ELECTRIFICATION AS A LAST RESORT: DECARBONISATION OF CITY LOGISTICS

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Summary

City logistics must be organized more sustainably and eventually decarbonize. To this end the focus is mainly on electrification as a technical measure, whereby conventional vehicles are eventually substituted by electric equivalents. There are, however, numerous decarbonization strategies for city logistics, some of which aim to reduce the number of vehicle movements by changing demand, more collaboration by sharing assets, a shift to other modalities and energy-efficiency of current modes. In addition to reducing CO_2-emissions, some of these measures also address other challenges – such as nuisance, congestion and safety – by reducing the number of vehicles. The applicability depends on the specific logistics pattern and segment. In this contribution we present a framework for the decarbonization of city logistics with different logistics measures that the diversity in types of movements into account.

1. City Logistics and decarbonisation

City logistics must be organized more sustainably. Currently, CO_2 emissions related to city logistics in the Netherlands are estimated to be 3.6 Mton on a yearly basis (out of a total of 10,6 Mton for logistics in the Netherlands; Topsector Logistiek & TNO, 2021). Those emissions are caused by vehicle movements that drive into and out of urban areas. In a recent study it was estimated that the majority of the emissions related to city logistics take place outside the urban areas (Topsector Logistiek, 2020c). The movements are very diverse with regard to type of vehicles, distances, number of stops, type of goods, etc. To structure this diversity, different logistics segments are distinguished: temperature-controlled, general cargo and retail, parcels, waste logistics, facility and service logistics, and construction logistics (Topsector Logistiek, 2017). Furthermore, the organization of the transport differs across those segments as it must consider commercial requirements (delivery time, location, etc.), legal requirements and local regulations such as driving times and rest periods, time windows, and low and (eventually) zero emission zones. For instance, a heavy truck delivering to a construction site in a city centre has to deal with other requirements than a parcel delivery van in a residential neighbourhood. Those factors determine how the logistics is organized, or in other words, the logistics pattern.

There are various decarbonization strategies for city logistics. The applicability (partly) depends on the logistics pattern and segment. Possibilities to decarbonize logistics vary from technical measures (e.g. vehicle technologies, alternative fuels) to innovations in the organization of logistics (e.g. sharing assets, multimodality, hubs) and changing behaviour (managing freight demand). Currently, to deal with the announced implementation of zero emission zones, focus is mainly on substituting current vehicles by zero emission equivalents. Electrification is considered as the most promising technology. Whereas this is a potential solution for numerous flows, there are various challenges. First of all, for organizations it leads to changes with regard to the planning of routes, (investment in) charging infrastructure and capacity of the electricity grid. Second, a vehicle that does not drive is more sustainable than a clean vehicle. In this regard, there are various ways to organize city logistics more efficiently; to transport the same amount of goods and services with fewer vehicles. This is particularly interesting as it also addresses other challenges that both transport companies and society are confronted with in urban areas: lack of space, congestion, safety, air pollution (also coming from tyres and brakes of electric vehicles). Moreover, in recent years companies are confronted with personell shortages.

For the decarbonization of logistics, McKinnon (2018) proposes the 'Green Logistics Framework'. This framework describes five decarbonization strategies for stakeholders in logistics (see figure 1):

1. Managing freight demand growth (reduce)
2. Smartly combine and use transport modes (multimodality)
3. Share fleets and assets to the max (optimization)
4. Use the most energy efficient fleets and assets (energy efficiency)
5. Use fleets and assets with the lowest emissions (clean vehicles).

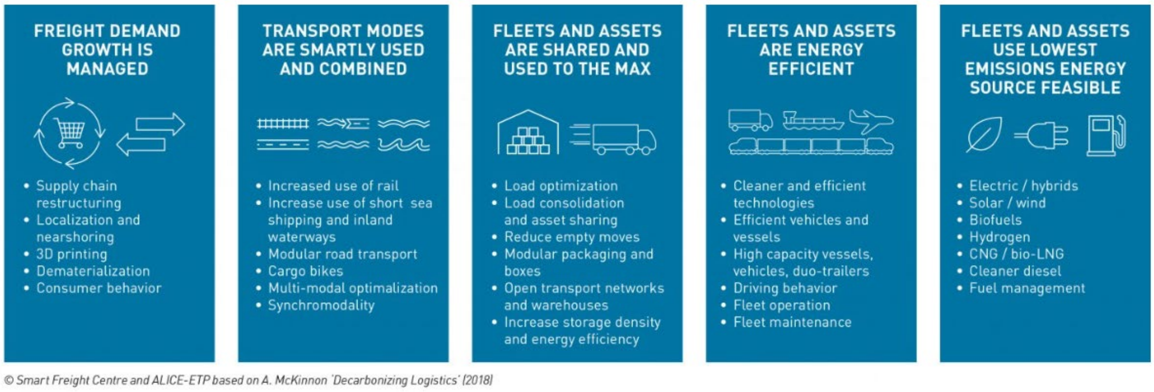

Figure 1. Decarbonisation measures in the 'green logistics framework' (Smart Freight Centre en ALICE-ETP based on McKinnon, 2018)

