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# Showing the cost benefits for commercial electric vehicles — Case Study of Battery Electric Vehicles in Urban Food Distribution

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**Abstract**

This study investigates the viability of Battery Electric Vehicles (BEVs) for urban food distribution, aiming to transition commercial transport towards zero net greenhouse gas emissions. Utilizing Vehicle Routing Problems (VRPs) solved with jsprit and MATSim, it demonstrates that BEVs can be used sufficiently with comparable daily costs as when driving with Internal Combustion Engine Vehicles (ICEVs), highlighting their potential economic feasibility in the transition to sustainable transport. Further analyses explore emissions and economic scenarios to enhance understanding of BEVs adoption in commercial transportation.



*Keywords:* freight transport; electrification; vehicle routing problem; agent-based modelling; MATSim; battery electric vehicles

## 1. Introduction and Literature Review

At the *Conference of the Parties to the United Nations Framework Convention on Climate Change* in Paris 2015, the participating countries agreed to limit global warming to below 2°C above pre-industrial level (United Nations, 2015). In 2019, the European Commission agreed to the *European Green Deal* to achieve zero net Greenhouse Gas (GHG)by 2050. This translates into a target to reduce emissions from transport by 90% by 2050 (European Commission, 2019). Germany, like many other countries, has its *Climate Action Plan 2050*, which aims to reduce GHG emissions from the transport sector by 40% by 2030 compared to 1990 (BMUB, 2016). As no major savings have been achieved in the transport sector in the last few years, a reduction in GHG emissions of 48% by 2030 is currently required (BMWK,

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2022). As commercial vehicles are responsible for 37% of GHG emissions in the transport sector, their shift towards net-zero GHG is imperative (BMWK, 2022).

Recent studies show that for short- and medium-range heavy-duty transport applications, Battery Electric Vehicle (BEV) are the most promising technological option, offering the highest GHG reduction potential paired with lower operating cost and better efficiency than Fuel Cell Engine Vehicle (FCEV) (Syré et al., 2024). In earlier studies, limited range and long charging times have been the main issues with the electrification of freight transport, which were often mentioned as a reason for the necessity of hydrogen or electricity-generated synthetic fuels in this sector. However, recent studies come to different conclusions. Jahangir Samet et al. (2021) conduct an extensive study on the electrification of commercial vehicles of different sizes in Sweden and Finland and show an electrification potential of 20 – 90%, depending on the application, with currently available technologies. Also Martínez et al. (2021) show that electrification of freight transport in urban environments is possible based on the use case of parcel delivery. It can be assumed that with rapidly developing technology, full electrification of freight transport is already technically possible today, at least for short and medium ranges and in urban areas.

In contrast to private transport, the vehicle purchase choice for commercial transport is mainly driven by costs. This leads to the assumption that if different technologies are available to fulfill orders, the company will choose the most cost-effective one. This implies that if the total operating cost of BEV falls below that of Internal Combustion Engine Vehicle (ICEV), it will propel the technology to a breakthrough. This assumption is backed by a recent survey of 5 freight companies in Stockholm, which found that the already lower costs of electric trucks today represent a significant driver for the technology (Melander et al., 2022). However, in many recent studies such as Martínez et al. (2021); Jahangir Samet et al. (2021); Al-dal'ain and Celebi (2021), this factor has not been included.

Therefore, this study investigates the viability of BEVs for urban food distribution, using currently available vehicles and including a total operating cost analysis. The use case is the supplying of supermarkets in Berlin, the capital of Germany. We present an update of an earlier study by Ewert et al. (2021), in which the restricted range was one issue preventing a complete transition towards net-zero GHG. The study from 2021 indicated that the most cost-effective solution without any additional carbon dioxide ($CO_2$) taxes was to use ICEVs for the majority of the tours and only a few BEVs (fleet: 246 ICEVs and 43 BEVs). Also with a $CO_2$ tax of €300/t$CO_2$, the number of BEVs only increased to 214 with a remaining fleet of 96 ICEVs. In this study, we aim to examine the impact of recent improvements in vehicle technology and battery sizes, as well as changes in energy and fuel prices, on previous findings.

