COST-BASED METHOD TO ESTIMATE ELECTRIFICATION POTENTIAL OF THE GERMAN ROAD FREIGHT TRANSPORT

Maybritt Schillinger[1], Michel Allekotte[2] and Julius Jöhrens[3]

[1, 2, 3] *Institut für Energie- und Umweltforschung, Heidelberg, Germany*

Abstract. We present an approach to analyse the potential of battery electric trucks (BEV) in Germany by investigating which truck usage pattern can be run by BEV profitably. The approach is based on a country-wide traffic model that specifies truck traffic volumes on relations, i.e. pairs of locations in Germany between which trucks travel. For each relation, we compare the total cost of ownership per kilometre of BEV and conventional diesel vehicles operating on that relation. The key unknown parameters per relation are annual mileage per truck and time delay costs due to charging for BEV with different battery sizes. Hence, we develop a method for estimating the annual mileage from the distance of the relation and a model to compute the time delay for different battery sizes.

1 Introduction and research question

Germany's transport sector accounts for 20% of CO_2 emissions in the country [1]. Despite of the climate targets to reduce its emissions by about 40% they have been constant or even rising during the past years [2]. To meet the ambitious goals in the future, a lot of weight is given to electric mobility. Since commercial vehicles are responsible for more than a third of the emissions in the transport sector [3], they will have to contribute significantly towards the climate goals. The German government seeks to decarbonize one third of the German heavy-duty vehicle fleet until 2030 [4].

In our study, we aim to analyse the application potential of battery electric trucks (BEV) in Germany. The main research question is which truck usage patterns can be run by BEV in a cost-competitive way, considering certain boundary conditions of truck operation. From this consideration, we expect to assess the potential for electrification of road freight transportation in Germany. Our approach is based on a Germany-wide traffic model and a total cost of ownership (TCO) calculation for different usage profiles. In this paper, we outline the challenges that arise when combining the data with the calculation scheme.

It is important to note that the presented approach does not seek to precisely "reconstruct" particular usage patterns of individual vehicles. This would not be possible due to inherent uncertainties in traffic models. In fact, the goal is to establish an electrification potential on a macroscopic scale, abstracting from certain (local) peculiarities of freight transport applications.

2 Methods

As a traffic model, we use PTV Validate [5]. It yields truck traffic volumes in all of Germany for individual relations. One relation is a pair of locations between which trucks travel. The number of trucks of a given vehicle class on a relation per day (and year) is known to us as well as the relation's total distance in kilometres, the trip duration and the percentage of road types (motorways, extra-urban, urban) used.
We develop a framework to compare the TCO per kilometre of internal combustion engine vehicles (ICEV) and BEV, for one particular truck operating on a specific relation, respectively. An overview of the TCO comparison is given in Figure 1. It shows the two steps required for the comparison: Based on evaluating the characteristics of each relation, cost values per km are determined for both ICEV and BEV trucks. Table 1 shows the different types of costs considered.

