Exploring electrification, consolidation, cargo bikes and automation using a sustainability performance assessment framework

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Abstract

The urban logistics transport system brings a significant burden to cities, as the transport-related externalities (e.g., CO2 emissions, noise, and congestion) affect the liveability of the environment and the health of the citizens. To contrast these externalities, urban logistics concepts (e.g., logistics strategies, different vehicle types and vehicle technologies) are being developed and implemented. However, in the literature, there is a lack of a comparative evaluation of different concepts. This evaluation provides useful knowledge for both public and private decision-makers in the system. The goal of this research is to close the knowledge gap by analysing the sustainability performance of urban logistics concepts. Using an existing framework of key performance indicators (KPIs), this study aims to evaluate four urban logistics concepts (i.e., consolidation, electrification, cargo bikes and automation) based on their sustainability performance. The inputs to the framework are findings from the literature, regarding the impact of the concepts on the indicators. These findings can be both qualitative and quantitative. To collect these findings, we performed a literature review on relevant case and simulation studies. The output of the framework is a sustainability performance assessment of the concepts, visualized graphically. The results of this work enable stakeholders to understand how urban logistics concepts can be effective in achieving sustainability. This knowledge can help the decision-making process, favouring choices that promote a sustainable system.

1 Introduction

The transportation system of today produces externalities that affect both the public's health and the environment [1]. In the urban context, these externalities are increasingly becoming an issue, due to increasing freight flows [2]. Since the vision of future cities is to be sustainable, there is a need of finding alternative means of mobility, both for people and goods. For example, Stockholm's vision for 2040 is to have fossil-free transport solutions [3]. In terms of urban logistics, the vision is for increased efficiency and coordination, to decrease congestion [3]. With the population expecting to rise to 1.3 million by 2040 [3], and the growth of e-commerce increasing the need for goods transportation [4, 5, 6], it is important to plan for a sustainable urban logistics system. As reported by Elbert et al., a growing environmental awareness is responsible for a trend towards sustainability. This trend is present both from the perspective of the local and regional governments, which are targeting urban logistics to mitigate the negative effects [7], and from the perspective of private entities, which are implementing measures adapt to the public policies and become more sustainable [7]. In this context, different concepts, innovations and technologies are being implemented [8]. However, urban logistics systems are complex systems, where different stakeholders perform a wide range of activities [7]. Given the diversity of the stakeholders, considering and balancing their needs is a complex task. To achieve this balance, there is a need of taking a holistic approach [9].

In the literature, there is a gap of knowledge in the assessment of the sustainability of these concepts from a holistic perspective. To address this need, the literature on the sustainability of four urban logistics concepts, i.e., electrification, consolidation, automation and cargo bikes, is reviewed in this report. These concepts are first defined and then described in terms of sustainability, using the sustainability performance assessment framework proposed in [10]. The framework is chosen because it provides a holistic perspective on sustainability in the urban logistics context. The framework is composed of indicators that need to be assessed to understand sustainability performance. Therefore, the result of applying the framework is the performance assessment of the four urban logistics context on the indicators. Moreover, research gaps are also identified, together with some direction for future research.

This report is structured as follows. A few key terms used in the report are defined below. The methodology used is described in Section 2, including the literature search and the framework for sustainability performance assessment. The four concepts are defined and described in Sections 3, 4, 5 and 6. A short summary is provided in Section 7.

Key terms

Urban logistics system. With urban logistics system is meant the system that allows the delivery of goods from outside to the endpoint in the city. The four stakeholders in this system are transport companies, receivers, policymakers and citizens living in the urban environment. The first three stakeholders take decisions in this system and make it possible for the deliveries to take place, while the citizens (the forth stakeholder) are the ones exposed to the externalities that transportation activity causes.

Urban logistics concepts. With urban logistics concepts, we mean both logistics strategies that are used to manage the goods flow (for example, consolidation) but also the usage of different vehicle types (for example, electric vehicles or cargo bikes) and vehicle technologies (for example, automation). In this report, four urban logistics concepts have been analysed, namely electrification, consolidation, automation and cargo bikes, defined in the respective subsections.

Sustainability. In this report, the definition of the International Institute for Sustainable Development for *Sustainable Development* is adopted: "Meeting the needs of the present without compromising the ability of future generations to meet their own needs." [11]. In the context of urban logistics, sustainability means considering and balancing the needs and expectations of all stakeholders (i.e., transport companies, receivers, policymakers and citizens living in the urban environment) [10].

2 Methodology

In this report, the framework defined in [10] is used as a tool for sustainability performance assessment. This framework is chosen because it bases on two sources: first, the Sustainable Development Goals (SDGs), developed by the United Nations [12], to ensure the inclusion of all sustainability perspectives; second, a review of indicators used in urban logistics, to ensure that the context is considered. Moreover, the framework includes indicators from a societal perspective and an organisational perspective. The societal key performance indicators (KPIs) represent the externalities of transportation [10]. The organisational KPIs enable the private sector to connect their operation to the societal KPIs and understand how sustainability goals could impact their organisation and economy [10]. Figure 1 shows the complete list of KPIs, adapted from [10]. The framework can be applied to case studies found in the literature, to make them comparable to one another [10]. The framework is used together with a semi-quantitative approach, which includes a combination of qualitative insights and quantitative results (both from simulations and case studies), as suggested in [10].

In the current logistics system, most of the deliveries are carried out by diesel vans, despite some logistics companies are shifting towards more environmentally friendly fuels (e.g., Ethanol, Hydrotreated Vegetable Oil and Compressed Natural Gas) [13]. Therefore, the assumption when estimating the change in the indicators is that the concepts analysed are compared with a system where diesel vans are the predominant mode of transporting goods in the urban environment.

