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# Does the introduction of small electric cargo vehicles into a logistics concept for last mile delivery of parcels and groceries in urban areas reduce its environmental impact ?

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## Abstract

The presented investigation analysed the environmental impact of introducing electric cargo vehicles into logistics concepts for last mile delivery of parcels and groceries in urban areas. In order to evaluate the environmental impact of substituting an electric cargo vehicle as e.g. an electric light duty vehicle (LDV), a batterv-electric passenger car (BEV) or an e-cargobike for a diesel light duty vehicle, a comparison based on a simplified Life Cycle Analysis (LCA) was conducted. Data from existing LCA studies of vehicles were combined with information on the actual transport service, i.e. the average cargo weight of vehicles. The expected change of the four chosen indicators cumulated primary energy consumption (for energy efficiency), $CO_2$ equivalents (for climate impact), NOx and PM (for air quality) and noise level was estimated. Results show that application of all investigated electric cargo vehicles has a potential to reduce the environmental impact of the logistics chain and that application of e-cargobikes has an especially high reduction potential.

*Keywords:* logistics concepts; electromobility; Life Cycle Analysis

## 1. Objectives

A growing number of international agreements and related EU legislation demand the introduction of alternative fuels for transportation, in order to reduce the negative environmental impact of transport emissions (see i.a. Austrian national strategy “Clean Energy in Transport” related to Directive 2014/94/EU). Applying vehicles powered by electricity from renewable resources reduces transport impact on climate change and local emissions at the same time (see Beermann et al. (2010), Winter et al. (2014), Fritz et al. (2016)).

In densely populated urban areas, the high space demand of cargo vehicles and especially the need for parking space are equally important challenges. An increasing number of enterprises therefore uses smaller cargo vehicles for delivery of small products such as groceries and parcels. Reorganising the logistics service chain faces technical challenges, e.g. limited capacity of the battery or smaller loading capacity of smaller vehicles, and may either reduce or increase the environmental impact of the service chain.

In order to support national strategies for introducing alternative fuels, strategic national and international research projects are launched, which develop concepts and conduct pilot trials within the existing national and regional transportation systems (see i.a. Quak et al. (2016)). The project EMILIA (Electric Mobility for Innovative Freight Logistics in Austria), a flagship project in the Austrian Climate and Energy Fund's programme "Leuchttürme der Elektromobilität" (Flagships of Electromobility), united 14 Austrian partners, ranging from large enterprises in logistics and grocery retail to vehicle technology and engineering firms as well as a startup company. The main goal of the project was to demonstrate that using electric vehicles in urban logistics is technically feasible, economically viable and has a positive environmental impact.

One subgoal was developing and testing an electric cargo tricycle (e-cargobike). The e-cargobike was used in two pilot applications. The first application focused on next-day and same-day express delivery of groceries in the city center of Vienna and dynamical optimisation of deliveries within given time windows. A part of the deliveries was carried out by the e-cargobike substituting a diesel passenger car. The second pilot application introduced a city hub as a distribution node for parcel delivery in a suburban development region of Vienna (Seestadt Aspern). An electric light duty vehicle delivered parcels to a city hub or directly to the customer in case of heavy and bulky goods, and the e-cargobike carried out the last-mile delivery from the city hub to the customer. Both electric vehicles substituted a diesel light duty vehicle.

In order to evaluate the environmental impact of substituting an electric cargo vehicle as e.g. an electric light duty vehicle (LDV), a batterv-electric passenger car (BEV) or an e-cargobike for a diesel light duty vehicle, a comparison based on a simplified Life Cycle Analysis (LCA) was conducted. Although several studies addressed the environmental impact of introducing electric vehicles using fleet-based life cycle approaches (for a review see Garcia R. and Freire F. (2017)), the system border of the analysis ended at the trip service and did not take into account the transport service (i.e. the transported cargo weight). Furthermore, the current guideline for calculation and declaration of energy consumption and greenhouse gas emissions of transport services (EN 16258) only comprises trip service, transport service and energy production and does not take into account vehicle production. Therefore the presented analysis had to extend the system boundaries compared to previous investigations.

The chosen indicators, which represent commonly used indicators for environmental impact of transport systems (see i.a. Fritz et al. (2016)), were cumulated primary energy consumption (for energy efficiency), $CO_2$ equivalents (for climate impact), NOx and PM (for air quality) and noise level.

