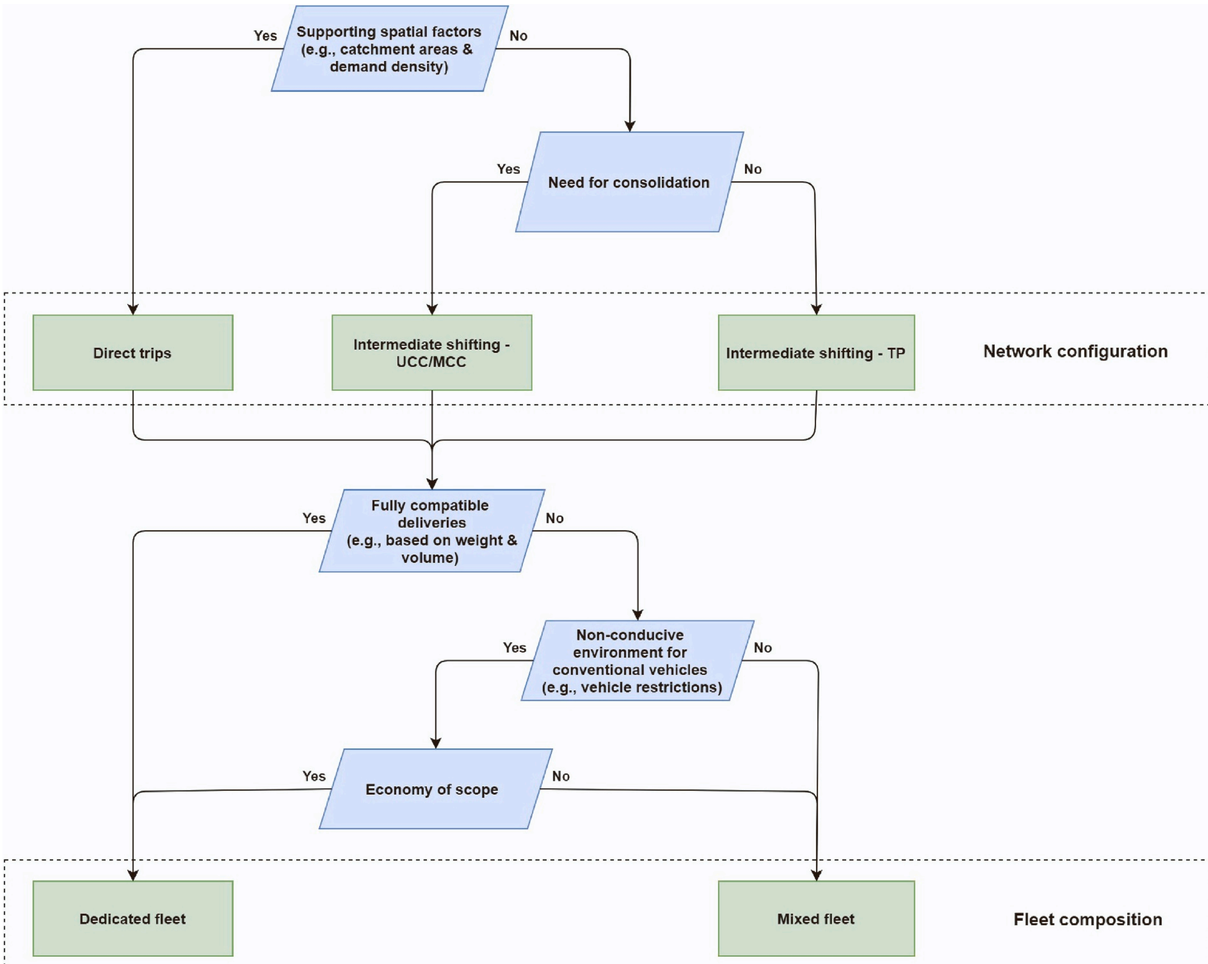


**Fig. 8.** Suggested decision making process for the application of E-cargo cycles.

early stage, there is a higher likelihood of failure.

Based on the above discussion, a number of decisions have to be made, when beginning to utilise E-cargo cycles. In order to facilitate the decision making process, a simplified scheme is presented in Fig. 8. This scheme has been devised, focusing on the selection of fleet composition and network configuration. As shown in the figure, direct trips are suitable when the spatial factors are supportive, e.g., smaller catchment areas and higher demand densities. In scenarios with unfavourable spatial factors, intermediate shifting is a necessity. Subsequent to the decision on the network configuration, the next step is to choose the fleet composition. If the items to be carried are fully compatible, e.g., with the load and volume capacity of cargo cycles, then a dedicated cargo cycle fleet can be introduced. If not, the prevailing conditions for the conventional vehicles has to be checked. In case the situation is non-conducive for the conventional vehicles (e.g., access restrictions) and it is possible to use cargo cycles without undue increase in cost (e.g., without requirement of an unreasonably high fleet size of cargo cycles compared to the current fleet size of conventional vehicles), a dedicated cargo cycle fleet can be implemented. Else, it is cost effective to use cargo cycles and conventional vehicles in tandem, i.e., a mixed fleet is suggested. Based on the existing literature, a threshold for the factors is not possible at this point. Similarly, a clear criteria cannot be suggested for sharing of the intermediate shifting facility. They are suggested for future research.

### 5.2. Policies

The policy requirements and suggestions observed in the existing literature can be grouped as (i) Infrastructural and safety related aspects, (ii) Regulatory measures, (iii) Incentives, and (iv) Awareness creation and mobility plans, as shown in Fig. 9.

#### 5.2.1. Infrastructural & safety related aspects

Policies aimed at improving pedestrian and bicycle mobility, in general, also improve the competitiveness of using E-cargo cycles (Tipagornwong and Figliozzi, 2014). For example, the necessity of better cycling infrastructure to support the use of E-cargo cycles in commercial transport has been described in several studies (Faxér et al., 2018; Greibe and Buch, 2016; Moolenburgh et al., 2019; Nürnberg, 2019; Rudolph and Gruber, 2017; Schliwa et al., 2015; Sheth et al., 2019; Tipagornwong and Figliozzi, 2014; Wrighton and Reiter, 2016). 65% of the respondents in Wrighton and Reiter (2016) would like an improvement in cycling infrastructure. Similarly, a majority of the respondents in Faxér et al. (2018) express safety-related concerns, when sharing the road space with conventional motorised traffic. Hence, dedicated cycle lanes are a necessity. The necessity of dedicated cycle lanes is also indicated in Sheth et al. (2019). In addition, introduction of cycle streets is also useful (Moolenburgh et al., 2019). It should be noted that cargo cycles are larger in size than normal cycles. Wider cycle lanes may have to be constructed because of the larger size of the cargo cycles (Faxér et al., 2018). However, current planning and design manuals for cycle infrastructure do not consider the dimensions of cargo cycles (Rudolph and Gruber, 2017). Besides, the effective width of the existing