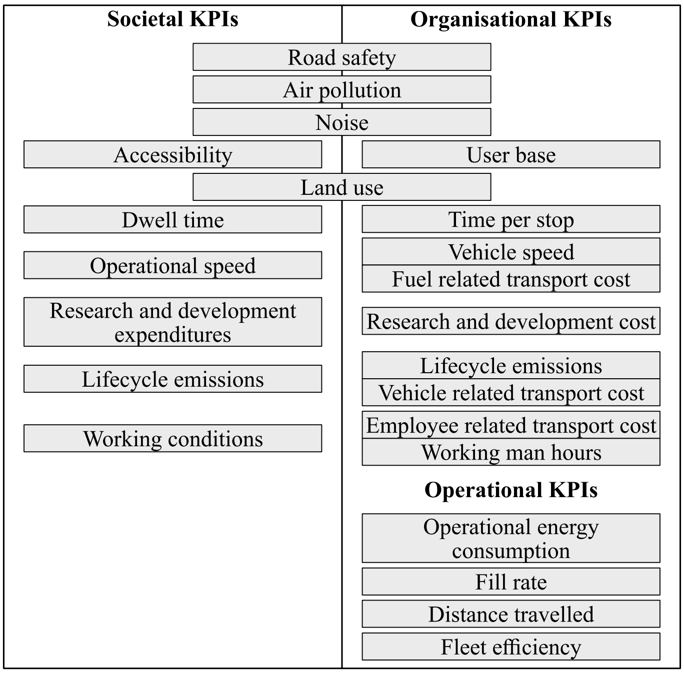

Figure 1: Key performance indicators, from [10]. For the complete definitions of the indicators, please refer to the original publication.

The input needed to use the framework is how different concepts impact the KPIs shown in Figure 1. Therefore, a literature review is performed to select papers that relate to the concepts of electrification, consolidation, automation and cargo bikes. The literature search is carried out using the database Scopus[1] and using snowballing. The performed searches are listed in Table 1: a total of 530 papers is obtained. Then, the abstracts of all 530 papers are read and the most relevant papers are selected. The selected papers contain results that can be used as input to the framework. The selection is also done by taking into account the scope and target of this paper (i.e., the context of urban logistics in mature cities). These results include both quantitative and qualitative results that can be connected to the KPIs present in the framework. The overall methodology of the report is visualized in Figure 2.

[1] `https://www.scopus.com/`

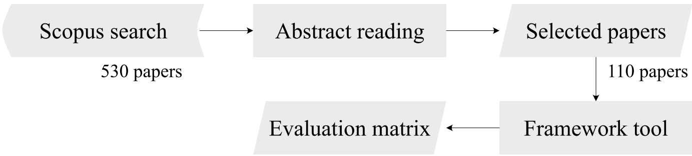

Figure 2: Flowchart representing the methodology followed in this report

Table 1: Searches performed in Scopus, together with the number of hits and the number of selected papers.

Searches performed in Scopus	**Total**	**Selected**
TITLE-ABS-KEY ((logistic* OR freight) AND (transport*) AND (urban OR city) AND (electrification OR "electric vehicles"))	252	50
TITLE-ABS-KEY ((logistic* OR freight) AND (transport*) AND (urban OR city) AND (consolidation))	198	41
TITLE-ABS-KEY ((logistic* OR freight) AND (transport*) AND (urban OR city) AND ("cargo bike*" OR "cargo bicycle*"))	45	30
TITLE-ABS-KEY ((logistic* OR freight) AND (transport*) AND (urban OR city) AND (automation))	80	11
Total[2]	530	110

3 Electrification

Electrification, referred to as the technological shift towards electric vehicles in this report, is addressed in the literature in 252 papers, of which 50 are selected and read. These papers address the need to change vehicles and fuels, to decrease pollution in the cities. Since the introduction of electric vehicles (EVs) enables this decrease, most of the literature concludes that this introduction in the urban logistics system is of key importance. However, their integration is not as straightforward as it might appear [7].

First, the problem of charging should be taken into consideration, and the charging demand should be further studied to understand the impacts on the current grid and how the grid should be modified to cope with the demand [14]. Some studies, therefore, investigate different types of charging networks (for example, [15]). Second, the cost is not always favourable to the purchase of EVs [16, 17, 18, 19, 20]. However, because of technological improvements, their economic feasibility is growing [21]. Third, the environmental assessment should not only consider the emissions that are avoided in the use phase, but should take into account the whole life cycle of the vehicles. A lifecycle assessment by [22] shows that the environmental impact of EVs is greater than the one of diesel vans in many impact categories.

[2]These numbers are not equal to the sum of the previous ones, since there are papers that fall in more than one category

3.1 Charging infrastructure and battery technology

Commonly, EVs rely on battery energy storage for range. This brings three challenges: range anxiety, risk of queuing at charging stations and a need for a reliable and suitable electric grid [23, 24]. Therefore, both charging services and battery development play an important role in the growth of the EV market [25].

The charging strategy can be either scheduled or trigger-based (i.e., emergency charging) [25]: the selection of the strategy depends on availability, operations and driver behaviour. Downtime charging is usually the default strategy [25], but there is also research regarding dynamic charging-while-driving systems. For example, a simulation model from [26] explores a system where the dynamic charging happens after the vehicle arrives at the consolidation facility, with a cooperative driving system. Moreover, in a case study from [27] the use of unloading bays as charging stations is studied, to improve the range of EVs. This method can significantly improve and extend the range of EVs while improving the flow of traffic [27]. Results from a parametric vehicle model that calculates energy consumption [28] show that opportunity charging (i.e., during breaks, shift changes, loading, and unloading) can significantly reduce the costs. A methodology for determining charging strategies using the results of an agent-based transport simulation is introduced by [29]. They use the methodology on a case study of the food retail and can compute the need for charging stations for completing 90% of the tours in Berlin. However, this results in a relatively high number of charging stations [29], which could potentially increase the burden on the electric grid and be a costly initial investment.

The driving range depends upon the battery technology development, and it is an important factor to reduce the costs [30]. If the daily trips are below 100km, electric vehicles are very effective, assuming operation modes characterized by low acceleration, frequent stops and low average speed [31]. Some studies prove that EVs range is not an issue in urban deliveries, as there is no need to recharge the battery when using a small van (i.e., cargo capacity of around 4 m^2) [32, 27].

