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Suitability of commercial transport for a shift to electric mobility

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Abstract

This paper identifies commercial sectors suitable for a shift to electric mobility. The paper concludes that the construction and the health care service sectors are the most suitable for electric mobility because many vehicles are registered in these sectors and daily mileage is reasonably low. They should be primary target groups of specific policy measures to promote the use of electric vehicles.

Denmark has only had a few incentives to promote the use of commercial electric vehicles. Until now electric vehicles do generally not show economic benefits unless travel distance is high. However, today the travel range of large vans is an important barrier for electrification due to the battery weight and the limitation of 3.5 tonnes gross vehicle weight for driving with a normal driving licence. The rule needs amendments for electric vehicles, as has been done in Germany. The paper recommends EU countries to follow the German rule allowing EVs up to 4.25 tonnes to be driven with a class B licence, thereby potentially creating a market for big electric vans.

1 Introduction

To promote the application of a more sustainable and cleaner freight transport, the use of electric vehicles (EVs) may be an attractive solution to improve air quality in the city centre, reduce CO_2 emissions, and reduce noise nuisance (Van Duin et al., 2013; Kemp et al., 2000). Until now, mainly private electric passenger cars have been studied. However, in recent years the use of EVs has begun to spread to other transport sectors as well. But while global retail and delivery companies have started to consider using alternatively fuelled vehicles, only a marginal share of the fleet has been studied so far (Bae et al., 2011). Most projects about EVs focus on private users and electric passenger cars, even though most EVs are registered in car fleets or as company cars (Mock and Yang, 2014). Especially due to the lack of electrified light duty vehicles, little is known regarding the use of electric vehicles for commercial transport, i.e. transport of goods and service delivery. But research into the potentials for passenger EVs in commercial applications is widely neglected, too.

Several requirements need to be fulfilled for a company to replace their conventional cars with EVs. Firstly, the transport requirements and expectations expressed by drivers and/or operators have to be met. This is clearly demonstrated by an evaluation of the Swedish electric vehicle procurement trial for commercial fleets in 2010-12 (Wikström, 2015; Wikström et al., 2015, 2014).The study is the most comprehensive study in Europe focusing on commercial use of EVs. Secondly, the EV has to be economically feasible or even more attractive than a conventional vehicle (Bae et al., 2011; COWI, 2014; Feng and Figliozzi, 2013). Thirdly, the vehicle needs to be accepted by the owner and/or the vehicle manager (Kaplan et al., 2015).

1.1 Policy to support development in the commercial EV market

In Denmark EVs were exempted from purchase tax and annual user tax from 2009 to 2015. This exemption is currently being phased out and disappears from 2020 (Skatteministeriet, 2015c). As only passenger cars and small vans pay purchase tax, this exemption mainly has an effect on the price of passenger cars. Furthermore, power suppliers can deliver electricity for free to companies when dedicated to mobility. During 2008 to 2015, the Danish government set up different EV programmes mainly dedicated to companies to support the introduction of EVs and the development of a charging infrastructure with an overall budget of €12 million (Energistyrelsen, 2015). The programme has resulted in an increasing network of fast charging stations and local low-power chargers. Free parking in city centres has been brought in by local initiatives and is now included in Danish legislation. In Denmark no economic initiatives dedicated to commercial EVs have been taken. In spite of a massive public support only around 8,000 EVs are on the streets by the end of 2015 (Dansk Elbil Alliance, 2015) most of them passenger cars.

1.2 The purpose of the paper

The overall purpose of the paper is to demonstrate possibilities to reduce the climate burden from commercial transport by shifting from combustion engines to electric drive with BEVs. The more vehicle kilometres (sum of annual kilometres driven by all vehicles) that can be shifted to electric drive, the higher is the potential for reducing the climate burden, especially when the power supply is converted to renewable energy. A shift from combustion engines to electric drive furthermore reduces local air pollution and noise, which are important problems in urban areas with high concentrations of people in the streets and residences along the roadsides. The aim of this study could also have been to reduce the burden on urban areas from commercial transport. However, as the main contribution of the work is focused on available statistical information about number of vehicles and vehicle kilometres, no knowledge is available about the areas where the vehicles are driving.

The objective to reduce the climate burden from commercial transport can be achieved by shifting to electric drive for a high number of vehicles and/or by a shift for vehicles driving many kilometres. As the driving range of EVs is limited, the objective can only be obtained by replacing as many conventional vehicles as possible with EVs.

The method of the present paper is to identify which economic sectors a) have a high share of commercial vehicles on the one hand, and b) are most suited for changing to electric drive due to their daily driving pattern. By focusing on these two parameters it should be possible to find the most cost-effective targets for potential policy measures and business cases for electric vehicles. This paper presents the results of statistical analyses of the commercial transport sector, enriched in a third step with more detailed analyses based on GPS tracking. The analyses show to which extent vehicles in the different economic sectors have a driving pattern making it possible to replace the existing conventional vehicles with electric vehicles.

Compared to private mobility, the transport needs of the commercial transport sector are much more diverse. Usage patterns are subject to customer requirements, financial and organisational conditions or restrictions (HEBES et al. 2010). However, there is no general pattern; rather, each economic sector and sub-sector may have its own particular way of organising its mobility. Transport surveys also show that driving patterns in some business branches are more suitable for the application of EVs than others. Thus target-group-specific policies for the promotion of electric mobility might be attractive. Christensen (2011), for instance, shows that for Denmark around 80% of vans and 70% of small lorries are driven less than 150 km per working day. Some sectors have highly identical uses of their vehicles over a long period, as is the case within the Swedish procurement programme (Wikström et al., 2015), whereas in other sectors the daily driven distance may vary strongly from day to day, e.g. in the service sector.