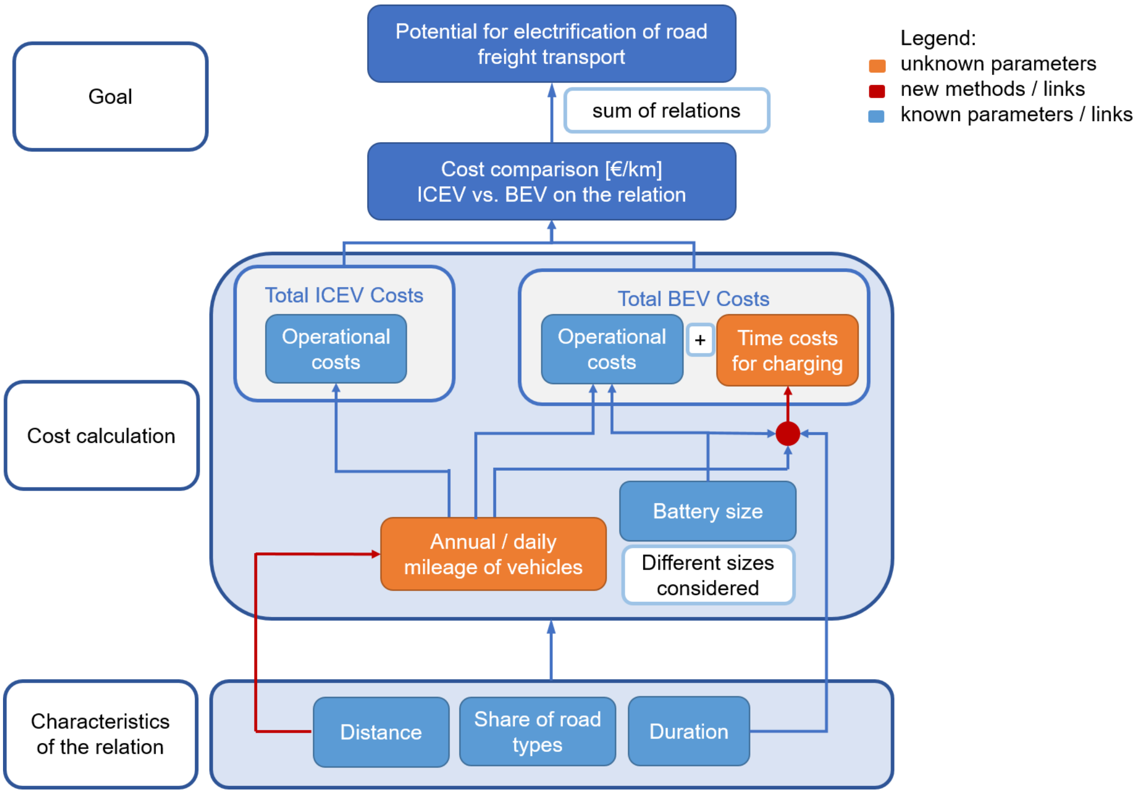

Figure 1. Overview of methods: In order to determine the potential for BEV, a cost calculation framework is developed. The relation data forms the basis of the approach.

Table 1. Types of costs in TCO calculation

Cost	Unit	Components
Vehicle costs	[€]	Vehicle purchase, battery replacement, financing
Fixed annual costs	[€/a]	Insurance, tax, maintenance
Variable costs per kilometre for each road type	[€/km]	Wheels, lubricants, AdBlue, toll
Energy costs per kilometre for each road type	[€/km]	Diesel or electricity
Time delay costs	[€/km]	Costs for time delay due to charging

The variable and energy costs are easy to compare for BEV and ICEV. The first challenge arises when considering the vehicle and fixed costs: In order to break those down to a value in €/km, the annual mileage for trucks operating on specific relations is required. However, our data is relation-specific and gives no detailed information on statistics for individual trucks.

To solve this problem, we derive the annual (and daily) mileage of trucks on a relation from statistics by the KBA [6] and TREMOD [7] depending on the relation length. The statistic indicates the annual mileage per size and distance class. Additionally, TREMOD is used in order to take the total vehicle stock and mileage of heavy duty vehicles in Germany into consideration. Specific functions are estimated for different size classes, as illustrated in Figure 2.

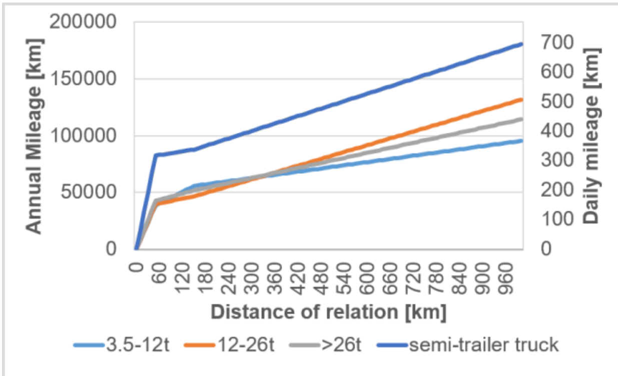

Figure 2. Annual and daily mileage in dependence of the relation's distance

This is a model assumption and the result will not exactly match particular usage patterns in reality. However, it enables us to extend the relation data such that it can serve as a base for certain macroscopic analyses.

The value for the annual mileage then allows to transfer the vehicle costs and annual fixed costs to a relation-specific cost value in €/km. The daily mileage is calculated from the annual mileage assuming 260 working days per year.

Furthermore, for BEV, the size of the battery is a key parameter in the cost analysis. On the one hand, larger batteries imply higher purchase costs and higher energy consumptions. On the other hand, small batteries could mean that the capacity is not sufficient for the usage profile.

To address this trade-off, we consider a set of several possible battery sizes. We do not consider a "hard" limitation of the range of the vehicle is not sufficient to drive the entire relation at once. Instead, we assume that recharging at charging stations along the way is possible. However, this will obviously cause a time delay, implying further costs. To quantify this time delay for a specific truck, we built a simple model for which key parameters are summarized in Table 2.

Table 2. Parameters relevant for time delay computation

Parameter	Assumption
Battery size	Various possible sizes considered
Energy consumption	Depends on battery size, vehicle class, payload and relation
Power of charging station	200 kW (in our example)
Charging possibility	Full charge overnight + recharge opportunities along the way
Maximum driving period without breaks	4:30 h (set by German legislation)
Duration of break after driving period	45 min (set by German legislation)
Time costs per hour of delay	Average driver's wage per hour (here 17 €/h assumed)

Figure 3 visualizes the possible cases during the trip: (1) If the legal driving period is over, we presume the driver can stop at a charging station and use the break time for charging without accumulating delay. (2) If the battery is depleted, the truck has to stop specifically for charging and accumulates time delay, but this time also counts towards the driver's break time. (3) Once the relation is finished, the truck possibly recharges at the destination and continues its daily trip, where a similar calculation is done. The length of the remaining trip is derived from the method mentioned above.

