Draft chapter for '*Handbook on Urban Freight*' edited by Marcucci, E. et al (2022). Not to be quoted or circulated without author's permission.

Environmentally sustainable city logistics: *minimising urban freight emissions.*

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1. Introduction

The environmental problems caused the movement of freight are at their most acute in urban areas. This is because in towns and cities high densities of population and freight traffic coincide, exposing large numbers of people to the air pollutants released from truck and van exhausts. Urban buildings also obstruct atmospheric circulation causing the pollutants to concentrate at levels harmful to health. In addition to these emission-related problems, urban dwellers typically have to suffer a range of other freight externalities, including noise, vibration, accidents, visual intrusion and community severance. Once allowance is made for all these adverse environmental effects one can see why freight traffic is widely considered to degrade the quality of urban life. No matter how essential this traffic is to the economic and social life of a city, people tend to perceive it negatively.

Over the past thirty years, however, freight vehicles have become much cleaner as a result of tightening controls on the amounts of nitrogen oxide (NOx) and particulate matter (PM) they can emit. For example, in Europe between 1992 and 2013 the maximum permitted emissions per kWh of nitrogen oxide (NOx) and particulate matter (PM) from new trucks fell by, respectively, 87% and 97%. The proliferation of low emission zones across European cities over the past decade has also given operators of freight vehicles a strong incentive to upgrade their fleets to the highest emission standard. The net environmental benefit of these favourable trends at a vehicle level has been partly eroded by a growth in the total amount of urban freight traffic. Among the fastest rates of traffic growth have been experienced in cities in less developed countries where the adoption of vehicle emission standards has lagged behind that of Europe and North America by 5-10 years or, in some countries, yet to happen. In these countries emission controls also take longer to reduce pollution levels because truck fleets are relatively old and vehicle renewal rates slow. As a consequence, much of the urban population of developing countries still inhales levels of freight-related pollution that can be seriously damaging to health.

In cities where air quality is poor and freight traffic largely to blame it is understandable that the main environmental concern is with local pollution. In more developed countries, where many years of emission regulation, has substantially cleaned the air, much of this concern has shifted to the global contribution of city logistics to climate change. Many cities are now setting ambitious targets to cut their greenhouse gas (GHG) emissions, in some cases to net zero by 2050 or earlier. Pressure is therefore mounting on transport planners and freight operators to find ways of decarbonising city logistics, especially as freight accounts for significant proportion of urban transport emissions. For example, in New York trucks emit 11% of transport GHG emissions (Repogle, 2020) while in London it is forecast, on a business-as-usual basis, that in 2025 just under a fifth of GHG emissions from transport will come from vehicles moving freight.

Fortunately, most of the available GHG-reducing measures also cut emissions of atmospheric pollutants in urban areas, thereby improving air quality while mitigating global warming. This chapter reviews the range of initiatives that the users, providers and regulators of freight services in urban areas can take to curb both categories of emissions. Before examining these interventions, it is important to give a greater sense of the gravity of environmental problems caused urban freight emissions.

2. Urban Freight Emission Problem

In recent years, epidemiological research has steadily extended the list of adverse health effects associated with air pollution and raised estimates of the numbers of people dying prematurely because of emission exposure. Particulate matter with a diameter of less than 2.5 microns (PM2.5), much of which comes from diesel-powered vehicles, has been shown to damage cardiovascular, respiratory reproductive and cognitive systems. Anenberg et al (2019) estimate that in 2015 emissions of PM2.5 and ozone from transport caused 385,000 deaths worldwide, depriving their victims of a total of 7.8 million years of life. It is not known what proportion of this mortality and wider health problems across the population was associated with urban freight emissions, but it is likely to have been substantial in those cities with the highest number of 'transportation-attributable' air pollution deaths.

In addition to particulate matter, nitrogen oxide and sulphur dioxide damage human respiratory systems and above certain concentrations pose a serious health risk to people with lung conditions such as asthma. In developed countries the diesel fuel burned by urban freight vehicles has a sulphur content of less than 15 parts per million (ppm), virtually eliminating it as a truck pollutant and permitting the use of emission abatement devices on the vehicles to control exhaust emissions of NOx and PMs. In 2018, however, 29% of the diesel consumed by road vehicles worldwide had sulphur emissions of 50ppm or more, constraining the use of such devices, thereby increasing pollution not just of SOx but also of NOx and PMs (Miller and Jin, 2019). In cities with large ports, air quality is further impaired by maritime emissions particularly of sulphur, but also NOx and PMs (Merk, 2015). As the Transport Decarbonisation Alliance (2019) acknowledges, '*almost all global trade originates from, traverses or is destined for a metropolitan area*'. Fortunately, sulphur emissions both from marine and road vehicle fuel are on a downward trend, but urban populations in many less developed countries will continue to suffer the related health problems for many years to come.

