36th International Electric Vehicle Symposium and Exhibition (EVS36)
Sacramento, California, USA, June 11-14, 2023

Flexibility potential of smart charging of electric trucks and buses

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Executive Summary

In addition to passenger vehicles, battery electric trucks and buses could offer substantial flexibility to the energy system. Unidirectional charging of trucks in five out of eleven applications common in Germany as well as city buses could provide up to 23 GW of down-regulating flexibility potential (i.e. in case of excess power supply) in 2040. The resulting revenues could contribute to reducing electricity costs for depot operators. These results illustrate the need to provide easy and automated market access to heavy-duty vehicle fleets.

Keywords: Heavy-duty, truck, bus, smart charging, market

1 Motivation and research question

The European electricity grid is maintained and operated by unbundled grid operators – for the ultra-high and high voltage levels by so-called transmission system operators (TSO). TSOs co-create and partly operate markets to solve physical challenges such as frequency deviations or bottlenecks in the grid (i.e., congestions). These are referred to as ancillary services [1] and can be split into four flexibility segments: the two ancillary services balancing power and congestion management as well as congestion alleviation and wholesale market. These flexibility segments consider regulatory, technological and economic framework conditions as well as the involvement of key stakeholders. Due to increasing share of electricity generation from renewables sources as well as increasing electrification of the heating and transport sector, more flexibility will be needed in the future, in particular from the demand side. The first two segments are the most promising for the integration of demand-side flexibility from, e.g., electric vehicles. They will be briefly introduced in the following and the temporal order of market closures in Germany is provided in Figure 1.

- **Balancing power** provides upward regulation (supplying additional energy to the grid) and downward regulation (drawing excess energy from the grid) to guarantee the constant equilibrium between electricity generation and consumption and, thus, maintain a stable system frequency of 50 Hz at any time. In particular, the uncertainty in wind and solar generation forecasts is an important driver for increasing need for flexibility to keep the system in balance. German TSO TenneT expects the need for flexibility to grow by up to 3 GW by 2030.
- **Congestion management** aims to solve an energy transmission (or distribution) problem by making use of remedial actions, such as redispatch and feed-in management. The task is to match the market outcomes, which only partly consider the physical electricity grid, with the physical restrictions of the

grid during real time operation. The locational shift of generation (wind and solar), increasing peak supply and new demand centres increase needs in this segment. TenneT expects additional flexibility need in this segment of up to 9 GW by 2030.