3.2 Financial and operational consideration

In terms of cost, the contributions from the literature show varying results. When talking about electric vehicles, the costs are differentiated between the cost of the vehicle and the cost of the fuel. For example, simulation results from [18] show that the vehicle cost is lower in a diesel vehicle, while fuel costs are lower for battery electric, mainly thanks to the higher efficiency of the electric drivetrain). Therefore, diesel vehicles are slightly cheaper when considering only daytime deliveries. Similarly, results from a case study [16] show that EVs are not economically viable without incentives. This is due to the high purchase price, which results to be the biggest obstacle to the uptake of the technology according to [16]. Results from a case study in Rio de Janeiro [17] show that the cost of an electric low-duty vehicle is around 138% of the cost of a traditional vehicle. However, they also mention that the high cost is likely to decrease with time and technological development [17]. At present, substituting diesel vans with EVs would increase the cost of the deliveries by about 6% [17]. It is also important to consider that, without fast-charging stations, the EV might take a longer time for charging than a diesel vehicle for refuelling [33]. Therefore, this could impact operational efficiency and cost. More positive results from a simulation in Italy [19] show that, considering the much lower electricity cost than the fuel cost, despite a higher purchase cost of the EV compared with the fossil fuel vehicle (around 25% higher) the costs in operation (assuming same trips and same lifetime), the economic savings could range from 5 to 25%. The savings depend mainly on the distance travelled (the greater the distance, the greater the savings) [19].

Since the total cost is uncertain, several papers investigate how the costs can be minimized in different ways. Results from [34] reveal that longer battery life and greater annual mileage increase economic viability. A simulation from [35] investigates what is the most optimal mileage of an electric medium-duty truck, with a payload of 2 tonnes. The simulation results show that the EVs are never more profitable than comparable diesel vehicles [35]. Low energy consumption and high utilization are the most important characteristics to play with: logistics companies should determine their operational profile to select the most cost-efficient configuration of EVs [35]. Another concept that is studied in combination with EVs is off-peak deliveries[3]. Combining the two concepts, EVs are cheaper than the corresponding diesel trucks: moreover, in combination with off-peak deliveries, the total number of trucks can be lowered since one EV employed for 24h can replace around 1.5 diesel trucks [18].

Some papers focus on how different policies can support the implementation of EVs in the urban logistics system. For example, [16] study the effect of carbon pricing as a possible incentive, and it is found not to be effective in the short term. [36] study especially three policies: purchase subsidy, zone fees with EV exemptions and vehicle taxes with EV exemption. They conclude that all three policies increase EV purchases, and the zone fee leads to the largest reduction in externalities (i.e., climate change, local air pollution and congestion) [36].

In terms of operations, a simulation study [22] compares a diesel and a battery-electric vehicle in a simulation of urban goods delivery, and claims that the energy consumption can be reduced by 50-55% using the electric vehicle, with higher benefits at higher loads. The energy consumption is also less dependent on the driving conditions, ranging from 20 to 30 Wh/km for the EV [22]. It is very important to estimate the energy consumption to predict charging needs: for example, [37] develop a tank-to-wheel energy consumption model for electric vehicles in urban areas. Simulation results from [38] show that the distance travelled is lower in certain cases (i.e., with large time windows and a large number of customers) when using modular EVs than diesel vans. They study a case where EV technology is combined with modular vehicles, to optimize the number of vehicles needed [38].

3.3 Effects on congestion and pollution

The importance of electric vehicles is that there is a substantial reduction of CO_2 emissions in the operational phase, and therefore they reduce local emissions in the urban environment [7]. However, although EVs ensure that there are no emissions during the operations of the vehicle, it is important to perform a full life cycle assessment when considering the introduction of EVs [39, 40]. Noise should also be considered as a positive impact of electrification, since EVs are more silent than diesel vans, as reported for example in [41].

The manufacturing of EVs produces more CO_2 emissions compared with the manufacturing of diesel vehicles, mainly due to the lithium battery production process and disposal. Simulation results from an Italian case study [19] show that if the vehicle is used for at least a certain amount of km in the urban environment, there are environmental savings (i.e. total CO_2 emissions lower than fossil fuel vehicles). Simulation results from a detailed life cycle assessment by [22] show that the production phase of an EV performs worse in all the impact categories[4] when compared with a diesel vehicle. When considering the whole life cycle, EV performs better in four of these impact categories [22]. [34] present a holistic view of a potential system of EVs in the urban logistics environment, exploring the environmental, social and economic impacts of EVs compared with old diesel vans.

[3] Deliveries that are shifted from peak hours (i.e., morning and afternoon) to off-peak hours (i.e., evenings)

[4] Abiotic depletion, global warming, ozone layer depletion, photochemical oxidation, acidification, eutrophication, cumulative energy demand.

They conclude that governments could at least provide incentives to EVs equal to the benefit they bring to society, especially if the transition starts with the replacement of old vans [34].

It is important to consider that electric vehicles have as the primary source of energy electricity. Therefore, a critical point to consider is the primary source of energy that is utilized by vehicles: if a technology shift brings also a primary energy source shift, i.e., from fossil to renewable, this should be accounted for in an environmental assessment [42]. If the electricity mix is relatively clean, CO_2 emissions and air pollutants decrease by around 90% when EV substitute diesel vans [34]. If the electricity mix is not clean (i.e., electricity coming from coal energy), CO_2 emissions decrease only by around 10% and other air pollutants between 0% and 90% [34]. [43] consider the European electricity mix, and they find a 50% reduction of CO_2 emissions in the use phase of electric vans when compared with diesel vans.

Accessibility can be increased due to the potential inclusion of routes with vehicle restrictions [44]. [21] try to represent the complexity of the freight system using accessibility as a measure, to evaluate the potential different zones for delivery with EVs. Finally, in terms of possible rebound effects, it is important to consider that congestion might be worse if the carrying capacity of the available EVs is smaller than the vehicles that currently perform the deliveries [20].

3.4 Matrix

In summary, the following KPIs are affected:

- **Air pollution** in the urban environment decreases substantially since the vehicles have no local emissions during the use phase.
- **Noise** decreases since the EV motor is more silent than a diesel engine.
- **Accessibility** increases, due to the potential inclusion of routes with vehicle restrictions.
- **Fuel related transport cost** decreases, due to a lower cost of electricity when compared to diesel fuel and due to the decrease in operational energy consumption.
- **Lifecycle emissions** are affected, and they can increase or decrease depending on how much distance the vehicles drive during their lifetime. The emissions in the use phase are affected by the electricity mix of the grid, which is therefore also important to consider.
- **Vehicle related transport cost** increases, due to the more expensive vehicle technology. This increase is likely to reduce once the technology develops further.
- **Operational energy consumption** decreases, thanks to the increase in the energy efficiency of the electric drivetrain when compared to the diesel one.
- One study also mentions that the **fleet efficiency** can improve since one electric vehicle operating during off-peak hours can replace 1.5 diesel trucks.

