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Overhead catenary vehicles in south-west Germany? A regional catenary vehicle network and its implications for electricity demand.

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Summary

The introduction of heavy-duty overhead catenary vehicles in the state of Baden-Württemberg in south-west Germany could have a noteworthy impact on the energy system. We elaborate when, where and how much additional energy is required, based on four levels of market diffusion. Roads to be electrified are selected based on the traffic volume. Hourly resolved traffic flows allow electric load analysis. In an ambitious market diffusion scenario, there is an 8% increase of the electricity demand. In two counties, Pforzheim and Baden-Baden, the total electricity demand increases by more than 30%. The average load increases by 650 MW but the highest hourly peak annually is even 3.5 times higher.

1 Introduction and Research Questions

A deep decarbonisation of the transport sector is one pillar to reach decarbonisation targets. Meanwhile, the transport sector is the only one, which did not reduce greenhouse gas emissions significantly in Germany since 1990. Today, about 20% of greenhouse gas emissions in Germany come from transport [1]. Approximately one quarter of them are from heavy-duty vehicles with a gross vehicle weight above 3.5 t (HDV) [2]. While there are several solutions for passenger cars, for heavy road transport no clear solution exists.

Germany is presently funding the construction and operation of three catenary HDV test tracks on public roads in Germany. One project for overhead catenary (OC) energy supply for HDV with a total length of four km (one direction) will be built in the state of Baden-Württemberg in south-west Germany until 2021. The switch to an electric heavy road transport could result in remarkable changes in the energy system [3]. Therefore, possible effects of an overhead catenary system in Baden-Württemberg on the energy system shall be investigated in the present paper. More specifically, we design a potential future catenary network and analyse three research question: When will the vehicles charge? Where will they charge? How much will they charge? [4]

In this paper, we will present possible implications of an overhead catenary system in Baden-Württemberg on the energy system, using real-world driving data from road traffic census.

2 Methodology

In the first part of this chapter, we give a short description of the data, used in the modelling. In the second part, we describe our methodological approach.

Data

The publicly available data from the road traffic census BW 2018 [5] forms the underlying database. In the census, all national and federal highways are split into 1202 sections. For each section, the average daily traffic (ADT) in several vehicle categories is available. For our calculation, we focus on HDV with a gross vehicle weight above 3.5 t. Moreover, the hourly data of the German-wide automated census of 2018 [6] is used for temporal resolution.

To calculate the electricity and power demand, we use the parameters in Table 1.

Attribute	Abbr.	Unit	Value
Electricity demand per vehicle	E_v	kWh/km	1.5
Power demand per vehicle	P_v	kW	120
Average speed of a vehicle	v	km/h	80

Table 1: Technical parameters based on [7]

Methodology

We use a four-step approach to investigate possible implications of OC vehicles on the energy system.

First, we determine where to build an OC system. In order to cover a growing OC system, four expansion steps are investigated. We start with a minimum network (210 km) of the most frequented highways between the major industrial cities in BW (Stuttgart, Karlsruhe, Mannheim, Heilbronn). Each of the following stages gradually adds the most trafficked routes that are directly connected to the previously defined network [7]. For every expansion step, we assume a growing market diffusion.

Second, equation (1) calculates the total daily electricity demand, equation (2) the total average power demand.

$$\sum_{i=1}^{I} p \cdot ADT_i \cdot E_v \cdot l_i = E_{total} \tag{1}$$

$$\sum_{i=1}^{I} \left(\frac{24\text{ h}}{p \cdot ADT_i} \cdot v \right)^{-1} \cdot P_v \cdot l_i = P_{total} \tag{2}$$

I:	Total number of sections in the scenario [-]
p:	Market diffusion of OC vehicles [%]
ADT_i:	Average daily traffic of HDV on section *i* [-]
l_i:	Length of section *i* [km]
E_{total}:	Total daily electricity demand of a scenario [kWh]
P_{total}:	Total average power demand of a scenario [kW]

Third, the total electricity demand is aggregated to NUTS-3 regions[1]. The electricity demand of each section is assigned to a region via its postal code [8]. We compare the additional demand in a region with a reference evolution without electrification of truck traffic in 2030 [9].