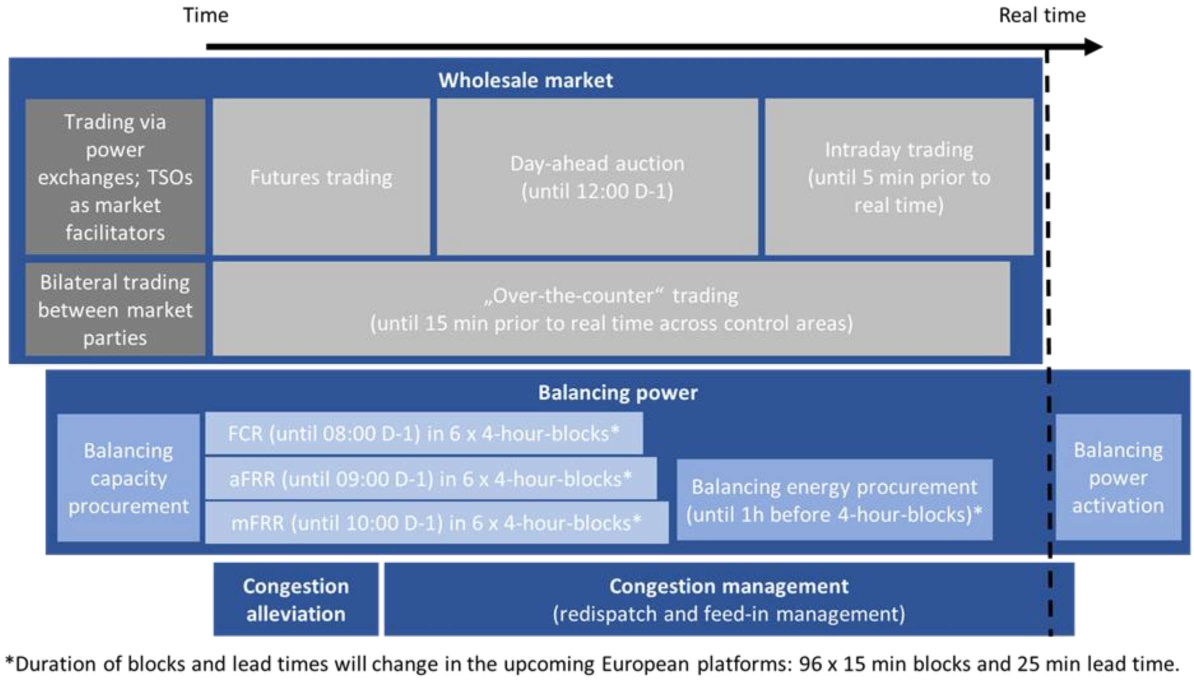

Figure 1: Temporal sequence of market closures for flexibility segments (dark blue) in Germany

While the use of battery-electric (BEV) passenger cars for providing flexibility to the power grid has been investigated extensively (e.g., [2-4]), the body of research on the flexibility potential of battery-electric trucks as well as buses is much smaller. In general, the impact of charging of electric trucks and buses on distribution grids appears significant [5, 6]. Meanwhile, Taljegard et al. [7] show that a completely electrified transport sector using bidirectional charging, including trucks and buses, would reduce necessary investments peak-power in the energy system by 50% in Sweden, Germany, the UK and Spain.

In contrast, we aim to investigate in some detail the flexibility and remuneration potential on a per-depot level, putting the focus on comparing different vehicle use cases. We consider unidirectional conductive DC-charging using the CCS2 charging standard. Since a refined market framework is currently only in place for balancing power our quantitiave analysis focuses on this flexibility segment rather than congestion management.

This feasibility study examines how electrified medium- and heavy duty trucks and city buses can provide flexibility to the energy system, investigating key economical, regulatory, legal and technical aspects. The study is structured as follows: Section 2 describes our methodological approach and use case assumptions. Results for initial considerations, technical flexibility and remuneration potential are discussed in Section 3. Section 4 concludes and discusses future work.

2 Methodology and use cases

The approach taken in this study is twofold: first, expert workshops with representatives from Daimler Truck and TenneT were held. The goal of the workshops was to establish a common understanding of the subject matter, further focus our approach and coordinate the quantification methodology. Secondly, flexibility and marketing potential were derived for a range of use cases and extrapolated over exemplary market ramp-ups.

The following three tables describe the parameters used to describe a city bus use case (Table 1) and major truck use cases (Table 2 and Table 3). The city bus use case is based on a large electrified depot in a major

German city. Other than in for the truck use cases, the columns in Table 1 describe spectrums for the various parameters rather than specific routes or use cases.

Table 1: Parameters for the use case “city bus”

Available battery capacity	kWh	350	
Max. available charging power	kW	80	
Energy demand per day	kWh	Min 200	Max 550
Time departure 1	h	Earliest 05:30	Latest 08:30
Time arrival 1	h	Earliest 11:00	Latest 15:00
Time departure 2	h	None, or earliest 13:30	None, or latest 17:00
Time arrival 2	h	None, or earliest 19:00	None, or latest 24:00
# vehicles in example depot		149	

The line haul segments (LH 1-3) summarize a wide variety of long, medium and short haul applications, transporting all kinds of different goods either on demand or on daily return trips. Retail and distribution routes (R/D 4-6) are usually shorter but more plannable (cf. “variability of departure”), often containing multiple trips per day to retail locations, supermarkets or distribution locations.