## 2. Methodology

An essential part of the study is the solution of Vehicle Routing Problems (VRPs) and thus the fulfillment of all necessary orders with the available vehicles. The VRP is solved for a single day, representing an average workday. The open-source tool jsprit (jsprit, 2018) is used to solve the VRP. The algorithm in jsprit tries to minimize the costs of the complete fleet, while fulfilling all orders and respecting all constraints. This involves all restrictions of each vehicle type, such as the maximum range of the BEVs, the maximum payload, and the maximum working time of the drivers. Time and distance-dependent costs of the vehicles are considered, as well as a fixed costs component per vehicle used. The solution of the VRP is a set of tours, each assigned to a vehicle of a specific type. To ensure realistic tours, the algorithm is run with up to 10.000 iterations.

Using the existing integration of jsprit into the open-source multi-agent simulation Multi-Agent Transport Simulation (MATSim) (Horni et al., 2016), the VRP is solved based on routing on a network, ensuring consideration of traveled distances. In the present study, recharging during the day is not possible, and the vehicle type specific maximum range is enforced as a range constraint when solving the VRP of the BEVs. This offers the advantage that charging infrastructure is only needed at the depot, which is a common setup in practice for short- to medium-range applications (Speth and Plötz, 2024).

## 3. Case Study: Urban Food Distribution

The study is based on a case study of the distribution of food retailers in Berlin (Schröder and Liedtke, 2014; Gabler et al., 2013). Compared to the previous studies of this case study, we do not change all demand related parameters (e.g., number of deliveries, locations of supermarkets and depots). The changes are only in the vehicle types and the energy prices.

| | **Light 7.5 tons** | | **Medium 18 tons** | | **Heavy 26 tons** | | **Heavy 40 tons** | |
|---|---|---|---|---|---|---|---|---|
| | EV 1 | EV 2 | EV 3 | EV 4 | EV 5 | EV 6 | EV 7 | EV 8 |
| Battery Capacity* (kWh) | 124 | 148 | 300 | 395 | 375 | 448 | 336 | 624 |
| Consumption (kWh/100km) | 85 | | 100 | | 113 | | 150 | |
| Range** (km) | 146 | 174 | 300 | 395 | 332 | 396 | 224 | 416 |
| Total price (€) | 79.168 | 143.900 | 218.823 | 243.395 | 190.841 | 304.107 | 322.921 | 344.271 |

Table 1: Basic vehicle type specifications of the possible BEVs. For each vehicle category, two vehicle types with different battery capacities (and ranges) are available: ODD numbers: medium, EVEN numbers: large; *usable, **calculated, vehicle types based on market available vehicles, values based on (ifeu, 2024) and own calculations

*Vehicles.* In comparison to past studies (e.g. Martins-Turner et al., 2020; Ewert et al., 2021), the current study integrates currently available BEVs to examine the effects on the resulting vehicle choice. In total, eight different vehicle specifications are available in the simulation. Each vehicle class (7.5t, 18t, 26t and 40t maximum gross weight) includes two vehicle types: A cheaper one with a medium-sized battery and a more expensive one with a larger battery size. The electric vehicle types used are shown in Table 1. We assume that the battery size is designed in a way that both BEVs and ICEVs have the same payload capacity. The cost values of ICEVs are used from the past study, since the prices have hardly changed.

*Energy Prices and charging infrastructure.* For the present study, we use energy prices from 2024 for electricity and diesel. This leads to a price for commercial customers of € 0.18/kWh for electricity and € 1.55/l for diesel (Gnann et al., 2024). Because the energy prices are very volatile, we used an optimistic diesel price estimation for this study to ensure that the results are robust. In Section 5 we will also show the results for different energy prices, including a significant increase in the diesel price in the coming years (Gnann et al., 2024).

