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Developing a Roadmap for the Introduction of Overhead catenary trucks in Germany

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Summary

Electric road systems for trucks have become a focus of recent research activities. The presented research describes a methodology to identify and prioritize suitable roads for introduction of an electric road system for heavy-duty vehicles. The methodology follows a total cost of ownership approach from a freight forwarders perspective. For each vehicle usage profile, the viability of electric drive is assessed and an optimized infrastructure expansion is calculated accordingly. We apply the methodology to the introduction phase of an overhead catenary system on German highways and exemplarily look at possible effects of a toll exemption for electric trucks.

Keywords: deployment, freight transport, heavy-duty, modelling, optimization

1 Introduction

Continuously growing volumes of road freight transport today are almost exclusively handled with diesel vehicles. This is a huge challenge for meeting the climate protection goals. One possibility alternative is the introduction of "overhead contact line hybrid trucks" (overhead catenary [OC] trucks). In electrical operation, catenary trucks draw their traction energy from a two-pole overhead line system. This enables an extremely efficient use of electrical energy and great potential for reducing GHG emissions when renewable electricity is used. Technical limitations of electric mobility such as battery storage (energy density, charging capacity, weight) can thus be circumvented. On the other hand, necessary infrastructural requirements are considerable and depend on political action to overcome the “chicken-or-egg” dilemma.

In this paper, we first describe some prerequisites for an advantageous use of OC trucks in an early phase of system introduction. We then use these to locate promising areas of application for OC trucks geographically by means of a traffic model. On this basis, a methodology for prioritization of OC infrastructure rollout in Germany on the way to a basic network shall be established in a systematic way. The analysis is carried out for the case study of Germany. The results shown in this paper are selected in order to demonstrate useful applications of the developed methodology rather than to derive particular recommendations.

2 Methodology

2.1 Focus of the analyses

In road freight transport, especially heavy trucks are responsible for a large proportion of CO_2 emissions. Here, alternative drive concepts can make a significant contribution to achieving climate protection targets. The articulated truck is particularly suitable for the implementation of alternative operating concepts, as only a small part of the entire vehicle population is affected (in Germany about 7 %), but it is responsible for almost 30 % of the mileage and more than 45 % of the greenhouse gases emitted in German road freight transport. For this reason, semitrailers are the focus of this paper. In addition, from the operator's point of view, the semitrailer truck with the separation of tractor and load carrier has clear advantages over the truck tractor and rigid truck, which concern, among other things, vehicle dynamics and manoeuvring, but also transhipment and route planning [1].

Furthermore, the scope of the analyses is narrowed down by the suitability of concrete transport relations for electrification by catenary line based on logistical criteria. The journeys taking place on the relations can therefore be examined with regard to their suitability for implementation of catenary lines. The suitability can be partly determined by the type of goods transported or at least correlates with it. Six criteria were identified and examined in more detail:

- Logistics submarket function: High share of goods in the planned and system-affine logistics submarkets. Examples of these submarkets are generally cargo transport, consumer goods distribution, contract logistics, CEP logistics and partly FTL transport.
- Logistics location function: High share of goods groups in the shuttle traffic-savvy warehouse and location types, e.g. import gateways, production logistics, network logistics
- Rail affinity: low share of freight groups in existing rail traffic
- Seasonality: minor sector fluctuations in the production and business cycle index during the year
- Price sensitivity: Low logistics share of total revenues
- End-customer affinity: High share of private consumption in the sector

In order to be able to take these criteria into account when selecting route sections suitable for OC trucks, the groups of goods stored in the traffic model were examined to see to what extent the individual criteria were fulfilled by the corresponding group of goods. The details of this process are described in [2]. In particular, agriculture and forestry products, energy sources and mining products show a particularly low affinity index and have been excluded from the following analysis.

2.2 TCO approach

An important prerequisite for the success of OC truck technology is its cost-effectiveness. This is analysed in the present paper from the point of view of the operator (forwarder, self-employed driver, etc.), since it is assumed that the infrastructure will be publicly financed in an early phase and that its costs will not be passed on to the vehicle operators in this early phase. In this context a profitable operation of the catenary truck means that the total costs associated with procurement, depreciation, operation and maintenance of the OC vehicle are lower than the costs of a comparable conventional truck.

The considered "Total Cost of Ownership" (TCO) is calculated for semitrailer tractors. The model is variable in time, i.e. both a starting year (year of commissioning of the vehicle) and a time horizon of operation must be defined. The time of operation is relevant because many boundary conditions, such as energy prices, vehicle costs or energy efficiency of the vehicles, change over time. Only monetary aspects are taken into account, while other aspects such as liquidity, risks or flexibility of use are not considered. Only payment flows are taken into account, whereby future payments are not discounted due to the short holding period of the vehicle. All payments are exclusive of value-added tax and are standardised as real figures for the year 2017. The relevant costs can be roughly divided into four categories: Vehicle costs, annual fixed costs (excl. vehicle), energy costs and variable costs (excl. energy). Detailed documentation on the cost assumptions can be found in [2].

Vehicle costs are calculated on the assumption that the vehicle is purchased at the beginning of its service life and sold again after a holding period of 5 years. The vehicle is financed by an annuity loan with an effective interest rate of 4.5 %. The real purchase price of the OC tractor unit is given as a function of the electrical power and the battery capacity, whereby economies of scale are assumed for 2030.

