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Electrification potential of an existing heavy duty vehicle fleet – a techno-economic analysis

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Executive Summary

This work determines the techno-economic potential of electrifying the truck fleet of the "Badische Staatsbrauerei Rothaus AG", based on the analysis of data containing two weeks of vehicle operation. The analysis reveals that overnight depot charging maximises potential, while daytime charging allows for longer tours using vehicles with smaller batteries. Economically, electrification of this fleet is beneficial, paying off within a few years as higher operation costs of the diesel fleet offset the high purchase price of electric trucks. Financial advantages increase with consistent usage and longer vehicle service life, supported by lower depot electricity prices. Sensitivity analysis shows that fuel prices, vehicle costs, and residual values of electric trucks significantly influence results, while charging infrastructure costs have less influence on the outcome. This study emphasises the feasibility and profitability of the electrification of truck fleets, identifies the most important influencing factors, and thus provides a basis for the targeted improvement of framework conditions.

Keywords: Heavy duty electric Vehicles & busses; electric Vehicles; Modelling & Simulation

1 Introduction and Background

This study utilises real-world driving data and information on operational conditions from the existing fleet of the case study partner "Badische Staatsbrauerei Rothaus AG" to examine the potential for complete fleet electrification. It addresses the central research question: What proportion of the fleet and associated trips can be electrified, under which conditions, and where do opportunities and barriers exist?

In a subsequent step, the economic viability of electrification is assessed by incorporating actual cost data and evaluating multiple scenarios. This leads to the secondary research question: Is full fleet electrification economically feasible, and which conditions enhance its viability? What are the potential opportunities and existing challenges? Both parts put special emphasize on potential intermediate charging.

Before delving into the analysis, the study provides an overview of the relevant political and technological context. To reduce transportation emissions, which account for 30 % of European Union (EU) greenhouse gases, Germany and the EU have set ambitious targets. The EU aims for climate neutrality by 2050, with a 55 % reduction in net emissions by 2030. Germany's national targets are even stricter, mandating a 65 % reduction by 2030 and climate neutrality by 2045. Heavy duty vehicles must significantly contribute to these goals, with one-third required to run on electricity or electricity-based alternative fuels by 2030. Germany has introduced a CO_2-based toll for heavy duty vehicles with additional costs of 11.56 cent per kilometre and a rising CO_2-price on fossil fuels (€55 in 2025), making diesel trucking more expensive and incentivising low-emission options like battery-electric trucks (BET) [1].

Studies indicate that BETs are the most promising emission-free option for heavy duty transportation, offering greenhouse gas savings of up to 92 % when using renewable energy sources [2]. Additionally, BETs have lower operational costs than diesel trucks, driven by affordable electricity and increasing diesel costs due to CO_2 pricing [23]. However, the high upfront costs for BETs and charging infrastructure represent a challenge to fleet electrification. Today, BETs cost around 1.8 to 2.5 times as much as a diesel truck, which is mainly influenced by the high battery costs [23]. However, major manufacturers predict that BETs will account for 50 % of new truck registrations by 2030 [4]. Today BETs have a battery capacity of up to 500 to 850 kWh, representing a range of up to 350 to 850 km. The vehicle's energy consumption is still unsure but estimated to be around 1.1 and 1.9 kWh/km and influenced by speed, road gradient, temperature, battery age and loading [[5], [14], [3], [26]].

The availability of charging infrastructure is critical for BETs adoption. Depot charging is expected to account for 50-80 % of future BET charging needs due to its cost advantages [6]. However, depot charging requires costly upgrades in areas with limited grid capacity, potentially leading to significant initial investments. In total the costs for building depot charging infrastructure is from €300 to €700/kW [[1] [24] [25]]. Depot energy prices are estimated around 22.8 ct/kWh declining in the next years [7]. Conversely, public charging stations are easier to access, but tend to come with higher energy prices of 29 up to 70 ct/kWh [8]. Today public charging infrastructure for BETs is still rudimentary and brings uncertainty about the future price, reliability and the available charging capacity. Although EU and German initiatives aim to improve public infrastructure, uncertainties remain regarding expansion pace and standardisation. While the EU seeks widespread public fast-charging availability by 2030, the variability in costs and availability presents challenges for long-haul BET deployment.

The case study partner is the "Badische Staatsbrauerei Rothaus AG", which delivers its own beer by regional transport. They are not a classic logistics company and generate their turnover in another economic sector. The company owns 20 heavy duty trucks with a total weight of 26 and 40 tons with an average lifetime of 8 years which can be interpreted as relatively long. Compared to a typical logistics company in Germany, the company has a relatively large number of vehicles, as the logistics sector is made up of many companies with 1-10 vehicles [9]. The company is located in the Black Forest in Germany and has its depots in Umkirch and Rothaus. This is a rural area with little development of fast charging stations. Due to the very mountainous topography, increased average energy consumption is to be expected. There is an altitude difference of 900 metres between the two locations. Around 60 % of the roads used by their trucks are toll roads. In addition, the temperatures in the area are very low compared to the national average. The company has its own charging infrastructure with a low depot electricity price of around 20 ct/kWh. The installation of 180 kW charging infrastructure cost €45,000. The case study partner has already purchased several e-trucks, which cost around twice as much as the equivalent diesel trucks (small diesel truck: €120,000, electric: €240,000; large diesel truck: €140,000, electric: €270,000), although it should be noted that vehicle financing from the federal funding programme KsNI may have influenced the prices when purchasing the small electric trucks. Research using data from the Federal Network Agency revealed that the number of public charging points at supermarkets and restaurants in the region has recently risen sharply, are mostly designed for cars and offer a charging capacity of 22 kW to a maximum of 150 kW [10].