## 2. Methods

Life Cycle Analysis (LCA) used a description of the production system with the unit processes vehicle production, battery production, disposal, fuel production, trip and transport (see Fig. 1).

- The unit processes are combined in a product*process matrix A. Then a demand vector d is defined for the production system, in case of a transport service it corresponds to 1 t*km transported cargo in the last row.
- From the process*product matrix A and the demand vector d a scaling vector s ( with $s = A^{-1} * d$ ) is calculated.
- For every process, the corresponding emission matrix E was extracted from the available resources, mainly the latest official report by the Austrian Environmental Agency (Fritz et al. (2016)). The results for primary materials were used in the LCA.
- The intensity of emissions was calculated by multiplying the emission matrix E with the scaling vector s.

More details on the methodology can be found in Heijungs (2002).

Life Cycle Analysis used a simplified approach with the following assumptions:

- The replaced vehicle and the vehicle substituted for it were produced at the same time, applying emission values from the latest available study in 2015.
- Emission values for energy production and vehicle operation were assumed to be constant during the lifetime of the vehicle, whereas they might change in reality (e.g. due to changing national power plants for electricity production).

A material balance for the e-cargobike was established based on confidential information of the manufacturer. From the material balance, the emission matrix for vehicle production was calculated with the tool GEMIS V 4.93

(see http://iinas.org/gemis-de.html). Use of primary materials (steel, aluminium, plastics) was assumed for vehicle production, as no LCA data on secondary materials were available.

No LCA data with all required indicators were available for the production of motorcycles and LDV. So energy demand and emissions for production of the diesel LDV were estimated from an average demand or emission per kg of produced vehicle for diesel vehicles, and energy demand and emissions for production of the electric motorcycle and the electric LDV were estimated from an average value for battery-electric vehicles. Similarly, energy demand and emissions for production of lithium battery were estimated from an average demand or emission per kg of produced lithium batteries. It should be noted that this estimation introduces uncertainty into the emission matrix of vehicle production.

A diesel LDV served as the reference vehicle concept for the LCA. According to information from the cooperating enterprises in logistics and grocery retail, the diesel LDV was assumed to have an expected lifetime of 10 years with an average yearly mileage of 25000 km, during which it can carry 125.000 t of cargo. For each vehicle concept, the number of cargo vehicles required to carry the same cargo weight as the diesel LDV (with an assumed average cargo weight of 0.5 t) was calculated: e.g. 10 e-cargobikes with an average cargo weight of 50 kg are required to carry the same cargo weight as an LDV with an average cargo weight of 0.5 t. For each vehicle concept, all emission values were multiplied with the number of required vehicles.

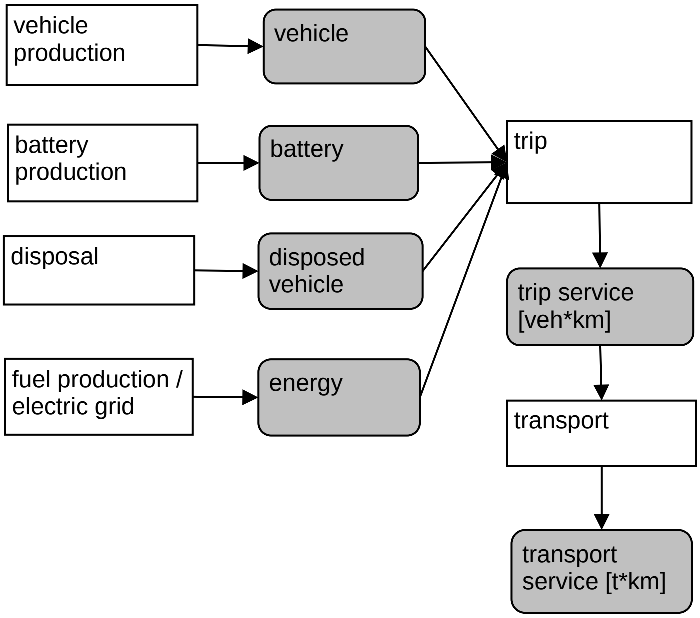

Fig. 1 Process-product-diagram for Life Cycle Analysis

As the data in the available reports were not provided according to the structure of the product*process system, the extraction of data proved to be laborious. Frequently results were reported per driven km without a clear documentation on the underlying lifetime and annual mileage. As regularly discussed, the quality and the usefulness of many LCA studies suffer from lacking transparency of the production processes and also a missing standardized structure for calculation and reporting (see i.a. Egede (2015), Heijungs (2002)).