The residual value of the vehicle is calculated as a percentage of the purchase price and in the simplified model only depends on the mileage of the tractor unit within the operating period. The residual value of the catenary truck is derived from conventional tractors. The same percentage depreciation is assumed for both technologies. The fixed costs are independent of the mileage and are calculated on an annual basis. They consist of motor vehicle tax, insurance, storage/garage, fleet management and inspection fees.

The variable costs relate exclusively to the mileage of the vehicle in kilometres and consist of lubricants, urea, tyres, repair/maintenance/care, toll and driver. Although highly relevant for freight forwarding operations, driver costs are not taken into account in the calculation, as no difference is assumed between the two technologies. Tire, lubricant, repair, maintenance and servicing costs show no or only marginal differences. In the cost calculation, the option for further analysis is given. For example, a toll reduction for catenary trucks can be defined depending on the type of road (electrified, not electrified), as we will see in the result section.

Energy costs depend on diesel and electricity prices as well as efficiency and are considered separately from other variable costs. While the conventional vehicle is operated exclusively with diesel, it is also relevant for the catenary truck whether a stretch of road is electrified and thus whether traction can take place with electricity from the grid. In addition to this distinction, the road category is also important, as the consumption of a vehicle depends considerably on the type of road. The model simply distinguishes between highways without catenary lines, highways with catenary lines and secondary roads. Figure 1 shows the difference in variable and fixed costs of an OC truck compared to a conventional truck. The values do not include the energy costs and possible subsidies. The variable costs of an OC truck are higher because of the higher purchase price of OC trucks (cost difference: 67,000 € in 2020 and 38,000 € in 2030) and the resulting higher loss in value. The fixed costs are higher due to higher financing cost.

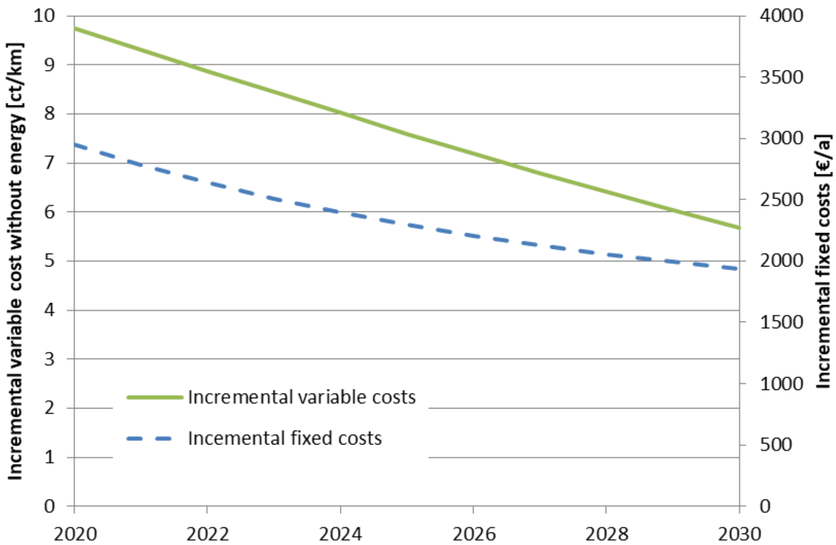

Figure 1: Difference in variable and fixed costs between OC truck and conventional truck

2.3 Trip data and simulation

For the analysis we use data from PTV Validate , which is a Germany-wide road transport demand model with consideration of the European reference [3]. Traffic volumes and traffic flows are mapped separately for cars and trucks. Thus, analyses can also be carried out for subareas/regions and individual route sections. The PTV Validate model spatially differentiates the traffic demand into more than 10,000 traffic zones on approx. 5.6 million individual routes (using the continuously updated HERE navigation networks) and maps approx. 120 million daily journeys. The traffic zones are oriented towards administrative borders and are connected to the route network via an average of four to eight connections. A comprehensive set of structural data is processed in the model, which includes not only residents but also schools and workplaces. In freight transport, the interrelationships are based on the basic data of the Federal Motor Transport Authority, supplemented by local differentiation with regard to the volume and production focal points. Another important comparison is the freight group-specific information from the Transport interconnectivity forecast 2030 by the German Federal Ministry of Transport and Digital Infrastructure [4].

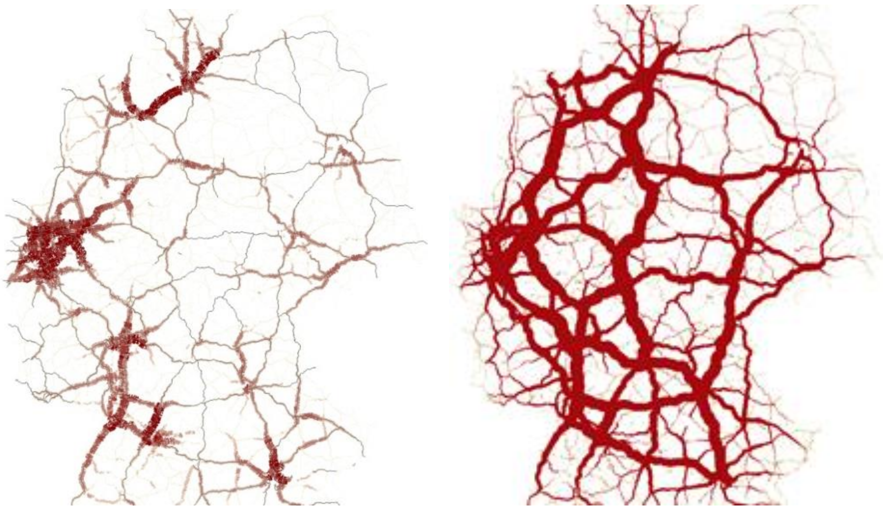

Figure 2: Traffic volumes of economically feasible trips for OC semi trucks on the German road network for pilot phase (~2020, left) and network phase (~2030, right)

Prior to the further analyses, we filtered the truck trips in VALIDATE (forecast 2030) according to the criteria described in Section 2.1 and 2.2. For details regarding the filtering criteria and process please refer to [2]. The resulting traffic volumes are shown in *Figure 2*.