CO_2 emissions from cities are an order of magnitude greater. According to Ribiero et al (2019), '*despite covering only 0.4–0.9% of global land surfaces, urban areas are responsible for more than 70% of such emissions'*. This is a higher proportion than the 55% of global population defined by the UN as living in urban areas and reflects both the higher average expenditure of city dwellers and concentration of economic and social activity in these locations. It is estimated that a third of the CO_2 emissions emanating from large cities are transport-related and that these emissions have been rising faster those from any other sector. According to the International Transport Forum (2019), at a global level around 14% of urban transport emissions come freight. This makes the movement of freight in urban areas a significant contributor to global warming.

In its 2011 White Paper on transport, the European Commission (2011) committed to '*achieving essentially CO_2-free city logistics in major urban centres by 2030*'. It is extremely unlikely that this vision will be realised by the target date, though research suggests that a combination of initiatives might deliver deep reductions in urban freight emissions in major European cities by then (Allen et al, 2017). In 2011, this zero emission goal was a novelty. Today, many countries, cities and businesses have committed to being net zero emission by 2050 or earlier – for very good reason. Climate modelling suggests that the remaining carbon budget for a maximum 1.5°C global temperature increase by 2100 is rapidly depleting. Even with the implementation of current policy commitments, GHG emissions will grow at a rate that will raise average global temperature since 1850 by around 3.5°C by the end of this century with dire ecological, economic and social consequences for future generations (UNEP, 2019). Current increases in the frequency and intensity of extreme weather events, the loss of biodiversity and sea level rise are a foretaste of the environmental catastrophe facing Mankind, particularly if climatic and geophysical tipping points are crossed over the next few decades (Lenton et al, 2019). It is for this reason that 38 national governments have now declared a climate emergency while the UN's climate change agency UNFCC (2020) is pursuing a 'Race to Zero' initiative' urging governments, cities and businesses to become carbon neutral as fast as possible and by 2050 at the latest.

In developing future urban freight policies, governments and municipalities must wrestle with both a climate emergency and what the World Health Organisation (2020) calls a 'global health emergency' caused by air pollution. Both emergencies have a common origin in emissions from the burning of fossil fuel. Minimising the amount of fossil fuel required to move freight in urban areas will therefore help to address both emergencies. In the remainder of this chapter we will explore ways in which this can be achieved.

3. Scoping the Reduction of Freight Emissions in Urban Areas

A municipal authority devising an emission-reduction policy for freight transport must first define the nature and scale of the problem. This can be done in relatively simple terms by saying that the objective is to reduce total emissions from all vehicles moving freight within the city's administrative boundary. For atmospheric pollutants whose environmental and health impacts are localised this may seem a sensible suggestion. In the case of GHGs, it is more questionable as their negative effects are global and they can be emitted by freight operations intimately linked to the city's economy but released beyond its official boundary. After all, no city is logistically self-contained. City boundaries, are criss-crossed by innumerable supply chains of varying length and complexity as reflected in the relationship between urban and inter-urban freight movements. These movements can be classified *intra-urban* where the origin and destination are within the city, *access* traffic where either the origin or destination are in the city or *through* traffic where both are outside the city boundary. This classification has particular significance for emission-reduction efforts for several reasons. First, the amount of policy leverage that a city authority can exert varies significantly between the different categories of freight traffic, being greatest for intra-urban journeys and least for through-traffic. Second, the relative proportions of traffic in the three categories varies widely by urban area making it necessary to tailor policy initiatives accordingly. Third, these initiatives must recognise differences in the vehicle composition of the three traffic flows, with long haul articulated trucks comprising a larger share of through traffic and vans usually handling most of the inter-urban movements. So what began as a reasonable straightforward proposition to delimit the emission-reduction challenge within an administrative boundary unravels once allowance in made for the logistical complexity of freight movement into, within and out of the urban area.

This complexity has increased as a result of the growth in online retailing and so-called last-mile logistics. Responsibility for moving retail purchases to the home has shifted from consumers to online retailers and carriers working on their behalf. This has transferred the movement of goods from cars and public transport, essentially personal modes, to vehicles partly or wholly used for moving freight, mainly vans. It has made the movement of retail purchases statistically visible as a freight movement and last-mile deliveries a major and rapidly expanding source of freight-related emissions in urban areas. In a pre-Covid study, CO_2 emissions from these deliveries were projected to rise by 30% between 2020 and 2030 in the world's hundred largest cities (World Economic Forum / McKinsey, 2020). It is important, however, to take a holistic view of retail distribution in urban areas when calculating the transport emission levels because last-mile deliveries often displace shopping trips which had a higher emission intensity per kilogram of product purchased. Over the past decade several comparisons have been made of the carbon intensity of conventional and online retailing, varying in their scope, methodology and assumptions (e.g. Edwards et al, 2010; van Loon et al, 2015; Shahmohammadi et al, 2020). Given the variability of key parameters on both sides of the comparison it is difficult to draw general conclusions, though it can be said that under certain circumstances online retailing can have a significantly lower carbon footprint than the shop-based alternative. While it is advisable to assess the environmental impact of B2C ecommerce on the urban transport system as a whole, analysis of the effects of other trends and initiatives on emission levels can be segmented between the freight and passenger parts of this system.