2 Methodology and Assumptions

The analysis was conducted in several stages. First, the dataset was cleansed and prepared for subsequent analysis. The technical electrification potential was then assessed, initially through descriptive evaluation and subsequently through a more detailed analytical approach. The share of routes and vehicles that could technically be electrified was determined for various scenarios, and the necessary conditions for electrification were identified. Based on these findings, further scenarios were developed – primarily differing in charging strategies and battery capacities – and their economic feasibility was assessed. This assessment also considered varying economic conditions, from which potentials were derived. Finally, the assumptions underlying both the technical and economic analyses were evaluated through sensitivity testing.

2.1 Literature review

The methodology of this paper is based on existing research about technological feasibility and economic viability [[5], [7], [3], [1]]. The studies used are very similar in terms of methodology, but different focuses were set and different detailed analyses were carried out. In addition, different locations and vehicle types were considered. The basis of the work is either real route data from a vehicle fleet or modelled or aggregated route data from hypothetical vehicles. These were then checked for their electrification capability by modelling electricity consumption, charging strategies and battery capacities. The electricity consumption is based either on averages or on a calculation of varying complexity with the help of influencing factors. To calculate the economic efficiency, the TCO (Total Cost of Ownership) for an electrified fleet was compared with the TCO for a diesel fleet. These were underpinned with different numbers of parameters. In some studies, price developments over the next few years were taken into account. Either current or forecast future values were used in the studies. This basic methodological framework forms the basis for the analysis carried out in this paper. The calculation was designed to be as comprehensive as possible in order to take into account as many influencing factors as possible. However, due to a lack of data or a limited scope of work, some steps had to be shortened.

2.2 Database and -quality

The analysis is based on a route list that records the start time, start location and loading for each vehicle and each day, as well as the time, address and unloading for each station on the route. It also contains information on driving breaks, their duration and the progress of the freight. The legally prescribed rest periods were taken into account [12].

The data was analysed using Python by converting the Excel spreadsheet into a matrix that stores a sequential list of activities (driving, standing) with relevant parameters for each vehicle and each day. The freight was calculated iteratively: the initial load was adopted and adjusted with each unloading, whereby one third of the unloaded weight was added as empties return. In addition, a flat-rate weight of 3,500 kg was taken into account for bar trucks and event equipment.

For geographical allocation, addresses were converted into coordinates using "openroute service", from which distances and height differences of the sub-routes were calculated [13]. The data cleansing included the correction of syntax and input errors, which were mostly due to typing errors, as well as the identification and correction of logical and value range errors, e.g. by checking unusually long time intervals or negative values. Plausibility errors were detected by determining the speed: significant deviations from the average led to manual checks and corrections. Despite extensive adjustment measures, two days had to be excluded due to unresolvable inconsistencies. The final analysis is therefore based on 99 valid days from the journeys of 13 vehicles. In addition, data on vehicle acquisition costs, energy prices, charging infrastructure construction expenses, and vehicle lifetime were gathered through direct discussions with the case study partner.

2.3 Technical Feasibility Analysis

2.3.1 Methodology for Technical Feasibility Analysis

In a first step, a table with average, maximum and minimum values was created for each vehicle and a graphical overview was generated for each day with the activities "Driving", 'Standing' at the costumers or the case partners depot and legally required break. The analysis of these two forms of presentation already indicated potential.

In the second step, a program was developed to model the battery state of charge (SoC) over the course of a battery-electric truck's journey. Each route was modelled individually for every vehicle and day. The vehicle is assumed to begin each trip with a fully charged battery, and the state of charge decreases progressively as the journey continues. Energy consumption is modelled as a function of freight weight, altitude gradient, travel distance, and ambient temperature.

$$\begin{aligned} \Delta Battery\ level\ [kWh] &= Consumption * Distance \\ &= Base\ consumption * Loading\ factor * Altitude\ factor * temperatur\ factor \\ &\quad * Distance \end{aligned}$$