A detailed picture of the variety of potential users and their requirements is necessary to assess the market potential for EVs and to develop adequate policy instruments to facilitate their introduction.

In this paper we analyse different business sectors in detail to enable national and local politicians to design stimulus programmes targeting the most suitable groups for a shift to EVs at the current state of technological development. The results are also valuable for the automotive industry to know for which business sectors EVs should be designed.

The paper is a result of the Select project in which suitability to shift to electromobility for commercial transport is analysed in three countries, Denmark, Germany and Austria. In a paper under review a comparison between suitability is compared between Germany and Denmark. The current paper is an edited excerpt of the more comprehensive paper.

2 Methodology

2.1 Assessment of the potential for EVs per economic sector

In order to assess the potential for EVs of each economic sector, three analyses were conducted:
Firstly, is presented an overview of the size of the commercial vehicle stock as distributed across economic sectors, enabling us to identify, which sectors have a high number of vehicles, and thus where the potential for the largest number of EVs may exist. The following sections will mainly focus on these sectors.

Next, the distributions of the average daily travel distances are analysed for passenger cars with a commercial owner, vans with a gross vehicle weight (GVW) up to 3.5 tonnes and lorries with a GVW of up to 12 tonnes for all economic sectors according to the statistical classification of economic activities in the European Community (NACE, see European Commission, 2015). Only these three vehicle segments are analysed as there are nearly no electrified heavy trucks available on the market. The objective is to uncover the variation in average daily travel distance of vehicles of different sizes and sectors, and to discuss these in relation to the possible range of commercial EVs. The daily travel distance is important to assess if the vehicles can drive a full working day without being charged.

Finally, in order to check the robustness of the results and the applicability of EVs, the daily variation in mileage of the vehicles in selected companies of some of the most promising economic sectors is analysed by GPS-logging. In daily life it is necessary for the EV owner to be able to drive every day without spending time charging unless it can be done simultaneously with other duties. An average travel distance per day calculated over one or more years does not show how many days the permissible mileage of the EV would be exceeded and therefore it is necessary to assess the daily driving pattern.

2.2 Criteria: maximum driving range

A limiting criterion of EVs is the maximum daily mileage for vehicles. It is therefore necessary to decide a threshold of the daily driving range we could measure against. The maximum driving range of most of the passenger EVs presently on the market varies between 130 and 200 km according to the manufacturers. An exception is the luxury and expensive passenger car from Tesla Motors with a maximum range up to 500 km. The maximum mileage of light duty vehicles (LDVs), according to the manufacturers, varies between 100 and 170 km.

However, in practise the travel range is not as long as promised by the test driving circles, according to results from the Danish support programme financed by the Energy Department (Energistyrelsen, 2015). The travel range depends on the individual driving behaviour related to speed, acceleration and breaking (Duke et al., 2009; Energistyrelsen, 2015; Fetene et al., 2015; Greaves et al., 2014). Furthermore, the driving range is reduced due to outdoor temperature (use of heating, air conditioning etc.) (Fetene et al., 2015), topography of the area and transported weight. By using the energy consumption model developed by (Fetene et al., 2015) on GPS tracking of conventional vehicles, both passenger cars and vans, driving during summer and winter periods the average driving range is derived in a Danish environment (Barfod et al., 2015). The resulting average driving range is 158 km during a summer period and 115 km during a winter period for passenger cars like Nissan Leaf, E-Golf and Mercedes B, which have an official driving range of 200 km. For the Nissan e-NV200 van, with an official range of 170 km when fully charged, the travel range in real traffic during a summer period is only 111 km. For all cars it is assumed that the drivers drive the car in the same way as they drive a conventional car.

Next, range anxiety has to be considered. (Wikström et al., 2014) show that employees who can choose between electric and conventional vehicles from a fleet with both kinds of vehicles generally choose a conventional vehicle if the expected distance to drive during the specific day might be more than approximately 70 km. When a vehicle is assigned to only one user, the user tends to choose a conventional car when a proper introduction on how to use EVs was not given initially. Especially in these situations, a daily mileage of up to 100 km puts stress on the users. In Swedish winter periods the EVs are used rather little and use was not higher during the second year of the trial, indicating that fleet drivers who have a choice are no more confident with the travel range and avoid EVs in cold weather.

(Sun et al., 2014) show, based on studies of mid trip charging by Japanese EV drivers, that a commercial EV during a working day will require 3.6-5.2 kWh as a minimum power left on the battery when charging begins. The level probably depends on the sector and the type of trip, but the observation is not further explained. With a 24 kWh battery, this equals 15-20 % of the capacity, which under average conditions reduces the above-mentioned travel ranges to 125-135 km for passenger cars in summer and to 92-98 km during the winter. For the van with the lower official travel range, the practical travel range will only be 88-94 km in a summer period.

Recharging during the day can extend the daily travel range. However, recharging may take several hours. When considering loss in the converter, a normal electric outlet allowing 10 Amp only delivers 2.1 kWh per hour (Christensen, 2011). Using fast charging a substantial recharge can be performed within 20 to 30 min. (up to 80% of the battery capacity), but fast charging facilities are still scarce and normally not available where commercial vehicles need them. (Wikström et al., 2015) therefore show that recharging is only very seldom applied by commercial EV users.
All together as an outset for the analyses two thresholds are applied:

- 50 km maximum driving range without recharging: Vehicles driving less than 50 km per day is deemed to be suitable for electric mobility in any case.
- 100 km maximum driving range without recharging: Most of the electric passenger cars and small vans are able to be driven up to 100 km even though they, with current technology, need to adapt their driving pattern in winter time. For an LDV with a GVW of 3.5 tonnes or more, this travel range can only be achieved with new models of LDVs with bigger battery capacity or next generations of electric LDVs.