The remainder of the chapter reviews the numerous options for cutting urban freight emissions. They are classified into five categories, adapting a 'green logistics' framework to the movement of freight in urban areas (McKinnon, 2015):

a) repowering urban freight deliveries with cleaner, lower carbon energy
b) increasing the energy efficiency of urban freight movement
c) improving the utilisation of urban freight capacity
d) shifting urban freight to greener transport modes
e) reducing the amount of freight movement in urban areas.

4. Repowering freight vehicles with cleaner, lower carbon energy.

As road vehicles are responsible for virtually all freight-related emissions in most cities, excluding those with major ports, attention will focus here on the repowering options for vans and trucks, the former handling mainly intra-urban goods flows and the latter much of the through and access traffic. This involves switching from the liquid fossil fuels of diesel and petroleum to alternative energy sources with lower emission-content. This switch can either be incremental where varying percentages of cleaner fuels are blended with fossil fuel or a complete substitution. The best examples of the former option is the blending of ethanol with petrol at 5% or 10% levels (E5 or E10) and of biodiesel with conventional diesel at a 7% level (B7), both now common in many countries. On a tank-to-wheel basis these blends cut emissions of pollutants and GHG. Life cycle analysis of the so-called 'field-to-wheel' emissions of these bio-fuel blends has revealed, however, that when emissions from the upstream processes and land use change are taken into account, much biodiesel actually emits more GHG than conventional diesel, respectively 18%, 113% and 203% more in the case of biodiesel produced from rape-seed, soya and palm oil (Ecofys et al, 2015). One has, therefore, to exercise caution in assessing the net emission-reductions from replacing fossil fuel with supposedly greener alternatives.

Switching from diesel fuel to liquid petroleum gas (LPG) or compressed natural gas (CNG) substantially reduces emissions of NOx and PMs, though has only a modest impact on CO_2 emissions. This can help to improve air quality in urban areas but makes only a small contribution to decarbonisation. Bio-LPG, on the other hand, made with renewable feedstocks, also cuts CO_2 emissions on a well-to-well basis by 86%. It is anticipated that all LPG will eventually come from renewable sources. The use of LPG in the freight sector, in both its fossil or renewable forms, is confined to vans. For heavier rigid and articulated vehicles, CNG and biomethane are the main low emission gaseous alternatives to diesel, the former, like LPG, offering large reductions in NOx and PMs but only marginal savings in GHG. Biomethane, on the other hand, produced by the anaerobic digestion of agricultural and food waste, emits on a WTW basis 78% less GHG than diesel fuel (Madhusudhanan et al, 2020). In most countries, however, the uptake of biomethane in freight vehicles is limited by a shortage of supply, competition from non-transport users and a lack of refuelling infrastructure. Moreover, as methane has a global warming potential 21 times that of CO2, great care must be taken to ensure that there no leakage of the gas from pipelines, refuelling systems and vehicles.

While vehicles powered with renewable forms of gas are likely to retain a presence in city logistics for the foreseeable future, it is likely that the main power shift will be from petrol and diesel fuel to electricity, taking advantage of the steady decline its carbon intensity. Average grams of CO_2 emitted per kWh of grid electricity dropped globally by from 525 in 2010 to 463 in 2019 and could plunge to 81 by 2040 (International Energy Agency, 2020) as renewables, and in some countries nuclear power, displace fossil fuel. What then will be the quickest and most cost-effective ways of powering freight movements in urban areas with this low, and ultimately zero, carbon electricity? In the case of vans and small rigid trucks the answer is likely to be the use of batteries. The electrification of urban van fleets is already well underway, particularly in those countries, such as France and Sweden, with low carbon electricity. Their limited distance ranges and stop/start duty cycles, typical of intra-urban deliveries, are well-suited to battery electrification. The commercial and operational case for battery electric vehicles (BEV) has also greatly strengthened in recent years as battery storage costs have been dropping sharply, recharging networks have expanded, distance ranges have lengthened and regulators have relaxed legal weight limits to allow for the additional battery weight. According to CE Delft (2017), the total cost of ownership (TCO) for small electric vans has already dropped below that of petrol and diesel vehicles while medium and large BEVs should achieve TCO parity by 2025.

There is much greater uncertainty about the choice of low carbon powertrains for heavy duty vehicles (HDVs) which account for much of the through and access traffic in urban areas. The main contenders are batteries, hydrogen-fuel cells and highway electrification, all of which can be hybridised both with each other and with various biofuel and synthetic fuel options. Several recent reports have compared these low carbon powertrain options on the basis of a range of economic, operational and environmental criteria (e.g. Neuhausen et al, 2020; Shell / Deloittes, 2021). They may all contribute to the future decarbonisation of trucking, though it is not yet clear in what proportions. Each will have commercial 'sweet-spots' offering a competitive advantage in the movement of particular densities of commodity over differing distance ranges. The resulting mix of low carbon truck technologies may then vary by country, region and city.