For the resulting trips, we use the vehicle simulation model VEHMOD to determine the route-specific final energy consumption for catenary trucks and conventional diesel trucks. VEHMOD is based on a forward simulation of different drive configurations of passenger cars and trucks and can process any driving cycle as input variable. Nominal data for power or torque at the corresponding speed are used to generate generic efficiency maps for diesel engines, electric motors and electric generators. These maps are used to calculate the current consumption or energy flow to and from the battery depending on the driving condition. Topographical route characteristics as well as auxiliary consumption of the vehicles are also taken into account.

2.4 Optimisation

The basic idea is to first identify routes on which vehicles might have the biggest financial advantage (in terms of total cost of ownership – TCO) from the technology shift. On this basis, we select motorway sections with high utilisation by these vehicles for electrification. The vehicles with their respective TCO and the motorway sections with their infrastructure status constitute the input for a linear optimization problem. *Figure 3* illustrates the optimisation process and the data pre-processing, i.e. the steps chosen in order to estimate the coefficients needed to formulate the linear optimization problem. These steps are explained in the following section.

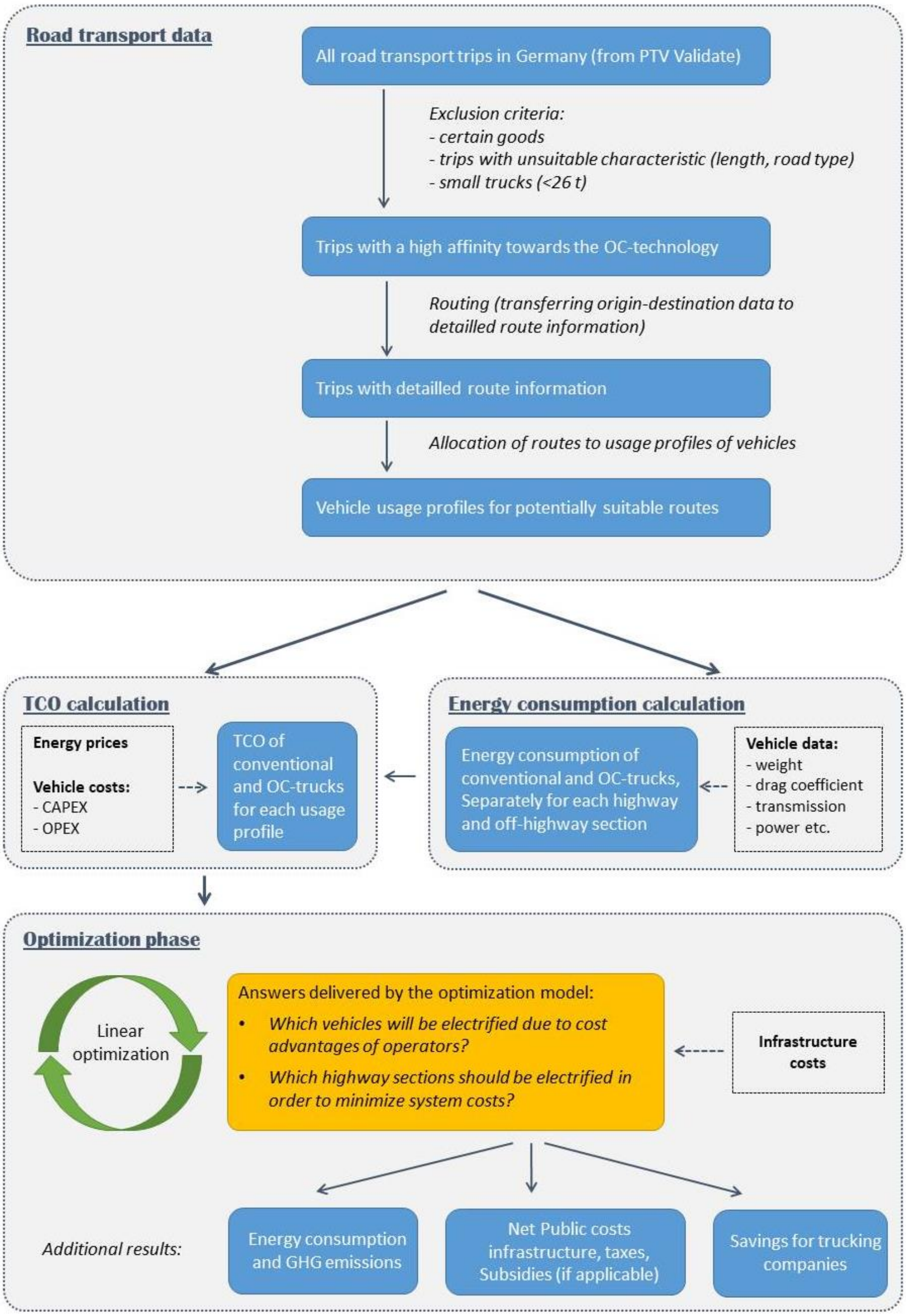

Figure 3: Methodology of calculating a cost-efficient roll out scenario for ERS using linear programming