In Figure 3 the impacts of the implementation of electric vehicles on the sustainability of the system are shown. The matrix serves as a visual representation of these impacts. The impacted KPIs are highlighted with a darker colour, and the arrows indicate if the KPI increases or decreases. The ? indicates instead that the literature does not agree on the direction of change of the KPI. The matrix can also enable a visual understanding of the research gaps: for example, road safety and working conditions have not been studied in connection with electrification. This is also a result, showing that either electrification does not affect these two indicators, or its effect has not been studied.

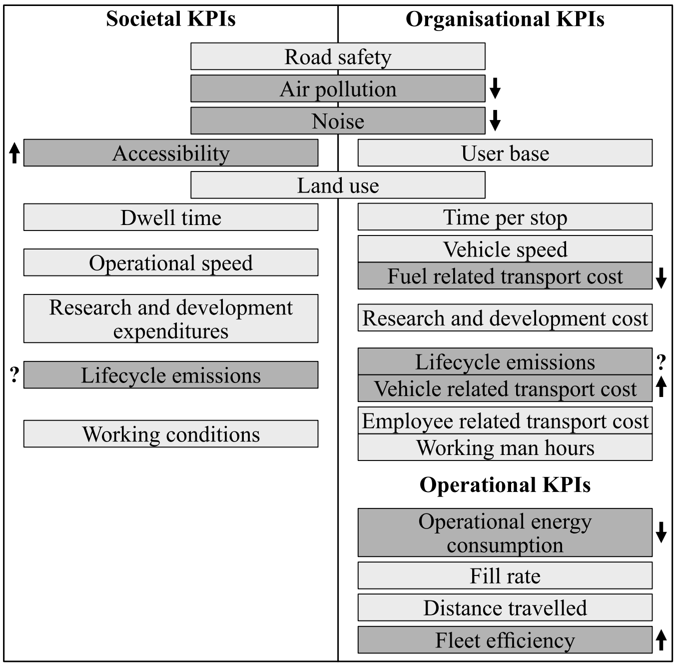

Figure 3: Summary of the impacts of electrification on the sustainability of the system, using the KPI framework suggested in [10].

4 Consolidation

Consolidation, as an urban logistics strategy, is mentioned in 198 papers in the literature. From these, 41 have been selected and read. Usually, the term consolidation refers to strategies to reduce the externalities of urban logistics transportation by combining different flows of goods, achieving a more effective transportation system [45]. These strategies are regarded as effective, especially in densely populated areas [46]. The consolidation concept is studied together with collaboration: according to a network flow model [47], collaboration is needed in terms of sharing the consolidation facilities, the business process and resources. Achieving collaboration is difficult, especially between different transport companies which usually are competitors in the market [48]. In the case of consolidation, stakeholders do not have a common agenda but consider their individual objectives [49], therefore it is a challenge to manage stakeholders' needs [9, 50].

One of the methodologies that have been used in the literature to analyse consolidation is a multi-actor multi-criteria analysis [51]. This type of methodology allows the stakeholders to express their preferences and participate in the planning phase. As one of the issues with consolidation centres is that the benefits are often not seen by all parties [52], this methodology can also help bridge this knowledge gap. One additional method that can be used to bridge the gap is the conversion of environmental and social effects in terms of monetary value: this can be a valid argument supporting why stakeholders should consolidate more [9].

In this report, the type of flow targeted is not specified. However, this is an important consideration that has to be taken into account before analysing consolidation strategies. According to [52], there are three types of applications in terms of flows: i) all flows are directed to the same urban area, ii) special applications (e.g., airports, hospitals, shopping malls), iii) construction sites. These three types should be analysed differently, leading to different possible consolidation schemes and potential policies [50]. One example of a specific flow type that has been studied in the literature is construction material [53, 54]: these flows have very different specificities and dimensions when compared to the other flows, therefore it must be studied separately. Another consideration is if the goods are perishable: this is important since it influences the characteristics of the delivery [50]: perishable goods usually require high frequency and small side, to guarantee the freshness of products.

4.1 Financial and operational considerations

Though consolidation is an effective method to reduce transportation externalities, it has the challenge of financial viability [49, 55, 45]. There is a lack of functioning business models that are economically viable and, at the same time, satisfy all the stakeholders' needs [49, 45, 56]. From a business model perspective, it is also hard to understand who should be the owner of the consolidation facility and resources. In the literature, different authors study the option of having a third-party logistics company that takes care of the last mile [57, 58]. Two other concepts that appear in connection with consolidation are electrification and cargo bikes, also discussed in this report [59, 60, 61]. A stakeholder investigation [62] shows that off-peak deliveries can be also considered in combination with consolidation.

In the literature, regarding costs, different results can be found. Simulation results from [45] show that, if collaboration is fully achieved, the cost can be saved up to 47%. Simulation results from [63] show that cost reduction can vary substantially, from 60% to 25%, depending on the congestion level (the higher the congestion level, the higher the reduction). Simulation results from [64] show less positive results, with a decrease in the cost of only 6 to 8%. Two case studies are analysed, and they both report a decrease in costs, of 20% in Brussels [65] and 8% in Warsaw [66]. One interesting finding from Brussels' case study is that the cost of human resources is by far the largest share of the costs (up to 75%) [65].

The case study results do not show a great decrease in costs, and it seems from the simulation results that these predictions are dependent on the context. To understand this dependency, a model is developed in [57] to study whether the potential costs are enough to pay the consolidation facility fee. This model depends on a list of parameters and shows if a consolidation strategy is advisable in a certain system configuration [57]. According to [67], the cost per delivery is lower when using a consolidation strategy: however, it important to consider that there is a minimum throughput required to cover costs and therefore make a profit. Similarly, results from a case study [65] and simulation results [68] conclude that the consolidation strategy must have a minimum throughput, and the resources must be optimized to follow the demand.

