REGIONAL GOODS DELIVERY: HOW TO REDUCE ITS CO_2-, NO_X- AND PM_{10}-EMISSIONS?

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ABSTRACT

Regional goods delivery fulfils an essential socio-economic function, in particular, in dense urbanized areas in countries like The Netherlands. Shippers (producers or traders), transport service providers, businesses and private households favour road transport, because of logistic and financial reasons. Delivery and pick-up vehicles are mainly powered by internal combustion engines (ICE). ICE is a major source of ambient air pollution by NO_x and PM_{10} and of global warming (CO_2). More recent and well-maintained engines have much lower emissions of NO_X and PM_{10} than older and less well maintained ones, but their CO_2-emission has not been reduced as much. With (local) freight transport growing exponentially, these emissions are likely to rise. The aim of the paper is to estimate how a combination of logistic, technical and policy choices may reduce emissions of CO_2, NO_X and PM_{10}. The authors follow an integrative, interdisciplinary approach, because the past has taught that alignment of decisions by companies and government is inevitable to effectively deal with the root causes of these emissions. The main research question is as follows: What is needed to reduce the key emissions by regional goods delivery? This was addressed by literature analysis and micro simulation. The latter was used to compare the emissions of diesel, CNG and electricity to power trucks and truck-vans combinations in a region to inner-city delivery scenario. CNG is currently the better option in terms of emissions for the whole trip, largely because of the Dutch grey electric power mix. Replacing the city leg of the trip by vans leads to more emissions, more vehicles, higher parking needs and logistic complexity. Full electric trucks and vans cut out the local air pollution, which is beneficial, but not the emissions by power plants. A green(er) electric power mix is necessary to go to zero emission regional goods delivery.

Keywords: CO_2-emission, Fuel consumption, Goods delivery, Practical implications, Technology.

1 INTRODUCTION

Goods delivery is a vital socio-economic activity. It is estimated that about 5% of the value added and 4, 5% of the jobs in The Netherlands are in transport and logistics [1], many of those are taken by less skilled workers, which is important, because of the tendency to automate such jobs [2].

The dark side of (regional) transport and logistics are its many externalities [3]–[6]. There is the dominant use of trucks and vans equipped with engines that combust fossil fuels. Fossil fuels are regarded as a depletable resource in a long-term perspective, while their combustion contributes to climate change and ambient air pollution. Goods distribution also disturbs neighbourhoods by the noise they produce, and there are conflict areas with pedestrians and cyclists in shopping and living areas.

Goods distribution contributes to road congestion and is also equally affected by it [7]. The vehicles also (temporary) need (large) parking spaces, which is a problem, in particular, in city centres.

It is fairly common in science to follow a mono disciplinary approach and devote time to either a deep problem analysis with a modest entry into solutions or to primarily focus on solutions at a certain level of abstraction. The authors of this paper follow an integrative, interdisciplinary approach, because the past has taught that alignment of decisions by companies and government is necessary to deal with the root causes of these emissions. Emission

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standards have guided technical decisions by vehicle producers, while incentives like lower fuel cost due to improved efficiency have encouraged vehicle owners to invest in cleaner vehicles. This is why international organisations like the European Union continue with their integrative strategy to combat transport-related emissions [8]. The need for integral city distribution concepts has been mentioned earlier [9]. The authors go one step further by integrating an intentionally simplified logistic concept (case study) with a choice of vehicle-engine technologies and policy-making. The paper contains three related topics. The primary topic is the problem of climate change and ambient air pollution partially caused by regional goods distribution. The secondary topic is the effects of current and future ways to distribute goods with alternative vehicle-engine combinations. Finally, a third topic is the conditions, which would allow alternative vehicle–engine combination to be deployed more effectively.

The main research question is as follows: What is needed to reduce the key emissions by regional freight transport?

The answer is given at the micro level (single trip), which is where logistics decisions are made and fuel is consumed. The following sub-questions help to answer this lead question:

Q1—What is meant by regional freight transport and a regional freight trip?
Q2—What are relevant logistic decision parameters in regional freight transport?
Q3—What are main emissions of regional freight transport?
Q4—What are potentially alternative regional delivery scenarios?
Q5—How do these alternatives score in terms of emissions?
Q6—Which alternative should be stimulated and how?

The home country of the authors is used as study object. In terms of topography it is a simple country, because most of the country is flat apart from some slopes and hills in the more rural east and south. It is among the smallest and densest populated countries in the world. The Netherlands is a key player in international transport due to its location, its accessibility by all modes of transport and high quality logistic service industry.