2.3 Data for statistical analyses in Section 3.1 and 3.2

Data sources for Section 3.1 are the Central Vehicle Register. The statistical analysis of commercial transport for Section 3.2 is based on a dataset with the results of odometer readings during mandatory vehicle inspections from 2007 to 2012 (called SynsData) maintained by Statistics Denmark. The inspection of passenger cars is made no later than 4 years after first registration date and every second year afterwards. For vans and LDVs it is made two years after first registration and once a year afterwards. SynsData is supplemented with data from other public registers in a closed computer environment at Statistics Denmark with access to the full databases with all vehicles. The calculations are run the following way:

1. From SynsData information is extracted about the date and mileage at each inspection, the owner (listed by a code for privacy), the number plate, type and GVW. The mileage between each inspection is calculated and divided by the number of days between two inspections.
2. The calculated mileage per day for periods before 2006 and from periods where the ownership was changed between the two readings is removed. Only data for vehicles with commercial owners are kept.

3. This dataset is merged with annual extracts from the Motor Register by the number plate. The company registration number by January 1st is extracted and kept.

This dataset is merged with a register with account data for firms and with a register of employees by the company registration number. The NACE code for the economic sector and a detailed branch code are extracted. Unfortunately, the project did not have access to the full company register with branch codes for all companies. The NACE and branch codes are missing for companies without employees or with an annual turnover under EUR 40,000.

The daily mileage as extracted from SynsData is, as suggested in (Christensen, 2011) recalculated to kilometres per working day, assumed to be 225 days per year on average (5 days a week and 45 weeks per year; vacations and public holidays this way being excluded). The number of travelling days might be higher for lorries and fleet vehicles used by several employees and therefore driving during holiday seasons and weekends, too. However, by using 225 days to calculate the daily average travel distance, we are more on the safe side and do not underestimate the daily mileage.

2.4 Data for driving behaviour analyses in Section 3.3

To assess the variation in daily travel distance and the effect of range anxiety, it is necessary to register the daily variation in travel distance over a longer observation period. However, contrary to private passenger cars, including a holiday period is not needed. A high number of vehicles in each company also illustrate the variation.

Vans or passenger cars from companies in different sectors were followed during periods ranging from a few weeks to half a year: Two companies in the Construction sector (NACE code F), an electrician and a decorator, and one in the Professional service sector (M), a chimney sweeper, were followed for 4-6 months and 2½ weeks respectively. Two taxi companies (transportation and storage sector (H)), one with primary basis in central Copenhagen (190 taxis), the other with customers in different towns on Zealand (9 taxis) and two companies in the Wholesale and trade sector (G) providing delivery services, one delivering food and groceries to private households in the Copenhagen region (47 LDVs) and the other serving the whole of Denmark (56 18-tonnes trucks) are recorded. The data of four companies were collected by GPS loggers, and the other three's data were supplied by the company's vehicle steering system.

The three companies from Construction (F) and Professional service (M) were chosen because they belong to sectors, which in Section 3.1 are shown to be potentially suitable sectors for a shift to electric vehicles. The two companies in the Wholesale and retail trade sector (G) represent a sector with very broad variation in daily travel distance and therefore a possible relevant company. The taxi companies represent a sector, which at the outset is not relevant, but some Danish taxi companies were considering changing to electric drive, especially if they could fast-charge during the day. They are therefore included to complete the analysis.

The included vehicles and sectors are not representative for vehicles potentially suited for a shift to electric drive. They only represent some interesting showcases, which can illustrate some of the problems with the shift to electromobility. A reason for this limited choice of companies is the difficulties with finding relevant companies willing to deliver potential information about their customers. Another reason is a limited budget, which did not allow for the cost of distributing GPS trackers to a high number of vehicles.

3 Results

The vast majority (88%) of the Danish commercial vehicle stock of up to 12 tonnes are vans with a GVW of 3.5 tonnes or less. Table 1 shows that 33% of the vans are registered in the construction sector (F). For all vehicle types, the wholesale and retail sector (G), which includes car dealers, has 23% (for passenger cars 33%). The Manufacturing (C) and Administration and support sectors (N) represent 8% each. Half of the lorries belongs to Construction (F), Trade (G) and Transportation (H) sectors. For 8% of the vans and 13% of the passenger cars, the sector could not be established.

Table 1 Registered passenger cars, vans and LDVs by economic sectors.

NACE	Sector (short)	Passenger cars Obser-vations	Passenger cars Share	Vans 0-3,5t GVW Obser-vations	Vans 0-3,5t GVW Share	Lorries 3,6-12t GVW Obser-vations	Lorries 3,6-12t GVW Share	Share of all vehicles
A	Agriculture	1,939	1%	13,720	6%	462	5%	4%
B	Mining	249	0%	326	0%	14	0%	0%
C	Manufacturing	12,251	9%	19,387	8%	663	7%	8%
D	Electricity, gas	592	0%	2,048	1%	127	1%	1%
E	Water supply	259	0%	1,479	1%	301	3%	1%
F	Construction	5,394	4%	80,137	33%	1,753	19%	22%
G	Wholesale and retail trade	47,003	33%	41,266	17%	1,782	20%	23%
H	Transportation and storage	7,219	5%	9,536	4%	1,185	13%	5%
I	Accommodation	1,235	1%	4,498	2%	36	0%	1%
J	Information, communication	6,759	5%	4,079	2%	42	0%	3%
K	Financial, insurance activities	3,447	2%	1,466	1%	24	0%	1%
L	Real estate activities	2,095	1%	5,004	2%	106	1%	2%
M	Professional, scientific services	6,942	5%	7,817	3%	144	2%	4%
N	Administrative and support	12,179	9%	19,592	8%	617	7%	8%
O	Public administration	2,902	2%	635	0%	57	1%	1%
P	Education	3,111	2%	1,805	1%	98	1%	1%
Q	Human health	6,876	5%	4,258	2%	126	1%	3%
R	Arts, entertainment	692	0%	1,251	1%	52	1%	1%
S	Other services	1,409	1%	2,963	1%	92	1%	1%
	Sector not revealed	18,264	13%	19,150	8%	1,376	15%	10%
Commercial vehicles in all[1]		154,743		243,912		9,950		100%
Commercial vehicles per 1000 inhabitants		*27.62*		*43.4*		*1.8*		*75.34*

Source: Own calculations using data from Statistics Denmark.