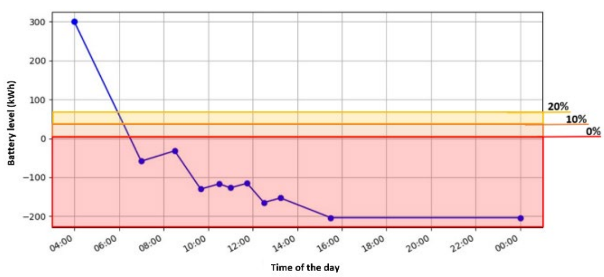

Figure 1: Battery level curve example

In the first scenario, the vehicle is not charged in between; in the second scenario, it is charged at legally required breaks and every unloading stop. The intermediate charged energy is calculated using a defined power and the duration of the stop or legally required break. During stops, the charged energy is offset against the battery level after the last sub-route. If charging takes place during driving breaks, the gain in battery level is offset against the consumption while driving. It is assumed that no additional stops were made for charging. This produces a battery level curve for each vehicle (see Figure 1). It was then checked for each day whether the battery level fell below 0, 10 % or 20 % during the trip. Scenarios with three different battery capacities were tested: 300 kWh, 450 kWh and 650 kWh. As described above, the latter is a realistic future scenario based on state-of-the-art technology. However, as Rothaus drives many shorter routes and trucks with a lower battery capacity are significantly cheaper, it was also checked how many of the routes are possible with smaller batteries. In order to check the influence of temperature, a temperature scenario was calculated and compared with the other results. In a final step, a sensitivity test was carried out in which the variables of the energy consumption function were varied in order to test their influence on the final results. To test the charge weight and the slope influence, the terms "charge factor" and "slope factor" were removed from the calculation of the battery level (see section 3.13). To investigate the influence of the base consumption, the base consumption was calculated with a factor of 0.9.

2.3.2 Assumptions for Technical Feasibility Analysis

Assumptions regarding consumption, vehicles and charging infrastructure were made for the analysis on the basis of scientific studies, technical manufacturer data and internal project estimates. As the case study partner uses battery electric trucks from Mercedes-Benz, the eActros 300/400 and eActros 600 in particular were used as a reference. The charging infrastructure is based on research results and an analysis of public charging points at the locations of use.

Based on an analysis of factors influencing the energy consumption of electric vehicles speed has the greatest influence on the consumption, followed by gradient, temperature, and battery level [14]. Loading has only a minor influence, but existing analyses were only conducted for passenger cars. Other research on trucks indicates a consumption increase of 4.6 % per ton [15]. The truck loading was calculated as the deviation from the average vehicle loading weight not including the vehicles weight itself. Gradients have a significant influence on consumption, with an increase of 1-3 % causing a 57 % increase in consumption, while a negative gradient of 1-3 % reduces consumption by 49 % [16]. As only altitude differences between the start and end points are available, a simplification was done. Whenever the average gradient of a trip was equal to or exceeded 1 %, the mentioned adjustments to energy consumption were applied. Due to the temperature, the range drops to 75 % at temperatures as low as 0°C or as high as 40°C and to 60 % at -10°C [17]. This was taken into account in a separate scenario with a range reduction of 25 % and a 17 % reduction in charging power, as low temperatures often prevail in the Black Forest.

The basic consumption was set internally in the project at 1.1 kWh/km, based on the eActros 300/400/600 vehicle data. A charging delay of 10 minutes was taken into account for driving breaks. The charging power was differentiated: Stops were given a realistic assumption of 20 kW, based on existing charging points at supermarkets and restaurants, while driving breaks were assumed to have 100 kW, based on the AFIR guideline and the assumption that drivers can choose charging locations more selectively during scheduled steering breaks. As fluctuations in charging power were not included, the assumed average value forms a realistic basis for the modelling.

2.4 Economic Viability

2.4.1 Methodology for Economic Viability Analysis

The methodological approach for the economic viability analysis is grounded in existing literature (see section 2.1). Economic viability is assessed by calculating the Total Cost of Ownership (TCO) over a maximum time horizon of 16 years, starting in 2025. The TCO is determined for two fleet configurations: one operating exclusively with diesel trucks and the other exclusively with battery electric trucks (BETs). In addition to the fleet-level analysis, individual vehicle-level TCOs are also calculated.

Two charging scenarios – with and without intermediate charging – are compared in terms of their cost implications. To enable a relative comparison between scenarios, the TCO of one configuration is divided by the other, resulting in dimensionless ratio values.

The basis for this analysis are the results from the technical feasibility assessment, cost data obtained through direct engagement with the case study partner, and supplementary information from the literature.

The technical feasibility assessment provides data on the distance travelled by each vehicle during a two-week observation period. This distance was considered representative and scaled to an annual value, assuming 50 working weeks per year. Based on this extrapolated distance, the energy or diesel consumption for each vehicle was calculated. Depending on whether the charging event occurs at the Rothaus depot, at a customer's depot, or at a public charging station, different electricity price assumptions are applied. Furthermore, the assessment determined the required battery capacities under both charging strategies. With intermediate charging, the following battery configurations were assumed: one truck with 650 kWh, six with 450 kWh, and six with 300 kWh. Without intermediate charging, larger battery capacities were required: two trucks with 650 kWh, nine with 450 kWh, and three with 300 kWh. As vehicle purchase prices are influenced by battery capacity, configurations with larger batteries result in higher upfront costs.

The TCO calculation additionally incorporates: The cost of depot-based charging infrastructure, equally allocated across the fleet, operating costs for the charging infrastructure, depreciation, residual value, inflation, and interest rates. Insurance, maintenance, and personnel costs were excluded from the analysis, as they are assumed to be comparable across scenarios. Consequently, the absolute TCO values should be interpreted with caution. Financing costs were also excluded, under the assumption that all vehicles are purchased outright.