Table 1 Analysed vehicle concepts and main assumptions

| vehicle concept | net vehicle weight [kg] | battery types | high-voltage battery weight [kg] | high-voltage battery capacity [kWh] | energy consumption [kWh/100km] | average cargo weight [t] |
|---|---|---|---|---|---|---|
| e-cargobike-elmix-AT | 58 | Li-Ion (10 a) | 2.7 | 0.5 | 3 | 0.05 |
| e-cargobike-elgreen-AT | 58 | Li-Ion (10 a) | 2.7 | 0.5 | 3 | 0.05 |
| motorcycle-elmix-AT | 158 | Li-Ion (10 a) | 27 | 3.8 | 8 | 0.06 |
| motorcycle-elgreen-AT | 158 | Li-Ion (10 a) | 27 | 3.8 | 8 | 0.06 |
| smallBEV-elmix-AT | 1187 | lead, Li-Ion (10 a) | 175 | 24.5 | 14 | 0.15 |
| smallBEV-elgreen-AT | 1187 | lead, Li-Ion (10 a) | 175 | 24.5 | 14 | 0.15 |
| largeBEV-elmix-AT | 1677 | lead, Li-Ion (10 a) | 200 | 28 | 20 | 0.2 |
| largeBEV-elgreen-AT | 1677 | lead, Li-Ion (10 a) | 200 | 28 | 20 | 0.2 |
| LDV-elmix-AT | 2200 | lead, Li-Ion (10 a) | 260 | 36 | 30 | 0.4 |
| LDV-elgreen-AT | 2200 | lead, Li-Ion (10 a) | 260 | 36 | 30 | 0.4 |
| LDV-diesel | 1800 | lead | - | - | 105 | 0.5 |

BEV: battery-electric vehicle, LDV: light duty vehicle
elmix-AT: Austrian electricity mix 2015, elgreen: electricity from renewable resources

## 3. Results

### *3.1. Primary energy demand*

Compared to the primary energy demand of a diesel LDV, primary energy demand is reduced by around 60 % for an LDV with the Austrian electricity mix in 2015 and by around 65 % for an LDV with electricity from renewable resources (see Fig. 2).

Using an e-cargobike results in the lowest primary energy demand among all electric vehicles, regardless of whether the Austrian electricity mix in 2015 (with 1.28 kWh primary energy demand per kWh energy supply) or electricity from renewable resources (with 1.04 kWh primary energy demand per kWh energy supply) is used. Compared to the primary energy demand of a diesel LDV, primary energy demand is reduced by around 75 % for the Austrian electricity mix in 2015 and by around 80 % for electricity from renewable resources. Using a small or a large battery-electric vehicle would reduce primary energy demand by around 50 to 55 %, using an electric motorcycle would reduce primary energy demand by around 45 to 55 %.