The time delay is calculated for several battery sizes and for each relation separately. To include the time delay into the TCO model, the time value has to be monetized. For a first exemplary analysis, we set the drivers wage as the only cost.

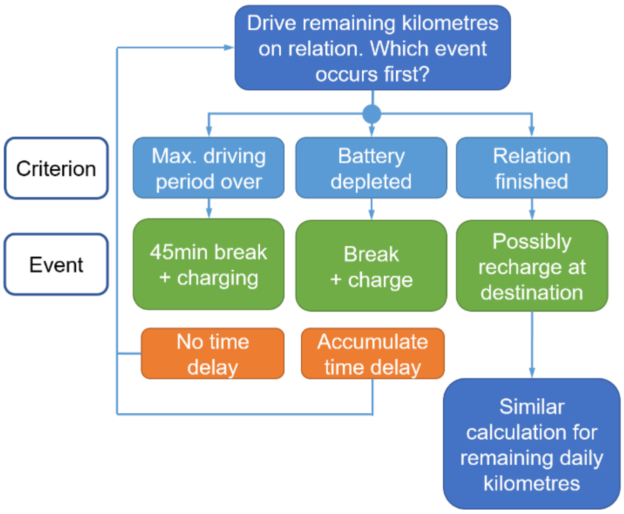

Figure 3. Visualisation of cases in time delay computation

3 Example calculation

To illustrate the described method, we consider a (fictive) example relation for vehicles of size class 12-18t in 2030 between Munich and Frankfurt, as shown in Table 3.

Table 3. Characteristics of example relation

Parameter	
Start	Munich
End	Frankfurt
Length	392 km; 1,3% urban, 2,7% rural, 96% motorway
Duration	5 h + 45 min break
Size class	12-18t
Year	2030

We look at BEV with four different battery sizes: 100, 200, 300 and 400 kWh. Each of them will need to stop for recharging along the way. The results of the time delay calculation are presented in Figure 4. For BEV 400, the mandatory driving break is enough to recharge and no time delay is accumulated, whereas the other vehicles need stops exclusively for charging.

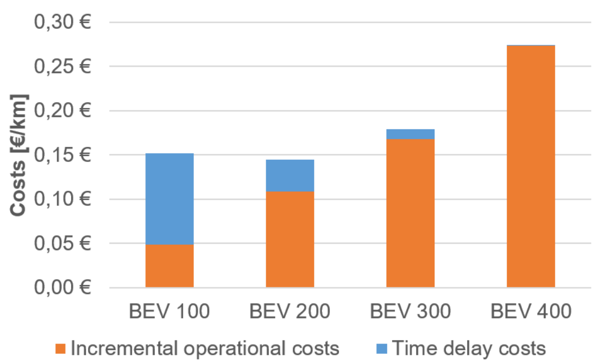

Figure 4. Incremental costs of BEV compared to ICEV. Main cost assumptions: energy consumption: BEV: 1.01-1.19 kWh/km; ICEV: 0.18 l/km; vehicle price: BEV: 140-

185 k€, ICEV: 78 k€; energy price: electricity: 0.17 €/kWh, Diesel: 1.22 €/l

Without taking into account costs for time delay, the larger the battery size, the more expensive a BEV is (orange bars). Including costs for time delay (blue bars), however, BEV 100 and BEV 200 are almost equal and turn out to be the least-cost battery sizes on this relation. Which one of these configurations is chosen would probably depend on further suitability parameters not included in the TCO calculation, such as a limitation in transport time. Figure 5 shows the time delay on the relation.

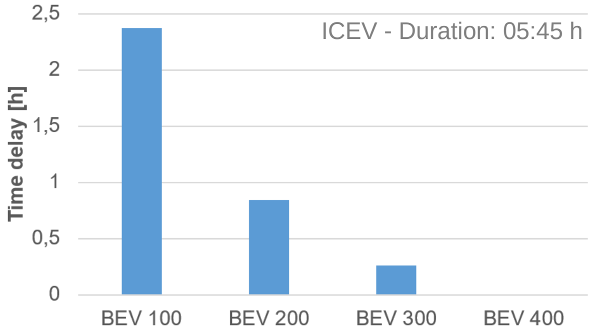

Figure 5. Time delay costs of BEV for different battery sizes. The mandatory break which all vehicles have to take is not included in the time delay.

At the conference, we will present an application of the described methodology to a larger set of relations.

4 Outlook

So far, we have only covered monetary aspects. However, in reality, many other conditions will influence whether a truck owner is willing to switch to an electric vehicle. These include e.g. availability of vehicles and infrastructure, confidence in the technology and predictability of framing conditions such as public subsidies. We will take those into account in the next steps of our work. Further, we plan to extend the methodology to not only consider BEV and diesel trucks, but also hybrid trucks with overhead catenary power supply and hydrogen vehicles. Moreover, based on our results on the potential BEV trucks driving each relation, we will derive charging infrastructure demands. We are confident that this will ultimately enhance the understanding of an efficient BEV truck introduction and facilitate the design of beneficial framing conditions.

References

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