The framework presents a sequence (from left to right) where first possibilities are explored to actually reduce the number of movements, after which the remaining vehicles are used as efficiently as possible with regard to capacity, followed by efficiency with regard to energy use. Finally, clean (zero emission) vehicles can be deployed.

In this paper we use this framework to develop an approach for the decarbonization of city logistics. The added value is threefold. First, the developed framework is used for logistics in general (Ghisolfi et al., 2022), but the application to city logistics (the last mile) and specific measures across the five strategies is lacking. Second, in this exploration, the decomposition of city logistics is considered as an additional component (see Kin & Quak, 2022). Finally, the focus is often on policy measures to decarbonize (city) logistics. Examples are different taxes (for instance a carbon tax), weight regulations and subsidies for clean vehicles (see Ghisolfi et al., 2022). In our exploration, the focus is on 'pure' logistics measures that can be taken by the private sector. Logistics is organized taking into account various factors such as existing policies, market developments, available infrastructure and technologies. Within these constraints, logistics is organized as efficiently as possible. Policy measures, market developments and infrastructural changes, can change these constraints. Logistics measures are therefore seen as a result of the constraints, or requirements. A change in requirements can lead to a different organization of logistics.

The paper is organized as follows. The next section presents the conceptual framework for the decarbonization of city logistics. Based on a literature study, interviews and expert opinion, logistics measures for city logistics are proposed and organized according to the categories as presented in figure 1. In addition, the specific segments to which these apply are given. This part builds further on the work that has been carried out with the zero emission zone-module of Decamod (Decarbonization model) (Topsector Logistiek, 2020c, 2020b). Section 4 describes the future developments, which includes a description of the calculations of the effects of logistics measures with regard to vehicle kilometers and CO_2 emissions in a case study.

2. Conceptual model: decarbonization of city logistics

A logistics system consists of various elements (decomposition) like the number and type of vehicles that are used to transport different types of flows into and out of urban areas. The composition of this system determines the CO_2 emissions. For vehicle movements related to city logistics this accounts for 3.6 Mton. Different factors determine the way logistics is organized across different (sub-)segments. A decarbonization in segments and logistics patterns is important as this also determines the possibilities to decarbonize.

For each segment, the logistics pattern is determined by the stakeholders (transport companies, shippers, and in some cases, the receivers) and by the requirements. The latter is diverse and includes delivery times, available infrastructure and regulations such as time windows. These factors determine how trips are being organized. In addition, there are various external developments that continuously determine how logistics is organized in terms of route planning, vehicle type, number of stops on a trip, etc. On a system level this composes the system and subsequently the effects such as the CO_2 emissions. In order to structure the external environment, or requirements, in which the system is organized, six external factors are used by McKinnon (2018):

- Technology: financial and operational feasibility of technology (e.g. electric vehicles).
- Infrastructure: existing and required infrastructure, with regard to public space and roads as well as space for (logistics) facilities.
- Market: demand by customers of goods and services that leads to demand for transport. These are primarily shippers and receivers. Market developments constantly change. An example are the instant deliveries.
- Behaviour by stakeholders in supply chains.
- Energy: energy use of transport and, related to that, costs.
- Regulation: on a European (e.g. EURO norm), national and local level. The latter is particularly relevant but influenced by national regulations. An example are the zero emission zones that are nationally announced and coordinated, but locally implemented. Other examples are weight restrictions and time windows.

These six factors determine the way the last mile is organized. Depending on the context and the external factors (that change), different logistical responses can be clustered according to the five strategies. The exact responses depend upon the segment. All together the responses determine the logistical system. If the requirements change, logistical responses change and effects possibly as well. An example is the implementation of a zero emission zone, which might lead to a change in vehicle technology, resulting in the same amount of kilometers but a reduction in CO_2 emissions. Other examples are car-free areas that might lead to a modal shift to cargo bikes for the last mile.