In the next section, an introduction is given on the challenges and choices of freight transport companies when transporting goods in- and outside regions. It addresses sub-questions 1 and 2.

2 THE SYSTEM AND THE PROBLEM

2.1 Regional transport trips

Transport is a basic necessity, because of the division of labour in modern societies, which implies that no individual or company is (fully) self-sufficient. Goods are imported and exported to and from other areas. The term region(al) refers to the spatial area in which goods are being transported. There is intraregional transport, for instance, between cities or between a city and a village. Regional transport may also involve transport inside a city or village. Interregional transport crosses regional borders.

Regional freight transport carries a wide range of goods and services, from building materials, waste collection, service and maintenance, to pick-up and delivery of (small) orders for businesses (business to business (B2B)) and private addresses (business to consumer (B2C) and consumer to consumer (C2C)). In this paper, the focus will be on a delivery trip starting in a regional goods distribution centre and finishing in a city centre after unloading goods locally.

2.2 Logistics of regional transport

Logistics is about delivery (or pick-up) of the right product to the right place at the right time [10]. Transport companies consolidate most orders and route shipments via collection and distribution centres (DCs). There may be urban, regional, national or even international DCs. Consolidation means combining single orders into one transport trips, thus serving many customers. How many trips a transport company can actually make and the average distance covered per day or hour depends on an array of factors like the number of customers, the density of their pick-up and delivery network, road congestion, etc.

Geography and topology matter in regional transport. Regions may have a different size depending on the characteristics of the country under study. They can be urbanized or can be rural or a mix of both. The soil in a region can be flat or contain hills or mountains. These factors influence the accessibility of locations and the time it takes to connect them.

Many decisions are made in day-to-day logistics: What to ship, how to ship, where to ship, when to ship, etc. These have an impact on the choice of transport mode (road, rail or other), vehicle size (truck, van, car; train or wagon) and transport means (container, pallet, box). Typical choice parameters are order size, order frequency, transport cost, accessibility of a location by the mode of choice, etc.

2.3 Growing (regional) freight transport, growing impacts

Climate change mitigation is now targeting the CO_2-emission of transport. One should not forget the other negative side-effects, however. Next to air pollution with NO_x and PM_{xx}, there is the contribution to heat building-up during summer time, noise and vibrations and traffic accidents, all of which affect the quality of life and have (very) serious consequences for the health of those living in urban areas. In 2016 more than 80% of the people living in those urban areas that monitor air pollution were exposed to levels exceeding WHO standards. The actual percentage varies per region and country, as in low-to-middle income countries this percentage is 98% compared to 56% in high income countries [11]. As a consequence, increasingly city councils introduce environmental zones to combat the most prominent negative side-effects.

Freight transport in urbanized areas becomes increasingly complex, especially in high income countries like The Netherlands. Demand for goods sold in brick-and-mortar shops is declining, while online shopping is booming. The latter leads to rather dispersed and inefficient delivery patterns and frequency compared to traditional shops [12]. Until now most of this transport is carried out by trucks and vans with ICE. With an increasing number of people living in urban areas, the above-mentioned problems may rise dramatically.

2.4 Climate change, CO_2 and public policy

It is safe to assume that transport (passenger and freight) has an average share of over 25% in the final total energy consumption in developed countries. Up to 25% of this stems from freight transport. These are relevant numbers. What puts them even higher on the policy agenda, is that the volume transported and fuel consumption are rising. A doubling of freight transport has been forecast for The Netherlands until 2030. A similar rise in CO_2-emission is likely with current vehicle technology and use of fossil fuels [13].

Climate change (mitigation) has become a key issue on the political agenda worldwide. The Kyoto Protocol and its follow-ups call for a rather dramatic reduction in greenhouse gas-emissions and a transition to non-fossil fuels [14]. An OECD initiative calls for Green Growth [15].

Fossil fuels differ in terms of CO_2-emission. If an engine is multi-fuel ready, then it can be temporarily used with a fuel with the lowest CO_2-emission. Economically, a transition period makes sense that it prevents early scrapping of vehicles. In the meantime, technical development may provide more cost-effective alternatives. This rather defensive scenario has been favoured by the car manufacturers and politicians for years. With current knowledge about (the pace of) climate change, this is not the way to go forward. A more definite solution should involve replacement of all fossil fuel vehicles in the foreseeable future.