Table 2: Parameters for the use cases “line haul” (LH 1-3) and “retail/distribution” (R/D 4-6)

		LH 1	**LH 2**	**LH 3**	**R/D 4**	**R/D 5**	**R/D 6**
Available battery capacity	kWh	600	600	600	600	400	400
Max. available charging power	kW	300	300	50	50	150	150
Energy demand per day	kWh	650	600	350	575	350	400
Time departure 1	h	05:30	06:00	07:00	08:00	05:00	05:00
Time arrival 1	h	17:00	16:00	15:00	16:00	13:00	13:00
Time departure 2	h	-	-	-	-	14:00	14:00
Time arrival 2	h	-	-	-	-	20:00	20:00
Variability of departure		avg.	avg.	large	low	low	low
# vehicles per example depot		50	50	45	20	30	30

Construction uses cases (Con 7-9) contain transportation of building material or equipment to and from construction sites as well as haulage within the site. Waste collection in urban environments and transport between collection and deposition/incineration sites are further prime uses cases for electrification (Wa 10-11).

Table 3: Parameters for the use cases “construction” (Con 7-9) and “waste” (Wa 10-11)

		Con 7	**Con 8**	**Con 9**	**Wa 10**	**Wa 11**
Available battery capacity	kWh	600	400	400	400	400
Max. available charging power	kW	150	50	50	50	50
Energy demand per day	kWh	475	300	275	375	300
Time departure 1	h	08:00	08:00	08:00	07:30	07:00
Time arrival 1	h	12:00	16:00	16:00	15:30	15:00
Time departure 2	h	13:00	-	-	-	-
Time arrival 2	h	16:00	-	-	-	-
Variability of departure		average	average	average	low	very low
# vehicles per example depot		10	10	10	15	30

While stylized, these parameters allow for a detailed modelling of flexibility potential from exemplary depots for every use case. We assume minimizing peak load as default charging strategy and as the baseline for the assessment of flexibility potential. Furthermore, we assume that a sufficiently sized grid connection exists/was built at the depot to enable the installed chargers to be used at maximum capacity imultaneously. In combination with over-night idle times these assumptions allow for the deterministic calculation of positive (delayed charging processes) and negative flexibility potential (accelerated charging processes) in MW per depot. The potential is assumed equal for every day of the week, weekends and bank holidays are not modelled.

In the next step, we created a ramp-up scenario for every use case for Germany using a Bass diffusion model [8] as applied by Ensslen et al. [9] for battery-electric passenger vehicles. Innovation coefficients are used to calculate the share of diesel vehicles being replaced by BEV over time. The scenario is based on expert assessments[1], market data [10] and an external source for the bus use case [11]. Furthermore, each use case has a cap on its electrification potential at full diffusion due to the limitations of BEV in, e.g., range, cargo load, or power demand of ancillary consumers, which is accounted for in the scenario. Looking only at the use cases most relevant for flexibility marketing (i.e., with sufficient idle time and early electrification potential) we focus the discussion on five out of eleven truck use cases and the city bus use case. Their scenario ramp-up numbers are listed in Table 4.

Table 4: Ramp-up approximation of number of vehicles on the road in Germany

Use case	2025	2030	2035	2040
Line haul 2	1,200	9,300	29,000	37,000
Line haul 3	8,300	31,300	68,000	94,000
Retail 5	5,000	22,800	58,000	86,000
Construction 7	200	2,300	13,000	22,000
Waste 11	1,500	6,500	13,000	16,000
All use cases	**30,900**	**151,700**	**411,000**	**606,000**
City bus	6,900	20,300	31,000	36,000

The flexibility potential per depot can then be scaled to the entirety of Germany and aggregated for flexibility marketing. The revenue calculations are based on market data of 2020 and 2021 from the German balancing market platform regelleistung.net [12] and consider both theoretical revenues from the power bid as well a conservative energy bid. Note that we did not model costs and therefore do not make any claim on profitability. Likely cost components are, e.g., increased grid fees, software licenses, prequalification, or market access fees.