Several scenarios are analysed (see Table 1). The two primary scenarios focus on the presence or absence of intermediate charging. In addition, two further parameters are varied to account for uncertainty. First, the purchase price of the electric trucks is considered under two assumptions: one based on cost data provided by Rothaus, and another based on literature values, which reflect more optimistic and potentially lower future prices for BETs. Second, the residual value of BETs, which is subject to significant uncertainty due to a lack of data, is treated differently across scenarios. In the first case, it follows the same depreciation curve as that of diesel trucks. In the second case, it corresponds exactly to the value for diesel trucks. Both scenario are based on approaches used in other studies [[27], [7]].

Table 1: Scenario overview for the economic viability analysis

		Vehicle purchase price	
		Rothaus (base) case	Optimistic case
Smaller batteries, more expensive Energy	Intermediate charging	1) Same residual value 2) Same residual curve	3) Same residual value 4) Same residual curve
Bigger batteries, cheaper Energy	No intermediate charging	5) Same residual value 6) Same residual curve	7) Same residual value 8) Same residual curve

A sensitivity analysis tested the effects of changed assumptions on the overall result by varying parameters by

10 %. The ratio of the costs of an electrified truck after 16 years to those of a diesel truck was defined as the overall result. This was based on the assumption of a charging strategy without intermediate charging, using the vehicle prices of the case study partner and an identical residual value curve for both drive types. The calculations were carried out in Python.

2.4.2 Assumptions for Economic Viability Analysis

A number of assumptions had to be made for the economic analysis, which are listed below. Many of the assumption are descripted in the introduction of this paper. It has to be emphasized that these assumptions come with uncertainties. The BET and charging infrastructure market is in an early stage and prices can change quickly. Moreover some important cost factors may not be included in this analysis.

The vehicle prices were defined for the two vehicle sizes using two scenarios: (1) based on the data of the case study partner (see chapter 1), (2) with more favourable, forecast prices for 2025: small diesel €89,000, electric €104,800; big diesel €103,000, electric €126,900 [7]. The battery costs were considered separately (€107/kWh) and calculated for each battery size individually. The installation of the charging infrastructure was calculated at €804/kW, based on real installation costs und differentiated by the different energy need depending on the charging scenario (based on night length of 14 to 18 hours, no intermediate charging: 157 kW, with intermediate charging: 89 kW). Diesel prices were forecast taking into account crude oil prices, taxes, CO_2 costs and tolls up to 2040 (€1.15/L in 2030, €1.95/L in 2040) [18]. The diesel consumption is defined as 0,216 L/km for small trucks and 0.256 L/km for bigger trucks [7]. Electricity costs were determined from literature values and Rothaus' information and offset against forecast electricity price fluctuations. For 2025, 20 ct/kWh was assumed at the depot, 26.3 ct/kWh at the third-party charging ramp and 29.8 ct/kWh at public charging stations (see chapter 1). Energy prices are projected to decrease by 11 % by 2030 and by 15 % by 2040 [18].

Statutory useful lives were used for depreciation: 9 years for trucks, 10 years for batteries, 19 years for charging infrastructure [19]. The battery residual values are based on an annual degradation of 2.3 % [20]. Inflation was set at 2.4 % [21], interest rate at 1.1 % [22], based on current economic forecasts.

3 Results and discussion

3.1 Technical Feasibility Analysis

3.1.1 Current state and potential

The analysis of the current state statistics and driving patterns (see Figure 2) shows clear differences in the driving profiles. While some tours have a few long sub-routes, others consist of numerous short sections. What all tours have in common is a high number of longer stops and regular driving breaks. In addition, the night breaks are consistently long, lasting between 14 and 18 hours. The average route length varies between 97 km and 247 km, with the longest single route being 538 km. There is an average of three to eight stops of 25 to 60 minutes per tour. Legally required breaks occur with a frequency of 0.4 to 1.1 per day and last an average of 31 to 47 minutes. The sub-route lengths are between 13 km and 81 km, with driving times of 20 minutes to 1 hour 12 minutes.

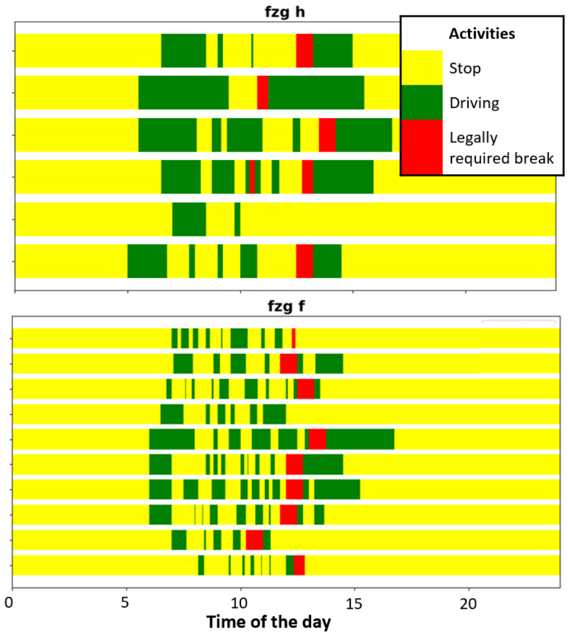

Figure 2: Activity pattern for two exemplary vehicles. Each row represents one day

Based on these patterns, potentials for the electrification of the vehicle fleet can be derived. Night-time charging at the depot offers the greatest opportunity, as the long and reliable downtime enables an efficient energy supply. At the Black Forest site "Rothaus", where four vehicles are stationed, there is great potential for an efficient charging infrastructure. The situation at the second depot in Umkirch is still unclear, but it is generally the case that charging at a depot is more reliable and cost-effective than on the road.