Since the costs for transportation are uncertain, simulation results from [55] show that it is important to focus on the transport companies and possibly incentivise their participation through administrative measures. They create a stochastic model for improving the efficiency of the dispatch problem, to make the distribution as efficient as possible and attract more transport companies [55]. A vehicle routing algorithm is built-in [58] to study the factors that influence the decision of transport companies to join a consolidation strategy. They conclude that the three main factors are the demand per customer, the consolidation fees and the length of customer time windows [58].

Finally, results from a case study [65] show that the cost attractiveness of consolidation decreases with the number of shops (i.e., it is more convenient for a transport company to join if they have few stops in the area) and with the amount of cargo (i.e., it is more convenient to join if they have less cargo per stop in the area).

In terms of operational considerations, the literature shows that consolidation can affect fill rate, distance travelled and fleet efficiency. Simulation results show that the fill rate of the vehicles can increase up to 65% according to [59] and up to 30% according to [61]. Simulation results show a decrease in distance travelled up to 39% according to [47] and up to 65% according to [55]. Real data results from Greece [69] show a decrease of over 40%. In contrast, a simulation model [57] shows that the promotion of consolidation does not necessarily reduce the distance travelled. Real data results from Greece [69] only show a 5% decrease in the number of vehicles entering the city centre.

4.2 Effects on congestion and pollution

According to [70], the benefits for the urban population of consolidation strategies are fewer economic losses due to congestion and pollution. These benefits should push the government to finance and incentivise consolidation schemes, and the policy setting is of utmost importance [52].

Regarding congestion in terms of vehicle speed, simulation results [61] show that the average speed increases with consolidation strategies. Simulation results from [63] show a reduction of congestion from 45 to 75%, depending on the congestion level (the higher the congestion level, the higher the reduction). However, simulation results from [71] show that an increase in congestion around the consolidation facility is expected. Similarly, real data from Greece [69] show that traffic is recorded to increase up to 40% around the consolidation facility if it is positioned close to the city centre. These results show that the positioning of the facilities is of crucial importance for traffic purposes. Therefore, it is important to study the impact of the location of consolidation facilities, as studied, for example, in [72].

The general conclusion regarding emissions is that consolidation strategies reduce emissions in the urban environment. However, the extent of the reduction is unclear. Simulation results from [45] show that emissions can be saved up to 42% when collaboration is fully achieved. Simulation results from [64] show similar results, with a reduction of 31-36%. Simulation results from [55] show a higher reduction, up to 70%. A case study from Warsaw [66] shows that the emissions can be reduced up to 8%. Another case study in Lucca [73] shows a reduction of CO_2 emissions ranging from 50 to 200 tons of CO_2 when using electric vehicles to deliver the last mile, calculated with a well to wheel approach.

4.3 Receivers' perspective

The receivers as stakeholders can perceive consolidation as a benefit since it can enable easier reception of goods and shorter time handling [50, 70]. According to a survey during a case study in Bristol and Bath [74], delivery to the stock room and security of delivery are seen as benefits by the receivers. Another type of benefit is related to the stock room size: if the consolidation centre provides just-in-time services, the receivers can reduce stock room and use the space for other activities, and can select a specific delivery time [50]. If the consolidation centre provides also waste handling, this is an extra benefit for the receivers [50]. Environmental sustainability is also often in line with the receivers' strategies and allows to have a green image, which is good for marketing purposes [50]. One potential barrier can be however the reluctance, from the receivers, to change the delivery service [50]. This reluctance can be connected with the already mentioned system inertia, and the unwillingness of some stakeholders to change a system that is already in place.

It is not possible to fit these benefits into the framework since no indicator is affected by them. However, it is interesting to note that the receivers could have a role in the development of consolidation strategies, as these can be perceived as beneficial, especially if they offer add-on services such as just-in-time deliveries, waste handling, and delivery to the stock room [50, 52].

4.4 Matrix

In summary, the following KPIs are affected:

- Emissions are expected to decrease in the urban environment, and therefore **air pollution** in the city is expected to decrease. The extent of this decrease is however uncertain.
- **Operational speed** and **vehicle speed** are expected to decrease, together with **fuel related transport cost**. However, the extent of this decrease is uncertain.
- **Lifecycle emissions** are expected to decrease, especially if the consolidation strategy is combined with the usage of electric vehicles.
- **Working conditions** in general as a societal KPI are therefore uncertain as well since not much emphasis is put on indicators that relate to employment.
- **Employee related transport cost** is uncertain since fewer drivers might be needed if consolidation is achieved through collaboration, however, a minimal throughput is needed to overcome the costs of consolidation fees (which mainly come from human resources costs).
- **Working man hours** are also uncertain, since the consolidation strategies can provide job opportunities connected with the operations of the consolidation facilities, but they could decrease the need for drivers.
- **Fill rate** increases with consolidation strategies.
- **Distance travelled** decreases to an uncertain extent.
- **Fleet efficiency** increases since a decrease in the number of utilized vehicles is expected. The extent to which this would increase fleet efficiency is uncertain.

In Figure 4, the impacts of the implementation of consolidation on the sustainability of the system are shown. The matrix serves as a visual representation of these impacts. The impacted KPIs are highlighted with a darker colour, and the arrows indicate if the KPI increases or decreases. The **?** indicates instead that the literature does not agree on the direction of change of the KPI. The matrix can also enable a visual understanding of the research gaps: for example, road safety and noise have not been studied in connection with consolidation strategies. This is also a result, showing that either consolidation strategies do not affect these two indicators, or their effect has not been studied.

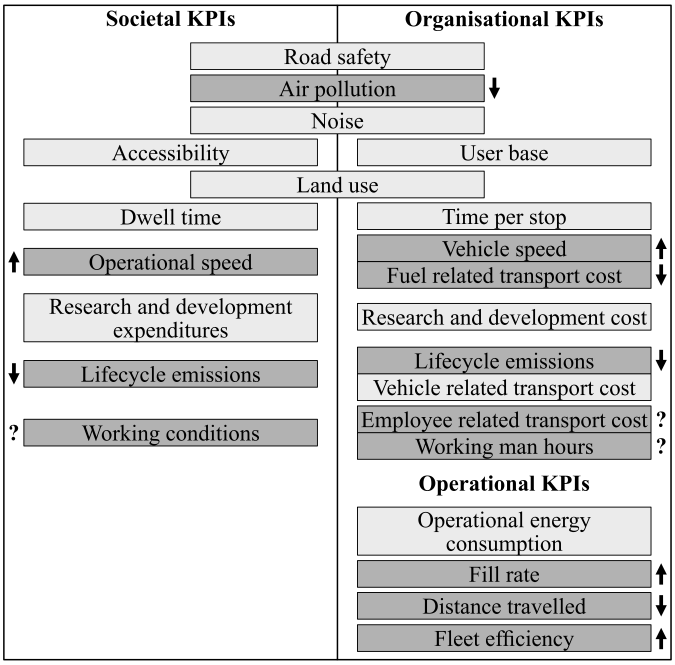

Figure 4: Summary of the impacts of consolidation on the sustainability of the system, using the KPI framework suggested in [10].