As heavy duty vehicles undertaking predominantly long haul, inter-urban deliveries release most of their emissions outside urban areas, it can be argued that their decarbonisation should not be an urban freight priority. Furthermore, municipal authorities can exert much less influence on the uptake of low carbon technologies in these vehicles than in vans and small rigid trucks much of whose movement is confined to urban areas. On the other hand, HDVs still represent a significant proportion of urban freight emissions and the switch to renewable energy will play a key role in reducing them. This decarbonisation and 'depollution' of HDVs fleets by means of electrification will, however, take much longer than the similar process for vans and small rigids. It has been estimated, for example, that in 2030, around 90% of trucks in the EU will still be diesel-powered (Neuhausen et al, 2020). In less developed countries, the transition from diesel to low carbon powertrains will take much longer as they rely heavily on the importation of used trucks from Europe and North America and it will take a while for the new generation of battery and fuel cell trucks to enter the global market for second-hand vehicles. Cities in low income countries with high HDV traffic volumes may therefore have a very long wait for the power shift option to deliver deep reductions in freight emissions. Although this option generally offers a quicker emission-reduction path for small and lighter freight vehicles operating in urban areas, it needs to be supplemented by other measures that can be implemented more quickly and cheaply. Collectively the next four categories of measure can substantially reduce the total amount of energy consumed by urban freight transport, thereby reducing the amount that has to be converted from fossil to renewable sources.

5. Increasing the energy efficiency of urban freight movement

Energy efficiency in this context is expressed as the ratio of the amount of fuel a freight vehicle consumes in travelling a given distance, typically litres of fuel per 100 kms. Efforts to improve the fuel efficiency of freight movement in urban areas can be divided into three broad categories relating to vehicle technology, driving behavior and operating practice.

Vehicle technology

Advances in vehicle technology have been raising the fuel efficiency of vans and trucks for decades, though in the case of European trucks the extent of the efficiency gains has been disputed (McKinnon, 2018). In many countries the upward trend has been reinforced by legal obligations on vehicle manufacturers to meet rising fuel economy standards. Such standards have been applied over a much longer period for vans (and cars) than for trucks, though the proportion of new truck sales subject to fuel economy standards has grown rapidly over the past six years reaching 70% by 2019 (International Energy Agency, 2020b). Within the EU, the standards have been defined in terms of average CO_2 emissions per vehicle-km rather than fuel efficiency though this will be the source of much of the improvement. For new vans, gCO2 per vehicle-km must drop by 31% between 2019 and 2030 while all new trucks sold after 2025 must be at least 15% more fuel efficient than the average new truck in 2019 and 30% more by 2030 (European Commission, 2019). As these fuel- and CO_2-efficiency standards only apply to new vehicles the rate at which they cut emissions depends on the average length of the vehicle replacement cycle which varies enormously by country and city. It is important therefore that the average fuel efficiency of the existing vehicle fleet is also upgraded. Technically this can be done by switching to low rolling resistance tyres and retrofitting devices to reduce engine-idling and improve aerodynamic profiling. As the emission savings from improved aerodynamics are largely a function of vehicle speed, they are much smaller in urban areas than on inter-urban trunk roads.

Driving behavior

Training truck and van drivers to drive their vehicles more fuel efficiently has been shown to be one of the most cost-effective ways of cutting pollutant and GHG emissions, particularly when it is supplemented with electronic monitoring of their subsequent performance and additional guidance where necessary. The environmental benefits of the resulting improvements in driving behaviour can be greater in urban areas because vehicles stop and start frequently and must negotiate roads with higher traffic density. One training scheme for van drivers achieved an average fuel efficiency improvement of 10.6%, saving 0.86 tonnes of CO_2 per driver per annum. Comparable fuel efficiency gains for HDVs have been around 5-10%. In recent years, and particularly during the pandemic, a vast number of new drivers have been 'recruited' many of them self-employed within the so-called 'gig economy' to deliver online orders. Relatively few of them have been professionally trained in eco-driving skills. Providing them with these skills could significantly improve the energy efficiency of last-mile logistics.

Operating practices

The relatively high levels of traffic congestion on urban roads carry a heavy fuel penalty. Initiatives which relieve traffic congestion in urban areas can therefore significantly improve the energy efficiency of freight distribution. The traditional 'predict and provide' approach to urban transport planning aimed to minimise congestion by providing additional road capacity. While road building continues in some urban areas, many municipal authorities now rely much more heavily on traffic management schemes to ease congestion. These schemes are usually targeted more at personal travel than freight transport, for example encouraging commuters to use public transport and imposing road-user and parking charges to discourage car use, particularly at peak times. City authorities can also manage road infrastructure in ways that more specifically reduces fuel use by freight vehicles. These vehicles often burn significant amounts of fuel when trying find roadside parking spaces near final delivery points. Even where spaces are designated for delivery vehicles they are often occupied by illegally parked cars. More effective management of this linear 'real estate' and tighter enforcement of parking regulations reduces unnecessary vehicle idling and detours in the vicinity of delivery (and collection) points.

Rescheduling deliveries to avoid periods of heavy traffic allows vehicles to travel at more fuel efficient speeds. Efforts have been made therefore to promote evening and night-time delivery, what in the North American is called 'off hours delivery' (OHD), partly to ease day-time traffic congestion but also to enhance the efficiency of urban distribution operations. Analysis of three OHD schemes in New York, Bogota and Sao Paulo found that it might be possible to cut CO_2 from freight deliveries by between 45% and 67% (Holguin-veras et al, 2016). These schemes are usually multi-stakeholder initiatives involving the supplier and receiver of the goods, the logistics provider and sometimes the municipal authority and local residents.