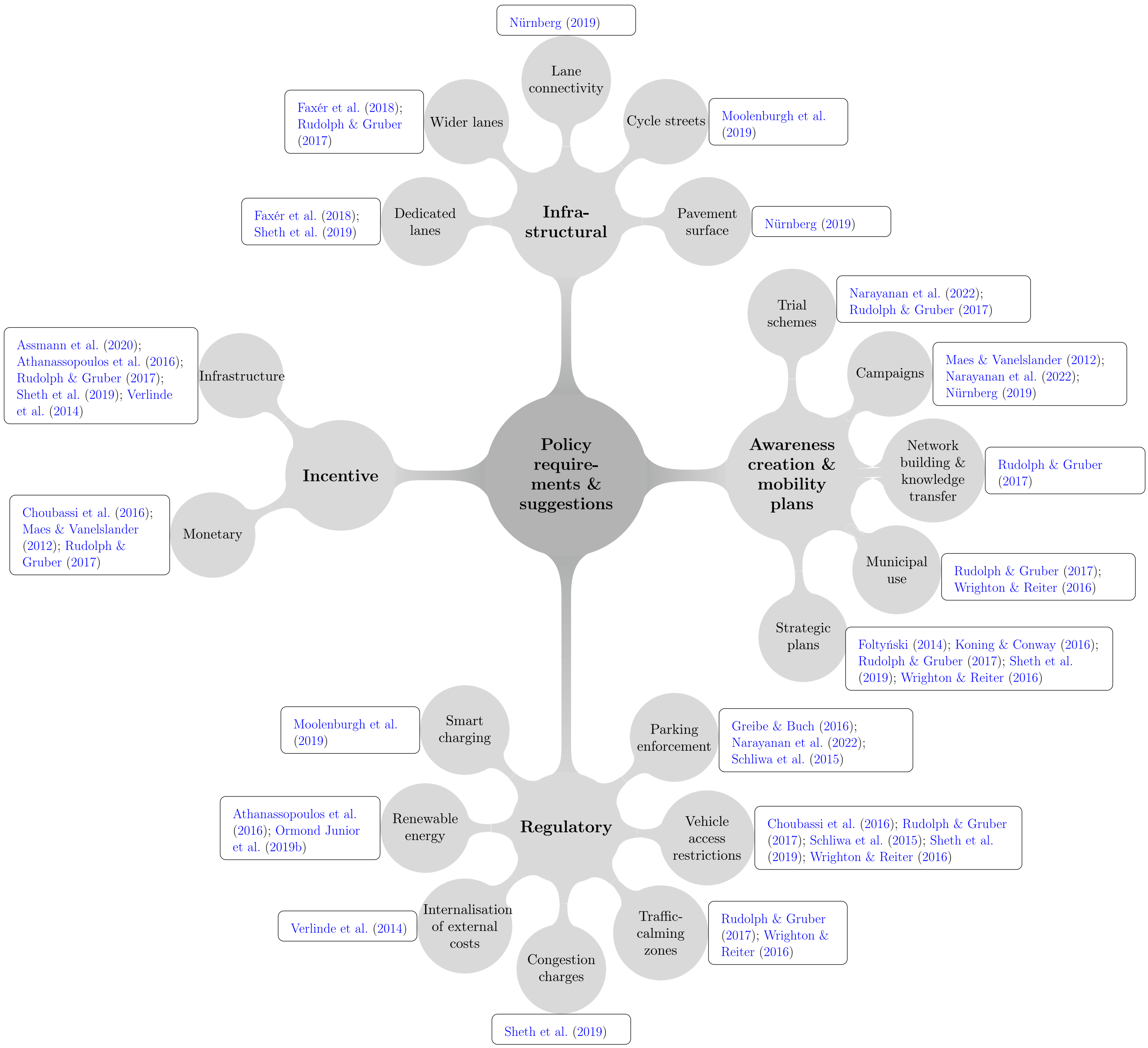


**Fig. 9.** Classification of the suggested policies and indicative references.

cycling lanes is reduced by cars parked in the road side next to the lanes (Greibe and Buch, 2016). Therefore, proper parking regulations should be implemented.

Although cargo cycles have a headway equivalent to 1.3 times of the headway of a normal cycle, they have been reported to reduce lane capacity by 3–4 times in reality (Greibe and Buch, 2016). In addition, cargo cycles have a higher chance of tilting at the corners and on roads with poor surface (Nürnberg, 2019). In general, heavier cargo cycles with higher load capacities can be used, if better quality of cycling infrastructure is provided. Another pertinent issue identified in Nürnberg (2019) is the abrupt ending of dedicated cycle lanes, thereby resulting in separate sections of cycling infrastructure rather than a continuous one. Well-connected cycles lanes are required (Faxér et al., 2018). A higher penetration of E-cargo cycles can lead to the need for proper curb-space management, which is another planning issue. All these have to be taken into account, when developing a cycling infrastructure. Furthermore, given there could be increased safety risks due to the higher speeds of electric cycle users (when compared to conventional cycle users), following measures are suggested: awareness campaigns and training (Haustein and Møller, 2016; Ma et al., 2019), and making E-bikes more distinct for view (Dozza et al., 2016; Haustein and Møller, 2016).

### 5.2.2. Regulatory measures

Another major factor that supports the penetration of E-cargo cycles is the implementation of regulatory measures (Choubassi et al., 2016; Rudolph and Gruber, 2017; Schliwa et al., 2015; Sheth et al., 2019; Wrighton and Reiter, 2016). Schliwa et al. (2015) suggest introduction of zero-emission zones, restriction on drive-through traffic and pavement parking enforcement. Sheth et al. (2019) recommend truck bans and congestion charges. Similarly, Choubassi et al. (2016) also propose the introduction of no-truck zones in certain parts of CBDs. Wrighton and Reiter (2016) advise to implement 20 km/h zones and access restrictions based on time, emission factors and weight. Access restrictions based on emission factors are also suggested in Rudolph and Gruber (2017), along with truck bans and traffic-calming zones. Furthermore, Narayanan et al. (2022) prescribe higher parking fines, while Verlinde et al. (2014) recommend internalisation of external costs.

Increased use of electric vehicles can result in peaks and troughs in energy demand. Although the electricity demands for E-cargo cycles are minor, when the operators use them in the fleet along with other electric vehicles (e.g., E-Vans), smart charging systems could be beneficial (Moolenburgh et al., 2019). In addition, the growth of E-cargo cycles should be combined with the use of renewable energy sources to ensure better environmental benefits (Athanassopoulos et al., 2016; Ormond Junior et al., 2019b). Although in many countries (especially European) E-cargo cycles share the use regulations with E-bikes, there is an increasing interest in framing a distinct set of regulation. For example, in 2020, German federal ministry of transport ministry introduced new street signs for cargo cycles (BMVI, 2020). Nevertheless, to our best knowledge, the legislation is yet to mature and a comprehensive outlook of the rules in different nations has to be explored in future, with the establishment of significant separate regulations for E-cargo cycles).

Besides the aforementioned measures and regulations, there is a growing concern to streamline the employment compensation and labour rights of freelance messengers and self-employed individuals of gig economy platforms (e.g., Uber Eats), in order to avoid labour exploitation. Existing app based on-demand services are associated with labour issues, due to the change of the labour conditions of the work itself (Glöss et al., 2016). The issues include, but not limited to, physical, financial and epistemic risks. Gregory (2021) indicates the personal responsibility of physical risks (e.g., accidents during deliveries), existence of blurred boundaries for financial risks (e.g., risks such as that the work may not be financially worth it) and presence of lack of transparency leading to epistemic risks (e.g., uncertainties related to how algorithms structure the work allocation, which obscures the organisation of the work itself). All these issues have been subjected to repeated legal scrutiny (Adams-Prassl and Risak, 2016). Nevertheless, these challenges may constitute an opportunity for further reflections on the development of protective schemes and legal interventions, showing the need for a regulatory structure that is representative of the distinct nature of gig markets.

#### 5.2.3. Incentives

Provision of incentives and funding from the city has a significant impact on the penetration of E-cargo cycles (Wrighton and Reiter, 2016). They are recommended by multiple studies to spur the growth of cargo cycle use (Choubassi et al., 2016; Rudolph and Gruber, 2017; Schliwa et al., 2015; Sheth et al., 2019; Verlinde et al., 2014; Wrighton and Reiter, 2016). Incentives could be in different forms, for example monetary (Choubassi et al., 2016), allocation of infrastructure for cycle storage (Sheth et al., 2019) and provision of locations for intermediate shifting (Assmann et al., 2020; Athanassopoulos et al., 2016; Verlinde et al., 2014).

Support of local public authorities is crucial (Navarro et al., 2016). Local public authorities can support operators by providing access to suitable locations for intermediate shifting (Athanassopoulos et al., 2016; Rudolph and Gruber, 2017). Since the public authorities aim for the common good instead of profit and have the regulatory power, giving affordable access to locations for intermediate shifting is feasible (Assmann et al., 2020). The shifting facilities should be developed with a consideration for the urban fabric of the district (subarea scale) and the street (micro scale), thereby integrating them into the social life of local people (Assmann et al., 2019). Estrada and Roca-Riu (2017) discuss the necessary conditions to ensure a minimal profitability of carrier-led consolidation strategies in urban distribution, including E-cargo cycles. These conditions represent the cost of the stakeholders involved: society, regular carriers, consolidation facility operator and environment (Estrada and Roca-Riu, 2017).