5 Cargo bikes

In the literature, 45 papers mention cargo bikes, of which 30 are found to be relevant for this report. According to [75], the use of such vehicles in urban logistics is increasing, especially in the last mile delivery of low weight parcels [6]. Cargo bikes are usually electrically assisted, and their models and structure vary in complexity [76]. The use of cargo bikes has many advantages, such as reduction of air pollution, noise and congestion [2, 77, 78, 75, 79]; however, it comes with problems, such as the need for adaptation of infrastructure and compliance with laws and regulations [75].

Due to the constraints of battery autonomy and loading capacity, cargo bikes may represent a higher cost [43]. Scenario simulations in [78] conclude that cargo bikes can replace up to 10% of the deliveries performed by traditional vans, without diminishing the overall network efficiency. According to a case study in the Netherlands [80], the potential of cargo bikes is high for small and light shipments, in areas with high network density, in an environment where there are opportunities for growth and innovation. According to a study in the UK [81], cargo bikes need an adequate infrastructure, a consolidation strategy that shortens distances, and adequate city geography. Moreover, [81] shows that the sector is mainly predominated by small businesses that do not seek to expand or suffer from the competition of bigger businesses. To facilitate the shift towards using more cargo bikes, the city authorities should raise the awareness of their potential and provide incentives for private companies to adopt them [81].

5.1 Financial and operational considerations

A simulation study in [43] compares cargo bikes with electric and diesel vans in terms of costs: the cargo bike travels on average three times less distance than a truck, for a daily cost that is around 20% lower than a truck [43]. This confirms that cargo bikes are interesting solutions for short distances. The results from [43] show that the daily operation is more economical when using cargo bikes. However, since the distance travelled per day is shorter with cargo bikes, in terms of km, the cargo bikes are the most expensive option [43]. In different case studies [44] the cost savings are up to 50-60% for personnel and vehicles in best conditions (i.e., short routes), but could also be only of 10% where routes are longer. The results [44] show that bike routes can be 15-20% shorter than car routes. Moreover, they also show that loading and unloading can be done faster (on footpaths), without having parking issues: deliveries can be up to 30% faster [44]. Different simulation methods in [6] conclude that cargo bikes are cheaper than diesel vans for deliveries close to the consolidation facility [6], where the density of stops is high and the volume of the deliveries low. They also find that the number of vehicles increases to a certain extent: when the number of cargo bikes needed to replace one van increases to a large extent, the cargo bikes solution is no longer convenient [6].

An increase in km travelled is expected if cargo bikes are used for a large portion of the system [82]. However, the space occupied on the road of a bike is smaller, and therefore the conflict is lower [83]. Other operational advantages are connected to the ease of manoeuvring: cargo bikes can be more easily driven through roads, bike lanes, sidewalks, and in pedestrian-only areas [6]. However, this can also create a conflict regarding curbside usage, not explored in the selected literature. One of the downsides in terms of operations of cargo bikes is that they have a lower average velocity compared to vans. The average speed, according to [84], is 15 km/h. For these reasons, some business stakeholders might be against cargo bikes as they believe they influence negatively the efficiency of their operations [51]. However, due to their increased manoeuvrability and ease of parking, the time spent per stop is expected to decrease [6].

5.2 Effects on emissions and working conditions

A comparison between the impacts of cargo bikes with the ones of diesel vans shows a 94% reduction of CO_2 emissions in the use phase (considering a European electricity mix for charging) when using cargo bikes [43]. Another study based on a model of Amsterdam urban logistics [85] shows that the reduction can be up to 80% if the van deliveries are substituted with a combination of ships and cargo bikes. There is a need to consider the overall life cycle. Compared with EVs, the batteries of cargo bikes are smaller. However, they still need to be considered in a life-cycle assessment. Especially due to the short lifetime, the environmental hazard of the batteries of electric bikes is high, and recycling and reuse should be a focus of industry and academia [86]. It is therefore suggested to establish a reverse logistics network system for spent battery recycling.

Two of the issues that are found in the literature but are not discussed greatly are safety and working conditions. There is a lack of data on the safety and working conditions of cyclists. [87] interview a number of workers in the field to understand what influences safety and working conditions. One of their findings is that the commission-based employment model favours speed maximisation and unsafe practices [87]. The transport with cargo bikes must be designed to provide comfort and safety to the cyclist, whilst allowing the transport operator to complete the transport task [75]. A general specification sheet for cargo bikes has been developed by [88], with requirements regarding the general structure of the bike, but also specifics on the additional equipment needed for the drivers' comfort and safety. One other aspect that needs to be raised is what happens to a system with cargo bikes in case of severe meteorological conditions (i.e., slippery roads due to snow or ice) [89].

An interesting application explored in [90] is the usage of cargo bikes on winter roads, in northern climates. The authors performed observations and GPS tracking on a cargo cyclist, and interviews as qualitative methodology [90]. They confirm that using the bike in winter is feasible, however, one prerequisite is to have micro hubs or consolidation centres, that would provide a warm place to take breaks and to load, but also to change and maintain the cargo bikes (since more maintenance might be needed due to the winter conditions) [90].