6. Improving the utilisation of urban freight capacity

Over the past 50 years, numerous studies have investigated ways of raising the load factors of vehicles transporting freight in urban areas, to reduce vehicle-kms and all the associated externalities. It is generally accepted that, on average, these vehicles are substantially under-loaded though very little hard data is available at an urban level to measure the extent of this under-utilisation and the potential for cutting it. Generally speaking, under-utilisation can be split between empty running and the partial loading or laden vehicles.

In an analysis of freight data for 14 urban areas in the UK, Allen et al (2012a) found much higher levels of empty running on outbound trips terminating beyond the city boundary. This partly reflected the fact that retail delivery networks in the UK are highly centralised with many shops supplied from regional or national distribution centres to which vehicles often return empty. Efforts have been made by retailers, their supplies and logistics providers to find backloads for returning store delivery vehicles, partly by 'triangulating' journeys and by assigning them reverse flows of waste, handling equipment and unsold inventory. Much intra-urban distribution, on the other hand, takes the form of multiple collection and/or delivery rounds on which only the first or last journey leg is run empty representing a small proportion of the total distance travelled. Such empty running is intrinsic to the urban distribution process but can be reduced by optimised vehicle routing (as discussed in section 8).

The under-loading of laden vehicles has traditionally been seen as more problematic than empty running in urban areas and more amenable to corrective action. The main action, which has been thoroughly researched, debated and trialled over the past forty years, is the consolidation of small orders into larger loads that use more of the available vehicle capacity. It has long been argued that this aggregation should take place at a new generation of 'urban consolidation centres' (UCCs), often located on the outskirts of towns and cities, where consignments destined for the same location / district would be combined into loads large enough to permit a direct delivery (Allen et al, 2012b). Radial deliveries by full vehicles would then replace multiple drop deliveries of small consignments to multiple locations. Initially this was seen as a way of rationalising retail logistics in urban areas though the same principle has also been applied to the supply of building materials to construction sites. Numerous pilot schemes have demonstrated that urban freight consolidation is workable and yields emission reductions, but very few have proved financially secure in the longer term. The Binnenstadt service for retailers in several Dutch cities (Rooijen and Quak, 2010) and the construction industry consolidation centres in London are notable success stories (Zanni and Bristow, 2010). In recent years, 'micro-hubs' have sprung up in several cities providing a similar freight consolidation service on a smaller spatial scale for last-mile delivery, often by bicycle.

The utilization of vehicles engaged in the last-mile delivery of online orders can also be enhanced by load consolidation at the front-end of the supply chain. This is where multiple orders are despatched to customer collection points rather than individually delivered to customers' homes. Average load factors are then maintained at a higher level and delivery distances reduced. This assumes, of course, that emission reductions on from consolidated deliveries to collection points are not offset by additional emissions from consumers driving to these points to pick up their orders. One study found that '*usage of automated parcel machines for the collection of a parcel emits 20.5% less CO_2 in comparison with the traditional B2C home delivery*' (De Maere, 2018).

Emission-reducing efforts to consolidate loads, particularly on the last-mile can also be counteracted in environmental terms by other online retail trends. As speed of delivery has become a competitive differentiator for online retailers, they have reduced the time available for carriers to bundle loads. Vehicles which used to set off with 120 orders for delivery over an eight-hour shift, might now leave with only 30-40 consignments for next- or same-day delivery. The 'internet of things' (IOT) is enabling smart kitchen appliances such as fridges and cupboards to automatically replenish supplies of food and household products, raising the prospect of home deliveries becoming more fragmented and carbon-intensive.

7. Shifting urban freight to greener transport modes

Among transport policy-makers and politicians, modal shift has long been regarded as the main way of reducing the environmental impacts of freight movement. This is understandable given that the average emission intensities (expressed as emissions per tonne-km) of rail and waterborne services are much lower than those of trucking. The commercial and operational case for switching freight to these cleaner, lower carbon modes, however, largely depends on the length of haul which is seldom great enough within urban areas. As rail and barge services are much more competitive over longer distances, modal shift has traditionally been seen as an environmental policy option for inter-urban, inter-regional and international freight movements. Examples of road-to-rail or road-to-water modal shifts at the urban scale are rare and generally confined to cities with dense waterway networks, such as Venice and Amsterdam, or heavy intra-urban traffic flows between rail-connected industrial premises, as between car plants in Dresden.

The definition of modal shift needs to be extended at the urban level to include other transport options which can cut freight-related emissions. Three options in particular have generated significant interest in recent years, cargo-cycles, drones / surface delivery robots and crowdshipping.