#### 5.2.4. Awareness creation and mobility plans

Narayanan et al. (2022) conclude that purchase subsidies combined with campaigns promoting the soft benefits of E-cargo cycles can have a substantial impact on their purchase. There are also other studies, which advocate campaigns. For example, Nürnberg (2019) suggests public presentations of the benefits of cargo cycles. Similarly, Maes & Vanelslander (2012) recommend the implementation of awareness campaigns, along with an introduction of a logo for non-fuel powered transport. Furthermore, Rudolph & Gruber (2017) prescribe network building and knowledge transfer. Local cargo cycle networks could be formed between local authorities, businesses, cargo cycle manufacturers and research partners to raise awareness on commercial E-cargo cycle use.

Trial schemes are effective in reducing the apprehensions towards E-cargo cycles and improving their acceptance (Narayanan et al., 2022; Rudolph and Gruber, 2017). Hence, cities can facilitate projects involving trial schemes. In addition, cities have to promote the use of cargo cycles by including them in their municipal fleets (Rudolph and Gruber, 2017; Wrighton and Reiter, 2016). In view of this, E-cargo cycles can be used for services, such as street cleaning, maintenance of public parks, waste collection and facility management.

Utilisation of E-cargo cycles in commercial transport should be included and discussed in city master plans and Sustainable Urban Mobility Plans (SUMPs) (Koning and Conway, 2016; Rudolph and Gruber, 2017; Sheth et al., 2019). Cities may not remodel roads and cycle lanes just for the purpose of cargo cycles (Rudolph and Gruber, 2017). Hence, a green vehicle strategy should be developed as part of a broader sustainable urban transport initiative, and regional approaches and partnerships with local associations are important in this regard (Foltyński, 2014). Policies aimed at establishing intermodal strategies (e.g., train-cycle deliveries) should also be explored (Wrighton and Reiter, 2016).

## 6. Private transport: typology, penetration and impacts

Although the existing use of E-cargo cycles is predominantly associated with commercial transport, they are also suitable for private transport. They can be used for commuting, shopping, leisure activities or transporting children. Concerning typology, E-cargo cycles can be either owned (Boterman, 2020; Riggs, 2016; Wrighton and Reiter, 2016) or shared (bike-sharing systems) (Becker and Rudolf, 2018; Hess and Schubert, 2019).

With regards to the sharing systems, Becker and Rudolf (2018) analyse a cooperative network of 46 urban cargo bike-sharing operators in Germany and Austria. In such a network, the cargo bike is available to everyone. The operators do not charge their users any rental fee, but rather ask for donations or voluntary engagement with the network. Thus, users become co-producers. The operators (civil society actors; individuals or associations) acquire financial aid through crowd-funding systems, and in some cases, local municipalities also support them. The users book through a common booking software, and the cargo bikes are made available through cafes, food shops, kindergartens or universities (collectively called as hosts). Although the economic sustainability of the system is unknown, 9,750 users have registered in a period of four years.

Hess and Schubert (2019) analyse the usage of the E-cargo cycle sharing system 'Carvelo2go'. Unlike the system examined in Becker and Rudolf (2018), Carvelo2go (Switzerland) charges its users. Thus, this service is not a cooperative one, but rather analogous to a system operated as a business by a private company. However, similar to the cooperative system, Carvelo2go also utilises hosts to manage the vehicle distribution to the customers. The hosts, as an exchange, get 25 h of free cargo cycle use per month and free advertising on the cycles.

### 6.1. Penetration potential and acceptance

Literature pertaining to E-cargo cycles in private transport is in general very limited. The topics explored in the pertinent literature are mostly on penetration related aspects. For example, Wrighton and Reiter

(2016) conclude that more than three-fourths of the shopping trips in urban areas can be shifted to cargo cycles. They state that the dense network of shops for daily supply in urban areas and the relatively light weight of the purchased goods are the reasons for the high penetration potential. Bjørnarå et al. (2019), based on a survey, indicate that E-bikes and electric longtails (a type of E-cargo cycle) are more suitable to transport children than non-electric bikes with trailers and non-electric longtails. Riggs (2016) confirms the relationship between cargo cycle use and trips that involve children. However in Becker and Rudolf (2018), contrastingly, the major objective behind using the shared E-cargo cycles is not transportation of children, but rather the transportation of food and bottle crates. Furthermore, the shared cargo cycles are also used to transport materials (e.g., from hardware stores), dogs and garbage (to the recycling station), and the facilitation of events within the city. Thus, it appears that the cargo cycles that are owned are utilised more for transporting children, while the shared system is utilised more for other utilitarian purposes. Interestingly, this is in line with the literature on E-bikes (Bourne et al., 2020; Lopez et al., 2017), i.e., E-bikes are mostly found to be used for utilitarian trips.

Although Becker and Rudolf (2018) are not able to establish a clear relationship between the type of goods transported and the type of cargo cycle used, three-wheeled cycles are observed to be more frequently used for events, and for transporting furniture. In addition, 35% of the respondents conveyed that they are planning to buy a cargo cycle. Thus, cargo cycle sharing schemes can induce purchase of cargo cycles. The remaining respondents still intend to use cargo cycles in the future, although they do not prefer to purchase.

Two major factors that can affect the penetration of cargo cycle sharing systems include information dissemination (especially through social media) and proximity of sharing station to home. For the early diffusion stage of shared E-cargo cycles, Becker and Rudolf (2018) state that cycling users are the most important target audience. However, Hess & Schubert (2019) conclude that the cargo cycle sharing system would directly compete with car sharing systems, since similar skills are required (e.g., the reservation procedure and the vehicle pick-up) and both systems have similar attributes (e.g., an inclination toward sharing). The objective of their study is to understand how practices, such as cargo cycle sharing systems, emerge when materials, meanings, and competences interlink. Factors identified to be affecting the penetration of cargo cycle sharing systems include cost, cycling infrastructure, safety concerns, gender, age, income, household size and possession of driver's license.

### 6.2. *Travel behaviour, safety & emissions*

A decline in car trips has been observed in Riggs (2016) and 68.9% of the survey participants have changed their travel behaviour after purchasing a cargo cycle. The number of car trips has declined by 1–2 trips per day (half of the car travel prior to cargo cycle ownership). The study concludes that the individuals who may not otherwise use normal cycles, would explore the option of cargo cycles as a substitute for cars. Becker and Rudolf (2018) also make a similar conclusion, i.e., E-cargo cycles (sharing system in this case) can reduce car use in urban areas. About half of the survey respondents (46%) indicate that they substituted their car trips with the shared cargo cycles. Other modes substituted include conventional cycle (about a quarter of respondents) and public transport (a small number of users). In addition, 13% of the respondents are found to have done new trips, i.e., utilisation of shared cargo cycles can result in induced demand. For more details and figures, the reader is suggested to check the original study. It is worthy to be noted that the literature related to the use of private E-bikes also conclude a similar relationship, i.e., use of E-bikes can reduce car use (Bourne et al., 2020; Cairns et al., 2017; Jones et al., 2016).

With regards to impact on safety, the aspects related to rider safety, which are discussed in Section 4.4 for commercial transport, are also applicable to private transport. Concerning emissions, Becker and Rudolf (2018) state that cargo cycle sharing systems have higher potential to reduce emissions than normal bike sharing systems, since the majority of users of the latter are those who switched from sustainable modes of transport, rather than from car. They conclude that around 920 kg of $CO_2$ emissions were eliminated by the cooperative cargo cycle sharing system users (n = 931) during the research period.