Finally, the temporal distribution of truck traffic is calculated based on the hourly data of the road traffic census. We focus on the average distribution over a week. For every hour of a week j, its share of the average weekly traffic volume in average over all weeks of the year and all sections is calculated based on the following formula.

$$\frac{1}{I}\sum_{i=1}^{I}\frac{AHT_{i,j}}{AWT_i} \tag{3}$$

I:	Total number of sections [-]
$AHT_{i,j}$:	Average hourly traffic of HDV on section i for week-hour j [-]
AWT_i:	Average weekly traffic of HDV on section i

In addition to this, the hours with most traffic in the year 2018 are determined for every section, to compare it to the average traffic intensity and to identify the maximum load of each section.

3 Results

Figure 1 shows the average traffic density as a heat map. Moreover, the four expansion stages are plotted. In stage one, two, and three, the expansion includes national highways. Stage four expands the network onto some federal highways. Due to the relatively low traffic density, the expansion on federal highways is the last step of an area-covering network. Table 2 provides the corresponding length of electrified roads.

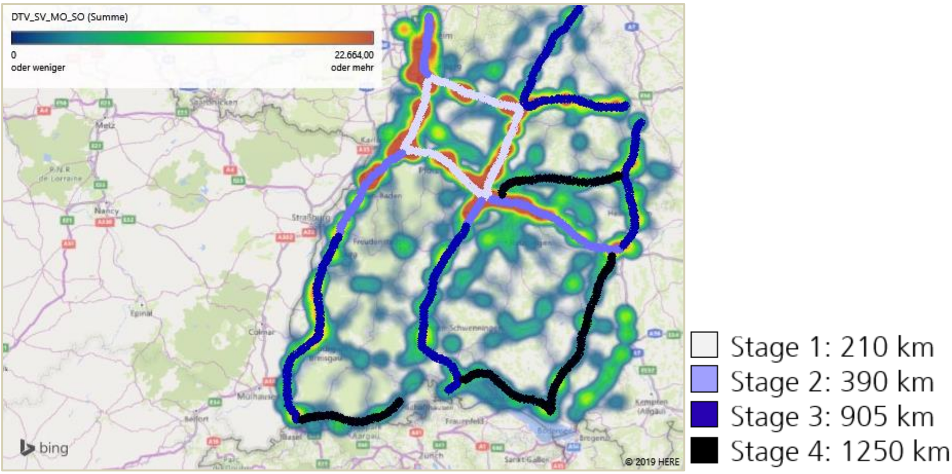

Figure 1: Expansion stages of OC system in BW (Background source: Bing-Maps)

[1] NUTS (Nomenclature des Unités territoriales statistiques, engl.: nomenclature of territorial units) is a system that divides the territory of the European Union into hierarchical levels. There is a total of 44 regions of level 3 in Baden-Württemberg.

Scenario	Total length [km]	Share of HDV traffic volume in BW covered [%]	Assumed market diffusion of OC vehicles [%]
Minimum Network	210	22.5	10
Core Network	390	38.4	20
Extended Network	905	64.2	50
State-wide Network	1250	68.9	100

Table 2: Characteristics of the expansion stages

Table 3 shows the total daily electricity and average power demand. An electricity demand of 5.7 TWh per year in the state-wide scenario accounts for about 8% of the expected electricity demand in Baden-Württemberg in 2030. This implicates that OC vehicles indeed have an impact on the electricity and power demand of BW.

Scenario	Total Electricity Demand [TWh/Year]	Total Power Demand [MW]
Minimum Network	0.2	21
Core Network	0.6	73
Extended Network	2.7	303
State-wide Network	5.7	651

Table 3: Total electricity and power demand in the scenarios

The regional resolution of the electricity demand is shown in figure 2. The colouring accounts for the percentage change in the expected electricity consumption of a region in 2030. The number of regions with a change above 1% as well as the amplitude of the change increases with growing OC network and market share. In the scenario with the largest network and assumed 100% OC HDV stock share, four regions experience a change between 20 and 30% and two regions an even higher change, namely Pforzheim and Baden-Baden. In these two regions, there are several highly trafficked highways and both regions only have a relatively low expected electricity demand for 2030. In general, the more highly trafficked streets a region has and the lower its expected electricity demand is, the higher is the estimated percentage change in the electricity demand.