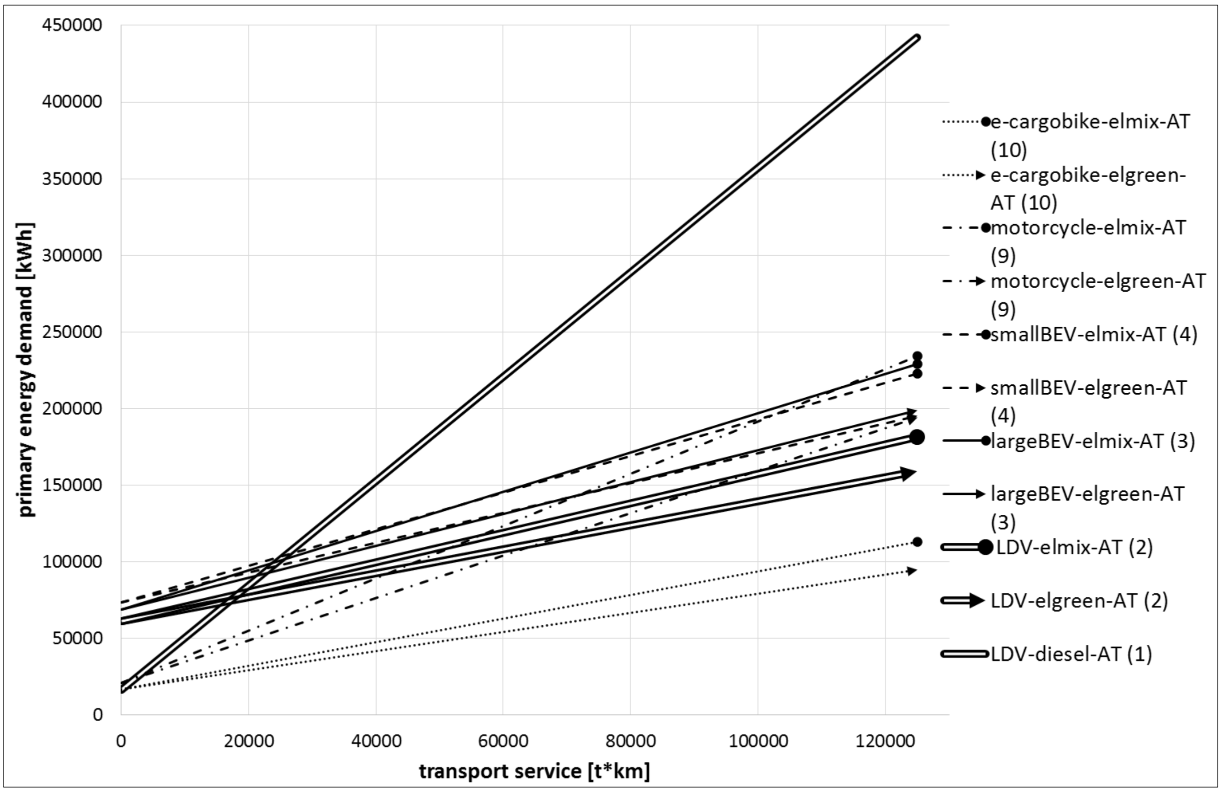

Fig. 2 Primary energy demand during vehicle life cycle

### *3.2. Climate impact*

Compared to the greenhouse gas emissions of a diesel LDV, greenhouse gases are reduced by around 55 % for an LDV with the Austrian electricity mix in 2015 and by around 75 % for an LDV with electricity from renewable resources (see Fig. 3).

Using an e-cargobike with electricity from renewable resources has the lowest climate impact, because both production of such vehicles and energy consumption during use have the lowest impact among all vehicles. Compared to the primary energy demand of a diesel LDV, greenhouse gases are reduced by around 75 % for the Austrian electricity mix in 2015 and by around 90 % for electricity from renewable resources. Using a small or a large battery-electric vehicle would reduce greenhouse gases by around 45 to 70 %, using an electric motorcycle would reduce greenhouse gases by 55 to 85 %.

Based on the Austrian electricity mix in 2015, the share of vehicle production ranges between around 15 to 50 %. With electricity from renewable resources, the share of vehicle production accounts for around 60 to 90 % of climate impact.