Figure 2 shows the conceptual framework. First of all, the logistics system and its composition (in CO_2 emissions, kilometers, vehicles,…) is delineated. In this case it applies to the city logistics system. Next, this can be decomposed in segments and/or modalities. Together this presents the baseline on which a potential goal takes place. In case of city logistics in the Netherlands the aim is to reduce CO_2 emission by 1 Mton. The external factors are being identified through a literature study and interviews (see CILOLAB, 2022). This is, in other words, the context in which the system and its elements are being organized (1 on the left). The effects can be calculated (1 on the right). Based on the response, requirements might change leading to another organization of logistics. For instance, subsidies make electric vehicle technology more affordable. This leads to other logistics responses (2 on the left) and subsequently to other effects (2 on the right).

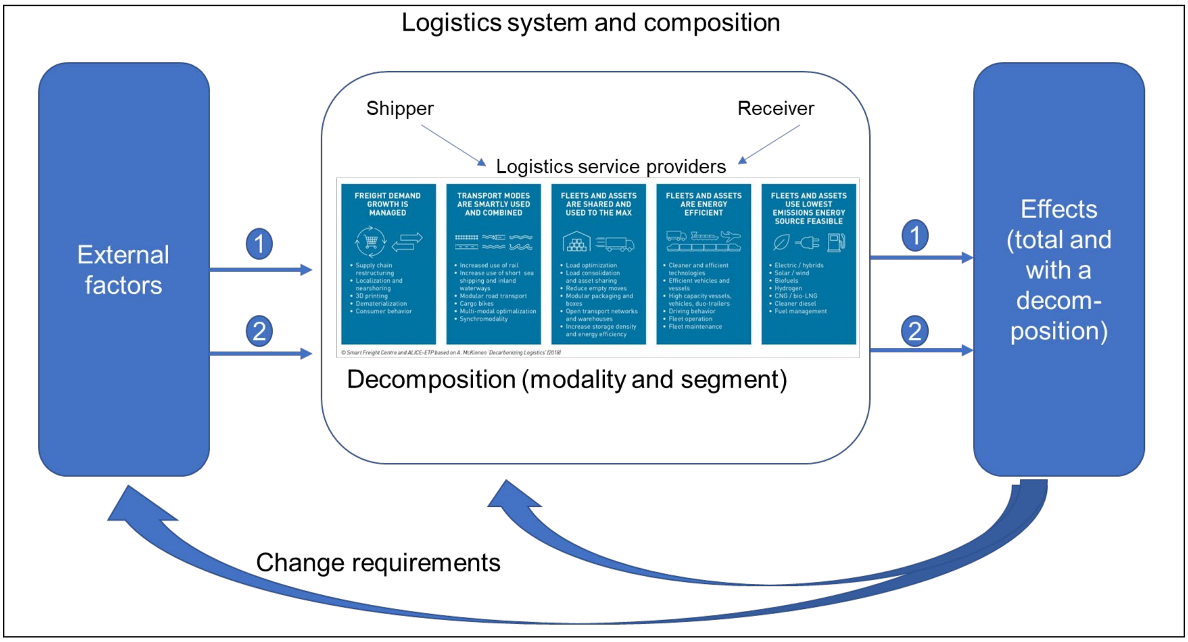

Figure 2. Conceptual framework

3. Logistics measures in city logistics

In this chapter we identify different logistics measures based on a literature study. An important part originates from the various Outlooks City Logistics in which interviews have been used in order to construct scenarios. The different responses are clustered across the different decarbonziation strategies of the Green logistics framework and applied to different sub-segments.

3.1 Managing freight demand growth

Measures in this category relate to reducing demand for transport, possibly by adapting demand, which leads to a reduction in vehicle movements. This particularly applies to the demand by receivers for goods/services that subsquently leads to a demand for transport by shippers. It includes five measures:

- Procurement: institutions (offices, education, health care, government,…) receive a lot of different freight flows. In procurement policies, requirements can be included (particularly to shippers) to reduce the number of vehicle movements by bundling freight flows. This can lead to a lower delivery frequency. This can also take place in the construction sector with deliveries to construction sites (Balm, 2020; Balm, Amstel, Habers, Aditjandra, & Zunder, 2016; Brusselaers, Fufa, & Mommens, 2022; Dreischerf & Buijs, 2022; Topsector Logistiek, 2020f, 2020e).