For the optimisation linear programming is used. Formally, linear programming is a technique for the optimization of an objective function, subject to equality and inequality constraints. This means a mathematical formulation of the system parameter that shall be maximised or minimized, while simultaneously maintaining certain boundary conditions. The coefficients of the objective function and constraints are in the presented model mainly given by the traffic flow and the OC system's costs (vehicles and infrastructure). Based on these input data a linear integer optimization is used to find a sequence of infrastructure deployment within the considered timeframe which yields minimum overall system costs (=

sum of trucking company costs and infrastructure costs). If the electrification of a specific highway section costs less than the savings resulting from the shift to OC-technology of trucks operating on this section, this section is selected for electrification. The model is built to encompass defined years e.g. infrastructure development until 2030 or more. This means that segments where electrification is not viable by itself might nevertheless be electrified if this pays off in the future when the whole infrastructure network is considered.

The objective function is the minimisation of the total costs, including the fixed and variable costs of the trucking firms and the infrastructural costs for construction and maintenance. The trucking firms' costs are defined as differential costs between an OC truck and a conventional truck. In the model all costs are given in equivalent annual cost. Thus, investment costs are allocated to the technology's life span. The costs and savings of the vehicles are defined as the cost difference between an OC truck and a conventional truck on the given route. The objective function is thus given by:

$$\min\{\sum_{i,t} v_{i,t} \cdot \mathrm{n}_{\mathrm{i,t}} \cdot \left(\Delta \mathrm{k}_{\mathrm{i,t}}^{\mathrm{veh,fix}} + \Delta \mathrm{k}_{\mathrm{i,t}}^{\mathrm{veh,off-highway}}\right) \rightarrow \text{differential fixed vehicle and off highway cost}$$

$$+\sum_{i,j,t} e_{i,j,t} \cdot \mathrm{n}_{\mathrm{i,t}} \cdot \Delta \mathrm{k}_{\mathrm{i,j,t}}^{\mathrm{veh,var,el}} \rightarrow \text{differential variable cost on electric highway}$$

$$+\sum_{i,j,t} d_{i,j,t} \cdot \mathrm{n}_{\mathrm{i,t}} \cdot \Delta \mathrm{k}_{\mathrm{i,j,t}}^{\mathrm{veh,var,d}} \rightarrow \text{differential variable cost on not electrified highway}$$

$$+\sum_{j,t} s_{j,t} \cdot \mathrm{k}_{\mathrm{j,t}}^{\mathrm{inf}}\} \rightarrow \text{variable and fixed infrastructure cost}$$

The italic letters symbolize the result variables that are calculated in the model. The constants are input parameters and are calculated prior to the optimization for each vehicle (Δk^{veh}) and road segment (k^{inf}) respectively based on sub-models for infrastructural costs and the vehicle's TCO. The following table indicates the used variables, indices and constants.

	Variables
$v_{i,t}$	Indicates if OC trucks are used on the trip *i* in the year *t* (0-conventional, 1-OC)
$e_{i,j,t}$	Indicates if OC trucks are running on electricity on the trip *i* and section *j* in the year *t* (0-no, 1-yes)
$d_{i,j,t}$	Indicates if OC-trucks are running on Diesel on the trip *i* and section *j* in the year *t* (0-no, 1-yes)
$s_{j,t}$	Indicates if the highway section *j* is electrified in the year *t* (0-no, 1-yes)
	Constants
$\mathrm{n}_{i,t}$	Number of trucks operating on the trip *i* in the year *t*
$\Delta \mathrm{k}_{\mathrm{i,t}}^{\mathrm{veh,fix}}$	Annual fixed vehicle costs (difference between OC and conventional truck) on the trip *i* in the year *t*
$\Delta \mathrm{k}_{\mathrm{i,t}}^{\mathrm{veh,off-highway}}$	Annual variable vehicle costs (difference between OC and conventional truck) on the trip *i* in the year *t* off the highway sections
$\Delta \mathrm{k}_{\mathrm{i,j,t}}^{\mathrm{veh,var,el}}$	Annual variable vehicle costs (difference between OC and conventional truck) on the trip *i* and the section *j* in the year *t*, if the OC truck is running on electricity
$\Delta \mathrm{k}_{\mathrm{i,j,t}}^{\mathrm{veh,var,d}}$	Annual variable vehicle costs (difference between OC and conventional truck) on the trip *i* and the section *j* in the year *t*, if the OC truck is running on Diesel
$\mathrm{k}_{\mathrm{i,t}}^{\mathrm{inf}}$	Equivalent annual cost of infrastructure of the section *j* in the year *t*

Several constraints are applied to the model. Some of these constitute an inherent part of the problem definition:

$I)\ 0 \leq v_{i,t}, e_{i,j,t}, d_{i,j,t}, s_{j,t} \leq 1\ \forall\ i, j, t$

→ All variables are binary.

$II)\ e_{i,j,t} + d_{i,j,t} = \mathrm{f}_{\mathrm{i,j,t}} \cdot v_{i,t} \forall\ i, j, t$ with $\mathrm{f}_{\mathrm{i,j,t}} \in [0,1]$

→ If OC trucks are used ($v_{i,t}$=1) on the trip *i* and in the year *t* the trucks must run either on electricity ($e_{i,j,t}$) or Diesel ($d_{i,j,t}$). The parameter f represents if trip *i* is via section *j* in the year *t*.