[1]From Statistikbanken, possibly including vehicles not currently registered.

3.1 Travel distances of commercial vehicles

The analyses below will determine the distribution of average daily travel distance separately for passenger cars and LDVs for each economic sector. It is only possible to calculate an average daily travel distance over a long period. Hence, this data cannot show the daily variance in distances driven.

Due to the methodology of gathering information about travel patterns by reading the odometers the results for Denmark in Table 2 are based on average figures during a period up to four years calculated with 225 working days. The table shows the share of vehicles driving less than 50 and 100 km, respectively, the average travel distance and the number of observations the calculations are based on. For sectors with very few observations figures are excluded. Figure 1 is furthermore showing a more detailed distribution of travel distances for selected sectors.

Danish commercial passenger cars are driven longer on average (103 km per working day) than commercial vans and lorries (see Table 2). The shares driving less than 50 km (27%) and less than 100 km (59%) are both much higher than for vans and lorries. It is opposite to Germany too, where passenger vehicles are driven the least. In no sectors (except the small Other services (S)) passenger cars are driven less than the vans in the same sector. Most extreme is Transportation (H), in which the average distance is 338 km and only 12% of the cars are driven less than 100 km per day. Of the observations recorded in the sector, 69% stem from taxis and a further 15% from other personal transport with e.g. tourists. For these companies it is misleading to calculate distances based on 225 working days, as they are used all year round by several drivers. Hence, using this approach, the daily average is 313 km. Figure 1 shows a group of sectors in which the passenger cars have more or less the same mileage distribution. Passenger cars in Manufacturing (C) are driven more than this middle group. Passenger cars in Human health (Q) are driven less.

Table 2 Share of daily average mileage less than 50 km and 100 km and the number of vehicles included in the calculations for passenger cars, vans and lorries under 12 tons GVW by economic activity in Denmark in 2010

		Passenger cars				Vans 0-3.5 tons				Lorries 3.6-12 tons			
		< 50 km	<100 km	Mean km	Observations	< 50 km	<100 km	Mean km	Observations	< 50 km	<100 km	Mean km	Observations
A	Agriculture	26%	67%	87	913	35%	81%	71	8,595	50%	85%	62	1,182
B	Mining				20				147				31
C	Manufacturing	18%	52%	108	1,911	38%	75%	74	8,000	33%	58%	98	1,752
D	Electricity, gas				42	62%	90%	51	719	46%	88%	55	328
E	Water supply				64	46%	83%	62	552	25%	62%	88	755
F	Construction	23%	65%	91	1,382	37%	81%	69	34,106	43%	80%	67	4,712
G	Wholesale, retail trade	27%	71%	87	5,978	33%	73%	79	16,364	26%	52%	111	4,441
H	Transportation and storage	6%	12%	338	6,347	30%	63%	110	3,368	20%	40%	165	2,818
I	Accommodation	34%	73%	81	339	38%	79%	71	1,850				65
J	Information, communication	24%	60%	94	782	36%	77%	72	1,160	65%	78%	58	113
K	Financial, insurance activities	27%	75%	79	460	41%	78%	70	533				73
L	Real estate activities	36%	72%	81	700	42%	83%	65	2,642	53%	82%	61	245
M	Professional, scientific	27%	68%	84	1,727	37%	76%	74	3,209	50%	83%	60	321
N	Administrative, support	21%	64%	92	1,444	27%	71%	82	7,503	40%	74%	82	1,611
O	Public administration	35%	79%	76	1,560	52%	84%	60	381	60%	80%	98	155
P	Education	30%	58%	108	1,536	60%	91%	51	915	65%	93%	41	224
Q	Human health	39%	75%	74	2,609	54%	89%	55	1,939	57%	90%	49	348
R	Arts, entertainment	33%	73%	85	228	40%	80%	69	577	67%	94%	42	127
S	Other services	41%	84%	66	503	35%	75%	76	1,224	14%	33%	177	254
	Sector not revealed	34%	63%	114	17,005	41%	97%	66	18,491	47%	63%	105	4,599
	Total	27%	59%	103	45,550	45%	80%	70	112,275	38%	65%	85	24,154

Source: Own calculations on Statistics Denmark's Synsdata at the end of 2010 and several sources on sectors

The group of vehicles for which the sector could not be established has an unclear distribution. Some are driven very little while others are driven very much. It is our assumption that the group consists mainly of the self-employed with no employees so that the car is driven by the owner. The group with a high daily mileage is possibly dominated by self-employed taxi drivers.

The lorries with a GVW of up to 12 tonnes are driven more than the vans. They are mainly driven by professional drivers and a high share probably is driven on more than 225 days so that the share driving less than 100 km is a somewhat under-estimated. The distribution of daily mileage is quite different across the sectors, with Transportation (H) driving most (dominated by goods distribution), followed by Wholesale and trade (G), which also includes many lorries distributing goods to shops and private households. Lorries in Construction (F), Professional service (M) and the small Others services sector (S) are driven the least. As with passenger cars, there are two main groups of self-employed vehicle owners, one driving very little and one driving a lot.