5.3 Matrix

In summary, the following KPIs are affected:

- **Road safety** and **working conditions** decrease, especially in the current system, where not so much attention is paid to the safety of the drivers.
- **Air pollution** in the urban environment decreases to a great extent since the vehicles have no local emissions during the use phase.
- **Noise** decreases since the noise level of a bike is lower than the one of a diesel van.
- **Time per stop** is expected to decrease, thanks to manoeuvrability and ease of parking.
- **Vehicle speed** is lower when compared to the current system of vans. However, the **operational speed** of the whole urban system increases due to reduced congestion.
- **Fuel related transport cost** is lower. Similarly to the case of electric vehicles, the cost of electricity is lower than the cost of diesel. In the case of cargo bikes, the fuel related transport cost is even lower due to the smaller operational energy consumption.
- **Lifecycle emissions** are expected to decrease, especially since the reduction of emissions in the use phase is great.
- **Employee related transport cost** and **working man hours** are uncertain and depend on the context.
- **Operational energy consumption** decreases when using cargo bikes. No study specifically points to a decrease in operational energy consumption. However, the actual consumption of the bike is smaller than a diesel van, considering that the bike drivers put their energy to drive the vehicle. Moreover, the batteries are significantly smaller.
- **Distance travelled** is unclear from the literature. The general conclusion is that cargo bikes can be used to a certain extent, for short trips especially.

In Figure 5, a summary of the impacts of cargo bike strategies on the sustainability of the system is shown. The matrix serves as a visual representation of these impacts. The impacted KPIs are highlighted with a darker colour, and the arrows indicate if the KPI increases or decreases. The **?** indicates instead that the literature does not agree on the direction of change of the KPI. The matrix can also enable a visual understanding of the research gaps: for example, land use has not been studied in connection with the usage of cargo bikes. This is also a result, showing that either cargo bike usage does not affect this indicator, or its effect has not been studied.

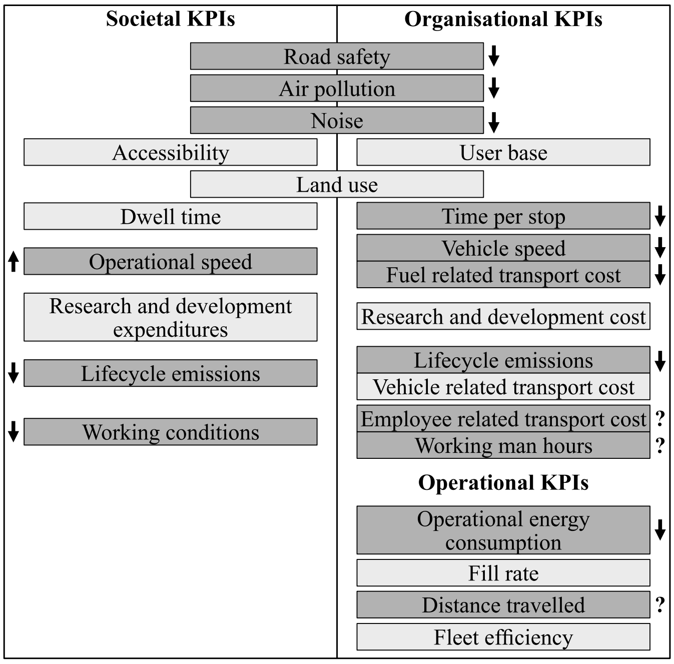

Figure 5: Summary of the impacts of cargo bikes on the sustainability of the system, using the KPI framework suggested in [10].

6 Automation

The definition of automated vehicles is in itself a hurdle. One can refer to the SAE Standard [91], where the driving automation is defined as the "performance by hardware/software systems of part or all of the dynamic driving task on a sustained basis". The dynamic driving task is defined as "all of the real-time operational and tactical functions required to operate a vehicle in on-road traffic" Standard [91]. The term sustained is also defined as "performance of part or all of the dynamic driving task both between and across external events, including responding to external events and continuing performance of part or all of the dynamic driving task in the absence of external events" Standard [91]. With automation, in this report, is meant the driving automation according to the SAE definition cited above [91].

6.1 Information and communication technologies as enablers of automation

To achieve automation in the supply chain, information and communication technologies are enabling factors [92, 56]. Internet of Things (IoT) will play an important role in logistics. For example, cargo carries sensors generating geospatial data enable tracking across the entire supply chain [93]. Some examples of functions that can be enabled using IoT are vehicle tracking, truckcam and drivercam [93]. These functions can enable reductions in both accidents and emissions. It is reported that the reduction of emissions from more efficient driving was 32% in the case study by [93]. Cameras enable filming both the video and audio in the cabin as well as the road ahead: this encourages drivers to behave responsibly and monitors distraction and fatigue [93].

Automation relies on accurate data: there is a gap between academic theory and supply chain practices when it comes to real-life cases of Big Data Analytics (BDA) utilization in the logistics industry [93, 94]. According to [93], both BDA and IoT would support logistics firms' strategies, improving safety, lowering operating costs and reducing environmental impacts. In this context, a system model for autonomous road freight transport is proposed by [92], where road transport becomes highly supported by information systems. The greatest impact of BDA, according to [93], is the reduction in traffic congestion. Moreover, processing and storing large data sets enables logistics companies to achieve improvements such as [93]: i) proactive alerts can be sent to drivers about possible hazards; ii) identifying factors that contribute to long idling times (and potentially reduce idling times, allowing a reduction of emissions); iii) optimal fuel purchasing, iv) maintenance of vehicles; v) real-time tracking of goods; vi) pickup and delivery window planning; vii) real-time warehouse activity.

Other benefits of automated vehicles are lower operational times, fewer accidents and less damage to cargo compared with traditional systems [92]. Moreover, automation is expected to reduce operational costs in the urban environment [56]. Automation will also affect the business since there will be a shift in required skills for drivers and other personnel: as recruiting drivers is a major challenge for haulage companies, this can be a potential solution to this growing problem [95].

6.2 Applications of automation in urban logistics

According to [56], automated vehicles that drive on public roads are mainly studied in heavy freight applications, not in urban logistics context. It is uncertain how fast such vehicles will be developed and implemented [95]. Three emerging concepts are explored by [56] regarding automation in the urban logistics context: automated micro vehicles (AMV), unmanned aerial vehicles (i.e., drones), and 3D printing.