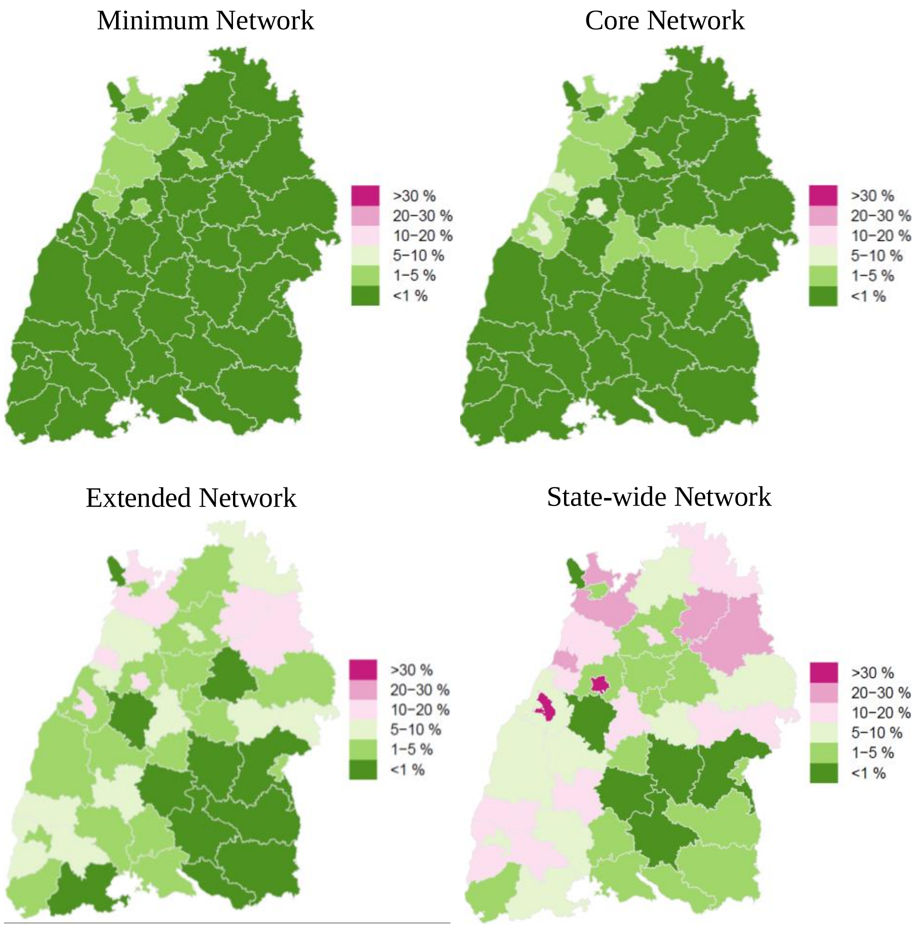

Figure 2: Regional electricity demand compared to a reference evolution without OC HDV in the four scenarios.

The hourly distribution of truck traffic is shown in figure 3. The first data point refers to the first hour on a Monday. The y-axis shows the share of the average weekly traffic volume. The peak is at the 11th hour on a Wednesday with traffic that accounts for 1.33% of the average weekly traffic. While the distribution among working days (Monday and Friday) is similar, there is a fundamental change during the weekend, including the ban of movement for most of the trucks with a gross vehicle weight above 7.5 t on Sundays [10]. This distribution directly relates to the temporal distribution of the power demand. Concerning the impact on the energy system, this fits the electricity supply in BW in a way that solar power is also higher during times of a higher load. Concerning other generation sources, the supply does not necessarily increase during times of a higher demand, which can be a challenge for the aim of a sustainable development of the energy sector.