$III)\ v_{i,t} \leq 1\ \forall\ i, t$

→ If $v_{i,t}$=0 a conventional truck is used on trip *i* in the year *t*. If the variable is 1 an OC truck is used.

$IV)\ e_{i,j,t} \leq s_{j,t}\ \forall\ i, j, t$

→ Electric drive is only valid on electrified highway sections.

$V)\ s_{j,t} \leq s_{j,t+1}\ \forall\ j, t$

→ Once a road segment is electrified, the infrastructure remains there for future years.

Additional constraints may be defined by the political framework. For example, a cap for CO_2 emissions for heavy-duty-vehicles can be easily integrated into the model. Also, feasibility considerations and infrastructural bottlenecks can be implemented by using constraints, such as a maximum annual infrastructure deployment.

3 Results

While the underlying project "Roadmap OH-Lkw" is still in progress, we will show two first exemplary calculations here. The results give some evidence as to where building up OC infrastructure might be appropriate. However, the final results of the project might differ significantly from the results presented in this paper since important assumptions (e.g. infrastructure and vehicle costs) are still subject to discussion. Besides, we currently improve the model in order to enhance its performance and capability to deal with more granular input parameters.

The following parameters and settings form the basis for the calculations shown here:

- We look only at the introduction phase of an OC system. We assume this phase to take about 10 years.
- We assume that OC system introduction starts in 2020. Thus, the input parameters (e.g. costs, prices and fuel efficiency) pose estimations for the period 2020-2030. Nevertheless, the initial deployment might start later than 2020, shifting the considered timeframe to the future. In order to account for a postponed start of system introduction, the input parameters would have to be adapted accordingly.
- Our assumptions for the energy prices are depicted in Figure *4*. The electricity price is on the level of industry rates in Germany and it's increase is moderate.
- We consider that the yearly expansion of OC infrastructure will be limited during the introduction phase by constraints like planning times, availability of building contractors and the allocated budget (see Figure *4*, right). Until 2022, we assume a pre-commercial phase where further technical experiences are expected. In the end of this phase, a political decision might be taken to start a commercial infrastructure rollout. The yearly expansion goes up then and further increases year by year as the market and confidence among the stakeholders grow.

- Currently, electric trucks benefit from a toll exemption on German federal highways [5]. However, the German government will reconsider this toll exemption periodically. Therefore, we will show two scenarios:
    i. First scenario: OC trucks have to pay the same toll as conventional trucks
    ii. Second scenario: OC trucks are exempted from the toll when operating on electric highways. For operation on non-electrified stretches, toll has still to be paid.

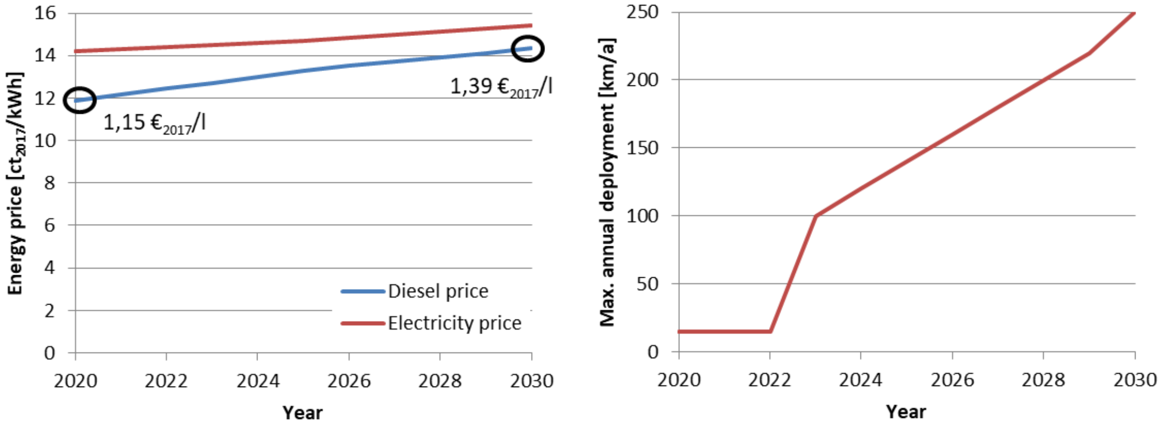

Figure 4: Assumptions regarding energy prices and maximum annual infrastructure deployment

We integrate the above-mentioned restriction regarding the maximum infrastructure deployment per year by using the following inequality as a constraint in the optimization model and apply it to both scenarios:

$$\sum_{j}(s_{j,t} - s_{j,t-1}) \cdot \mathrm{l_j} \leq \mathrm{MaxDepl_t}\ \forall\, t$$

3.1 Scenario 1: Regular toll for OC trucks

The optimisation yields the following infrastructure deployment for the scenario without toll exemption (*Figure 5*). In this scenario, the initial hotspots of the OC technology are on the axis Lübeck-Hamburg-Bremen-Hannover. Here, OC trucks might be profitable already with a small infrastructure extension of less than 150 km. In order to establish a network which attracts more than the few early adopters, the expansion could spread out to Hannover and further towards the "Ruhrgebiet" (Dortmund) and Magdeburg. Sequentially the grid extends towards Frankfurt and a separate part of the network starts to spread beginning in the region of Karlsruhe.