The vans are driven the least. A smaller group of vans with a GVW of under 2 tonnes has a mileage distribution, which is not very sector-specific (see also Figure 1) even small vans in the Transportation sector (H) are driven at the average level. The average distribution of small vans is only a little different from larger vans. Of the vans between 2 and 3.5 tonnes, one sector (Transportation (H)) has a higher mileage than average and three groups have a lower average: Human health (Q), Construction (F) and the self-employed. Self-employed van owners probably consist of a high share of construction workers running their own businesses with private home renovation and repair. The shortest distances are driven in Human health (Q) with 65% driving less than 50 km and 90% driving less than 100 km. Around 37% of the big vans in Construction (F) and 45% of the self-employed are driven less than 50 km and more than 80% are driven less than 100 km.

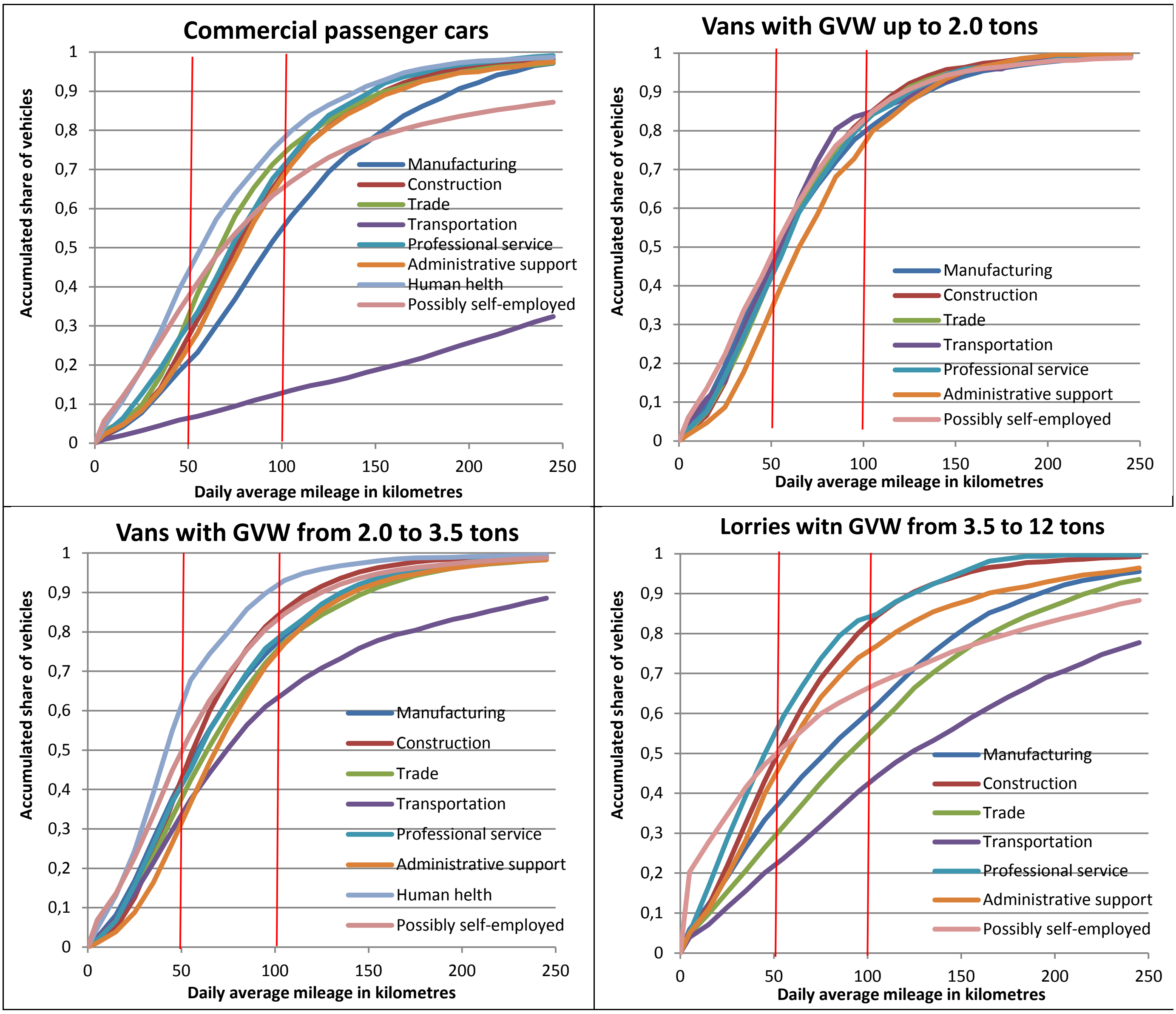

Figure 1: Accumulated average daily mileage by economic sector for passenger cars and vans of different size, Denmark

3.2 Inter-day variation of travel distances

Average figures as presented above are not fully useable for the assessment of the fleet's suitability for electric mobility. A shift to an EV is only of interest to a company if the car also covers days with longer distances than the average value. It is therefore the maximum mileage during a long period, which sets the threshold for the options. This subsection presents results from daily data analyses over a longer period, covering some weeks to half a year depending on the company.

Figure 2 illustrates some results from the two companies in the Construction sector (F), represented by two vans smaller than 2.0 tonnes and 12 vans of 3.5 tonnes, which were tracked for 4 and 6 months respectively. The two companies are located in the western suburbs of Copenhagen and serve a wide area in the region. On 68% of the working days of the analysed vans, the mileage is less than 100 km. On average, two of the vehicles are driven more than 100 km per day, and one close to 100 km. However, all the vans are driven more than 100 km in at least 10% of the analysed period, and several are driven longer on half of the days.

In both companies the employees use the van for commuting. Most of the employees live in a radius of 10-20 kilometres from their company, but two live much further away. Very often the employees drive directly from their home to the customers and most often they do not visit the company address more than a couple of times during the week.