2.5 Alternative directions

The current dominance of ICE in freight transport is the result of past decisions and based on what was then available technology. Today, there is a choice of alternative engine–fuel combinations, next to non-motorized options (not further elaborated here). There is a choice between different fossil fuels (diesel or gas for trucks, petrol or gas for smaller vehicles like vans) and between fossil fuels and electricity (batteries). Hydrogen (fuel cells) is regarded as an alternative for the longer term [16]. The actual choice depends in particular on the following:

- Ease of use and range anxiety—the driving range allowed by one tank of fossil fuel compared to (fully) charged batteries and en route recharging opportunities;
- Cost—the total cost of ownership (TCO) over the lifetime of the vehicles;
- Business policy or marketing—green image of the customer and/or transport company;
- Policy making—upcoming regulations regarding fuel efficiency and emissions and a not unlikely ban on the production of ICE in freight transport.

3 METHODOLOGY

In this paper, the central actor is a decision maker working for a government agency or transport company. He or she is interested in potential 3P (people-planet-profit) trade-offs related with his or her policy- or business decisions. The analysis is at the level of single actors, because by understanding the micro level it is relatively straightforward and transparent to scale-up the results to the macro level (if needed). If a macro approach would be chosen initially, then there is a risk that the analysis does not arrive at the micro level, hence does not provide a meaningful advice to involved actors.

A model can provide decision relevant information. Hence, an MS© Excel© model, that was already successfully used in earlier papers, was enhanced to estimate the fuel consumption and emissions of trip scenarios with different vehicles and engine–fuel combinations. The main modules of the model are:

- A module to build trip scenarios. A scenario describes an origin–destination pair (transport link) in km, the mode of transport, engine technology, energy category (diesel, alternative) and fuel specification (fuel-blend), electricity composition (grey, green);
- Tables with fuel consumption and emission factors (EF). Fuel consumption data and emission factors from public sources (academic and professional) was used to estimate emissions. Only tank-to-wheel emissions were considered;
- An output module to present the results of the simulation.

To simplify the modelling and subsequent analysis, a few tactics were used. One was a simplified point-to-point routing of the vehicles instead of detailed network maps. To estimate the fuel consumption various approaches could be followed. In an ideal world, the authors would have followed one of the following approaches:

- Access a logistic service provider and ask him/her to carry out the proposed trip, and then receive either the fuel bill or kilometres driven. This information would then be entered into the ideal model, which then would calculate the emission with very high precision.
- Fully rely on a very advanced model to simulate a whole vehicle (combination) and component testing [17].

The authors do not have these options. Instead they estimate fuel consumption by distribution trucks and vans as the sum of the estimated fuel consumption per length of a network section. Emission factors are speed-dependent and were treated as such to estimate the emissions of CO_2, NO_x and PM_{10} by this simulated trip. The impact of a changing load factor of the vehicles due to loading and unloading was not taken into account in order to reduce complexity of the simulation. Instead an average load factor was used. It has to be realized though, that PM_{10}, because of the larger particle size, is known to be less damaging for human health than $PM_{2.5}$. Data for the latter was not available, however, hence the choice to stay with PM_{10}-emissions.

The time horizon is manually adjustable in the model, which allows for a partial upgrading or replacement of the truck fleet and fuel infrastructure in line with regular technical- or investment policies for such facilities because of technical, economic or policy-related reasons.

4 CASE STUDY

A reference scenario is introduced. Two alternatives will be discussed, namely trucking only and a combination of trucking for regional transport and vans for (inner)city transport. The analysis is used to address subquestions 3–5.

4.1 Reference truck scenario: estimated emissions

The reference scenario features a standard European heavy-duty road truck–trailer combination of 40–44 metric tons equipped with a Euro 6 ICE in use between a regional distribution centre and inner-city distribution points (stores). It is assumed that this trip is 60 km long. The fuel consumption differs per road section. Driving on highways tends to take less fuel than driving in inner-cities under normal conditions, hence a correction factor is applied to simulate these differences. The air pollution by this trip is shown in Table 1.

4.2 Alternative delivery scenarios: estimated emissions

About a decade ago trucks (and buses) started using CNG. Due to the lower power-density ratio of CNG compared to diesel, mileage per full fuel tank is lower, but the 60 km trip

Table 1: Reference scenario.

		Emissions (g/km)		
Trip scenario	Transport option	CO_2	NO_x	PM_{10}
Regional DC to inner-city (60 km)	Truck and trailer (Euro 6 diesel)	1,764	7.3	1.7

Table 2: Emissions per fuel type of a standard truck–trailer combination.