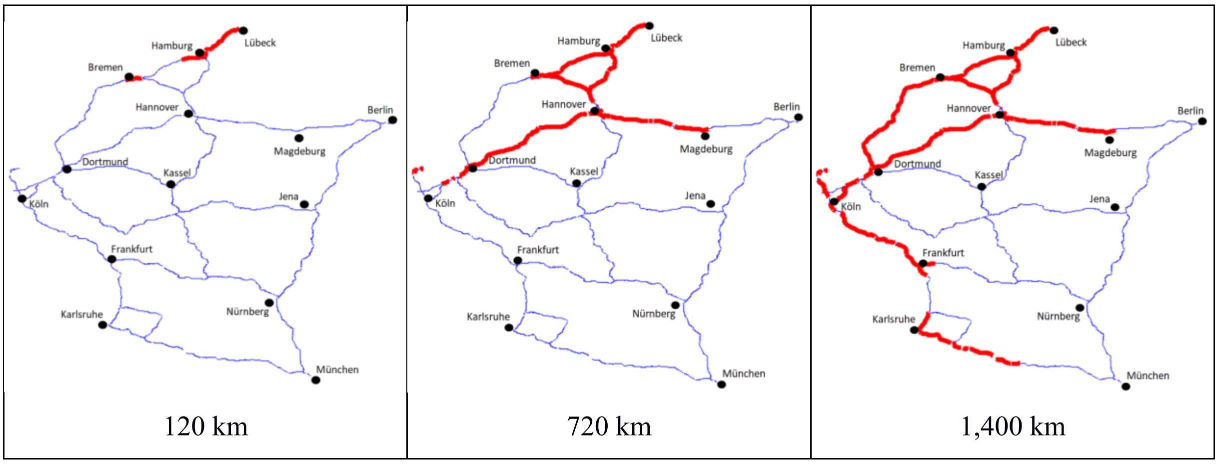

Figure 5: Optimization results for infrastructure deployment in Scenario 1 (toll for all trucks)

Additionally, the model estimates the total direct GHG emissions and the direct subsidies and reduced fiscal income. Hereby, the CAPEX of the infrastructure is about 1.5 million €/km and the OPEX 29,000 €/km/a [6]. Energy taxes on Diesel and electricity as well as the toll are kept constant on the current rates. The emissions and the costs are compared to a business-as-usual (BAU) scenario in which only conventional tractors are used.

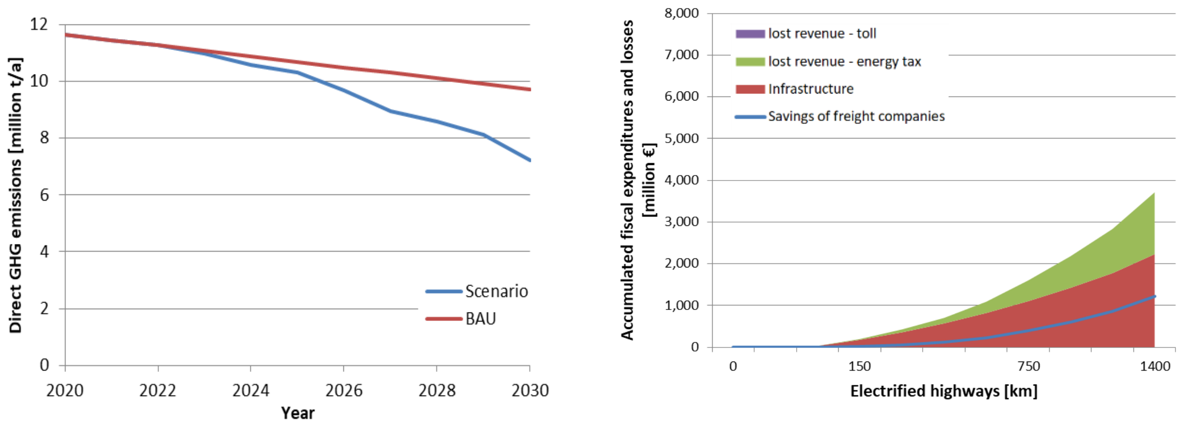

Figure 6: Direct CO_2 emissions compared to the BAU scenario and exemplar y accumulated savings of freight companies and fiscal expenditures and losses for various grid lengths

The mitigated CO_2 emissions add up to 8.7 million tonnes over the considered period if emissions from electricity production are not taken into account. The dominant costs in the initial phase are the expenses for infrastructure deployment. Until a grid deployment of 150 km more than 90 % of the fiscal's costs arise from the infrastructure. If the grid is extended up to 750 km the mileage of OC trucks increases significantly. At that stage almost 13,000 OC trucks are in duty. As consequence, the losses due to lower energy tax income increase. With 1,400 km of the highways electrified, 40 % of public expenditures are due to energy tax losses. In the period considered the state has direct investment costs and indirect losses of approx. 3.5 billion €. Freight companies benefit from the lower energy costs. The savings add up to 1.2 billion €. In the end of the considered period, 59,700 OC trucks are operating.

3.2 Scenario 2: Toll exemption for OC trucks

In case of a toll exemption for OC trucks on electric highways, we observe a shift of electrification priority from the North-West axis to the centre axis via Kassel (see Figure 7). In this calculation, motorways A7 between Hannover and Würzburg and A44 (Kassel-Ruhrgebiet) are preferred to the A1 between Bremen and Ruhrgebiet. The residual network stays roughly the same. The CO_2 emissions, costs and savings are given in Figure 8. The mitigated CO_2 emissions add up to 11.9 million t. In the period considered the state has direct investment costs and indirect losses of approx. 7.5 billion €.