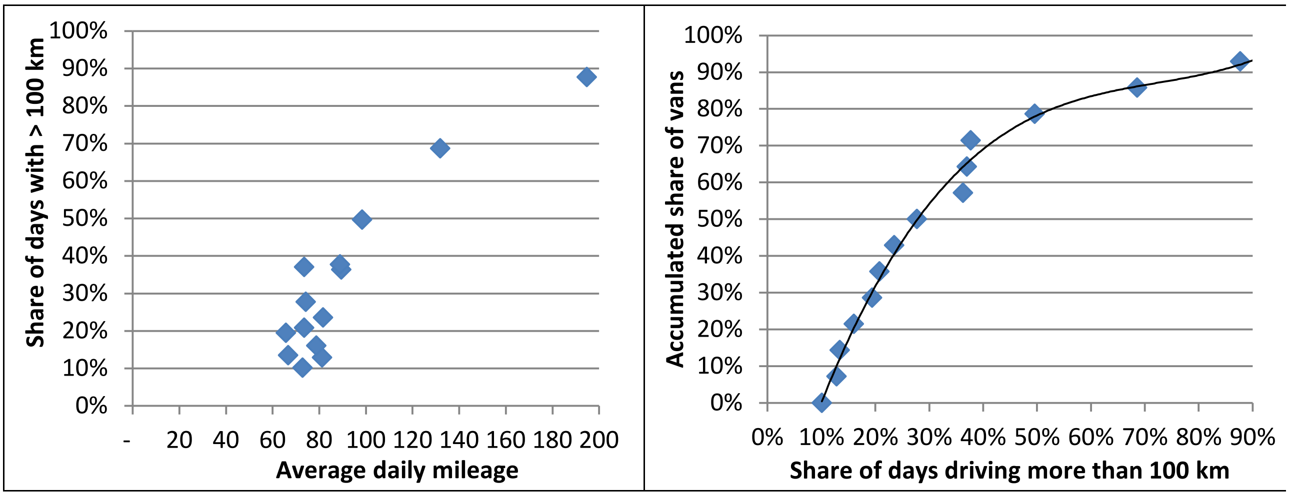

Figure 2 To the left the share of days the vans driving more than 100 km as a function of the average daily travel distance. To the right the share of vans driving longer than 100 km for a given share of the analysed period.

Furthermore, the pauses from work duties are typically too short for charging enough power to overcome the daily mileage if the vehicles were electric.

The chimney sweeper is located in the municipality of Copenhagen and has a licence to serve all houses in a certain area of the municipality. The small vans used by the company are parked at the company's address overnight. Two vans are followed during two and a half weeks each. The vans were driven 50-60 km on 40% of the days, less than that on a further 40%, and more on the remaining few days. Only one car was driven once more than 100 kilometres. It happens when it drove out of the district, probably to collect something from a supplier.

Figure 3 use the Synsdata to show the distribution of the average daily mileage of all vans from different sub-sectors of the Construction sector (F), similar to the analysis of all Danish vans in the above section. More than 70% of the vans owned by the companies in the traditional construction sector are driven less than 100 km per day, whereas only 15-20% are driven less than 50 kilometres in average. The travel pattern of the different sectors' vans seems to be quite similar. Other groups in Construction (F), such as building contractors of different kinds, drive a little longer (not shown). These results show that the two detailed analysed companies in construction drive a little longer than similar companies on average, probably due to a location in the Copenhagen region. On the other hand, the chimney sweeper might be more similar to companies serving a certain district for repair, homecare etc.

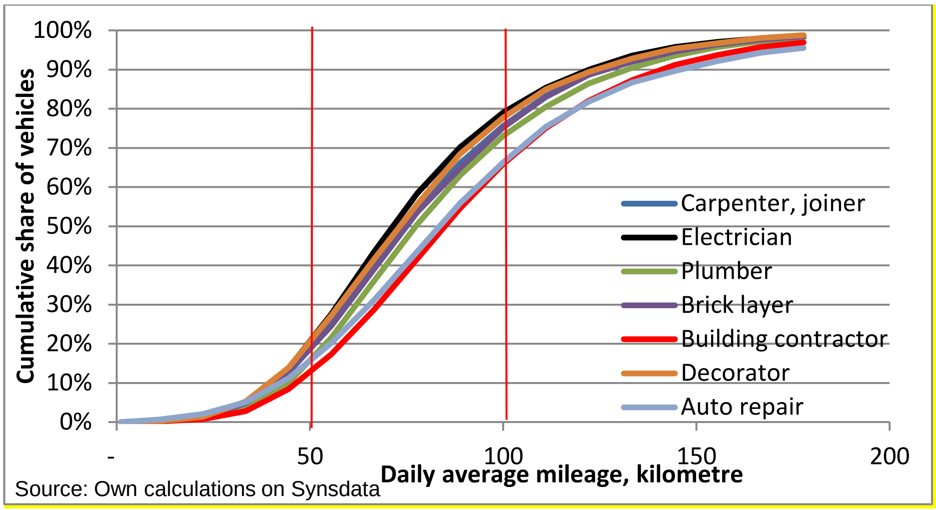

Figure 3 Daily mileage of vans by different professional groups in Denmark

The taxis' driving behaviour corresponds well with the rest of the sector as described above (the presented results are referred from the project report (Barfod et al., 2015)). Only in 10 to 23% of the days the taxis are driven less than 100 km. in 60 to 75% of the days the taxis are driven at least 150 km and in several days

more than 500 km. A few taxis – probably owners with no employees – have a daily mileage less than 100 km most of the days. Only on 7% of the days would taxis, which are driven during the summer period, be able to manage without charging during the day. The company driving during the winter period has no days where it would be able to manage without charging during the day.
For the nation-wide delivery service, only 7% of the vehicle-days are shorter than 100 km. On 83% of the days the trucks are driven more than 150 km, and on 25% even more than 500 km. The other delivery company drives less. However, this company leases their lorries from a transport company so that they can deliver in the morning. The rest of the days the lorries are probably used by others. But even in 'their' part of the vehicle-day, one third of the lorries are driven more than 100 km. Only the company with the short delivering period would manage without charging during the day with a shift to EVs.