Stops at costumers loading ramps offer medium potential, as these are often numerous and long. However, many stops are made at inns or smaller retailers where there is no reliable charging infrastructure. Legally required breaks also represent a possible charging window, as they occur almost daily and could be linked to public charging stations with higher charging capacity. However, there is uncertainty regarding the availability and charging capacity at these locations. In addition, not every trip involves a break from driving.

In summary, night-time charging at the depot offers the most promising solution for electrifying the vehicle fleet. Nevertheless, intermediate charging during the tour could make a supplementary contribution at lower charging capacities. Therefore, these two approaches are examined in more detail.

3.1.2 Analysis

To analyse the electrification options of the case study partners fleet, two charging strategies, three battery capacity scenarios and one scenario incorporating low ambient temperatures – which are expected to reduce the range of BETs – were evaluated.

The analysis was carried out by evaluating each day and its tour in terms of their electrifiability, whereby four categories were distinguished: fully electrifiable (green), low risk (yellow), high risk (orange) and non-electrifiable (red). Each row represents one vehicle and gives an overview regarding the whole fleets electrifiability (see Figure 3).

In the first scenario "depot charging only" with a battery capacity of 300 kWh, 72 % of the tours and 3 total trucks can be replaced by BETs without restrictions. Increasing the capacity to 450 kWh increases this value to 89.9 % and 7 trucks, while a further increase to 650 kWh enables 96 % of tours and 10 trucks to be electrified. Nevertheless, one tour cannot be electrified due to long distance travelled and high loading.

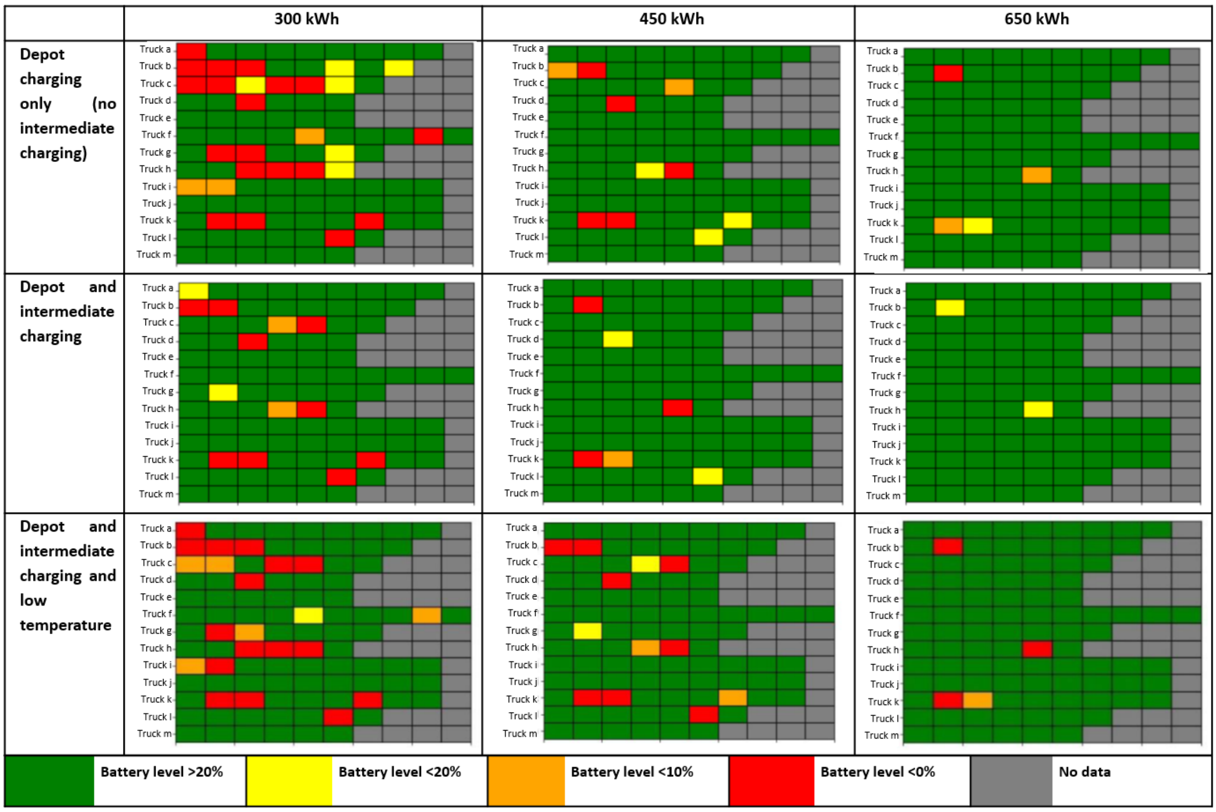

Figure 3: Overview of electrifiability of all vehicles and routes.
Each image represents one scenario and each row one vehicle.