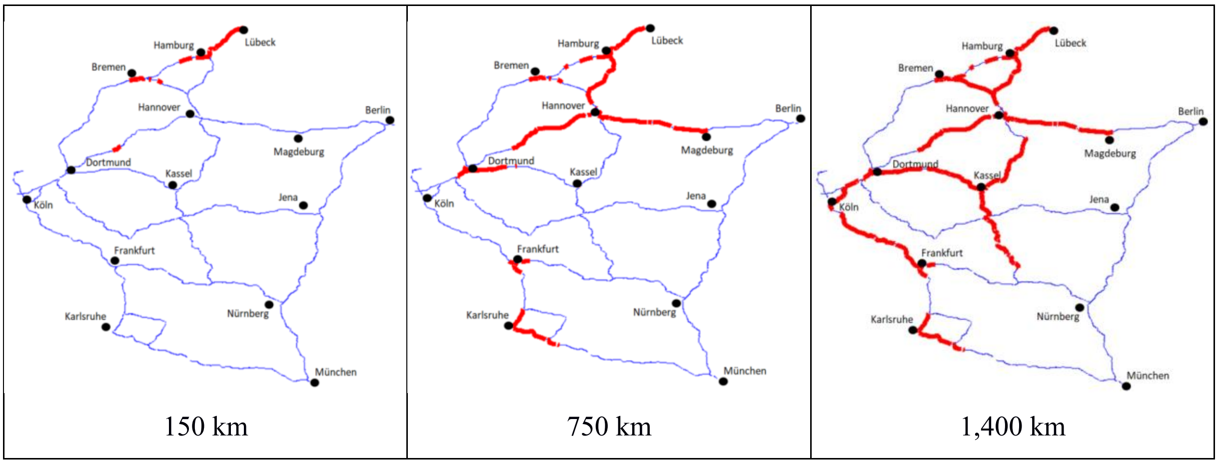

Figure 7: Optimization results for infrastructure deployment in Scenario 2 (toll exemption for OC trucks on electrified highways)

In scenario 2 the infrastructure has a share of 80 % of total cost until a grid deployment of 150 km. In the following years the mileage of OC trucks increases. Thus, less energy taxes are payed. Additionally, the state's income from toll decreases. The share of infrastructure on the total fiscal cost decreases to 38 % for an OC infrastructure length of 750 km. As soon as 1,400 km of the highways are electrified, the share is only 29 %. In the full period the state's cost are 7.5 billion €. Freight companies save 4 billion € compared to the BAU scenario. The total number of OC trucks is at the end 104,700.

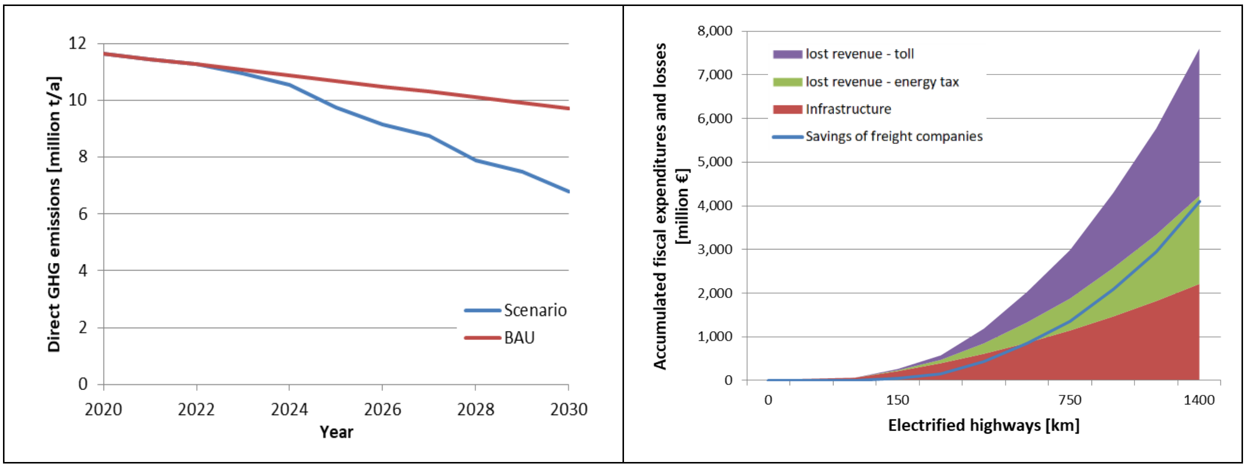

Figure 8: Direct GHG emissions compared to the BAU scenario and exemplary accumulated savings of freight companies and fiscal expenditures and losses for various grid lengths

3.3 Discussion of the Scenarios

If we assume a toll exemption for OC, the resulting network generally becomes more scattered. An exemption makes operation of electric vehicles more attractive also with comparably short electrified highway stretches. This results in a more distinct correlation between the total traffic flow on a given highway segment and its electrification. On the other hand, if no toll exemption is in place, only OC vehicles with a high share of electric drive will have a cost advantage for the operators. This implies longer contiguous sections with OC infrastructure. Consequently, the share of electric drive in scenario 1 (68 %) is distinctly higher than in scenario 2 (54 %). Although, the OC trucks are running more on electricity in the first scenario the number of OC trucks in operation is higher in the toll free scenario. Thus, the total mileage of OC trucks is in the toll free scenario with 9.3 billion km higher than 5.4 billion km resulting in the first scenario.