[96] present a state of the art search on AMV, concluding that this is a promising solution for urban logistics: AMVs are a major trend, despite limited data availability and the need for more research. The lack of specific supporting policies is a barrier to the adoption of automated vehicles, together with the extent of their technological development and lack of economies of scale [56]. [97] also demonstrate how such robots can be combined with the traditional van delivery: the van drops the robot at a parking node, the robot makes the deliveries and returns to a parking node to be replenished or charged. They also introduce a two-echelon van-based robot last-mile pickup and delivery system model to solve the routing problem [97]. Results from the model show that if in the system there is an area banned to vans but where robots could deliver, the system efficiency is much greater [97].

One of the possible autonomous vehicles that we can expect to change the transportation sector are drones, technically referred to as Unmanned Aerial Vehicles (UAV) [42]. Mainly vehicles with a maximum payload of 5 kg are under trial in the logistics sector (trialled by Google, Amazon and DHL) [42]. This would mean that one van has to be replaced by a large number of drones, even over 15 [56]. One of the considerations about drones is that they are shown to have a high energy consumption (when compared to running the same route with diesel trucks), especially in dense areas [42]. These drones are mainly optimized for longer routes, where the time of take-off and landing is very short compared to the total trip time [42]. They are, however, more efficient in rural areas, where the stops are fewer and the distance higher [42]. Another simulation study [98] shows that it is likely that delivery drones would be used only for shorter distances, and can be used building upon the current infrastructure of the urban logistics network. [98] build their calculations on a case using a multi-copter with a 4km range, and show that they consume less energy per package, but have additional warehouse energy consumption requirements. However, they show that the total impacts of delivery by small drones are smaller than ground-based delivery [98]. Moreover, other barriers should be mentioned, such as: i) safety and security issues (hacking for malicious use or theft of personal information); ii) acoustic pollution, iii) negative ecological impact on bird-life [56].

One more automated option for urban freight is 3D printing. The process of 3D printing allows the users to print products directly in their home, by a software transmitting the design instructions [56]. This would allow the removal of all needs for transportation. However, this comes with barriers such as the available printers are not yet able to produce sophisticated products and the high cost, which makes the printers generally not a good option for a private household [56].

6.3 Matrix

In summary, the following KPIs are affected:

- **Road safety** is increased, as the number of accidents decreases. However, new safety concerns are introduced, for example, the risk of hacking for malicious use.
- **Air pollution** decreases as well thanks to the reduction of congestion.
- **Dwell time** and **time per stop** decrease thanks to the use of drones or delivery robots.
- Both **Operational speed** and **vehicle speed** increase, as congestion is reduced when using big data analysis.
- **Fuel related transport cost** decreases thanks to both the reduction of congestion and optimal fuel purchasing.
- **Employee related transport cost** is reduced from a transport company perspective, as there is a shift in required skills, from drivers to other working opportunities.
- **Operational energy consumption** is reduced thanks to the optimization of the routes. However, we have seen that special applications such as drone has a much higher energy utilization. Therefore, this parameter is marked as uncertain.

In Figure 6, a summary of the impacts of automation on the sustainability of the system is shown. The matrix serves as a visual representation of these impacts. The impacted KPIs are highlighted with a darker colour, and the arrows indicate if the KPI increases or decreases. The **?** indicates instead that the literature does not agree on the direction of change of the KPI. The matrix can also enable a visual understanding of the research gaps: for example, noise and fill rate have not been studied in connection with automation. This is also a result, showing that either automation usage does not affect these two indicators, or its effect has not been studied.

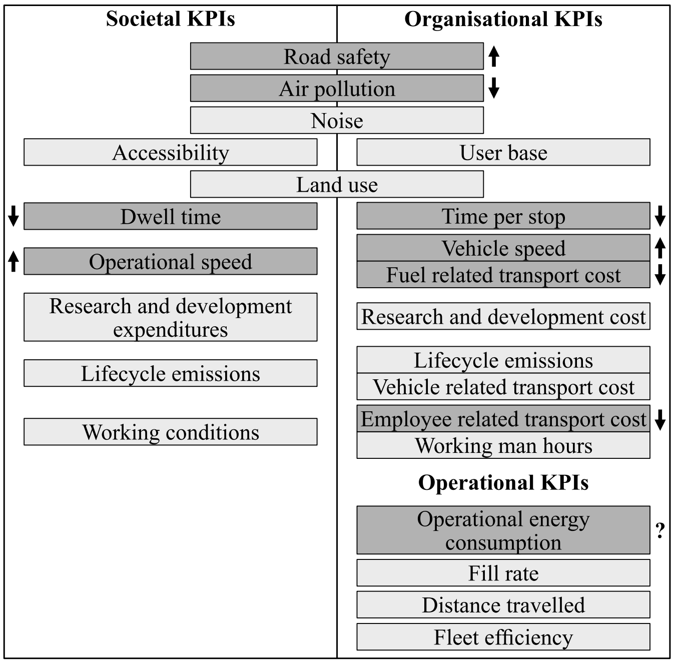

Figure 6: Summary of the impacts of automation on the sustainability of the system, using the KPI framework suggested in [10].

7 Summary

In summary, in this report, sustainability performance is assessed for the concepts of electrification, consolidation, cargo bikes and automation, using the framework proposed in [10]. From the over one hundred paper analysed, the main results of this work are the four graphical representations (i.e., Figures 3, 4, 5 and 6). This report provides also a good example of how the framework can be used, with findings in the current literature as input. The framework has proven to be a useful tool to combine knowledge of different case and simulation studies into one single figure. However, after a qualitative analysis of the impacts, it emerges the need of quantifying the impacts as well. The quantification of the impacts is not part of this work, since the analysed literature showed varying results for almost all the indicators. This shows that the results of the applications of urban logistics concepts are highly context-dependent and therefore difficult to generalize. In this report, these results are collected and a generalization of the direction of the impacts is attempted (i.e., if the application of the concept results in an increase or decrease of the indicators in the framework).

Moreover, this report provides research gaps: these are directions for future research and case studies. More research on the impacts of the concepts in urban logistics should be carried out from a holistic perspective. Other future work includes combining this knowledge in one single representation, to allow comparability between the concepts. Moreover, the same framework could be applied to other concepts: this report shows an example of the application of the framework and can be used as a guideline. This report is far from being complete in terms of sustainability in the urban logistics context. The findings presented here are a first step towards enabling stakeholders to make informed decisions, based on the knowledge of the impacts of different concepts on the urban logistics system from a holistic perspective.

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