- *Pricing* deliveries to change ordering behaviour, which mainly applies to home deliveries (parcels, groceries and fresh), but also to deliveries to SME (horeca and retail). There are limited studies focusing on this measure (Bahrami-Bidoni & Montreuil, 2021).
- A reduction in kilometers by ordering and delivering more locally in *local-for-local* and *ship-from-store* concepts. Deliveries are often carried out by light electric freight vehicles such as cargo bikes. This applies to home deliveries but also to deliveries from construction centres (wholesalers). On a yearly basis it is estimated that there are 50 million (local-for-local) orders (Ploos van Amstel, Weltevreden, Quak, & Hopman, 2021).
- *Gebiedsgericht afval aanbesteden*: instead of collecting waste per company, this can also be done via joint collecting in an area. Calculations show that this could lead to a 50% reduction in vehicle movements (Topsector Logistiek, 2020d).
- Innovations in the construction sector, such as prefabrication, can lead to a reduction in vehicle movements (Topsector Logistiek, 2020e, 2020h).

3.2 Smartly combine and use transport modes

This category includes responses that aim at smartly combining different modalities leading to a potential reduction in vehicle kilometers and increased energy efficiency of transport (energy used per transported kilogram). These measures often require a different organization of the supply chain with cross-dock locations:

- A modal shift to *rail* is often less applicable to city logistics, but can have a potential impact in kilometers towards cities. It is an interesting option for heavy material in construction logistics and transporting waste out of urban areas (Diziain, Taniguchi, & Dablanc, 2014).
- *Barge* has similar possibilities to rail (if waterways are available). Diziain et al. (2014) show that barge in Paris was used to transport 300,000 tonnes of waste, which led to a reduction in CO_2 emission of 30% and avoided 500-600 vehicle movements. In Amsterdam, Utrecht and Paris, barge is also used to transport fresh goods, retail and construction material (TNO, 2020; van Rooijen & Quak, 2014).
- *Light rail* can be used for the transport of heavy material under stringent requirements. Alternatively, it can be used for parcel deliveries whereby the deliverer uses public transport.
- The use of *light electric vehicles* grows for different applications including parcels, fresh goods and service logistics. These vehicles vary from (cargo)bikes to light commercial vehicles such as the Goupil G4. Research shows that this can be mainly applied in dense, and partly car-free, areas (Assmann, Müller, Bobeth, & Baum, 2020; Dalla Chiara, Alho, Cheng, Ben-Akiva, & Cheah, 2020).
- The use of long and heavy trucks (LZV in Dutch) can lead to a reduction in vehicles.
- Other modalities that are being studied, but not widely applied, include drones, pipelines and autonomous vehicles/lockers.

3.3 Share fleets and assets to the max

Those possibilities aim for more efficiency by maximizing utilization of existing vehicles and (logistics) facilities. In terms of vehicles, this potentially leads to a higher vehicle fill rate and therefore fewer vehicles in urban areas.

- By *aligning delivery times* with receivers and shippers, routes could be planned more efficiently with a reduction in vehicle kilometers. Eventually this could lead to deploying fewer vehicles (Quak & de Koster, 2007).
- *Horizontal collaboration* between shippers or transport companies, whereby loads are exchanged, can lead to a higher fill rate and fewer vehicles. In the Netherlands there are different collaborative networks such as Transmission and Teamtrans (Quak, 2012). Krajewska et al. (2007) show in a modelling study that collaboration between two transport companies could lead to a 10% reduction in vehicles.
- *Supply chain collaboration* is a form of vertical collaboration between shippers/transport companies/receivers in a supply chain. This can be organized in different ways such as vendor managed inventory (VMI), Collaborative planning forecasting and replenishment (CPFR) and collaboration in construction logistics (Gonzalez-Feliu & Salanova, 2012; Topsector Logistiek, 2020e).
- Different types of *hubs* or *urban consolidation centres* provide a high potential to bundle (or decouple) freight flows and reduce the number of vehicles on the last mile. In CILOLAB (2022) the requirements and barriers for upscaling are discussed. This could also be a physical outcome of one of the other measures mentioned above; i.e. a location where collaboration or a modal shift takes place.
- Instead of a location where goods are condolidated, such a location can also be used to reduce the number of rather service-driven trips. Possibilities are *carpooling* or a *park and ride* (possibly close to a public transport station or shared mobility). More than 50% of the vans in urban areas are estimated to be more service-driven than used for the transport of freight (Topsector Logistiek, 2020c).
- For trips with a truck, where electrification is not feasible, decoupling points with a detachable swap body is an option. This requires a location from where the last mile can be carried out zero emission.
- Decoupling can also take place inside instead of outside the city, by using a microhub or a pickup point (CILOLAB, 2022; Katsela, Günes, Fried, Goodchild, & Browne, 2022; Topsector Logistiek, 2020g).