In the second scenario "depot and intermediate charging", the electrification capability improves significantly. With a capacity of 300 kWh, the proportion of tours that can be electrified without risk increases to 87 % and 5 trucks. An increase to 450 kWh enables 94 % of all tours and 8 trucks to be electrified, while with 650 kWh almost all trips can be electrified (98 %). A comparison of the charging strategies shows that intermediate charging offers a decisive advantage, especially with smaller battery capacities: At 300 kWh, the electrification capability increases by 15 percentage points, while the effect is lower at 450 kWh (4 percentage points) and 650 kWh (2 percentage points). Additionally, both scenarios indicate that the non-electrifiability of certain trucks is primarily attributable to one or two specific routes.

The scenario with extreme temperature takes into account a 25 % reduction in battery capacity and a 17 % reduction in charging power. This significantly reduces the electrification capability. At 300 kWh, only 78 % of trips can be easily electrified (15 percentage points less than in the normal scenario). At 450 kWh, the proportion is reduced to 88 % (minus 6 percentage points), while at 650 kWh, 96 % of trips can still be electrified (minus 2 percentage points). In addition, more trips are classified as "high-risk" or "cannot be electrified" in this scenario.

In summary, the analysis shows that a combination of depot and intermediate charging significantly improves the electrification capability of the vehicle fleet, especially with lower battery capacities. In addition, electrification under extreme temperatures remains challenging, especially for energy-intensive tours. Additional charging stops were not taken into account, but could improve the electrifiability of some critical routes.

3.1.3 Sensitivities

The above analysis is based on several assumptions. Above all, the energy consumption per distance is decisive for the results. For this reason, a sensitivity analysis was carried out. The influence of the level of basic consumption, the load weight factor and the gradient factor on the overall result was examined. All three assumptions have a significant influence on the analysis result, but do not substantially change the pattern and direction of the results. Thus, the previously conducted analysis is not falsified by the consumption assumptions made, but even gains in accuracy, as the important factors of weight and gradient can be taken into account. Nevertheless, it can be discussed whether the influencing variables were chosen correctly.

3.1.4 Discussion

The technical potential analysis shows that the greatest electrification potential lies in night-time charging at the depot, while intermediate charging during stops and driving breaks offers a medium but still relevant potential. These assumptions were supported by a trip model: The majority of trips could be completed on a single battery charge. An intermediate charging solution increases the electrification capability by 15 percentage points with a battery capacity of 300 kWh. As the battery capacity increases, the benefit of intermediate charging decreases, as more tours can be covered anyway. The few critical tours that prevent electrification can usually be attributed to one or two outlier tours per truck. Restructuring could help here, for example through the targeted use of fewer vehicles with high battery capacity. At the same time, a capacity of just 300 kWh would be sufficient for 87 % of tours – possibly even less if tours were optimized.

Extreme weather conditions, especially temperatures below 0 °C, have a negative impact on range. Nevertheless, even under these conditions, 78 % of trips can be completed with 300 kWh. The remaining trips could be covered by higher battery capacities or additional charging points.

These findings are in line with existing research that confirms the technical feasibility of electrifying various fleet constellations [[1], [4], [3], [23]]. Nevertheless, uncertainties remain: The assumption that charging can take place at every break is not yet fully realistic. In the future, however, the charging infrastructure could also be expanded at smaller stops, especially if this generates economic added value. Furthermore, the results are based on two exemplary weeks, which do not allow seasonal fluctuations to be fully reflected. Longer tours in other periods may require higher capacities. The personnel costs for route planning, charging infrastructure management and driver training should also not be underestimated.

3.2 Economic Viability Analysis

3.2.1 Analysis

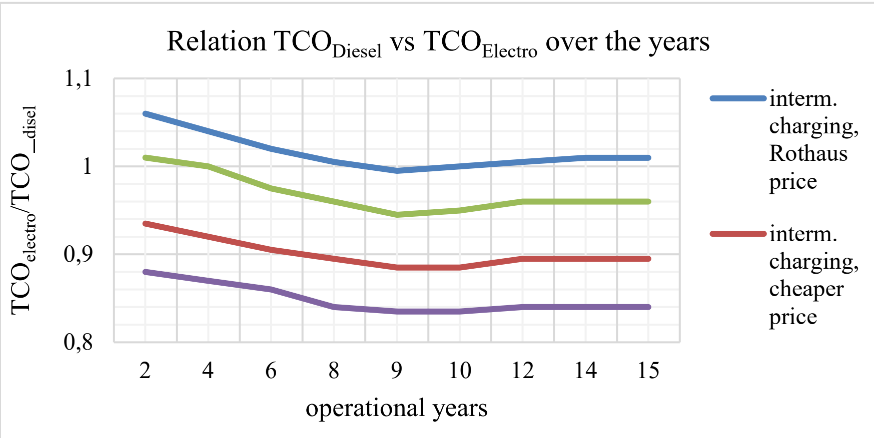

Figure 4: Ratio TCO$_{Diesel}$ vs. TCO$_{Electro}$, for different scenarios, both cumulated over the year interval, same residual value curve assumed, $y = \frac{TSO_{Diesel}}{TCO_{Electo}}$

In this techno-economic analysis, the total costs of a conventional diesel fleet are systematically compared with those of an electrified fleet. The largest cost factor for the electrified fleet is the vehicle purchase price, while the ongoing operating costs (especially fuel) account for a significantly larger proportion of the diesel fleet. The charging infrastructure, on the other hand, is of little economic significance. In the 9th year, there is a marked kink in the cost trend, as this is when the tax depreciation period ends. From this point onwards, the annual tax advantage decreases, which is noticeable for all scenarios and vehicles as well.