Trip scenario	**Diesel Euro 6**			**CNG Euro 6**			**FET, FEV grey grid**[1]		
Emissions (g/km)	CO_2	NO_x	PM_{10}	CO_2	NO_x	PM_{10}	CO_2	NO_x	PM_{10}
Regional DC to city access point (50 km)	755	3.1	0.7	596	0.79	0	910	0.75	0.02
Inner-city transport (10 km)	1,009	4,2	1	797	1.1	0	1,217	1	0.02
Total (g/km)	1,764	7.3	1.7	1,393	1.89	0	2,127	1.75	0.04

[1] "Grey" Dutch electric power mix.

between a regional DC and inner-city shops is feasible. The first generation of fully electric trucks (FETs) has been introduced recently. Table 2 shows the emissions per fuel type for the same trip as in the reference scenario. All scenarios are on a tank-to-wheel basis.

Interestingly, a CNG-fuelled truck-trailer combination performs better than a diesel equivalent. Even more interesting is that a CNG fuelled one also challenges a FET if its batteries are charged by electricity from the Dutch grid. In terms of payload a CNG truck may outperform the first generation of FET. This is not further explored here. It is imaginable that with minor tweaks a CNG truck performs even better regarding NO_x and PM_{10}. In this scenario, operational and environmental criteria would suggest decision-makers to pursue replacement of diesel by CNG and not by FET.

While local emissions can be reduced drastically by switching from diesel to CNG, the same does not hold for CO_2-emissions. FET could become the preferred option in this trip scenario if their batteries are charged with green electricity. The FET used for such a trip should of course be highway legal and have a battery of sufficient size, otherwise it cannot carry out the full simulated trip. These constraints will be tested in a regional pilot [18].

There is an important caveat here, namely that fuel consumption and emission factors are (greatly) influenced by the quality of maintenance of the truck–trailer combination. For instance, a less well-maintained Euro 6 truck may perform worse than a well-maintained Euro 5 equivalent. In general though, obviously, older trucks will perform worse, because the emission standards were (much) lower in the past than they are today.

4.3 Replacement of trucks by vans in inner-cities estimated emissions

In the previous scenario, truck–trailers were used for the whole trip. This is common and from a logistic point of view efficient if they have to serve large shops, like supermarkets. This scenario works very well if the shopping centre is not in the inner-city, but the situation becomes more complicated if it is. Lack of available parking lots, temporarily blocking of roads and interference with other road users and pedestrians are a daily reality in many inner-cities. This is why many large retailers are delivered in the early morning, late evening or even during the night, if the latter is practically feasible and legally allowed.

In centres, whether historic or more modern, restrictions on the use of trucks may lead to the use of vans. For smaller shipments these are already used to a large extent; up to 80% of all cargo traffic in an average street has been mentioned for The Netherlands [19].

Table 3: Emissions per fuel type of truck–trailers + vans.

Trip scenario	**Diesel Euro 6**			**CNG Euro 6**			**FET, FEV grey grid**		
Emissions (g/km)	CO_2	NO_x	PM_{10}	CO_2	NO_x	PM_{10}	CO_2	NO_x	PM_{10}
Regional DC to city access point (50 km)	755	3.1	0.7	596	0.97	0	910	0.75	0.02
Inner-city transport (10 km)	2,501	10.38	2.43	5,603	7.47	0.1	2,359	1.95	0.04
Total (g/km)	3,256	13.48	3.13	6,199	8.44	0.1	3,269	2.7	0.06

The impact of adding fully electric vans (FEV) to the distribution trip can be found in Table 3.

There are two caveats here. The first is that trans-loading from trucks to vans is necessary, most likely in a city distribution centre, which will likely make logistics more complex, adds time and cost to the distribution process. An in-depth logistic analysis is not part of this study, but such details are important. Second, vans have a much smaller loading volume than trucks. In [20] it was mentioned that up to 13 average size vans are needed to replace a full truck.

A technically up-to-date truck–trailer combination emits less than a combination of truck–trailers and vans. There are differences between the fuels used, but all score better than a combination of trucks and vans. The emissions change drastically if green electricity would be used to power the FET/FEV, however.

5 POLICY ASPECTS

5.1 Towards a greener electric power mix

Sustainability is high on the agenda of businesses [21] and policy-makers. Logistic companies are investing in more energy-efficient vehicles. In order to achieve the largest reduction in emissions, electric vehicles are potentially the best technical option at the moment. This brings us to the role of governments in zero emission goods distribution and the final sub-research question.