3.4 Use the most energy efficient fleets and assets

This category focuses on saving energy of existing vehicles. There are roughly three possibilities. The first is to deliver outside peak hours, in the early morning, late evening or at night. Several pilots show that this leads to a reduced fuel use and a CO_2 reduction of 28% (in Belgium; Mommens et al., 2018), whereas Holguín-Veras et al. (2018) even report a reduction of 45-67% based on measurements in Bogota and São Paulo. Other possibilities to drive more energy-efficient are timely *maintenance* and *driver training*. The latter could lead to 3-6% fuel savings (Arvidsson, 2013).

3.5 Use fleets and assets with the lowest emissions

As a last resort, the remaining vehicles can be replaced with clean (zero emission) equivalents. There are different possibilities where the emission factor (in CO_2/km) is lower than conventional diesel vehicles (in general EURO5/6). First of all there are options to use cleaner fuel types such as LNG and biofuels. Second, plug-in hybrid vehicles are available. These are mainly considered as either a transition technology or as a possibility if driving range of an electric vehicle is insufficient. Finally, full electric vehicles are available. For vans the TCO is becoming increasingly comparable to a diesel vehicle (Kin, Hopman, & Quak, 2021).

4. Future developments

From the conceptual framework as presented, there are three future developments that are undertaken. First, continuous data enrichment is required to better estimate the effect of (city) logistics. This can be done on a national scale, on the level of a city, a specific modality or segment. In any case, a decomposition is important as this allows tailored calculations and advice for different segments. Based on the current available data, estimations are now made but this should constantly be enriched if more detailed data become available. In TNO (2022) possibilities are more elaborately described. In addition, data now mainly include vehicle trips with vans and trucks, whereas light electric freight vehicles are excluded. Furthermore, an important aspect is to get a better grip on kilometers that are driven outside urban areas. An important challenge lies in data collection for movements by SME and particularly service-driven trips (see for instance Wigan et al., 2002).

The logistics measures as listed above are collected in a toolbox. In this toolbox the (sub-) segments and vehicle types to which these measures apply are categorized across the five decarbonization strategies. The potential effect of each measure is added. In total, there are three possible effects of a measure:

1. There is a change in trips and/or vehicles.
2. There is a change in the kilometers driven on existing trips.
3. The emission factor per kilometer changes because of improved energy-efficiency or the use of clean vehicles.

The effects are estimated, based on available cases, pilots and (modelling and simulation) studies. Some are already listed in chapter 3, such as the potential CO_2 reduction with off-hour deliveries. The toolbox should constantly be updated for improved calculations of the effects. Most effects are now estimated based on small use cases or a limited number of interviews. The different possibilities can be grouped in scenarios of which the effects can be calculated. This is another addition: the development of scenarios. Some possibilities to develop scenarios include:

- Scenarios for different years
- Scenarios with different effects (low, medium, high). For example, for 2030 effects can be estimated with a zero emission zone or without, which leads to different logistics measures.
- Scenarios with a focus on different decarbonization strategies, whereby one scenario could mainly focus on the effects of changing demand and optimizing trips and another purely on electrification.

- Scenarios to calculate the (expected) effects of different policies. For instance, subsidies of electric vehicles, stimulating transshipment locations (decarbonization strategies 2 and 3), restrictive policies on certain vehicles, etc.

Scenarios can be developed based on desk research, but preferably with input from experts and different stakeholders involved in city logistics. An outcome of the calculations can be policy advice on how to stimulate different effects in order to maximize the effects of promising decarbonization strategies. Joint collection of waste is, for instance, a promising and effective measure. If, a modal shift potentially has a large impact, (synchromodal) transshipment locations could be facilitated.

The final development lies in the actual calculations of the effects. To this end, we aim to further develop Decamod that has been used to calculate the effects of zero emission zones in Utrecht and Rotterdam (Topsector Logistiek, 2020c, 2020b), but also of different measures on hinterland transport (Topsector Logistiek, 2020a). Decamod serves as the toolbox (described above) as well as a calculation tool. Various improvements include adding more specific emission factors, adding light electric freight vehicles, calculating other effects in addition to CO_2 emissions and kilometers, such as air pollution and congestion. Furthermore the interaction effects are interesting to include as some responses could enhance or weaken other effects. This is important to provide action perspective and get an idea on the (cost-)effectiveness interventions. Altogether this leads to more clarity on the action perspective for companies in light of the climate goals and policy advice on the decarbonization task.

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