3 Results

3.1 Expert workshops

The workshop series yielded three key take-aways:

1) Logistics businesses will not use electrified vehicles if there is no positive business case depending on, e.g., vehicle price, electricity costs, incentives for earning additional revenue by providing flexibility services.
2) Promising flexibility segments are balancing power and congestion management (i.e. redispatch).
    a) While for balancing power the asset location (e.g. depot) is less important, it is crucial for congestion management because spatial bottlenecks in the electricity network are to be solved.
    b) Technically, trucks and buses can participate in all three balancing types Frequency Containment Reserve (FCR), Automatic (aFRR) and Manual Frequency Restoration Reserve (mFRR). However, the “higher quality” balancing types FCR and aFRR are most suitable because charging of batteries can be adjusted quickly, and they have enough capacity that can be shifted.
    c) In Germany, the regulatory framework for loads and storages under “Redispatch 3.0” is still to be shaped, while in the Netherlands the GOPACS platform already offers market-based remuneration.

[1] The vehicle ramp-up at the basis of this analysis represents a potential scenario and does not represent a sales prognosis of Daimler Truck AG.

Depot operators only provide the redispatch service if they reduce their electricity costs from a market-based remuneration. Therefore, it was decided to to focus the following quantification on balancing power within the market framework currently available.

3) The Crowd Balancing Platform “Equigy” enables a more efficient provision of balancing power and congestion management from decentral, distributed flexibility sources.
   a) The Crowd Balancing Platform is not a marketplace, but it creates the framework conditions for a decentralized prequalification and efficient accounting for the increasing amount of small and distributed asset. This ultimately lowers market entry barriers.

3.2 Flexibility and revenue

The positive and negative flexibility potential [MW] for grid operation is illustrated in Table 5. The technical flexibility potential is substantial for the line haul and retail truck use cases and also large bus depots play a substantial role in the early morning hours. With a theoretical potential of over 4 GW of positive and negative flexibility from 4 pm to 4 am (peaking at over 23 GW of negative flexibility in the 4-hour-block 20:00-24:00 and at over 7 GW of positive flexibility in 00:00-04:00), all examined use cases combined could have a significant impact on, for example, the balancing power market in 2040. For context, the current demand in 2022 for positive and negative balancing power in Germany is around 7.1 GW.

Table 5: Maximum positive (+) and negative (-) flexibility potential for Germany in 2025, 2030 and 2040 [MW]

	00:00-04:00	**04:00-08:00**	**08:00-12:00**	**12:00-16:00**	**16:00-20:00**	**20:00-24:00**
2025	529	13	4	0	266	354
	-1,146	-26	-13	-47	-659	-1,048
2030	2,210	46	13	0	1,238	1,613
	-5,960	-77	-39	-138	-3,981	-5,765
2040	7,066	154	23	0	4,183	5,542
	-22,593	-137	-70	-245	-16,095	-23,113

Figure 2 illustrates the potential revenue from flexibility provision and therefore the reduction potential for the total cost of ownership [EURct/kWh] for truck customers. In practice, depot operators may have electricity contracts with flexibility aggregators who grant remuneration or rebates on electricity price in exchange for flexibility. The revenue potential is larger on the aFRR market, and the largest revenue results for truck use cases line haul 2 and waste 11, while the bus use case and truck use case retail 5 have the lowest potential. For aFRR the revenue potential can be very significant given average electricity prices for German industry at around 20 EURct/kWh. If transport companies could facilitate flexibility marketing reliably, significant rebates on their electricity costs would be possible.