For the BEVs, we assume that the charging infrastructure has to be set up at the depots of the food retailers. No intermediate fast charging at supermarket locations or public areas is assumed. We provide one 50kW charging station for each BEV. This is sufficient to charge the vehicles during the night, as the vehicles are only operated during the daytime and have at least 12 inoperational hours at night. The costs for each charging station is € 26.200 (ifeu, 2024) and we assume that the charging station is used for 16 years on 250 workdays per year. This results in a daily cost of € 6.55 and an annual cost of € 1.638 per vehicle.

*Scenarios.* The **Base Case** is the scenario where only ICEVs are available to fulfill the orders. In the **Policy Case** BEVs and ICEVs are available. In this case, the algorithm can choose between the ICEVs and the two BEVs options (medium or large battery) for each vehicle category.

## 4. Results

Comparing the simulation outputs from the base with the policy case, leads to the following results.

### 4.1. Tour characteristics and costs

Table 2 shows the overall costs and Vehicle Kilometer (*vkm*) for the base and the policy case. These costs are calculated for the total fleet, including fixed and variable costs for the driver, the consumption and the charging infrastructure for each BEV. In general, both cases are similar in terms of the overall costs for the total fleet operation € 86.814 vs. € 84.826 and for the daily *vkm* driven: 36.198 vs. 36.709.The number of vehicles used is lower in the policy case compared to the base case. This is most probably due to the higher fixed costs per BEV compared to the same sized ICEV, so the algorithm finds a solution with fewer vehicles.

Figure 1 shows the *vkm* for each vehicle. In the base case only ICEVs are available. In the policy case, many of the tours are operated with BEVs (see also Table 2). Moreover, BEVs are also used for long tours up to approx. 400 km. For the larger vehicles with a permissible total weight (in tons) (PTW) of 26 or 40 t , the ICEVs are used for a small number of short tours – presumably, the tours are so short that the larger fixed costs of the BEVs are not recovered. For the small vehicles (7.5 t PTW) ICEVs are used for the longer tours due to their limited maximum range with the small battery.

| | **ICEVs** | | **BEVs** | | **Total** | | **Costs** |
|---|---|---|---|---|---|---|---|
| | Number | Distance (km) | Number | Distance (km) | Number | Distance (km) | (€) |
| Base Case | 272 | 36.198 | 0 | 0 | 272 | 36.198 | 86.814 |
| Policy Case | 14 | 1.451 | 243 | 35.258 | 258 | 36.709 | 84.826 |

Table 2: Number of vehicles and driven kilometers per vehicle type in the base and policy case. The costs are calculated for the total fleet, including, fix, variable costs for the driver and the consumption and the charging infrastructure.