The graph illustrates the ratio of the TCO between the electric fleet and the diesel fleet. This ratio indicates the relative cost-effectiveness of the electric fleet values above 1.0 signify higher costs compared to the diesel fleet, while values below 1.0 indicate cost savings. Overall, the ratio is higher in the initial years but decreases progressively over time. However, the rate of decline slows down, which can be attributed to factors such as inflation, residual value trends, and interest rates. This implies that the economic advantage of the electric fleet becomes more pronounced over longer time horizons. In a scenario that includes intermediate charging and vehicle prices provided by the case study partner, the electric fleet is 1.06 times more expensive than the diesel fleet after two years. By year eight, the TCO of the electric fleet reaches parity with the diesel fleet, though it does not fall significantly below a ratio of 1.0 thereafter. Under more optimistic assumptions, using lower vehicle purchase prices derived from literature, the electric fleet is already more cost-effective from the outset, costing only 0.94 times as much as the diesel fleet initially, and decreasing to a ratio of 0.88 after nine years.

In a scenario without intermediate charging and with higher vehicle costs, the electric fleet reaches cost parity after four years, and by year nine, it costs 0.94 times as much as a comparable diesel fleet. With lower purchase prices, the results improve further: the TCO ratio is 0.88 after two years and decreases to 0.84 after nine years. The assumption of reduced vehicle purchase prices significantly enhances the economic viability of electrification, as the lower operating and maintenance costs associated with electric vehicles have a stronger impact.

However, under a more conservative assumption regarding residual values – where BETs retain the same absolute residual value as diesel trucks – the results are less favourable. In this case, for the higher vehicle prices paid by Rothaus, the electric fleet does not achieve cost parity within the analysis period. After 8 years it costs 1.2 and 1.3 as much as a diesel fleet. For scenarios with lower vehicle prices, cost parity is reached after six to eight years.

A look at the absolute total costs over time shows a similar picture: assuming realistically low vehicle prices, the difference in favour of the electric fleet increases steadily from the second year onwards. After eight years, the advantage is around €300,000, after 16 years around €500,000. With even more favourable vehicle prices, the difference even increases to €700,000. These differences represent a substantial economic relief. However, the analysis at vehicle level confirms that the benefits are not evenly distributed. Large 40 ton trucks with high utilisation and medium to long distances achieve the best results (e.g. vehicle “i”), while smaller vehicles with lower utilization (e.g. vehicle “m”) are less economically advantageous, even in the long term. The differences in the economic efficiency of individual vehicles amount to up to 50 percentage points. The electrification of trucks with low mileage and few days of use is particularly inefficient, despite having the same battery capacity as more economical vehicles.

The charging strategy is a key influencing factor. The comparison between the scenarios with and without intermediate charging shows that the scenario without intermediate charging is economically more favourable in almost all constellations. The relative difference here is between 0.86 and 0.98 times the costs with intermediate charging. The biggest difference can be seen in the ninth year, which in turn is due to the expiry of the depreciation period. After that, the difference flattens out. The strategy without intermediate charging is particularly profitable for large, heavily used vehicles (e.g. vehicle “f”), while it only brings limited benefits for some others. Overall, the analysis shows that electrification makes economic sense if suitable framework conditions are in place: low vehicle prices, adapted residual value models and an efficient charging strategy are crucial. Electrification pays off most for large vehicles with high utilization rates – smaller trucks, on the other hand, require careful consideration on a case-by-case basis.

3.2.2 Sensitivity Analysis

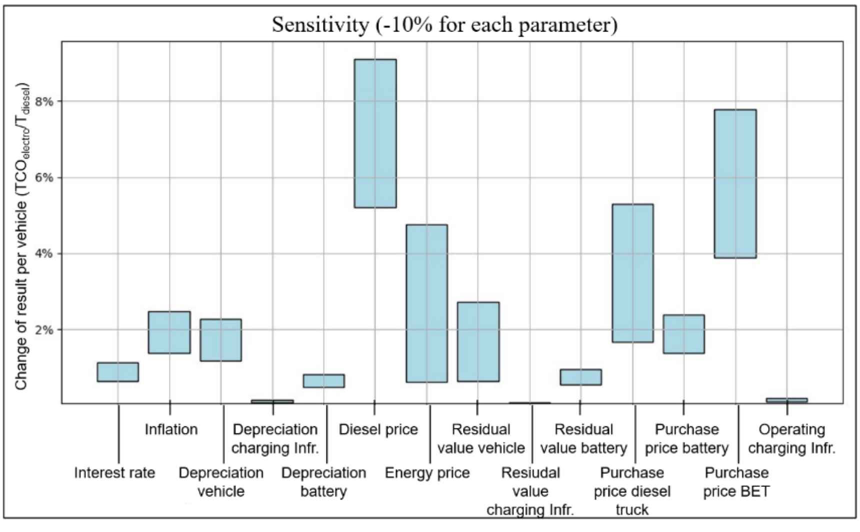

Figure 5: Graphical representation of the impact range resulting from parameter variation (multiplied by 0.9) for each vehicle.