The road from zero *local* emissions to zero *regional* emissions goes via a greener electric power mix. This provides a major challenge, because at the beginning of 2018 just 6.6% of the Dutch electricity production came from renewable sources (including biomass, etc.) [22], which is nearly the lowest in EU-29 [23]. There are also several factors preventing a (fast) rise of the percentage of renewables in the total electric energy production. First is the rising demand for electric energy over time. Demand for electricity grew by 4.5% per year on average between 1950 and 2008, after which a down turn was calculated [24], but one may expect an upswing due to rising economic activity and a higher penetration and use of electric equipment [25].The next factor is the decision by the national government to ban the consumption of natural gas by 2050. The Dutch government gradually raises taxes on fossil fuels to realise the transition towards renewable fuels and to make citizens more aware of their energy consumption. Without a major reduction in energy consumption, a much higher demand for electricity seems inevitable, which cannot be served by a growth in use of renewables alone, as yet.

5.2 A stable electric power supply

A greener electric power mix in itself is not a sufficient condition for a successful transformation process, because renewable sources are not as flexible and reliable as fossil fuel sources. Key renewables like wind power and solar panels have a modest average utilization rate, because their actual production varies strongly per unit of time due to the weather conditions (wind/no wind, sun/shades/no sun), the time of the day (day/night), season (summer/winter) and operational and technical constraints (such as a lower panel efficiency on sunny days and prevention of overheating and closing down of wind power at very high wind speeds).

It is still a practice to rely on back-up power plants, which use fossil fuels, to stabilize the grid. A transition towards renewables ask for more advanced solutions, including excess capacity of renewables, local temporary storage in battery packs or electric vehicles, smart grids or more import of green energy. Whatever the energy transition scenario, large investments are necessary to realise it, on land and at sea. It may take decades to add such a large capacity [26].

5.3 Vehicle-type restrictions in cities

Policy-makers are tempted to restrict the number and frequency of truck delivery in parts of their cities to deal with congestion, parking problems, perceived or actual traffic safety and liveability. Not to doubt the validity of these issues, but it is clear that a van-scenario for (inner-)cities leads to much more vehicles on the road and requires more parking lots. It will also impact traffic safety. Emissions increase compared to a truck-only scenario. If future FET and FEV are powered by green electricity, then at least the emission issue is solved, but the traffic issues remain. A zero emission scenario will take a very long time, however. A delivery scenario with trans loading in a city distribution centre and multiple vehicles may make retail logistics more challenging and increase delivery time and costs.

In many cities new legislation is put in place that will change the face of goods distribution structurally. Major cities like Amsterdam and Utrecht want to become emission-free by 2025 [27].

It becomes apparent that a combination of policy instruments in different areas is needed to reduce the emissions of CO_2, NO_x and PM_{10} by regional freight transport to the required levels. Private and public investments in, respectively, vehicles and electric infrastructure are needed to achieve these aims. Increasingly stricter local policies guide the private sector in the chosen direction.

6 CONCLUSIONS

Freight transport is a major source of CO_{2}-emissions (hence climate change) and air pollution. Relevant aspects of regional freight distribution have been discussed in order to answer the research questions. The merits of alternative distribution scenarios have also been elaborated.

Micro simulation was used to discuss the state-of-the-art in fuel technology and compare diesel, CNG and electricity to fuel trucks and truck–vans combinations in a region to inner-city delivery scenario for not further specified shops. CNG is currently the better option in terms of emissions for the whole trip, largely because of the Dutch grey electric power mix.

The model allows one to explore the impact of distinct vehicle scenarios on emissions. Various trade-offs become apparent. For instance, banning large vehicles is not beneficial from a pollution perspective, not to mention the impact on traffic and logistics.

Replacing diesel fuel by CNG helps to reduce emissions. It has already been practiced with buses and certain maintenance vehicles, such as those removing waste, but the environment and air quality could improve significantly from more CNG-fuelled vehicles on the road. This does not mean that CNG is the best overall solution. After all, mining and transport of natural gas creates many environmental problems as well. However, the paper did not explore the well-to-wheel, but only the tank-to-wheel phase and impact. In the long-term green electricity (or green hydrogen) seems the way forward. Full electric trucks or vans are not preferable over CNG equivalents unless the FET/FEVs are powered by green electricity. This assumes a drastic change of the input sources of the electricity production. The demand for electricity is on the rise due to consumer choices and interventions by the national government. FET/FEVs are still much more expensive than fossil-fuelled trucks or vans, which reduces the pace of change towards sustainable regional goods delivery (somewhat). One has to keep in mind that transport is not a profitable business as such, but many businesses are busy with sustainability, which may change their perspective on sustainable investments in logistics and transport as well.

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