The number of OC trucks in operation at the end of the considered period is significantly lower if OC trucks have to pay the regular toll (59,700 OC trucks compared 104,700 OC trucks in the case of toll exemption on electrified stretches). However, the additional OC trucks in scenario 2 due to toll exemption yield a significantly lower CO_2 mitigation per vehicle with only a reduction of 27 % in total emissions compared to scenario 1 (see Figure *9*). On the other hand, the public costs are about twice as high for scenario 2. This is an indication that the cost-effectiveness of a toll exemption should be carefully analysed when deciding over its future application.

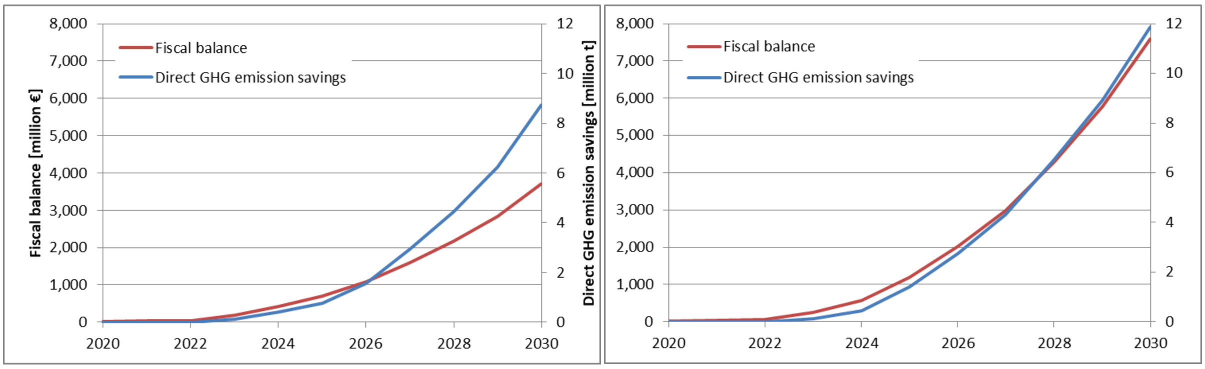

Figure 9: Direct CO2 emissions and net fiscal balance for both scenarios

4 Conclusions

We developed an optimisation model in order to identify possible rollout scenarios for road electrification with overhead catenary lines in Germany. Then, we used this model to compare two scenarios that differ with regard to the toll for OC trucks on electric highways. Although the results concerning the prioritization of specific highway sections vary in some details between both scenarios, we observe a tendency of road electrification in the North-West. If freight companies do not have to contribute to infrastructure cost, the use of OC trucks might be profitable already on a small grid.

The results indicate that toll exemption for OC trucks is an effective measure to achieve a fast market diffusion of OC trucks. However, this involves considerable indirect costs for the state due to a lower income from toll. Additionally, a high share of OC trucks causes a reduction in Diesel consumption and thus a lower state income from energy taxes. Both indirect costs might exceed the infrastructural investment costs and must be taken into account for political measures. In the long run, energy taxation should be designed in a way that sustains public revenues and poses enduring incentives for energy efficiency.

Besides, the calculations show that the political framework – here the toll exemption – might affect the prioritization of a cost optimal infrastructure deployment. Consequently, fiscal incentives need to match with the decision when and where highway sections should be electrified. Besides the toll exemption, we will continue to analyse further policy variables such as electricity pricing, subsidies for vehicle purchase and vehicle taxation. Furthermore, we will address the question when and to what extent vehicle operators can contribute to infrastructure funding.

Beyond that, the optimization can help to answer further questions:

- How much electricity is needed and where does the demand occur?
- Which impact does the increase in electricity demand have on the power grid?
- When is the breakeven reached at which the system is profitable without subsidies?

Overall, the approach is very versatile and may be applied to a wide number of questions. The results can of course only be as good as the underlying data. Particularly regarding the traffic flows, it has to be noted that these are in turn a model output (from PTV Validate) and have some known limitations. However, it is principally possible to integrate additional data for the traffic flows (e.g. floating car data) which will be a part of future work.

Acknowledgments

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Julius Jöhrens studied physics and political science at the University of Jena. Since 2010 he has been working at ifeu in the Transport and Environment department. He manages various projects in the field of alternative drive technologies, electricity-generated fuels and energy efficiency in transport. His focus lies on the analysis and simulation of usage profiles in order to assess feasibility of electric drivetrains for passenger as well as commercial vehicles.

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Jan Kräck, B. Eng. for Renewable Energy Technologies, has been working in the "Transport and Environment" department at ifeu since 2014. His work focuses on the alternative drive train technologies with an emphasis on the technological and environmental aspects of electric mobility, the modeling of motor vehicles and the analysis of mobility data. He is currently involved in the modeling and simulation of (partially) electrified trucks as well as truck fleets.

Hinrich Helms studied geography at the University of Heidelberg. Since 2002, he has been a research assistant and senior scientist of the "Transport and Environment" department at ifeu. He has carried out and managed numerous research projects on environmental impacts of transport and suitable measures (climate protection, air pollution). The main focus is on work in the field of environmental implications of different drive technologies for electromobility. On the basis of the life-cycle assessment model "eLCAr", generic drive technologies are compared.

Volker Waßmuth graduated from the University of Darmstadt with a Diploma in Civil Engineering. With respect to his ensuing scientific work at the Institute for Transportation Studies, he received a PhD in Civil Engineering/ Transportation from the University of Karlsruhe in 2001. That year, he entered PTV as transportation planner and today he is heading the Transport Planning & Traffic Engineering Business Unit of the PTV Transport Consult GmbH. He has collected experience in demand modelling, integrated transportation planning, traffic engineering as well as urban and spatial planning.