### 6.3. *Societal norms & public health*

Boterman (2020) concludes that (electric) cargo cycle users are often seen to be elitist by members of the Dutch public, with the authors hypothesising that it is due to the visible difference in comparison to the cheaper bicycles. Furthermore, mothers who use cargo cycles are considered to be self-confident, while fathers are considered to be soft and free-spirited. A crowd-sourced documentary film named 'Motherload' conveys that driving cargo cycles provides a feeling of connection to the natural environment, while cars do not, as they allow only visual interaction (Martinko, 2020). Female interviewees in the documentary perceive cargo cycles to be granting women a life-altering mobility opportunity. However, they experience harassment of some kind, and are being told by the harassers that transporting children with cargo cycle is dangerous. Hence, awareness and safety training, along with infrastructure developments, could be beneficial (Hess and Schubert, 2019).

With regards to public health, based on a study on E-bike (Jones et al., 2016), it is possible to conclude that E-cargo cycles can also increase or at least allow an individual to maintain some form of physical activity. A concern for public health may arise due to the motorised assistance of an electric cycle, which decreases the physical activity, thereby reducing the assumed health effect of cycling. However, based on a survey of 340 E-bike users in Norway, Sundfør and Fyhri (2017) state that the substitution effect on physical activity with the introduction of an electric cycle is not substantial. Stronger interested towards electric cycles are found among those with little levels of physical activity. Therefore, the effect of introducing electric cycles appears to be positive from a public health perspective.

## 7. Conclusions and research gaps

A single system can never offer a solution to all issues pertaining to the transport sector, including E-cargo cycles. A logistics system based only on E-cargo cycles may not be realistic. Likewise, in the field of private transport, they cannot be utilised for every trip made. Similar to other modes, E-cargo cycles do have merits and demerits. A sustainable option is to identify and exploit their potential, and utilise them for a right application in an optimal way, in combination with other available options. Therefore, a properly developed system is necessary.

Therefore, this comprehensive review aims at discerning knowledge from the existing literature to obtain insights related to various facets of E-cargo cycle deployment. This research is carried out with an initial focus on the typology for commercial transport, to obtain an overview of different systems possible to be implemented. E-cargo cycles can be utilised for both delivery and service trips. Furthermore, they can be used in combination with other modes or a dedicated E-cargo cycle fleet system could be developed. The choice between the two depends on the nature of operations. Likewise, network configuration also differs based on the nature of operations. There could be a necessity for a transshipment point (intermediate shifting) in certain situations, while direct trips can be made using E-cargo cycles in other situations. A combination of the two is also a possibility.

Studies pertaining to the penetration of E-cargo cycles show that they are suitable for a substantial portion of commercial trips, and their potential is yet to be fully exploited. Their practical use depends on a number of factors, which belong to operational, vehicular, infrastructural, workforce, organisational and policy related aspects. In general, E-cargo cycles are perceived to be suitable for areas with narrow streets, high delivery density and commercial activity (e.g., CBDs and historical centres), and low parcel volumes. They predominantly replace cars and light commercial vehicles. Furthermore, low catchment area of commercial trips (with linear distances up to 20 km per trip), provision of adequate charging stations and overnight storage facilities, managerial support and regulatory measures that deteriorate the conditions for conventional motorised vehicles are conducive for E-cargo cycle penetration.

E-cargo cycles are generally viewed as a means to reduce environmental impacts. However, findings on impacts show that their penetration can result in a number of other positive impacts. With a right application, the pertinent literature points out economic (reduced cost and extra revenue), societal (increased employment, better health and improved liveability), traffic (reduced congestion) and safety, and operational benefits (better access and higher service level). There might be a need to increase the fleet size in certain cases. Nonetheless, it should be noted that E-cargo cycles are comparatively cheaper than conventional motorised vehicles, and consume less space. If used for suitable deliveries (in terms of volume and load), E-cargo cycles can result in reduced cost per delivery, when compared to conventional vehicles. A number of decisions have to be made, when beginning to utilise E-cargo cycles. The simplified scheme suggested in this research could be utilised to decide the type of network configuration and the fleet composition.

Although there is a greater potential for E-cargo cycles in commercial transport, certain supportive policies are a prerequisite to accelerate the shift from conventional motorised vehicles. Regulatory measures that deteriorate the conditions for conventional motorised vehicles (e.g., vehicle access restrictions and better parking enforcement) are stated to be the major factors for the interest towards E-cargo cycles. In addition, provision of incentives (monetary and infrastructural) and development of better cycling infrastructure (larger dedicated cycle lanes, lane connectivity and better pavement surfaces), along with awareness creation through campaigns, networking and knowledge transfer, municipal use and trial schemes, support their growth in commercial transport.

With regards to private transport, the typology is based on whether the vehicle is owned or shared. Within the shared system, commercial and cooperative sharing is observed. E-cargo cycles are suitable for commuting, shopping, leisure activities, and transporting children. Car users who test E-cargo cycles are generally found to like them, since they have electrical assist and higher load capacity. Also, they have better dynamics and stability than normal E-bikes. Concerning the penetration of E-cargo cycles in private transport, owned vehicles are found to be used more by parents for transporting their children. However, shared vehicles are used for transporting food, bottle crates, materials from hardware stores, and garbage. With respect to mode substitution in private transport, E-cargo cycles predominantly replace cars, although substitution for conventional cycles and public transport is also observed. In addition to mode substitution, E-cargo cycles can also result in induced demand (in the form of new trips). Results pertaining to their impacts show that they can reduce emissions, and provide enhanced mobility for women. They provide a feeling of connection to the natural environment, which cars do not provide.

Despite the growing literature on E-cargo cycles, a number of research gaps still exist. Though there exists a substantial potential for E-cargo cycles for private transport and service trips, the majority of the studies reviewed concentrate on delivery trips. This trend needs to change and focus shall be placed also on research pertaining to the utilisation of E-cargo cycles for private transport and service trips. In some countries, based on size and load capacity, there could be restrictions for E-cargo cycle use in cycle lanes and passenger walkways. However, existing literature do not explore such aspects. Hence, country-specific restrictions need to be researched in future.

Looking into the studies on delivery trips, the majority of the results are based on data from trial schemes, pilot projects and small independent analysis. It is impossible to evaluate a wide variety of scenarios through such trials and analysis. Therefore, scepticism still exists when it comes to large scale deployment. Use of transport models and simulations could be useful in this regard. Simulations, especially at city and regional level, allow for evaluating a wide range of scenarios, policies and applications. However, they are seldom adapted and used for evaluating E-cargo cycles. Hence, projects focusing on developing and using simulation based approaches are needed. Where data availability is an issue, assumptions can be made and scenario analysis can be carried out.

A reduction in cost for operator can lead to a decrease in the service charges for the customers. This, in turn, can result in an increase in demand. Although the existing literature explores the reduction in cost for operator, a decrease in the service charges and the potential increase in demand are not yet researched, and is a topic for future research. In certain countries, conventional motorbikes are used for delivering small goods. To our knowledge, many E-cargo cycle models have a higher payload volume than motorcycles. Furthermore, motorbikes are usually not allowed to use exclusive cycle lanes, while E-cargo cycles are allowed to use cycle lanes in several countries. Hence, there is a high potential for E-cargo cycles to substitute motorbikes. However, the impacts of such a substitution have not been studied yet, and therefore, this is also a topic for future research.

To increase the efficiency of consolidation centres, multiple operators could be allowed to shared a single centre and the effects of such a scenario are to be explored. The studies related to emissions consider only the emissions during Well-to-Tank and Tank-to-Wheel. However, a pertinent missing aspect is the emissions related to the production and recycling of vehicles, which is lower for E-cargo cycles, compared to the traditional fleet, due to the lesser amount of materials consumed. This aspect should be researched in future. At the least, the emission rates should corrected by an adjustment factor to account for emissions during vehicle production and recycling. With regards to important operator parameters like deliveries per hour, the existing literature is still sparse and more research is needed in this direction, especially to have a comparison with different standard delivery vehicles and for different parcel types.

