Electric Mobility in Last Mile Distribution

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Abstract Electric mobility is a major development trend and future expectation for transport and logistics, especially in the first and last mile context of modern city logistics concepts. Nevertheless, logistics research has been dominantly engineering research in this field and aspects of cost and resource efficiency have been neglected so far. This contribution outlines a concept for a cost and sustainability evaluation regarding the use of electric vehicles in last mile distribution schemes and therefore provides a first insight into the application business value of electric mobility concepts for logistics. The results show that electric vehicles will provide no "one-size-fits-all" solution but are reasonable only in specific segments due to their maximum payload and range restrictions as well as still very high purchase price levels. Moreover, especially small and medium sized logistics companies will refrain from this trend due to high risks and fixed system costs within overall logistics processes as well as regarding training requirements.

Keywords Electric mobility · City logistics · Sustainable logistics · Cost and sustainability evaluation

1 Introduction

Electric vehicles are expected to play an important role in future mobility and transport concepts [1, 2]—due to long-term resource shortages as well as the negative effects of traffic greenhouse gas emissions such as carbon dioxide and methane. Because the expected effects of climate change and the global threat to ecosystems are in particular attributable to the emission sources like "private transport, transport processes" [3, p. 13] the caused harmful environmental

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processes must be reduced at least in their impact. Common rethinking in terms of developing environmental awareness and the realization that sustainable development only works with the conservation of ecosystems have already begun [4]. The focus on sustainable development motivates companies to integrate the increasing ecological demand in their service and product cycles. In particular the logistics industry, as a major issuer of greenhouse gas emissions in large quantities, has understood the requirements of "practical implementation guidelines of green business strategies" [5, pp. 41, 42] and hence satisfies the demands of their industry and retail customers. In the logistics industry environmentally friendly and resource-efficient business activities are increasingly gaining in importance [6]. One feasible measure implementing this sustainability strategy in logistics could be the commercial use of electric vehicles.

But today research regarding electric vehicles is mainly addressing engineering questions. Only a minority of publications addresses information, infrastructure and logistics questions related to the introduction of electric vehicles [7–12]. This research suggests an evaluation of the use of electric vehicles in last mile distribution concepts in terms of two important perspectives—sustainability and cost efficiency:

1. *Cost efficiency*: Recent research suggests that there are many areas in logistics companies and processes with heavy adaption requirements when electric vehicles shall be used in last mile distribution [13].
2. *Sustainability*: The major question if especially the carbon dioxide emissions are reduced with electric vehicles instead of diesel-engined trucks is hard to answer as the current electricity production mix has to be taken into account. This mixture is differing heavily from country to country (even among the different German states) and also will be undergoing heavy changes due to the exit in nuclear electricity production in Germany in the next years. This perspective has to calculate the bottom line of CO_2 emissions per ton-kilometer in last mile distribution of electric vehicles compared to diesel-engined vehicles.

In order to combine these two perspectives, a field study deploying last mile transportation systems is used to evaluate these perspectives with extensive process mapping and process cost evaluation efforts. As a result structure the matrix in Fig. 1 is suggested in order to enable further research and transfer options for these results.

The EU and NRW funded research project 'E-Route' evaluates the *practical implications of electric vehicles* in last mile distribution processes with the project partners FOM Hochschule, University of Duisburg-Essen, Deutsche Post Bonn and NOWEDA Essen.

In this research setup Sect. 2 describes the necessary and expected changes in logistics processes, using i.e. an AHP evaluation among logistics experts. Section 3 described a draft calculation regarding the subsequent cost implications of these changes towards electric mobility in logistics. Section 4 outlines the sustainability implications and Sect. 5 combines these evaluation perspectives in the proposed evaluation scheme. The conclusion in Sect. 6 provides some further research implications and an outlook.