(i) *cargo-cycles*: Replacing motorized transport with human 'pedal-power' can eliminate urban freight emissions but only over a very limited distance range for smaller, lighter consignments (up to around 25kg). Electrically-assisted, purpose-built cargo cycles, particularly those with three or four wheels and trailers, can deliver much heavier weights (up to 250kg) over wider catchment areas. As these areas are much smaller than those of vans, it is often necessary to insert an extra tier of 'micro-hubs' into an urban distribution system where loads are transshipped from vans and trucks to cargo bikes. On the basis of simulation modelling in Porto, Melo and Baptista (2017) estimated that electric cargo cycles could replace around 10% of an urban van fleet, cutting CO_2 emissions by around 73%. Cairns and Sloman (2019) review the results of numerous trials and studies confirming that the switch from vans to electric cargo-cycles yields deep reductions in emissions. The gradual electrification of van fleets and decarbonisation of the electricity supply will narrow this differential, though bicycle deliveries will continue to offer other environmental benefits. Asian cities have had a long tradition of moving freight by bicycle, while in their European and North American counterparts this practice is being revived after many decades of decline. In Europe, the number of cargo cycles has been growing at 50-60% per annum in recent years, while one study has forecast that by 2030 the continent could have two million cargo bikes, half of them operated commercially and the remainder by private individuals. The expansion of cargo cycle logistics is predicted, therefore, to make a significant contribution to the decarbonisation of last mile logistics (World Economic Forum and McKinsey, 2020).

(ii) drones and surface delivery robots: the substitution of vans by these battery-powered autonomous aerial or surface delivery vehicles also offers a means of reducing emissions of GHGs and air pollutants (Stolaroff et al, 2018). Using US data, Figliozzi (2017) found that delivery by drone emitted 2.8 times less GHG than a typical non-electric van but this GHG advantage was negated when the van was electrically-powered and, on average, delivered to more than ten customers on a single route. A later analysis (Figliozzi, 2020) referring to aerial and surface robots revealed that 'these new autonomous vehicle types have the potential to reduce energy consumption and a vast potential to reduce CO_2 emissions when replacing ICE delivery vans. In many instances autonomous delivery vehicles are even more efficient than E-vans currently in the market'. The commercial application of these autonomous delivery systems is at a very early stage, however, and it is uncertain how widespread it will be become even once the technologies and their supporting logistics systems reach maturity. Several studies have suggested that parcel delivery by drone will be a niche service catering for those willing to pay premium rates for express delivery (Sesar, 2015; McKinnon, 2016a). One study of the 'viable market potential' for last mile delivery by drone sees the most realistic scenario being one in which 'drone delivery from drone-beehives could reach a population of 40 million people (about 7.5% of the EU28 population).' If and when this happens, most urban van delivery will probably be powered by low or zero carbon electricity, largely eroding any carbon advantage drones might offer.

(iii) crowdshipping: As discussed earlier, the growth of online retailing and last-mile logistics has redefined the interface between freight and personal movements in urban areas. The collection of goods on personal shopping trips is increasingly been replaced by deliveries to the home or nearby collection points. Most of these deliveries are currently made by van, though the practice known as crowdshipping offers the prospect of them being delivered by personal travel modes in the course trips that people would be making anyway. As originally defined by the US Postal Service (2014), crowdshipping involves 'enlisting people who are already travelling from points A to B to take a package along with them, making a stop along the way to drop it off'. This can be construed as a form of modal shift, ironically reversing the recent trend from car-based shopping to van-based delivery. The main difference, however, is that someone other than the consumer transports the retail purchases and are paid to do so. It can be seen as 'a web-enabled form of carrying other people's shopping' (McKinnon, 2016b). If, as originally conceived, crowdshipping integrates commercial freight movement into existing patterns of personal travel, it can yield emission reductions by decreasing total vehicle-kms in urban areas and, where it involves the use of non-motorised or public transport modes, also cutting emissions per vehicle-km.

Online platforms promoting crowdshipping, such as Deliv and Nimber, emphasise its potential environmental benefits. These benefits only accrue, however, where there is a net reduction in traffic levels and / or there is a modal shift to bicycles or public transport. In practice, much crowdshipping, or 'crowd-sourced logistics', fulfils neither of these conditions. Many of the citizens offering their services on the relevant websites act as couriers, using mainly cars to make separate parcel deliveries, additional to the trips they make for other purposes. Large online retailers, most notably Amazon, logistics businesses and Uber entered the market, recruiting a new pool of part-time drivers to expand the capacity of the last mile delivery market. According to Marcucci et al (2017) such '*dedicated trips cannot properly be defined as crowdshipping'*. Where crowdshipping creates a parallel, predominantly car-based delivery system with minimal synergies with personal travel there are usually few if any emission savings. This was confirmed by a Belgian study which concluded that '*vehicle detours and additional trips prevent crowd logistics from abating emissions, despite the initial premise of the sharing paradigm*' (Buldeo Rai et al, 2018). The original expectation that crowdshipping might offer a means of reducing urban traffic level, and thereby emissions, appears not, as yet, to have been fulfilled. The next section examines other ways in which urban freight emissions can be cut by lowering traffic levels.