With growing E-commerce activities, there is an increasing potential for E-cargo cycles. However, no significant literature exists, which quantifies this relationship. Therefore, this should be analysed in future. Pandemics like COVID-19 further increase E-commerce activity. Future research should also study this aspect, i.e., the possibility of pandemics like COVID-19 to influence the penetration potential of E-cargo cycles. Further suggestions for future research include identification of optimal nodes in logistics systems for the deployment of E-cargo cycles, quantification of the effects of incentives and regulatory measures, comparison of different network configurations (UCCs, MCCs, or TPs, and their location with respect to delivery zones), assessment of the impact of average distance to delivery location on number of deliveries per hour, evaluation of the influence of demand density on vehicle kilometres travelled, analysing the need for dedicated vs mixed fleet under varied distribution networks and the impact of energy mix in the electricity generation.

## Declaration of potential conflicts of interest

None.

## Author statement

**Santhanakrishnan Narayanan** Conceptualization, Methodology, Investigation, Data curation, Writing – Original Draft, Writing – Review and Editing, Visualisation. **Constantinos Antoniou** Conceptualization, Methodology, Writing – Review and Editing, Funding acquisition.

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## Appendix

**Table A1**
Description of the studies reviewed.
Study type - A: Studies based on surveys/workshops/interviews; B: Studies based on pilots/trial schemes; C: Simulation based studies; D: Review papers; E: Optimisation programming; O: Others; Note: Studies are sorted by year and then alphabetically by authors.

| Study | Study type | Model/Analysis framework | Remarks |
|---|---|---|---|
| Leonardi et al., 2012 | B | Analytical model | Assessment of the impacts of E-cargo cycles on traffic and environment. E-cargo tricycles and electric vans, along with a consolidation centre, is used by a major stationery & office supplies company. While the electric vans have a load capacity of 445 kg and a load space of 3 $m^3$, the cargo cycles have a capacity of 180 kg and a space of 1.5 $m^3$. 6 tricycles and 3 electric vans are used (7 diesel vans were used before the trial) and overnight charging is done for both the vehicles. A total of 1,200 *parcels/day* are delivered. Place of study: Central London |
| Maes and Vanelslander (2012) | A, C, D | – | Evaluation of economic viability of bike couriers as a sustainable alternative for fossil fuel powered transport. A literature review is conducted, followed by a market study of the Belgian bike couriers through surveys and round table discussion. Seven bike couriers participated in the discussion. Calculating the cost per stop for economic feasibility is conducted by simulating a round trip delivery scheme for bike couriers and vans. The simulation approach is not clear. Place of study: Belgium |
| Yao and Wu (2012) | A | Binary logistic regression & structural equation model | Identification of risk factors influencing the involvement of E-bike riders in accidents. Data from 603 E-bike riders are collected through a survey. The survey was carried out on both workdays and weekends. The minimum age for participation is 18, and the individual must be a regular E-bike rider (riding at least once a week). Place of study: Beijing, Hangzhou |
| Gruber et al. (2013) | A | Analytical model | Examination of substitution potential for cargo bikes and user requirements. Data from eight different courier companies are used for the analysis. Data pertaining to 117,198 delivery trips (type, volume and weight of delivery) are processed to derive the substitution potential for a 2-wheel E-cargo bike (with a payload capacity of 100 kg and a payload volume of 176 L). In addition, 188 messengers are surveyed to determine the user requirements. Majority of the surveyed messengers can bundle several deliveries per trip, with 3 packages per bundle being the most common. Place of study: Germany |
| Lenz and Riehle (2013) | A | – | Exploration of the current use of cycle freight across Europe and deriving their potential use. A multistage research by surveying (snowball sampling) cycle freight experts, manufacturers and trades people is conducted. The survey includes 116 respondents. A subsequent detailed survey is also conducted for a sub-group of 38 respondents. These respondents offer services in different areas like logistics, warehouse activities, retail services, trades and last mile concepts. Additionally, in-depth interviews are carried out with experts from commerce, manufacturing and research. Place of study: Europe |
| Foltyński (2014) | B | – | Presentation of an overview of electric urban freight mobility using examples from European cities. The study explores the technical, legal and social factors, which are relevant for small and medium sized cities. Place of study: Europe |
| Gevaers et al. (2014) | C | Analytical model | Development of a model to calculate the total last-mile costs. Independent variables are based on specific last mile characteristics, such as average number of stops per delivery route and handling time. The developed model is applied for comparing the costs of delivery by van and cargo bikes. Place of study: Belgium |
| Gruber et al. (2014) | A | Binary logit | Determination of potential market for E-cargo bikes, its perception by bike & car messengers and factors affecting the willingness-to-use them. One year trip data from eight German courier companies are analysed. Catchment areas of the companies are determined based on 752,334 deliveries. 59,501 car shipments and 88,391 bike shipments of a Berlin based company is used for an in-depth analysis. A survey of 191 messengers is used to ascertain messengers' willingness-to-use an E-cargo bike. Place of study: Germany |
| Papoutsi et al. (2014) | A | Abbreviated Injury Scale (AIS) handbook 2008 | Evaluation of E-bike accidents and injuries in an acute hospital setting. The research include a 18-month observational study, from April 2012 to September 2013, on adult patients (>15 years old), admitted to the Emergency Department. Following data related to E-bike injured patients are analysed: gender, age, time, season, cause of accident (being caught in a tram rail, vehicle collision and self-accident, severity of injury, medical diagnosis, and the outcome (treated as outpatient or inpatient, kept in the intensive care unit, and mortality). Place of study: Bern |
| Pattinson and Thompson (2014) | D | – | Examination of the safety issues caused by large trucks, which are utilised in logistics sector. Place of study: Australia |
| Sadhu et al. (2014) | A | Multinomial logit regression | Assessment of the impacts of Cycle Rickshaw Trolley (CRT). The study is based on a survey of 2000 CRT drivers. The sample consists of CRT users from commercial (50%), industrial (30%) and residential areas (20%). The factors affecting the monthly savings of CRT drivers is assessed by estimating a logit model. Place of study: Delhi |

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**Table A1** (*continued*)