4 Discussion

4.1 Results from the analyses

In terms of size of vehicle stock, overall mileage and average daily travel distances, vans in Construction (F) and passenger cars in Human health (Q) are most suitable for a shift to electric mobility. Vans from Human health (Q) might be relevant too. Commercial passenger cars – except for the Human health (Q) and a smaller share owned by self-employed without employees – are driven very far and only a few are suitable for electric mobility. Lorries over 3.5 tonnes GVW are not suitable either.

When only considering the average daily mileage, a little less than half of vans in the chosen sectors are driven less than 50 km per day and therefore suitable to be replaced by EVs. When including the inter-day variation in the daily mileage, the share which could be replaced is substantially lower. In most of the companies many cars exceed the current travel range of EVs - at least on some days during the analysed periods. Indeed, the analyses are far from being representative for the part of the commercial sectors, which are shown to be relevant for electric mobility. Consequently, the share of the vehicles, which can be replaced by an EV cannot be stated but it is clearly lower than half of the fleet.

The strength of the three-step methodology used here is that it is possible to point to sectors with a big potential for electric drive for each vehicle type. On the other hand, the weakness of the analyses of statistical data is that it does not show the daily variation in travel distances. This is well known for passenger cars and confirmed by the analyses in Section 3.2 for the analysed commercial fleets in specific companies too. The main difference seems to be between vehicles only driving in a predefined area or fixed daily routes and vehicles serving a large area with more random customers. The information based on average travel distances collected over one or more years does not reveal the variation in companies' behaviour. The analyses in Section 3.2 are not representative enough to indicate the size of the problem on a national scale.

4.2 Technical issues of importance for the deployment of commercial EVs

The current low deployment of EVs in general and in the commercial sector especially (see Section 1.1) might be due to both economic and practical reasons.

To overcome the problem with the daily variation in travel distance it might be a possibility to keep a few conventional cars in the fleet that can be used for extra-long trips. For vans serving a certain district, such as the chimney sweepers', and not being used for commuting it might be possible to organise which routes should be served by the EVs and which by a conventional car in case of a mixed fleet. For this purpose, a fleet managing system to optimise or at least organise the distribution of daily mileage on the vehicles in the fleet might be useful. Another option is to recharge the EVs during the day, either with a fast-charging facility en route – since the majority of the stops are too short to recharge with a substantial amount of kwh with a slow-charging facility – or by the customer during the course of their work, either on the customers' private premises or at a public charger close to them. None of the available options are optimal. Charging en route takes time from work and might only be an option during e.g. a lunch break. Only with a very dense charging network would a charging close to the customer be an option, and is therefore only relevant in dense city areas and in areas with dedicated charging poles. Charging at the location of the customers might be difficult in relation to billing in case of private households and small companies and an agreement needs to be made with the customer. At construction sites it might be included in a tender and therefore easier to handle.

Another technical restriction for commercial transport is the higher weight of the vehicles due to the battery weight. This additional weight can reduce the payload by 200 to 400 kilos. Especially vans with a GVW close to 3.5 tonnes are remarkably affected by the reduced payload. The advantage of these vans is that they can be driven with an ordinary passenger car licence (licence type B). For heavier vehicles a special truck driving licence is needed. In the Construction sector (H) some vehicles are used to carry relatively heavy materials (e.g. by masons) for which the payload is of significant importance. Others bring heavy tools or an entire workshop including heavy material (e.g. plumbers). However, most often the payload of the van is of minor importance. Especially in the parcel distribution sector most parcels are lightweight (e.g. 1-5 kg). Instead the volume of the car is of importance, resulting again in a van at 3.5 tonnes GVW. If batteries are added to the car, it cannot be driven with a type B licence. These big vans will therefore suffer from limited battery capacity and thereby shorter travel range than what is of interest to companies.
Since the beginning of 2015 a change in the German driving licence regulation allows persons with a driving licence class B to drive electric vans with GVW up to 4.25 tonnes (see Bundesministerium für Verkehr und digitale Infrastruktur, 2014). This initiative might be an important support to the use of electric vans in companies for which either weight or size of the van is of importance, because it makes it possible to add heavy batteries to the big vans close to 3.5 tonnes GVW and thereby increase the travel range. The new German rule is too new to evaluate if the change has attracted more companies to buy EVs.

4.3 The influence of economy and tax policy

In another part of the actual project the suitability for electromobility has been compared between Denmark and Germany (Christensen et al., n.d.). This shows a difference in the size of the commercial vehicle fleet and the mileage by different types of cars between Denmark and Germany. Germany has in 2010 85 commercial vehicles per 1000 inhabitants whereas Denmark has 75, but of these 52 are passenger cars in Germany and only 28 in Denmark. Contrary, 14 are vans in Germany versus 43 in Denmark. 50% of the commercial passenger cars in Germany drive less than 50 km per day while the same share is 27% in Denmark.

Furthermore, the analyses unveil that the share of vans suitable for transition in Denmark is lower than for Germany. In Germany 53% of the LDVs with pay load up to 3.5 toms drive less than 50 km whereas 45% of the vans up to 3.5 tons GVW in Denmark drive less than 50 km. LDVs with a pay load up to 3.5 tons are comparable with vans with a GVW up to 9-10 tons and therefor includes an unknown share of vans over 3.5 tons GVW of which only 38% in Denmark drive less than 50 km. A much higher share of the German LDV are therefore driven less than 50 km than the Danish LDVs.