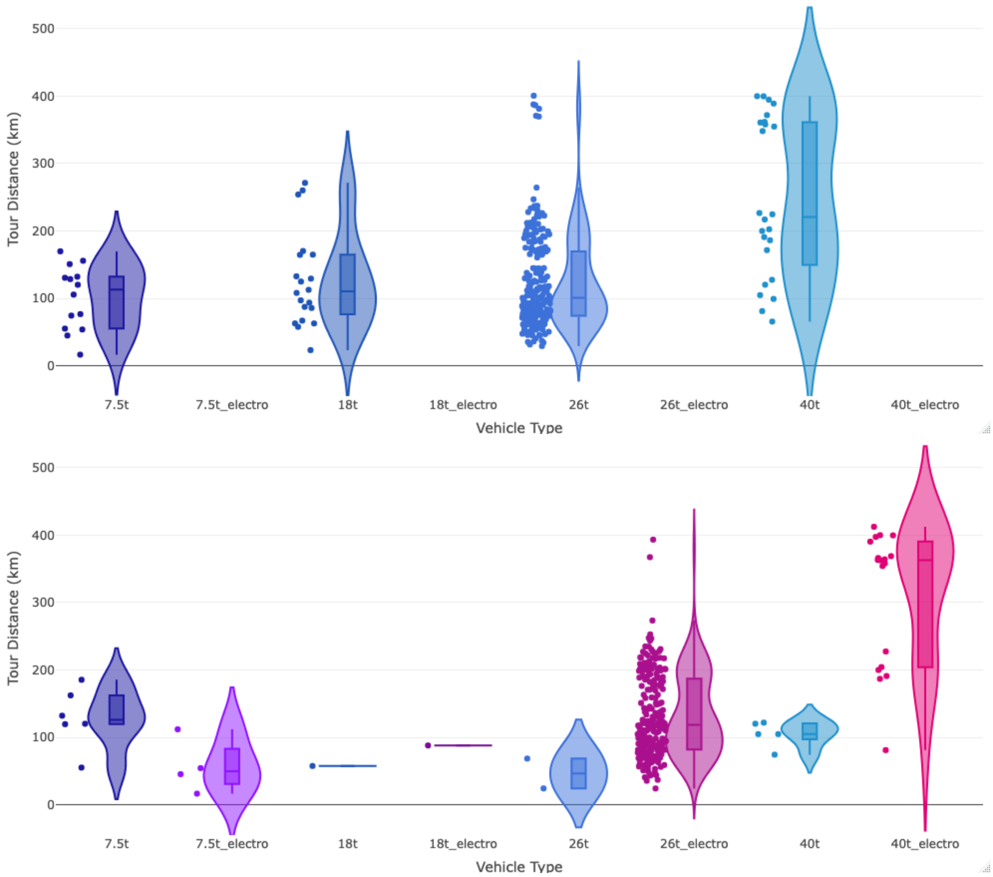



Fig. 1: Vehicle kilometers travelled per vehicle tour differentiated by vehicle type. Each dot stands for one vehicle tour; TOP: Base case with only ICEVs available. BOTTOM: Policy case with ICEVs and range restricted BEVs.

### 4.2. *Emissions during operations*

In Table 3 aggregated emission values are given for selected emission components. They are calculated by using the Handbook on Emission Factors for Road Transport (HBEFA) database, and thus only consider the direct emissions from operating the vehicles. To calculate the annual values, 250 workdays/year are assumed (Planco et al., 2015). Summarized, the different exhaust emissions are reduced by approx. 96%. Vehicles also cause other, so-called *non*-exhaust, air pollutant emissions such as particular matter < 10$\mu m$ ($PM_{10}$), particular matter < 2.5$\mu m$ ($PM_{2.5}$) or black carbon ($BC$), while driving. They arise from the degradation of brakes, tires, and road surfaces, as well as the re-suspension of road dust. (Grigoratos and Martini, 2014; INFRAS, 2019). As a consequence, even if most tours are driven by BEVs, only approx. 19% of $PM_{10}$, approx. 36% of $PM_{2.5}$, and approx. 73% of $BC$ emissions are saved.

Table 3: Aggregated emissions of selected emission components from vehicle operations in kg per year. All values are calculated, using the HBEFA database. Some components are only exhaust emissions from the combustion process, e.g., carbon dioxide ($CO_2$), while other components also have a non non-exhaust source, e.g., $BC$.

| Emissions component | | Base: only ICEV | Policy: ICEV and additional BEV |
|---|---|---|---|
| particular matter < 10$\mu m$ ($PM_{10}$) | (kg/year) | 1 445 | 1 164 (- 19.4%) |
| particular matter < 2.5$\mu m$ ($PM_{2.5}$) | (kg/year) | 804 | 512 (- 36.3%) |
| black carbon ($BC$) | (kg/year) | 210 | 57 (- 72.9%) |
| nitrogen oxides ($NO_x$) | (kg/year) | 17 633 | 671 (- 96.2%) |
| carbon monoxide ($CO$) | (kg/year) | 6 386 | 254 (- 96.0%) |
| carbon dioxide ($CO_2$) | (kg/year) | 5 910 350 | 217 947 (- 96.3%) |