| Study | Study type | Model/Analysis framework | Remarks |
|---|---|---|---|
| Schepers et al. (2014) | A | Logistic regression | Comparison of the likelihood of crashes between electric bicycles and conventional cycle users. A survey of victims treated at emergency departments was done, and only those who are above the age of 16 were included. Furthermore, those hospitalized at an emergency department were compared with those sent home after the treatment, to analyse the injury consequences between electric and conventional cycle victims. Place of study: Netherlands |
| Tipagornwong and Figliozzi (2014) | E | Vehicle Routing Problem (VRP) | Development of a cost model that incorporates vehicle ownership and logistics constraints like time window, cargo capacity, fuel consumption and energy use, along with operation model. Furthermore, the cost model includes unit purchase cost, unit resale cost, unit energy cost, per mile maintenance cost, unit labour cost and unit $CO_2$ emission cost. The analysis if based on the goods delivered from a distribution centre to shops and retail stores by a freight tricycle delivery company, B-Line. Scenarios analysed include a weight constrained scenario (e.g. office staples) and a time constrained scenario (2–4 h). Place of study: Portland |
| Verlinde et al. (2014) | A, B | Multi-actor Multi-criteria analysis | Assessment of the feasibility of using a mobile depot to make urban express deliveries. The study is based on the deliveries carried out by TNT Express for a period of three months in 2013, as part of the European FP7 project STRAIGHTSOL. The study area spans over 12 square kilometres, and is densely populated. Electrically driven cyclocargos are used for delivery from the mobile depot, and also to pick up goods from the customers. During the testing period, 1,292 pickups and 5,286 deliveries were completed. Emission calculations are based on STREAM emission factors, which take into account vehicle type, load factor and road type. To know the opinion of the public, people on the streets (near to the mobile depot) are surveyed, along with six planners and five dispatch riders. Place of study: Brussels |
| Schliwa et al. (2015) | A, D | – | Development of a topology for cycle logistics and identification of major barriers to a wider city level implementation. Expert interviews with cycle logistics consultant and case study interviews with operators took place. 22 interviews with cycle logistic operators and experts, and bike service providers are conducted. A sustainable city logistics framework for urban governance and logistics operation is also presented. Place of study: UK |
| Athanassopoulos et al. (2016) | B | Life-cycle assessment | Examination of the impacts of alternatives to classic diesel drive technology. Three alternatives, electrically driven cars and E-cargo tricycles with or without a parcel storage container, are tested by the company UPS. Delivery with two different E-cargo cycles are evaluated, which are called cargo cruiser and cyclo cargo. While the cargo cruiser has a payload capacity of 306 kg and a volume of $2.2m^3$, the cyclo cargo has a payload capacity of 220 kg and a volume of $1.5m^3$. The test duration ranges from a minimum of 10 weeks to a maximum of 54 weeks. Total costs of the delivery options include costs of maintenance, fuel costs, labour costs, along with consideration for depreciation, insurances and taxes. Apart from the economic and ecological impacts of the aforementioned three alternatives, the influence of the national electricity mix is also assessed. Place of study: Hamburg |
| Choubassi et al. (2016) | E | Optimisation (Capacitated vehicle routing problem with time window) & Analytical model | Analysis on the economic benefit of moving from long life vehicles to cargo cycles in three urban contexts within the city and in different traffic conditions. Two different types of cargo cycles, cargo bike and cargo trike, are considered. In addition, two types of electrical propulsion systems are analysed: pedelecs (a small electric motor provides assistance when pedalling) and completely electric (batteries operate during the entire trip duration, with no requirement of pedalling). The pedelecs are assumed to have a maximum operating speed of 10*mph*, while the latter can reach a speed of 15*mph*. The analysis include two categories of urban setting, which are high density (CBD and UT neighbourhood) and low density (Far West), as well as three kinds of depots and consolidation centre locations. The travel speed is assumed to be 10*mph* during congestion and 15*mph* under normal conditions. Cycles have dedicated lanes. A total of 36 scenarios are assessed based on cargo cycle type, traffic conditions, urban setting. A loading time of 5*s* per package is assumed. A heuristic solution algorithm based on the principle of ruin and recreation is used. Furthermore, a 24-year financial cost model is developed, which includes the monetary value of the purchase cost, fuel or electric motor cost, maintenance costs, labor costs, emission costs and battery replacement costs for each vehicle. Place of study: Austin |
| Dozza et al. (2016) | B | Odds ratios | Assessment of the behaviour of E-bike users. A naturalistic data from 12 cyclists (who used instrumented electric bicycles) were collected for two weeks. A total of 1500 km of data were analysed, which include 88 critical events (crashes and near-crashes). A comparison between electric and conventional cycles was carried out using the data from a previous study, which was conducted an year earlier. Within this previous study, a similar kind of data was collected for conventional cycles, using the same instrumentation as in the current study. Place of study: Sweden |
| Greibe and Buch (2016) | O | Analytical model | Examination of the influence of the cycle lane width on behaviour, flow and capacity of bicycle traffic. The study is based on an empirical data pertaining to 8,925 cyclists, collected at 8 different locations through video recordings. Characteristics of the locations are high cycle traffic volumes and absence of traffic lights/junctions/bus stops/zebra-crossings. Place of study: Copenhagen |

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**Table A1** (*continued*)

| Study | Study type | Model/Analysis framework | Remarks |
|---|---|---|---|
| Gruber and Kihm (2016) | A, B | Binary logit | Assessment of the perceptions of messengers to estimate market potential for E-cargo cycles and identify barriers for their uptake. 40 E-cargo cycles are made available to the messengers, as part of the project 'Ich ersetze ein Auto'. These vehicles have a payload capacity of 90 kg and a storage volume of 200 *L* 127,000 shipments, accounting for about half a million kilometres, were carried out during the trial period. In addition, a survey of 63 messengers from the eight participating companies is conducted. A binary logit model is used to analyse the survey, for identifying the factors influencing the rejection of E-cargo cycles. Place of study: Germany |
| Haustein and Møller (2016) | A | Linear regression | Examination of the factors contributing to perceived E-bike safety and involvement in safety critical incidents. Internet based survey was conducted to enquire E-bike users, who had an E-bike for atleast a month and used it regularly. A total of 685 individuals participated in the survey. Place of study: Denmark |
| Heinrich et al. (2016) | A, B | – | Exploration of the impact of product failure of E-cargo cycles on their diffusion, and the importance of early adopters. The study is based on the testing of E-cargo cycles by seven local businesses, along with a survey of them. Place of study: Herne, Germany |
| Jones et al. (2016) | A | Qualitative analysis | Investigation of the motives for E-bike purchase, rider experience and perceived impact on mobility, health and wellbeing. The study is based on interviews of 22 adult E-bike owners. Place of study: Netherlands, UK |
| Koning and Conway (2016) | A | Analytical model | Evaluating the increasing use of bicycles and tricycles for transporting commercial goods and the resulting transport externality savings. 9 bicycle freight operators are surveyed, and four types of environmental damages from freight operations are evaluated: CO2 emission, local pollution, noise pollution, and congestion. $CO_2$ emission factors are obtained from the French Agency for Environment and Energy Management. A total of 10,206 scenarios are analysed by varying the emission factors, peak hour travel share and vehicle load factor. Place of study: Paris |
| Navarro et al. (2016) | B | Analytical model | Examination of the impacts of E-cargo tricycles, when used along with transshipment terminals or urban consolidation centres. For the last mile delivery, different transport operators share the same vehicle. Two E-cargo tricycles with a payload capacity of 280 kg and a storage volume of $1.5m^3$ are used. The cycles are $2.78m$ long, $1.03m$ wide and $1.95m$ high. Place of study: Barcelona, Valencia |
| Nocerino et al. (2016) | B | Analytical model | Analysis on the performance of E-cargo cycles and E-scooters for goods delivery in urban areas. 12 months testing data from four Italian pilots (three in Genoa and one in Milan) are analysed. Place of study: Genoa and Milan |
| Riggs (2016) | A | Binomial logistic regression | Investigation of the potential of (E−)cargo cycles to contribute to the mode substitution behaviour. Surveys, before and after the use of cargo cycles, are carried out, and 194 individuals are part of the survey. Place of study: California |
| Wrighton and Reiter (2016) | B, D | Analytical model | Based on the Cyclelogistics project, the study aims to demonstrate the shift potential from motorised vehicles to bicycles or cargo bikes in urban areas. Place of study: Virtual European city with 0.24*million* inhabitants |
| Anderluh et al. (2017) | *E* | *Two-echelon, multi-trip vehicle routing problem with temporal synchronisation* | *Investigation on efficient organisation of goods distribution in cities. A reedy randomised adaptive search procedure with path relinking is used as a solution algorithm. Customers are divided into two groups: bike customers (located within the city centre) and van customers (located outside the area). The real-world test instance is based on 100 pharmacies that are randomly located. An average speed of 15 km/h is assumed for the cargo bikes. For vans, floating car data from FLEET is used to calculate the travel times. Three different distribution policies (a van only scenario, and a van and cargo bike scenario with and without temporal synchronisation between them) are investigated. Place of study: Vienna* |
| Arvidsson and Pazirandeh (2017) | A | Analytical model | Ex ante evaluation of a integrated and multimodal freight distribution using a bus as amobile depot. Data from a medium sized parcel distributor (520*trips/year*; 41, 600*parcels/year*, each weighing 4 kg on average and having an average volume of 19.5 $cm^3$) are used for the evaluation. Two vans with a payload capacity of 815 kg and a storage capacity of 5.9 $m^3$ are required to fulfill the demand in the conventional distribution model. The freight bus is assumed to make six stops in city centre, following the same van route. The operating costs of the distribution systems include the standing costs, running costs and overhead costs. Sensitivity analysis is carried out by varying the labor costs, fuel costs, delivery rate of parcels per stop, delivery speed of the distribution vehicles, congestion charges and parking fees. Scaled scenarios are also evaluated, wherein the utilisation rates of the freight bus is varied as 25%, 50%, 75% and 100%. Two workshops are also conducted as part of the study, with the participant selection based on a snowball sampling. Place of study: Gothenburg |
| Cairns et al. (2017) | B, D | Descriptive statistics | Assessment on the impacts of E-bikes on travel behaviour. The study is based on a review of European literature and trial scheme, wherein 80 employees were given an E-bike for a period of 6–8 weeks. Place of study: Brighton |
| Estrada and Roca-Riu (2017) | C | Stakeholder analysis and analytical simulation model | The cost variation due to consolidation facilities is estimated. Formulas are developed to assess the temporal and distance costs difference between regular distribution and the distribution through a Consolidation Facility (CF). Place of study: Barcelona |