We assess these differences mainly to be due to a very different structure of vehicle taxation. Danish passenger cars are 2-3 times more expensive than German ones due to high purchase tax and VAT. Vans are on the other hand subject to a lower purchase tax in Denmark compared to passenger cars. If the backseats are removed from passenger cars and a few other smaller adjustments are made, the car is considered a van with a lower purchase tax and a small annual fee for the allowance to drive privately too (Skatteministeriet, 2015d).

Furthermore, the rules for taxation of company passenger cars used by employees are not very favourable for the choice of EVs. The company is allowed to pay all maintenance and running cost for the employee, but, for the user of the company car, 25% of the value of the car up to €40,000 and 20% of the remaining value is treated as taxable income (Skatteministeriet, 2015a). On top of this, since 2010 an environmental fee has been added with the purpose of making it attractive to choose a low emission car. It is therefore often more attractive for employees who drive an average daily mileage for the company to use his/her own car and get a tax free reimbursement per documented kilometre for business trips, because the reimbursement equals the marginal cost of owning and using a small family car. In Germany a monthly rate of 1% of the value of a company car is treated as taxable income for private use of a free company car which equals only 12% of the value annually.

An effect of the rules is, as shown in Section 3.1, that commercial passenger cars in Denmark is the type of commercial vehicles with the highest daily average mileage. In Germany commercial passenger cars are driven less than vans.

The result of the generally extensive use of commercial passenger cars in Denmark is that they are most often not suitable for being replaced by electric vehicles. In cases where the company car is neither used for representative purposes nor privately, the company will often choose a van instead of the passenger car. Their use might rather be comparable with the passenger cars in Germany and therefore, a potentially attractive group for electric mobility in Denmark in line with the German passenger cars. This is probably the reason why small vans have the same mileage distribution, independent of the sector (see Figure 1)

Another taxation rule of importance for the differences between the two countries is that employees in Denmark who have a company van with a special adaptation (e.g. stalls for materials and tools) are allowed to use the van for their commuting trips without paying company-car tax for this if it is equipped for the commercial use (Skatteministeriet, 2015b). If they use it for further private transport, they have to pay a minor tax for the extra kilometres. The result is, as the example in Section 3.2 shows, that the construction workers and other engineers with changing customers from day to day often use the van for commuting instead of leaving it at the office/workshop. The result is that some of these vans have a high daily mileage and are therefore not suitable for electric mobility unless the companies' policy on the use of the vehicles for private commuting is changed.

An analysis based on more than 2,000 interviews with a representative sample of company owners in the two countries (and Austria) shows that the Danish owners are less willing to introducing EVs in their vehicle fleets than the Germans (and Austrians). The described difference between the taxation structure and the resulting behaviour in the two countries might be a part of the explanation of the different attitudes (Kaplan et. al., 2015).

Total Cost of Ownership (TCO) has been developed (COWI, 2014) to help people and companies assess if their travel pattern is attractive for shifting to an EV. By using the calculator it can be shown than an EV as the Nissan eV200 is approximately €6,500 more expensive than a similar ICE van when considering Danish registration taxes (without taxes and VAT, the EV is approximately €11,600 more expensive). In the case of leasing, the TCO is € 0.06 to € 0.15 higher per km by average use of the vehicles, ranging from 5-15,000 km per year. However, although the purchase price is higher, the TCO per kilometre decline when the EV is used more, since travel costs are lower than for conventional vehicles. Also, driving in urban conditions will favour EVs, since the energy use for conventional vehicles is relatively higher at lower speeds. Overall a shift to electric mobility might be economically more or less equal in big cities when considering the full costs. But, especially in the big cities, the driving pattern might be less attractive due to a dispersed localisation of customers and businesspeople. The paradox is therefore that, in situations where the electric vehicle should be economically attractive, the practical driving behaviour is a limitation instead.

5 Conclusions

The resulting overall mileage and variation of daily mileage showed that the Construction sector (F) and the Health care service sector are suitable for the use of electric vehicles given the present technological state of the art. Professional services (M) show a possible relevance too, but only for a low share of the vehicle stock.

The analysis of the travel patterns of vehicles by GPS tracking in the Construction sector (F) shows significant inter-day variations in travel distances, resulting in a share of days where the travel range is exceeded. Thus the share of vehicles, which could be replaced by electric vehicles is lower than the statistical results predicted. On the other hand, companies, which serve a defined small area and/or have fixed daily routes, could easily shift their fleet to EVs. Most of them would possibly need a few conventional cars to cover trips exceeding electric driving ranges. Companies with huge catchment areas are less suitable for the use of EVs.

The results regarding the Transportation sector (H) are ambiguous: A high share of companies travel long daily distances, as confirmed by the analysis of taxis and food distribution companies. Therefore, most of this sector is not suitable for electric mobility and fast charging will probably not solve the problem. On the other hand, the vans of some parcel distribution companies used for city logistics exhibit daily mileages mainly not exceeding electric driving ranges. Post Denmark therefore experiment with rebuilt electric vans for parcel distribution.

Analyses reveal that the share of vans suitable for transition in Denmark is lower than for Germany too. This is due to a Danish right for construction workers and entrepreneurs to commute with the company car without paying tax for a company car. When analysing commercial driving patterns in other countries, one should be aware of the consequences of a similar rule.

This paper suggests other countries should consider changing their driving licence regulations so that electric LDVs with a GVW up to 4.25 tonnes can be driven by type B driving-licence holders, as has been done in Germany. If this rule were adapted by many EU countries, the car manufacturers might have a greater interest in a market for large electric vans with battery packs of up to 500-700 kg. This could lead to a greater supply of different models with higher performance. However, the paradox of a van which can be driven the necessary kilometres possibly costing so much that the kilometre price is on a par with conventional vans might still be relevant.

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