### *4.3. Well to wheel emissions*

To analyze the environmental impact of the simulated scenarios, GHG emissions from the production of diesel and electricity as well as from their use in the vehicles are estimated following the Well-to-Wheel (W2W) methodology JRC et al. (2014). Unfortunately, HBEFA does not (yet) provide differentiated energy consumption values for BEV above 12t. In this study, three out of four used vehicle sizes are larger than that. As a consequence, it is not possible yet to base a meaningful Well-to-Wheel (W2W) analysis on glshbefa. Therefore, the energy consumption per vehicle type is calculated by multiplying the $vkm$ driven with an average diesel or electricity consumption. The resulting energy consumption is then multiplied with the W2W emissions factors. The diesel consumption for the ICEVs were extracted from Planco et al. (2015) and goes from 13.57 l/100 km for trucks with a PTW of 7.5 t up to 37.45 l/100km for the trucks with a PTW of 40 t. The vehicle type-specific energy consumption for the BEVs is between 85 and 150 kWh/100km (see Table 1). Three different emission factors were used to show the effects of electrification, depending on from the electricity production. For calculating the per year emissions, 250 workdays/year are assumed (Planco et al., 2015). The following factors are assumed to calculate the W2W GHG emissions from *electricity* production Syré et al. (2024): 490 g $CO_2eq$/kWh in 2023, 251 g $CO_2eq$/kWh in 2030, and 94 g $CO_2eq$/kWh in 2050. For *diesel* 3 170 gCO2eq/l diesel is assumed DIN EN 16258:2012 (2013).

Combining these factors leads to the vehicle type-specific W2W emission factors (in carbon dioxide equivalents ($CO_2$)) per $vkm$ provided in Table 4. It also shows that the footprint of a BEV fleet changes over time, along with the changes in the energy production, while for ICEV it remains stable as long as there is no significant amount of synthetic diesel available for trucks.

Table 4: Well-to-Wheel (W2W) emissions factors per 100 Vehicle Kilometer ($vkm$). For the BEVs, three different values are computed, based on the (assumed) electricity production in 2023, 2030 and 2050

| | W2W factor [kg $CO_2eq$ / 100 km] | | | |
|---|---|---|---|---|
| Vehicle type | ICEV | BEV 2023 | BEV 2030 | BEV 2050 |
| 7.5 tons | 43.02 | 41.65 | 21.34 | 4.17 |
| 18 tons | 104.99 | 49.00 | 25.10 | 4.90 |
| 26 tons | 104.99 | 55.37 | 28.36 | 5.54 |
| 40 tons | 118.72 | 73.50 | 37.65 | 7.35 |

*Results.* We can observe a reduction of the W2W emissions from approx. 9 500 t $CO_2eq$/year using ICEVs to approx. 5 400 t $CO_2eq$/year (-43%) by adding BEVs and assuming electricity production in 2023. Assuming the expected German electricity production in 2030, approx. 2 900 t $CO_2eq$ /year (-70%) were emitted with when adding BEVs. With the expected German electricity production in 2050, the GHG emission would decrease to approx. 792 t $CO_2eq$/year (-92%) (see Figure 2).

## 5. Sensitivity Study

The energy costs for the future will most probably not be stable and challenging to forecast. Therefore, we are providing in the following a sensitivity study as already mentioned in Section 3. We run several other simulations with the combination of a diesel price and an energy price of representing different years. The general idea is that the diesel price per liter will significantly increase over time (2024: € 1.55; 2030: € 1.78; 2050: 3.2). For electricity, we assume two different price schemes per kWh: a higher (2024: € 0.24; 2030: € 0.21; 2050: 0.21) and a lower one (2024: € 0.18; 2030: € 0.18; 2050: 0.18) (Speth and Plötz, 2024). All other settings and values remain unchanged. Summarized, the sensitivity study starts from the case study from above, supplemented by a scenario with a lower estimated price for electricity. Additionally, we assume a linear increase of all energy prices between the given values over the years. In this following, we differentiate between two types of sensitivity cases:

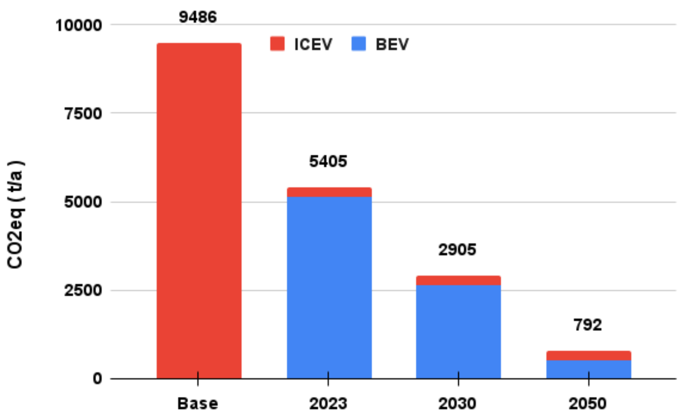



Fig. 2: Calculated W2W emissions per year. For the policy case with the BEVs, three different electricity mixes are assumed (year 2023, 2030, and 2050).

- **Development of fleet costs over the years**: In this case, we assume that in year 2024 the decision about the fleet composition is made. The base of this decision is the most cost-effective solution based on the different scenarios of the energy prices. For the following years, we use different energy prices, as described before. But we will not change the fleet composition. The results are shown in Figure 3 and Figure 4.
- **Different decision points for the fleet composition**: In this case, we investigate the different fleet compositions based on the different energy prices for 2024, 2030, and 2050. The results are differentiated by the year in which the decision is made, but can also be interpreted as a sensitivity analysis for the development of the energy prices. The results are shown in Figure 5.

The results of all sensitivity cases indicate that the most cost-effective solution is to use BEVs for the majority of the tours, and that the cost advantage of the BEVs increases in the future. The main results are:

- In 2024 only the scenario with the higher electricity price is more expensive than the base case with ICEVs. In all following years, all scenarios with BEVs and ICEVs are less expensive than the base case with only ICEVs (see Figure 3).
- The cumulated advantage of the mixed fleets until 2050 is at least € 57 million (-9%) compared to the base case with ICEVs (see Figure 3).
- The share of the charging infrastructure costs is marginal for the BEVs (see Figure 4).
- The consumption costs for the ICEVs will increase significantly over the years, while the consumption costs for the BEVs stay stable (see Figure 4, Figure 5b).
- Under the given energy prices for 2030 and 2050, the remaining fleet of ICEVs will be reduced more and more (comparable ratio to the driven kilometers, see Figure 5a).

## 6. Conclusion and Outlook

The findings from this study underscore the significant potential of Battery Electric Vehicles BEVs for urban food distribution as one example for the small-scale delivery with trucks in urban areas. The results demonstrate that BEVs can achieve cost benefits with Internal Combustion Engine Vehicles ICEVs for daily operations under certain conditions. This is particularly true given recent advancements in vehicle technology, increased battery sizes, and the assumptions of the energy and diesel prices in the future. Additionally, the environmental benefits of transitioning to BEVs align with broader goals of reducing greenhouse gas (GHG) emissions as part of global climate action commitments.

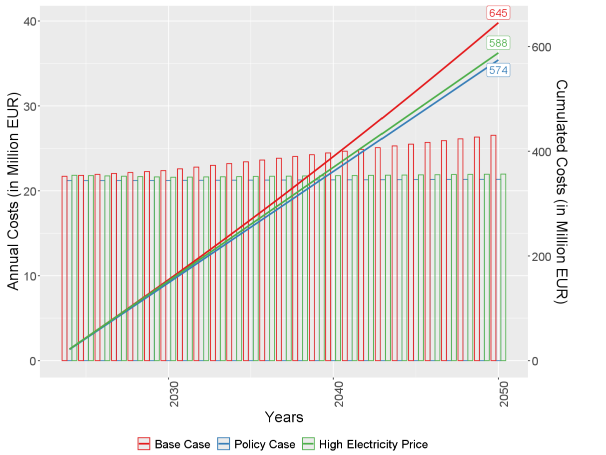



Fig. 3: Annual total costs per scenario for the different years. The results are based on the most cost-effective solution fleet for a scenario in year 2024 and an assumed energy price for the following years. The bars show that annual costs for each year (left y-axis) and the lines show the cummulated costs (right y-axis).