8. Reducing the total amount of freight movement in urban areas.

This concluding set of initiatives can be labelled 'freight demand management' (FDM). Holguin-Veras et al (2015) define this subject as *'the area of transportation policy that seeks to influence the demand generator—to achieve urban freight systems that increase economic productivity and efficiency; and enhance sustainability, quality of life, and environmental justice*'. On the basis of this broad definition, they identify eight forms of FDM in urban areas, most of which directly or indirectly impact on emissions, but often via the four sets of interventions discussed in earlier. The intention here is just to focus on ways of reducing the freight transport intensity of cities, expressed, for example, by average tonne-kms or cubic-metre-kms of freight moved per resident. This can basically be done by suppressing two variables: the average amount of stuff per person and the average distance it is transported.

The first option essentially involves 'dematerialisation' and relates to wider issues of living standards, sustainable consumption, household size, life-styles and product development which are beyond the scope of this chapter. Suffice to say that average consumption of physical goods per capita varies enormously by city, country and region and is currently subject to conflicting pressures. On the one hand, it is being driven up by increasing wealth, packaging, food waste and product replacement rates, while, on the other hand, digitization, product down-sizing and lightweighting, and the growth of the circular and share economies are pushing it in the opposite direction. In the longer term, 3D printing may also help urban economies to dematerialise, though it is likely to have minimal effect on urban freight traffic levels and emissions for the foreseeable future (McKinnon, 2016a).

The second option, reducing the average length of haul for urban freight, can be split into two initiatives whose impact can be felt over differing time-scales:

(i) *Land use planning*: if it were possible to adopt a 'clean slate' approach to urban development, zoning policies could be used to optimise the spatial distribution of freight generating and receiving activities in a way that minimised the total amount of freight movement. This, however, would not necessarily maximise the well-being of the residents, the profitability of businesses or the general aesthetics of the urban environment. In the real world, trade-offs between freight minimisation and other land use planning objectives are tightly constrained by the physical fabric of the city which is difficult to alter in the short-to-medium term. They are also subject trends in the urban property market, some of which have been lengthening urban freight hauls in recent decades. The most prominent and most researched of these trends has become known as '*logistics sprawl'*, defined by Dablanc and Rakotonarivo (2010) as '*the historical trend towards spatial deconcentration of logistics terminals in metropolitan areas*'. They calculated that in Paris, over the period 1974 to 2008, the '*flight to the suburbs'* by many parcel and express transport terminals had increased their average delivery distance by 10 kms and in the process inflated annual freight-related CO_2 emissions by 15,000 tonnes. This form of sprawl has been the result of several centrifugal forces, including companies centralising logistical activities in larger facilities that could not be accommodated in inner city locations, urban redevelopment pressures and logistics being outbid for urban space by other types of commercial property. As Heitz et al (2020) point out, however, '*Logistics activities are not condemned to flee into the suburbs. Under certain conditions, these activities can stay in the denser parts of a conurbation'*, particularly where it has polycentric structure, as in the Dutch Randstadt, rather than a monocentric one.

The concept of the '*logistics hotel'* has also been advanced as a way of returning logistical activities to inner urban areas where they can serve their respective markets with fewer vehicle-kms and emissions. Logistics hotels are modern multi-storey, multi-functional buildings which use inner urban land intensively enough to compete, in terms with land values and rents, with alternative land uses. Two such hotels are now operating in Paris (Dablanc, 2019), though their development took many years and it is not yet known by how much they have cut freight traffic levels and emissions, if at all.

The transformation of shopping from a physical to an online experience is fundamentally changing the logistical geography of cities. This, combined with the post-Covid shift from office- to home-working, is likely to result in widespread 'repurposing' of commercial buildings in urban areas. Coordinating these trends with the proliferation of parcel collection points and micro-hubs will create an opportunity in the medium-term to rationalise the pattern of freight flow in towns and cities and reduce related emission levels.

(ii) *optimised routing*: even if the spatial distribution of freight origins and destinations remained fixed, the average distance travelled per consignment could be cut by routing the delivery more efficiency. Computerised vehicle routing and scheduling (CVRS) has been widely applied by carriers in urban (and rural) areas for several decades and has recently been substantially upgraded with the use of big data, predictive analytics and artificial intelligence. Traditionally, CVRS algorithms have had as their objective functions the minimization of distance travelled, transit times or delivery costs. Minimising these variables, however, need not minimise fuel consumption and emissions (Eglise and Black, 2015). A recent study in Stuttgart found that a routing model which minimized travel distance performed poorly in reducing total cost as well as fuel consumption and emissions (Emhke et al, 2018). It discovered that, '*optimizing for total cost has the benefit of also lowering fuel consumption and thus emissions relative to the traditional objectives of distance and duration*'. So, in the interests of cutting emissions, it is not always desirable to minimise the distance urban freight travels. Once allowance is made for variations in road type and traffic conditions, more circuitous routes can have lower total emissions. This illustrates the importance of aligning urban freight performance metrics with emission levels.