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**Table A1** (*continued*)

| Study | Study type | Model/Analysis framework | Remarks |
|---|---|---|---|
| Hofmann et al. (2017) | C, E | GIS-based discrete event simulation model coupled with tour planning algorithm | Development of a simulation-based assessment tool for different distribution schemes using cargo cycles. Two scenarios, a conventional van only scenario and a multimodal truck and cargo cycle scenario, are analysed. All incoming goods are assumed to be consolidated at an UCC located 12 km southwest of Grenoble. Unloading time at the transfer points is assumed to consist of a fixed value of 3 min and a variable value of 0.5 s per kg demand unit transferred. For loading, the fixed share is assumed to be 5 min. The demand for simulation is based on the logistics requirements of 127 shops, which are obtained through a survey conducted by laboratories CERAG and G-SCOP. The preferred time for delivery is in the morning between 6 and 10 a.m., and the weight and volume of orders are assumed to be uniformly distributed. Place of study: Grenoble |
| Lopez et al. (2017) | A | Descriptive statistics | Exploration of the of the mobility behaviour of E-bike users. The study is based on GPS data of 10,000 E-bike trips, recorded for a period of about 30 weeks. Place of study: Belgium |
| Oliveira et al. (2017) | D | – | Identification of the different vehicle types for the sustainable last mile freight distribution. Only vehicle based solutions are investigated and other potential alternatives such as parcel lockers or crowd-sourcing are excluded. Place of study: NA/NA |
| Rudolph and Gruber (2017) | A, D | – | Identification of the relevant commercial transport market segments for cargo cycle use and categorisation of drivers and constraints of cargo cycle adoption. The study is based on a desk research and 45 expert interviews with corporate fleet managers, urban planners, and representatives from municipalities and bicycle associations. The interviews were conducted face-to-face using voice recorder or through phone. Place of study: Germany |
| Melo and Baptista (2017) | C | Aimsun | Assessment of the impacts of E-cargo bikes. The total transportation cost estimated includes transport and emission costs (when driving and idling) and labour cost. The input demand for the base scenario is based on traffic counts. The scenario tested corresponds to the daily peak of deliveries (8.30 a.m.–9.30 a.m.). E-cargo bikes serve within a pre-defined area of 2 km, replacing diesel vans. E-cargo bikes are assumed to be 2*m* long and 1*m* wide, with a an average speed of 20 km/h. A Well-to-Wheel (WTW) approach is used for estimating energy consumption and $CO_2$ emissions, which include Tank-to-Wheel and Well-to-Tank stages. Replacement of vans by E-cargo bikes is tested for various market penetration rates: 0%, 3%, 5%, 10%, 20%, 50%, and 100%. Place of study: Porto |
| Sundfør and Fyhri (2017) | A | Structural equation model | Examination of the influence of E-bikes on physical activity levels. A survey sample of 340 people was used for the analysis. Before purchase and after purchase data were collected. Furthermore, a comparison group of 1995 individuals were also surveyed. Place of study: Norway |
| Becker and Rudolf (2018) | A, B | Analytical model | Examination of the impacts of cooperative cargo cycle sharing system, along with an analysis on user behaviour. An empirical survey of 931 users of the 30 cargo cycle sharing operators is used as the basis for the examination. The mean age of the respondents is 38 years, with one third of them having a children. 63% of them are men. Furthermore, 92% of the respondents are concerned about climate change. The sample majorly consists of cyclists (71%), followed by 13% of public transport users. Place of study: Germany |
| Faxér et al. (2018) | A, B | Qualitative content analysis | Assessment of the potential of E-cargo cycles to replace cars and vans in public sector. Two versions of E-cargo cycles with weather protection are tested, by providing them to four professional organisations. Semi-structured interviews of the users, manufacturers of E-cargo cycles and municipal transport planners are conducted. Place of study: Gothenburg |
| Fikar et al. (2018) | C, E | Agent based simulation, Optimisation (Local search) | Presentation of a decision support system for facilitating efficient urban last mile distribution in a highly dynamic setting. A fleet of conventional vehicles and cargo bikes (operated by freelancers) is used to carry out the deliveries. Generation of shipment requests is based on a Poisson distribution. While a cargo bike can carry a maximum of 10 shipments, a van can carry 50 shipments. The number of orders ranges between 1174/day and 2935/day. Place of study: Vienna |
| Marujo et al. (2018) | B,C | Analytical model with Monte Carlo simulation | Analysis on the use of E-cargo tricycles along with conventional trucks in a mobile-depot based distribution system, to overcome the restrictions for conventional vehicles. Data is collected from a beverage company through GPS tracking. The tricycles have a payload capacity of 250 kg and can fulfill 2.2 orders. Place of study: Rio de Janeiro |
| Niels et al. (2018) | B,E | Optimisation implemented in ArcGIS | Identification of optimal and practical locations for intermediate shifting. The study is based on the data collected for an year from a CEP company. While higher than 60,000 packages are delivered in the Northern project area, higher than 10,000 packages are delivered in the Southern project area, with 65% of the deliveries accounting for commercial customers and the remaining for private customers. 2 Containers (Northern area) and 1 truck -trailer (Southern area) served as depot. An average speed of 15 km/h and a service time of 2min per delivery are assumed. Place of study: Munich |
| Sardi and Bona (2018) | C | Macroscopic simulation in MS Excel | Examination of two-stage and three-stage logistics systems, which are based on cargo cycles and electric trucks. Data from 2000 shops of 18 shopping malls are used for the analysis. The weight of the delivery goods is randomly generated based on daily minimum and maximum weight. Place of study: Budapest |
| Assmann et al. (2019) | D | – | Development of a framework for planning urban transshipment facilities (UTFs) for last mile logistics. The framework covers multiple planning perspectives, and is based on the interdisciplinary expertise from urban logistics, urbanism, sociology and psychology. Place of study: NA/NA |

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**Table A1** (*continued*)