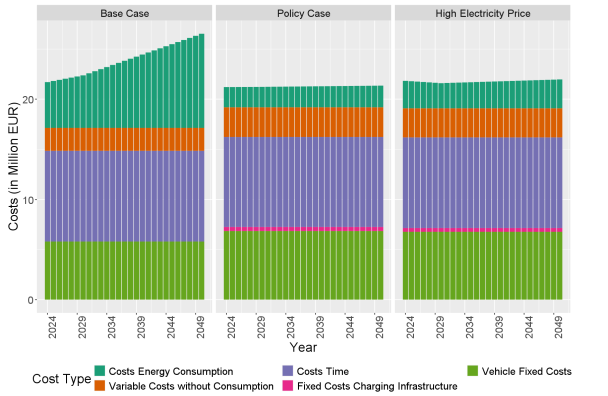
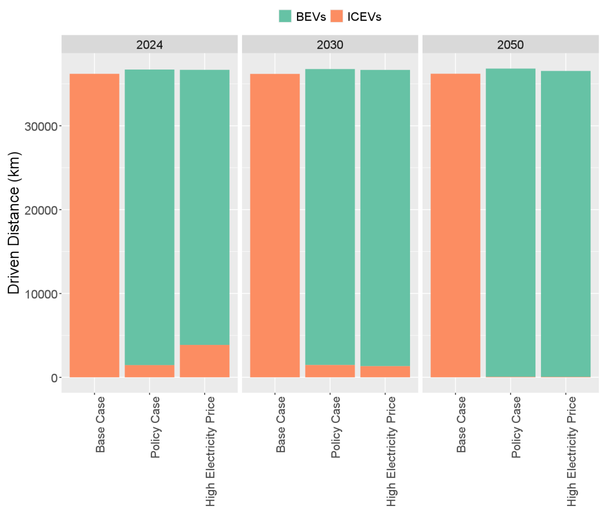


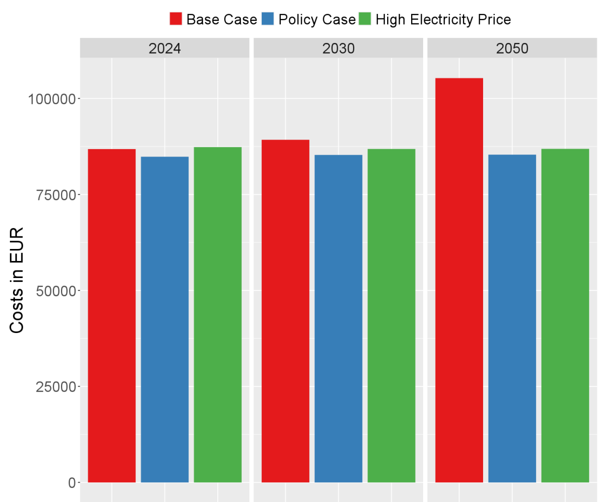

Fig. 4: Annual costs per cost type per scenario. The results are based on the most cost-effective solution fleet for a scenario in year 2024 and an assumed energy price for the following years.

However, the study also highlights some challenges that need to be addressed. The restricted range of BEVs, although improving, still poses limitations for longer routes or routes with higher variability in daily patterns. Additionally, the necessity for adequate charging infrastructure, primarily at depots, remains a critical factor for the successful deployment of BEVs in commercial fleets. So, we need to give companies the right conditions so they can start to invest in their charging infrastructure.

In conclusion, while challenges remain, the outlook for BEVs in urban food distribution is promising. Continued technological, infrastructural, and policy advancements will be key to realizing the full potential of BEVs and achieving significant reductions in urban transport emissions.




(a) Daily driven distance per scenario




(b) Daily total costs per scenario

Fig. 5: Comparison of the driven distance and the costs used in the base case with ICEVs and the policy cases with BEVs. The results are based on the most cost-effective solution for a simulation with the assumed energy prices for the corresponding year.

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