9. Limitations and future research directions

The previous five sections have outlined the many ways in which emissions of pollutants and GHGs from urban freight movements can be reduced. These measures are diverse and, in most cases, mutually-reinforcing, giving municipal authorities and businesses flexibility in the design of emission-reduction strategies. Their implementation at a municipal level usually involves the participation of several stakeholders and can be incentivised by a mix of fiscal, regulatory and advisory policies. Setting meaningful targets for cutting urban freight emissions and developing realistic plans for achieving them remains challenging, however. This is partly because of a lack of data and knowledge in several areas of sustainable city logistics, such as:

(i) *Establishing baseline conditions and emission reduction potentials:*

Viewing the emission of pollutants and GHGs from city logistics as a system, it is important to make an initial calibration of the key input and output variables. On the input side are *vehicle* parameters, such as body type, size, capacity, age and emission standard, *operational* parameters, such as distance travelled, average load factor and average fuel efficiency, and *energy* parameters, such as energy type, GHG intensity and pollutant content. In most countries, collection of the first two categories of data is conducted at a national level in a way that makes it difficult to distinguish urban from non-urban freight transport and with sample sizes that do not permit data disaggregation to specific towns or cities. To obtain the necessary degree of granularity, cities generally have to collect their own freight data, something that has traditionally been very expensive, though is becoming more affordable as GPS, driver apps and onboard vehicle sensors become more widespread. The main output variables are the amounts of the various exhaust emissions and, in the case of pollutants, their concentration in particularly locations at certain times of day. They can be monitored both at the vehicle tail-pipe and on a zonal basis, the latter making it difficult to attribute the pollution to particular sources.

Very few cities currently have the data required for such a baseline calibrations, especially of the input variables. It is therefore hard to assess the nature and scale of the emission problem and the potential emission savings likely to accrue from both particular interventions and a sustainable urban freight plan as a whole.

(ii) *Cost-effectiveness of emission reduction measures*:

At both corporate and municipal levels it can be difficult to determine the relative cost of emission-mitigation measures. In the case of carbon emissions, marginal abatement cost (MAC) analyses have been conducted to estimate the costs of a range of freight interventions per tonne of CO_2 saved. Most of these analyses have been undertaken at national level (e.g. Greening et al, 2015) and could usefully be replicated at an urban scale. They suggest that most emission reductions resulting from increases in vehicle loading and fuel efficiency have negative mitigation costs, in other words they save money as well as cutting emissions and would represent good business practice even in the absence of environmental gains. Exploiting this 'low hanging fruit', however, will only take cities some of the way to meeting zero emission targets for freight transport in the longer term. To close the gap they will eventually have to apply other initiatives with much higher emission-mitigation costs and longer payback periods. The economics of getting city logistics onto a zero emission trajectory need to be more fully investigated.

(iii) *Digitalisation*:

A recent survey of senior executives in Europe found wide agreement that the digitalisation will have a *'transformational'* impact on logistics over the next five years (McKinnon and Petersen, 2021). This suite of web-based technologies and applications will exert much of its influence on freight operations in urban areas, particularly on the efficiency of last mile delivery operations. If, on balance, it raises vehicle load factors and permits more fuel-efficient routing it should help to cut emissions. More research, however, is required on the nature and scale of digitalisation-driven reductions in urban freight emissions. Cruetzig et al (2019), for example, have shown how digitalisation can be 'leveraged' to improve the sustainability of personal travel in urban areas. Comparable research on the movement of goods in urban areas would be welcome.

(iv) *Retail transformation:*

As noted earlier, numerous studies have compared urban transport emissions from shop-based and online retailing, their analytical sophistication steadily increasing. This comparison, however, is neither binary nor static. With the development of 'omni-channel retailing' hybrid forms of fulfilment have emerged, such as click-and-collect and work-place delivery, which need to be 'emission footprinted'. The relative carbon intensity of retail purchases made through the various channels is constantly changing as consumer behaviour, delivery systems, vehicle technology etc. evolve. In countries with high online retail penetration rates, such as the UK, the switch to ecommerce is undermining the viability of retail property, changing the physical fabric of urban areas. Research on the effects of this transformation of the retail system on urban freight emissions must therefore be an ongoing process.

10. Conclusions

The main objective of emission-abatement policies in urban areas is shifting from the improvement of local air quality to climate change mitigation. This shift is already well underway across the developed world but at an earlier stage in less developed countries where high concentrations of pollutant emissions, due in large measure to trucks, continue to cause high levels of death, suffering and ecological damage. It is natural for cities to prioritise the alleviation of local environmental problems over the global climate change challenge where these problems are still acute.

Fortunately, as far as city logistics is concerned, the same set of measures can be used to cut emissions of both atmospheric pollutants and GHGs, removing the need to make difficult environmental choices. It is also fortunate that there are many such measures and that, in many cases, they are mutually-supportive and self-financing. In this chapter, the measures have been divided into five categories with attention focused on the first three as they typically yield the greatest emission reductions at an urban level: i.e. repowering freight transport with cleaner, lower-carbon energy, improving energy efficiency and more fully loading the vehicles. These measures can be supplemented, to a limited extent, by a modal shift to rail, waterborne and non-motorised services and more generally, in the longer term, by land use planning policies designed to lessen the overall demand for urban freight movement. By the time these policies take effect, however, the urban freight emission problem may have been largely solved by the low-carbon electrification of city logistics.

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