| Study | Study type | Model/Analysis framework | Remarks |
|---|---|---|---|
| Bjørnarå et al. (2019) | A, B | non-parametric methods (Fisher's Exact test, Mann-Whitney *U* test, Wilcoxon Signed Rank test) | Investigation of the impacts of providing different bicycle types (E-bike including a trailer, a human-powered cargo (longtail) bike, and a traditional bike including a trailer) to parents with kindergarten children. 36 parents recruited for a randomized, controlled trial are divided into an intervention (n = 18) and control group (n = 18). The intervention group are provided with the three types of bicycles during three consecutive time periods of three months, totalling a test period of 9 months. The participants of the control group maintain their usual transportation and physical activity habits. Place of study: Southern Norway |
| Gruber and Narayanan (2019) | B | Random intercept regression model | Examination of the travel time performance of cargo cycles against conventional vehicles for commercial trips. Real-life trip data from a trial scheme is used for the examination. The sample from the trial scheme contains 1,421 cargo cycle trips, made by 84 commercial users from 44 German municipalities. A wide variety of business sectors, such as cafe, construction firm, copy shop, courier logistics, facility management, flower delivery, gardener, movie production, municipal agency, pharmacy delivery, and photographer are part of the sample. Place of study: Germany |
| Hess and Schubert (2019) | A, B | Multilevel regression | Investigation of active, inactive, and potential members and uninterested non-members of an E-cargo bike sharing system. The study is based on a survey of 301 individuals (192 members and 109 non-members). Active members (n = 153) are assumed to be those with a value of higher than 0 for kilometres driven. Multi-level regression model (logistic regression model using membership/non-membership as binary outcome, followed by assessing group affiliation using multinomial logistic regression) is used for the analysis. Place of study: Basel |
| Lee et al. (2019) | E | Simulated annealing | Development of a truck-bike mixture model for reducing the operating costs of deliveries. E-cargo bikes are operated in evade areas (restricted areas due to narrow streets and emission zoning). The payload capacity of the cargo bike is 350 kg, with a battery range of 20 km. Teh trucks are assumed to travel at a speed of 30 km/h, while the cargo cycles travel at 10 km/h. Place of study: Seoul |
| de Mello Bandeira et al. (2019) | A, B | Analytical model | Assessment of alternative strategies for last-mile parcel deliveries of a postal company. Current distribution process (operated with diesel propelled light duty vehicles) is considered as the base scenario, and the alternative scenarios include delivery using electric LDV or E-cargo tricycles. Data is collected by monitoring a postman for 10 working days, 5 for the electric LDV scenario and 5 for the tricycle scenario. The calculation of cost per km include costs related to vehicle depreciation, maintenance, taxes, compulsory insurance, fuel and energy consumption. Emission factors from the Brazilian Ministry of Mines and Energy are used to estimate CO2e emissions. Place of study: Rio de Janeiro |
| Ma et al. (2019) | D | – | Analysis on the risky riding behaviour of E-bike users from three aspects: the characteristics and causes of accidents, the characteristics of users' traffic behavior, and the prevention and intervention of traffic accidents. Place of study: China |
| Moolenburgh et al. (2019) | A, B | – | Evaluation of the requirements for a successful deployment of light electric freight vehicles for urban logistics. The study is based on eight case studies, which are part of LEFV-LOGIC project. In 5 different Netherlands cities, experiments are conducted to test and gather knowledge, firstly through stakeholder assessments and secondly by monitoring vehicles using GPS loggers and cameras. Place of study: Netherlands |
| Naumov and Starczewski (2019) | C | Mathematical model | Development of a distribution system model in Python. Place of study: NA/NA |
| Nürnberg (2019) | B | Empirical experiment | Examination of the possibility to use cargo bikes for the needs of local government administration. The study is based on Low Carbon Logistics project. Cargo bikes are tested on three different routes to ascertain the suitability of road infrastructure for the safe movement of cargo bikes and ease of use. Place of study: Stargard |
| Ormond Junior et al. (2019a) | D | – | Exploration of the use of E-cargo cycles, combined with transshipment centres, to replace conventional diesel fleets. Place of study: NA/NA |
| Ormond Junior et al. (2019b) | B | Analytical model | Comparison of the operational costs and emissions of diesel fuelled vans with an alternate fleet of E-cargo tricycles. The study is based on the empirical data from TNT express, collected through direct observation and company sources. An UCC is installed for intermediate shifting, from where the goods are delivered using vans and E-cargo tricycles. A 18-ton heavy goods vehicle is used to transport goods from the warehouse to the UCC. The total cost calculation includes costs related to vehicle purchase, labour wages, vehicle maintenance, insurance and fuel, along with a $CO_2$ emission cost. Place of study: São Paulo |
| Perboli and Rosano (2019) | B, E | Sequential simulation-optimisation | Investigation of the integration of traditional and green logistics, from both business and operational perspectives. The investigation is based on a Monte Carlo simulation-optimisation decision support system tool, which is capable of assessing mixed-fleet policies. The cost structure includes both economic and environmental costs. The study follows GUEST methodology (GO, Uniform, Evaluate, Solve, Test). Three week data from an international parcel delivery company is used to estimate the distribution of customers and the daily delivery volumes. The calculation of total cost per kilometre include both operating costs (variable costs such as gasoline) and ownership costs (fixed monthly costs). Scenario analysis is conducted by varying the carbon tax (e.g., 17 €/t as in France and 150 €/t as in Sweden), total time per stop, travel speed and delivery times for the traditional and green contractors. Place of study: Turin |

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**Table A1** (*continued*)

| Study | Study type | Model/Analysis framework | Remarks |
|---|---|---|---|
| Sheth et al. (2019) | A, D | Analytical model | Comparison of the route cost of delivery trucks with E-cargo cycles. A route with eight delivery stops is analysed. Each stop may include multiple deliveries, with deliveries on almost every floor of several tall office towers. Apart from deliveries, parcel pickups have to be completed. Scenario analysis is carried out by varying the number of stops, distance between each stop, number of parcels per stop and distance between the distribution center and the delivery neighbourhood. Cost calculation includes driver wages and operational costs. The truck is assumed to be able to carry 400 parcels, and the cycle can carry 40 parcels. Furthermore, the speed of truck is 32 km/h, and the speed of the cycles are assumed to be 24 km/h. Place of study: Seattle |
| Assmann et al. (2020) | O | Mathematical model implemented in MS Excel | Assessment of different strategies for siting transshipment points and related impacts. The reference scenario is based on deliveries by vans. Two different population scenarios are evaluated: a residential and a mixed-use quarter. Similarly, two transshipment point strategies (singular and cooperative) and four network vehicle configurations are analysed (E-vans, E-cargo bike and trucks, E-cargo bike and vans and E-Cargo bike and E-vans). Emission calculation is based on Handbook Emission Factors for Road Transport (HBEFA 4). The number of parcels per quarter is estimated based on population density. 60% of the deliveries are business-to-customer, while 40% are business-to-business. Place of study: Germany |
| Boterman (2020) | D | Qualitative content analysis | Examination of national newspapers to discuss the transformations of urban space from the perspective of class and gender. Place of study: Amsterdam |
| Bourne et al. (2020) | D | – | Analysis on the impact of E-bikes on travel behaviour. Studies for the review were extracted from six databases and two grey literature plaforms, using a standardised extraction form. Place of study: NA/NA |
| Dalla Chiara and Goodchild (2020) | O | Regression model | Exploration of the parking cruising behaviour of commercial vehicle drivers in urban areas. The study is based on a GPS data, corresponding to 2900 trips performed by a fleet of commercial vehicles. Place of study: Seattle |
| Dalla Chiara et al. (2020) | C | Simulation | Simulation of the performance of a cargo cycle scenario with mobile hubs, under different delivery demand and parking conditions. The simulation model consists of three submodels: a demand generation model, a (tour) scheduling model, and a vehicle assignment model. The data for simulation is obtained from a parcel delivery company, which includes 20,000 deliveries that are performed in a period of 3 months. Here Maps API is used to obtain travel times, while start and end timestamps of individual deliveries are used to estimate truck dwell times. Dwell times of cargo cycles are assumed to be 40% less than trucks. Sensitivity analysis is carried out by varying dwell time reduction and capacity of the cargo cycles. Place of study: Singapore |
| Enthoven et al. (2020) | E | Two-echelon vehicle routing problem with covering options | Development of a two-echelon vehicle routing problem with covering options. Trucks transport goods from depot to two types of locations (satellite and covering) in the first echelon. While the customers can pick up goods themselves from the covering locations, goods are transferred to cargo cycles for delivery in satellite locations. The objective is to minimise the operational costs. Scenario analysis is carried out by varying the percentage of customers opting for one of the two options, i.e., home delivery or pick up from a covering location. Place of study: NA/NA |
| Llorca and Moeckel (2020) | D | Freight Orchestrator for Commodity Flow Allocation (FOCA) & Matsim | Assessment of cargo bike use under different modal shares between cargo bikes and vans, demand conditions, and micro depot densities. The focus is on parcels. German nation-wide commodity flows is disaggregated and the last-mile delivery within Munich is used for the analysis. The load capacity of cargo bikes are assumed to be one tenth of a van. Vans are associated with a distance cost of €0.77/km, while cargo bikes with a cost of €0.47/km. €28.8/hr is used as driver cost for both van drivers and cargo bike riders. Place of study: Munich |
| Narayanan et al. (2022) | A, B | Binary logit | Identification of the factors influencing the purchase intention and the actual purchase decision of cargo cycles for commercial use. The study is based on the survey and the empirical data from the largest European cargo cycle testing project 'Ich entlaste Städte', wherein different companies are provided the opportunity to test a cargo cycle for three months. The study sample consists of data from 400 companies, which are located across Germany. Place of study: Germany |
| Naumov (2021) | C | Mathematical model | Development of a distribution system model in Python and demonstration of the same for a real-world case. Place of study: Krakow |

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