The sensitivity analysis shows that the diesel price has the strongest effect on the overall result – a variation of 10 % leads to a deviation in the result of 5.2 % to 9.1 %, depending on the vehicle. This is followed by the e-truck purchase price (2.8 % to 7.8 %), the diesel vehicle price (1.7 % to 5.3 %) and electricity costs (0.6 % to 4.8 %). These four parameters show substantial effects with a wide range between individual vehicles. The residual value of the vehicles, inflation, depreciation and battery price cause moderate changes of 1 % to 2.5 %. The discount rate and residual battery value follow with around 1 %, while the charging infrastructure only has a negligible impact of around 0.1 %.

The influence of residual value assumptions should be particularly emphasised: An equal reduction in the residual values of both drive types shows only minor effects. However, if, as shown in earlier analyses, only the residual value of the e-trucks is modified – for example by assuming an identical absolute residual value instead of an identical percentage curve – the overall result changes by up to 20 percentage points. This underlines the central importance of plausible residual value forecasts for assessing the economic viability of electric heavy duty vehicles.

3.2.3 Discussion

The economic analysis of the electrification of the truck fleet of Badische Staatsbrauerei Rothaus AG shows that battery-electric trucks are financially worthwhile in the long term in most of the scenarios considered. Profitability increases with each additional year.

The useful life of the vehicles is a key influencing factor: At the end of an average service life of 8 years five out of 8 scenarios show an economic advantage for the electric fleet, one scenario is not in favour of diesel or electro and 2 scenarios see a clear disadvantage for the electrification. Low utilization and many intermediate charges significantly worsen the profitability. Smaller vehicles in particular are less economically advantageous to electrify, as the acquisition costs are higher in relation to the vehicle size.

A comparison of the charging strategies shows that exclusive charging at the depot is clearly economically superior. Depending on the vehicle type, it is 15 to 48 % cheaper than a strategy with intermediate charging. This is due to the lower electricity prices at the depot, which offset the higher costs for larger batteries and infrastructure. In addition, this strategy reduces dependence on public charging infrastructure – a relevant factor given the company's rural location.

An electrification strategy with depot charging, high capacity utilization and long vehicle use is therefore particularly profitable. Sensitivity analyses show that diesel prices and vehicle costs have the greatest influence. Both parameters are subject to uncertainty. Political measures such as a rising CO_2 price could additionally improve the economic efficiency of battery-electric trucks. It is also expected that the prices for battery-electric vehicles will fall as the market matures.

The purchase and operating costs dominate the economic efficiency – costs for charging infrastructure, on the other hand, are of secondary importance. These results are consistent with current studies that classify electrification as economically advantageous [[1], [4], [3], [23]]. Nevertheless, all calculations are based on numerous assumptions, particularly with regard to residual values and vehicle prices, which are associated with considerable uncertainties.

4 Conclusion

The electrification of heavy duty vehicles is considered a promising way to reduce emissions in road freight transport. This paper examines the techno-economic electrification potential of the fleet of a case study partner as part of a larger project for the market introduction of battery-electric trucks. For this purpose, a proprietary methodology was developed that takes into account political framework conditions, the state of the art and economic factors. After a description of the case study partner "Badische Staatsbrauerei Rothaus AG", a technical and economic potential analysis was carried out.

The analysis shows that the electrification of the majority of the fleet is both technically feasible and economically viable. Depending on the scenario, 71 to 87 % of the tours with a battery capacity of 300 kWh can be electrified, at 450 kWh it is 90 to 94 %, and at 650 kWh the proportion rises to 96 to 98 %. The technical analysis highlights the potential of night charging at the depot, while intermediate charging increases availability and reduces the required battery capacity. Intermediate charging can increase the share of drivable tours by 15 percentage points at 300 kWh. Efficient electrification is possible in particular by clustering the trips according to distance.

The economic analysis shows that electrification is particularly economical if charging primarily takes place at the depot and vehicle utilization is high. A strategy without intermediate charging incurs only 0.86 to 0.95 times the costs of a strategy with intermediate charging. After eight years, an electrified fleet costs depending on the scenario from 0.84 to 1.3 times as much as a diesel fleet, which can correspond to total savings of €300,000 to €400,000. The amortisation period is between zero and 8 years, with two scenarios not amortising at all. Diesel prices and the purchase costs of electric trucks in particular have a significant impact on profitability.

The analysis also highlights the uncertainties of many assumptions due to the market situation and the lack of stable framework conditions. Further research is needed to produce more reliable forecasts on vehicle prices, charging infrastructure, CO_2 prices and residual values. Reliable political framework conditions are also necessary in order to develop better models and provide transport companies with a sound basis for decision-making.

The results are specific to the fleet studied and should only be transferred to other companies with caution. Nevertheless, they provide valuable insights into the technical feasibility and economic viability of electrifying heavy duty vehicles.

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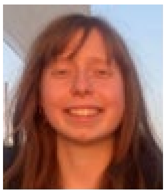
Presenter Biography



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