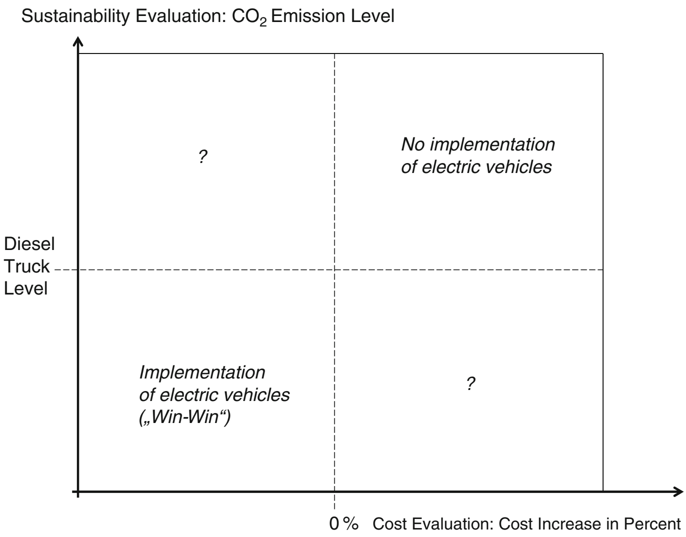

Fig. 1 Evaluation matrix for electric vehicles in last mile distribution

2 Logistics Process Changes

Currently logistics companies modernize their vehicle fleet. For example, the logistics service provider Deutsche Post DHL has expanded 10 % of its worldwide car pool to vehicles with innovative propulsion technologies. With regard to this, the use of electric vehicles (EV) plays a significant role [14].

A large number of challenges prevent a widespread use of EV in logistics today. For example the limited maximum range constrains the application fields, so that currently EV are only to be used for urban delivery trips. Especially in urban areas EV show a high potential in terms of an acceptable implementation of electric mobility [15]. According to this, the advantages of the EV are especially the noise-reduced and low emission transport. From today's perspective the use of EV, in particular when used in last mile traffic is reasonable and shall be scrutinized and implemented further.

To increase the use of EV, research efforts are driven in many ways, especially in engineering. In this field research is focused for example on the improvement of the battery technology for improving energy supply and increasing the range of the EV. From a business perspective the commercial launch and the use of the EV are prohibited by a lack of knowledge. Because of "limited resources" [16, p. 15] it is a challenge—particularly for small and medium-sized enterprises—to calculate the important operational adjustments and business investments necessary for electric mobility.

The objective is to investigate only the changes in costs and operational processes caused by the use of EV in last mile-distribution of logistic and trading companies.

The accomplishment is based on a simple-designed and practical investment analysis in terms of a comparative vehicle cost calculation. In the first step of this research the fundamental effects, concerning changes in costs, are shown by a comparison of a conventional diesel-engined vehicle versus EV. The second step indicates the specific cost changes for an exemplarily selected operational change area by using EV. This knowledge increases the transparency of costs for practitioners who seek an extension or conversion of the own fleet with EV.

In the course of first research activities operational change areas were identified and queried in an expert survey, using the method of Analytic Hierarchy Process (AHP). The analysis of the results showed that in particularly the core logistics processes like transportation and scheduling as well as transport goods and fleet management are relevant operational change areas by using EV. The high weighting of the operational change areas transportation and scheduling is caused by the restricted range of EV which requires an adjustment of the route and tour planning. The reason for the significance of transport goods is the limited payload of EV (Fig. 2).

Due to the different drive concepts arise, in the comparison of the two types of vehicles, significant differences in the payload. The EV is able to load 510 kg less than a comparable diesel-engined vehicle. To verify and extend the results of the expert survey, the processes of participating project partners were evaluated

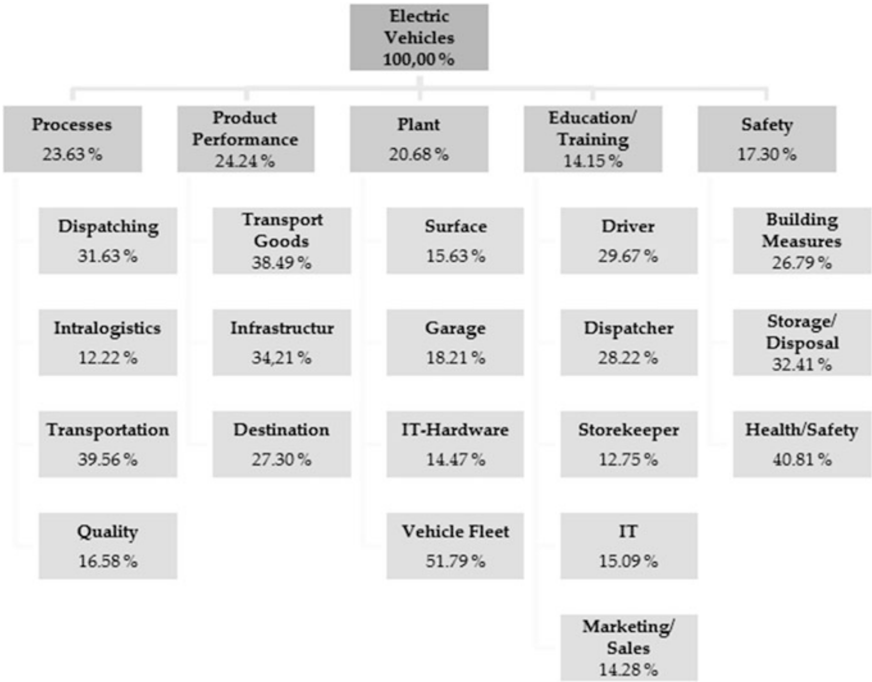

Fig. 2 Operational change areas: local weighting

further, with the goal to identify company-specific operational change areas by using EV. The findings of the affiliating processes complement the results of the expert survey with the AHP method.