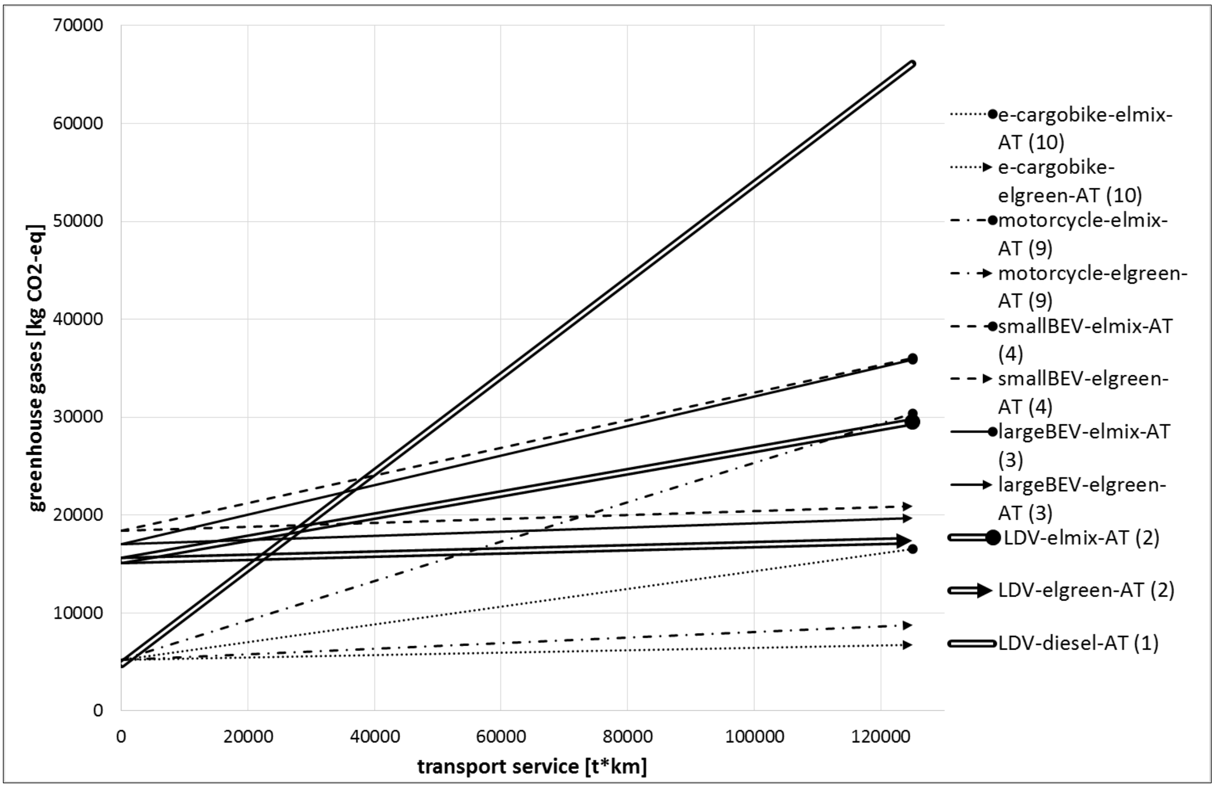

Fig. 3 Greenhouse gas emissions during vehicle life cycle

### *3.3. Air emissions*

Compared to the NOx emissions of a diesel LDV, NOx emissions are reduced by around 35 % for an LDV with electric engine (see Fig. 4).

Using an e-cargobike with electricity from renewable resources has the lowest NOx emissions, mainly because production of cargo vehicles has the lowest NOx emissions among all vehicles. Using an e-cargobike causes around 75 % less NOx emissions than using a diesel LDV. Using a small or a large battery-electric vehicle would reduce NOx emissions by around 25 %, using an electric motorcycle would reduce NOx emissions by around 45 %.

The share of vehicle production ranges between around 25 and 65 % of NOx emissions for both sources of electricity.

Concerning emissions of fine dust (particulate matter, PM), the share of vehicle production ranges between around 55 to 95 % of PM emissions. The main source of PM emissions is located in steel and aluminium production.

So the LCA results rely on a good documentation of the production process, e.g. whether primary or secondary materials were used or whether one or two batteries were included into the calculation. Unfortunately the available reports did not include a clear description of these assumptions. In addition, values for vehicle production had to be estimated, adding to the uncertainty of the results. Therefore the results concerning PM emissions have to be interpreted with a large uncertainty in mind.

Compared to the PM emissions of a diesel LDV, PM emissions seem to be increased by around 155 to 160 % for an LDV with electric engine. Using e-cargobikes seems to cause around 40 % more PM emissions than using a diesel LDV. Using a small battery-electric vehicle would increase PM emissions by around 245 to 250 %, using a large battery-electric vehicle would increase PM emissions by around 270 to 280 % and using an electric motorcycle would increase PM emissions by 5 to 15 %.