Moreover, the highest section-average traffic volume of the year is 3.2 times higher than the average annual volume. In worst case, this accounts for an extra load of 3 MW per km of a section. This implies that network operators should take additional loads above average into account to guarantee uninterrupted power supply.

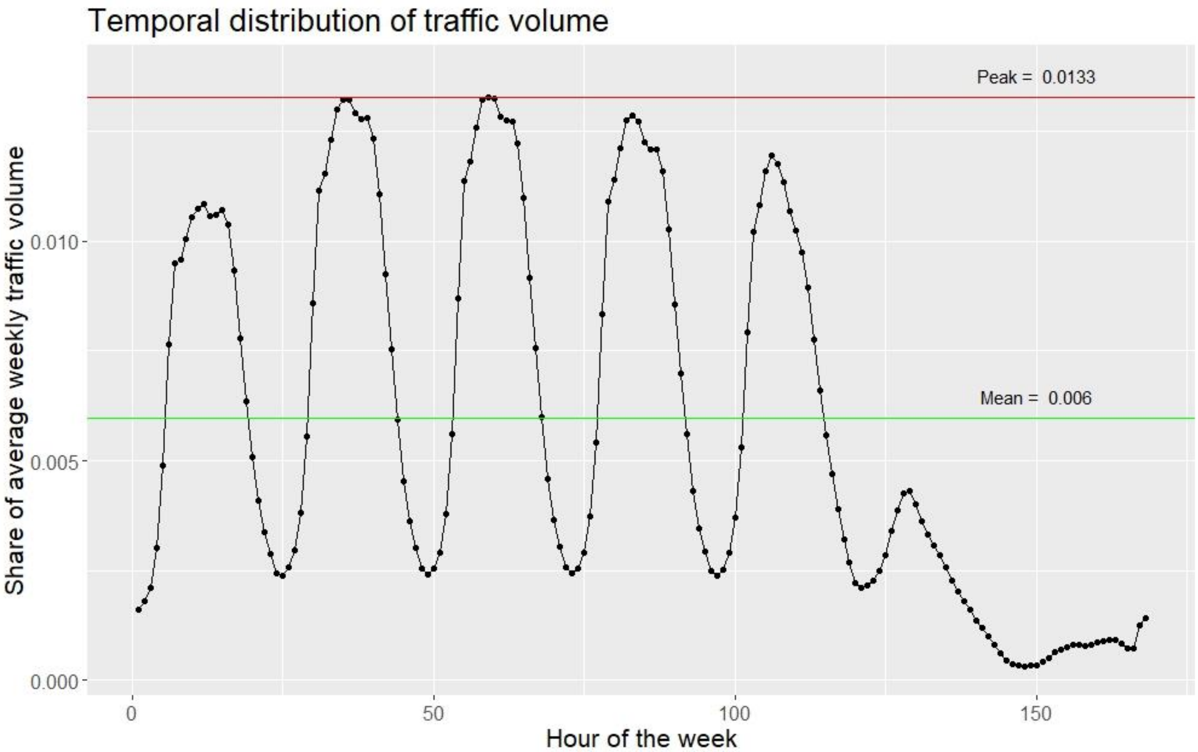

Figure 3: Average distribution of truck traffic over a week

4 Discussion and Conclusion

Our results show that OC vehicles can have a significant impact on the energy system in BW. Especially for some smaller regions of BW, the implications on the local energy system can be noteworthy. Moreover, the load of OC trucks is inflexible, which poses an additional challenge for grid operators. All this indicates that there are several aspects for further investigation.

Our findings come with some uncertainty. In [7] it is assumed, that only vehicles with a maximum allowed weight above 12 t are worth to be considered for OC. With this restriction in mind, only about 70% of the distance covered by HDV in the census can be targeted as OC vehicles. Moreover, a market diffusion of up to 100% in the upcoming years is unlikely. On the other hand, there is no recharging assumed in our calculations. Recharging almost doubles the electric energy demand of a single vehicle [7]. Therefore, our results can be interpreted as conservative in the sense that the actual values could be lower.

Acknowledgments

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