3 Cost Implications

With regard to short-distance traffic in particular last mile-traffic, it is difficult to assign the costs to individual orders or shipments. The reason for this is the large number of different loading and unloading places. The transport costs for the forwarding services are therefore calculated at average costs based on a weight of 100 kg. Insofar the average costs for the price calculation per vehicle depend on the following facts:

- kilometre rate,
- daily rate,
- annual running performance,
- transported goods per account period [17].

The kilometre rate and the daily rate are due to the vehicle cost calculation. To calculate the kilometre rate different types of costs such as costs for fuel, tires or repair are used. These are costs that depend on usage. To determine the kilometre rate, the costs are divided by the annual running performance. The daily rate is calculated from the fixed costs, such as costs for drivers, vehicles and overhead, divided by the time. These costs arise in subject to the particular account period and are thus time-dependent [17]. To evaluate the cost effect of payload differences between diesel-engined-vehicles and EV, following assumptions were made in context of an exemplary calculation (Table 1).

For the diesel-engined-vehicles the assumptions in Table 1 base on technical data of a IVECO Daily and for the EV on technical data of the IVECO Daily Electric. The detailed calculation of the kilometre rate for both vehicles can be found in Table 2.

The purchase price of the vehicle as part of the depreciation is part of the annual vehicle cost accounting and is consulted to calculate the use- and time-dependent vehicle costs. With depreciation of light transport vehicles usually a high proportion of the time-dependent costs are applied. In this exemplary calculation

Table 1 Data for an exemplary vehicle cost calculation

	Diesel-engined vehicle	Electric vehicle
Purchase price	35,170 €	100,000 €
Running performance/day	80 km	80 km
Transported goods/day	800 kg	800 kg
Payload of the vehicle	Maximum 1.310 kg	Maximum 800 kg
Utilization/day	59 %	100 %

Table 2 Kilometre rate diesel-engined vehicle versus EV

	Diesel-engined vehicle Ct/km	EV Ct/km	Cost benefit (+) or cost disadvantage (−) for EV Ct/km
Depreciation	5.86	16.67	−10.81
Fuel costs	17.02	7.43	−9.59
Lubricant costs	0.17	0.00	−0.17
Tire costs	2.67	2.67	0.00
Maintenance costs	10.00	5.00	−5.00
Miscellaneous costs	0.50	0.50	0.00
Kilometre rate	**36.22**	**32.26**	**−3.95**

therefore 30 % of the annual depreciation amount is attributed to the usage-based vehicle costs and 70 % were assigned to the time-dependent vehicle costs. The usage-based vehicle costs are included in the calculation of the kilometre rate, the time-dependent vehicle costs are part of the daily rate.

To calculate the fuel costs, the expenses for diesel and electricity base on the specific average values of the year 2012. At that time the price for diesel was 147.8 Cent per litre and for electricity 14.02 Cent per kilowatt-hour [18, 19]. The costs for lubricants of diesel-engined-vehicles are recognized with 1 % of fuel the costs. Costs for lubricants will not be charged for EV, because this type of vehicle does not use lubricants [20, pp. 29–33]. The tire costs are taken into account with 400 € per tire and an annual running performance of 60,000 km for both vehicle types. In the example 20,000 km annual running performance is used as a basis for the exemplary calculation.

Hence one-third of the tire costs are recognized. For repair and maintenance for the diesel-engined vehicles 10 cents per kilometre are estimated. An electric engine consists of about 200 engine parts and has significantly fewer components than an internal combustion engine with more than 1,400 parts. Therefore, the EV is considerably less maintenance. For repair and maintenance 5 cents per kilometre are recognized for the EV. The miscellaneous costs are equal for both vehicles.

The higher daily rate for EV is based in particular on the higher purchase price. In addition to this it is believed that the use of EV needs higher qualified personnel, especially for driving activities as well as for planning and scheduling. So for EV higher costs for drivers and commercial personnel will be accepted. To calculate the cost effects of the payload differences, the vehicle costs per 100 kg of a diesel-engined-vehicle and an EV is first calculated (Tables 3 and 4).