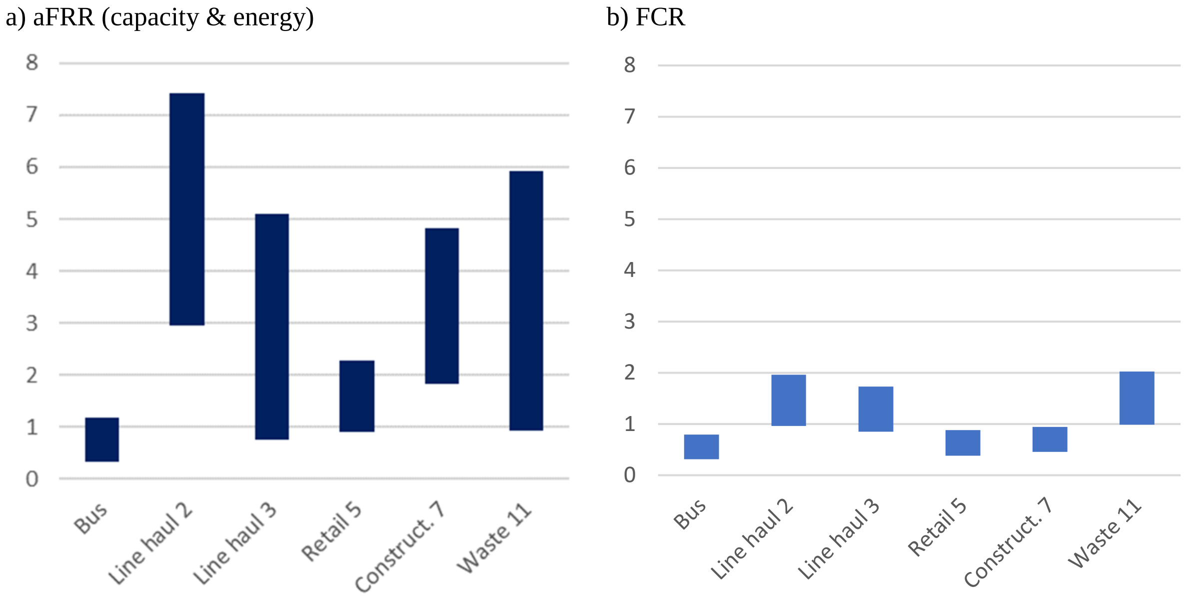

Figure 2: Range of maximum possible revenue per consumed kWh from flexibility segments, in EURct/kWh (minimum revenue with 2020 prices, maximum with 2021 prices)

There are several limitations to these findings: First, the analysis does not allow for profitability conclusions because only the revenue side is presented (i.e. costs are not included). Second, the flexibility potential assumes that it can be offered over the entire bid timeframe, which is in practice not possible because actual flexibility delivery can reduce the potential considerably. Furthermore, the flexibility potentials are based only on a selection of bus and truck use cases (six out of twelve) and consider only weekdays (neither weekends nor bank holidays). Finally, we used market data from 2020 and 2021 to illustrate revenue ranges; predictions of future prices require further analysis.

4 Conclusion

This study lays the foundation for a mutual understanding of the interaction of energy and transport sector by assessing flexibility and revenue potentials from electrified trucks and buses. We showed the significant technical potential of shifting charging times of specific truck and bus use cases for offering balancing power. Furthermore, this offering could lead to notable revenues that should be used to compensate depot operators for the provided flexibility.

Policy recommendations for balancing power are that the prequalification criteria should avoid redundancy and minimize costs for balancing service providers (e.g. by establishing largely automated prequalification processes). Furthermore, the vehicle operators' risk of insufficient state of charge must be nullified through smart IT solutions. Due to a current lack of marketability, we excluded congestion management from the quantification analysis of this study – despite the expected impact of truck and bus charging on distribution grids [5, 6]. A market-based approach should complement the existing cost-based provision of redispatch services and address these decentralized generation or consumption assets for which there is no mandatory participation in the current redispatch regime. This means that an attractive market solution is needed to allow for voluntary participation from consumers and businesses rather than mandatory load reductions.

A full economic examination regarding the profitability potential is advisable. This includes in particular a quantitative assessment of the cost side and of the effects of the delivery of balancing energy on the flexibility potential. Further research is needed to quantitatively compare other marketing options, e.g., congestion management, intraday arbitrage trading, or even pure behind-the-meter cost minimization using on-site solar generation. A logical expansion of the model could be bidirectional charging, which should further increase flexibility potentials, especially when considering weekends and public holidays. Furthermore, a technical pilot can inform on open topics in standardization or availability of equipment.

Acknowledgments

We would like to thank the co-authors and participants from both companies for their invaluable input and support. This study did not benefit from public funding.

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Presenter Biography

Christian Will has been working at Mercedes-Benz Cars and Daimler Trucks for seven years. He is responsible for liaising between European utilities and logistics customers as well as enabling the electrification of the transportation sector. Christian obtained a Master's degree in Industrial Engineering and Management at the Karlsruhe Institute of Technology (KIT) and is currently working on his PhD at KIT and the University of California, Davis. His research focuses on electric vehicles and power markets.