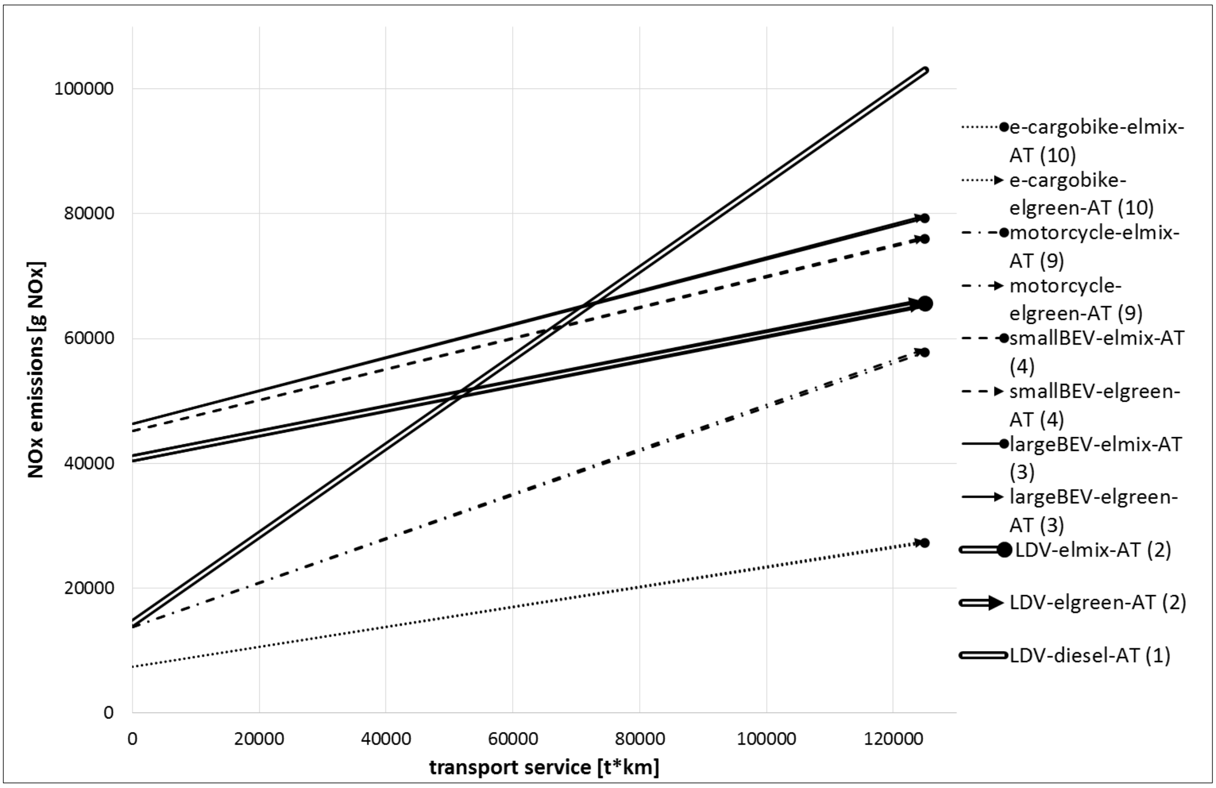

Fig. 4 NOx emissions during vehicle life cycle

### *3.4. Noise*

Battery-electric vehicles contribute to noise reduction in inner-urban traffic, because noise emissions from the vehicle engine are louder than vehicle rolling noise at speeds below 35 to 40 km/h. At speeds above 35 to 40 km/h rolling noise dominates the noise pressure level, and therefore no relevant reduction can be expected from a battery-electric vehicle.

As reported in Hanappi et al. (2012), using a battery-electric passenger car results in a noise pressure level reduction of 2 - 4 dB for speeds between 30 to 50 km/h and of 7 to 8 dB for stop-and-go traffic. Noise reduction is a non-linear function of the share of electric vehicles.

As e-cargobikes usually drive at speeds up to 25 km/h, an e-cargobike can be expected to have a reduced noise pressure level compared to a vehicle with a combustion engine.

## 4. Conclusions and Outlook

The presented investigation analysed the expected environmental impact of introducing electric cargo vehicles into logistics concepts for last mile delivery of parcels and groceries in urban areas. In order to evaluate the environmental impact of substituting an electric cargo vehicle as e.g. an electric light duty vehicle (LDV), a batterv-electric passenger car (BEV) or an e-cargobike for a diesel light duty vehicle, a comparison based on a simplified Life Cycle Analysis (LCA) was conducted.

Data from existing studies on the LCA of vehicles were combined with information on the actual transport service, i.e. the average cargo weight of vehicles. The expected change of the four chosen indicators cumulated primary energy consumption (for energy efficiency), $CO_2$ equivalents (for climate impact), NOx and PM (for air quality) and noise level was estimated. Application of all investigated electric cargo vehicles was found to have a potential to reduce the environmental impact of the logistics chain, application of e-cargobikes was found to have an especially high reduction potential.

Uncertainties in the emission matrix for vehicle production and simplifying assumptions for Life Cycle Analysis were described. The sensitivity of the found results on these uncertainties and assumptions should be the topic of further investigations.

Because recycling of vehicles is mandatory (according to Directive 2000/53/EC on end-of life of vehicles), also bicycles should be recycled and recycled materials should be used for bicycle production in order to further reduce the environmental impact of vehicle production (e.g. PM emissions).

Application of smaller cargo vehicles increases labor intensity for the same transport service. In order to make the replacement of larger cargo vehicles by smaller cargo vehicles feasible or attractive in a financial respect, it is necessary to reduce additional costs related to human work and to increase energy-related costs for goods transport.

## 5. Acknowledgements

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