At a touring range of 80 km and a shipping weight of 800 kg, a cost difference stems from the previous exemplary calculations, compared between a diesel-engined vehicle and an EV. In comparison the EV is per tour 3.11 € more expensive than the diesel-engined vehicle (Table 5). The utilization of the EV here is 100 %. The utilization of the diesel-engined vehicle is 59 %. With a full utilization of diesel-engined vehicle is resulted in a cost difference of 12.89 € per tour.

With regard to the expert survey of operational changes the criterion transport goods, as a subcriterion of product performance has been identified as particularly

Table 3 Costs per tour per 100 kg of a diesel-engined vehicle

Vehicle costs	Calculation	Vehicle costs/tour/100 kg
Kilometre-based costs	80 km/tour × 0,3622 €/km = 28,98 €/tour	(28,98 €/tour: 1.310 kg) × 100 kg = 2,21 €/100 kg
Time-based costs	172 €	(172 € × 1.310 kg): 100 = 13,13 €/100 kg

Table 4 Costs per tour per 100 kg of an EV

Vehicle costs	Calculation	Vehicle costs/tour/100 kg
Kilometre-based costs	80 km/tour × 0,3226 €/km = 25,81 €/tour	25,81 €/tour: 800 kg) × 100 kg = 3,23 €/100 kg
Time-based costs	200 €	(200 € × 800 kg): 100 = 25,00 €/100 kg

Table 5 Comparison of costs between EV and diesel-engined vehicle

	EV	Diesel-engined vehicle	
	Transport weights per tour		
	800 kg	1.310 kg	**800 kg**
Kilometre-based costs per tour	3.23 €	2.21 €	3.62 €
Time-based costs per tour	25.00 €	13.13 €	21.50 €
Total costs per tour	**28.23 €**	15.34 €	**25.12 €**
Utilization	**100 %**	100 %	**~59 %**

relevant for use of EV. Due to the limited payload of the EV for these vehicles a potential cost disadvantage is resulted. Firstly there is a risk of a constraint service due to the limited payload. Thus, transport goods with a high specific weight are less suitable for transportation by EV. Secondly, the higher transport costs have a negative impact on operating profit.

In the exemplary cost account the largest identified cost factor is the depreciation which base on the purchase price and which are used to calculate the kilometre rate. Half of the purchase price of the EV consists of costs for the batteries. In addition to that EV are produced in small series. With increasing mass production, as well as product and process innovations plus economies of scale, there is the possibility of reducing costs of the EV [21]. In terms of decreasing purchasing costs, the costs for depreciation will be reduced. In this way, the negative effect of the limited payload of EV is alleviated and the cost gap between diesel-engined vehicles and EV is smaller.

For further evaluation of cost implications the following distribution of last mile delivery tours compiled by logistics experts from the research project E-Route will be used, dividing the tours into distinctive distance and weight classes (distribution matrix in percent, Fig. 3). This is highly relevant as EV have only limited payload and rang capabilities—with major impacts on the logistics cost structures as shown above.

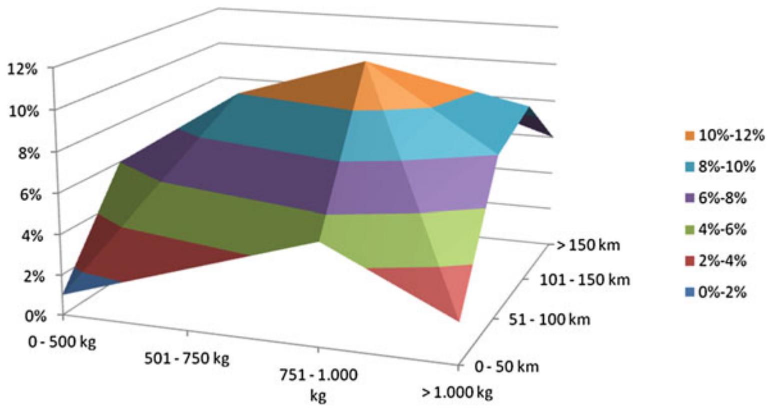

Fig. 3 Expert estimate distance-weight-matrix classification for last mile tours

4 Sustainability Implications

Measuring carbon dioxide emissions for electric vehicles is extremely difficult and has so far only achieved in research for cars (in comparison to diesel an hybrid cars for example, leaving electric vehicles with a slightly better sustainability balance sheet based on the current electricity production mix in Germany). The major problems regarding this evaluation are:

- The electricity production mix based on different energy sources (renewable, gas, oil, nuclear) is highly influencing the overall sustainability evaluation of electric mobility—whereas in countries with "clean" energy sources as for example Norway with 100 % water-based electricity production also electric cars and trucks are a green mode of transport, in countries with an electricity production scheme based on gas or coal the carbon dioxide emissions caused finally also by EV are higher multiple times;
- The inclusion of infrastructure implications on the sustainability evaluation are still an open research question—with the major assumption in question the probability of electric supply infrastructures to be additional or replacing the existing diesel and gasoline supply infrastructure;
- Due to restricted payloads and ranges, EV may induce more traffic and require a larger number of trucks to be used to transport the same amount of goods—where it is still unclear how to include this into CO_2 and sustainability evaluations.

Therefore it has to be assumed in line with previous publications that a comprehensive sustainability evaluation for electric mobility in last mile distribution can only be reached through a comprehensive evaluation in combination with the overall electricity production and distribution system, depending heavily on national and regional power and utility policies [22].

5 Comprehensive Evaluation

Figure 4 provides the overall comprehensive evaluation of application fields of electric vehicles in last mile logistics concepts.

The results outlined above show cost as well as sustainability evaluations regarding electric mobility in last mile distribution to be heavily dependent on the questions of average tour payload as well as average tour length: For higher payloads and longer tours, electric vehicles are up to 90 % more cost-intensive and even not feasible for tour lengths above 100 km on average (box A).

Two further insights have been (1) the facts of a hard (i.e. variable) sustainability evaluation due to the dependency of electric vehicles of the factual electricity production mix—which varies strongly in different regions and with different suppliers. If a completely green electricity production from renewable sources is assumed, EV may reach better sustainability evaluations. But as for example coal-fired plants are used in electricity production, EV may even have higher CO_2 emissions than existing diesel-engined vehicles in a comprehensive well-to-wheel-calculation (box B). (2) Second it has also become obvious in the process evaluations of the research project, that energy-intensive last mile transport tasks as e.g. temperature-controlled environments (pharmaceuticals, food) are unfeasible for electric transport as the additional energy for heating or cooling cannot be taken from the electric power system due to battery restrictions. This implies that secondary systems (also for cabin heating in winter times) are necessary today, inducing further cost burdens on EV for such applications (box C).

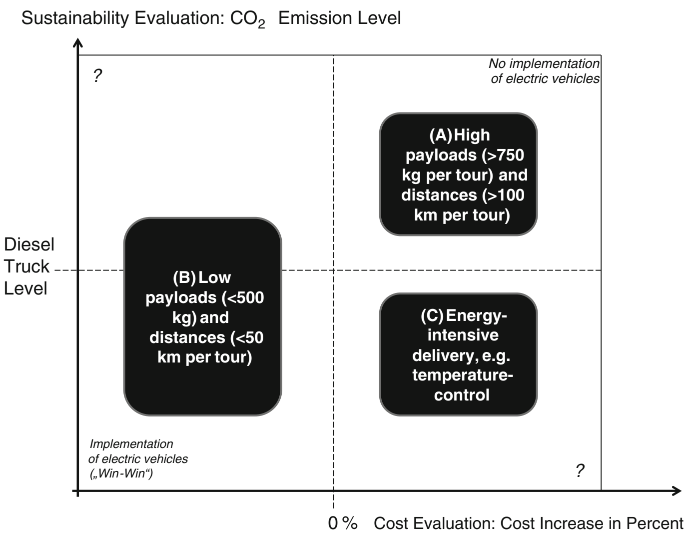

Fig. 4 Comprehensive evaluation scheme for last mile distribution

6 Conclusions

This research evaluation scheme for electric mobility in last mile distribution has shown the general feasibility as well as the necessary process changes in logistics for the changeover to electric vehicles. Besides the detailed cost implications mainly caused on a long-term basis by the still lower payload and the higher purchase price levels, cost increases have to be expected in general, varying strongly depending on product weights to be carried on last mile tours.

Furthermore, it is already obvious that electric vehicles will provide only niche solutions even in the narrow field of city and last mile distribution logistics as for example for energy-intensive areas such as temperature-controlled transports electric vehicles are not feasible.

Finally, further research is necessary especially on the question of sustainability as the overly evaluation in this regard depends on the applied electricity mix (production scheme), which is varying heavily depending on region and electricity provider, a general evaluation of electric mobility is hardly possible with the information and research methods of today.

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