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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 net-zero 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 net-zero 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, 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).

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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 transport tasks, the company will choose the most cost-effective one. This implies that if the total operating cost of BEVs falls below that of Internal Combustion Engine Vehicles (ICEVs), 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. Our approach is based on the methodology described in Göhlich et al. (2021). The use case is the supply 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 (corresponding to ca. €0.95/liter diesel), 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 capacity, 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 different vehicle types are considered, as well as the specific fixed costs component per vehicle used. The fleet size and mix is not a given, but part of the VRP. Taking all these aspects together, a separate *Capacicated Vehicle Routing Problem with Fleet Size and Mix and Time Window (CVRPFSMTW)* is solved for each carrier. The solution of each 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 transport 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).

	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. 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 the ICEVs are taken from the past studies since the prices have hardly changed (48,475 / 86,200 / 96,900 / 93,000 EUR for the four weight classes).

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 a rather low 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 twelve 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 kilometers (*vkm*s) 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. and for the daily *vkm* driven. 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 but larger vehicles.

Figure 1 plots 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, some ICEVs are used for short tours. This comes that the ICEVs have lower fixed costs, but higher variable costs per km compared to the BEVs, so they are economically beneficial on short trips. 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. All values refer to one simulated (average) day.

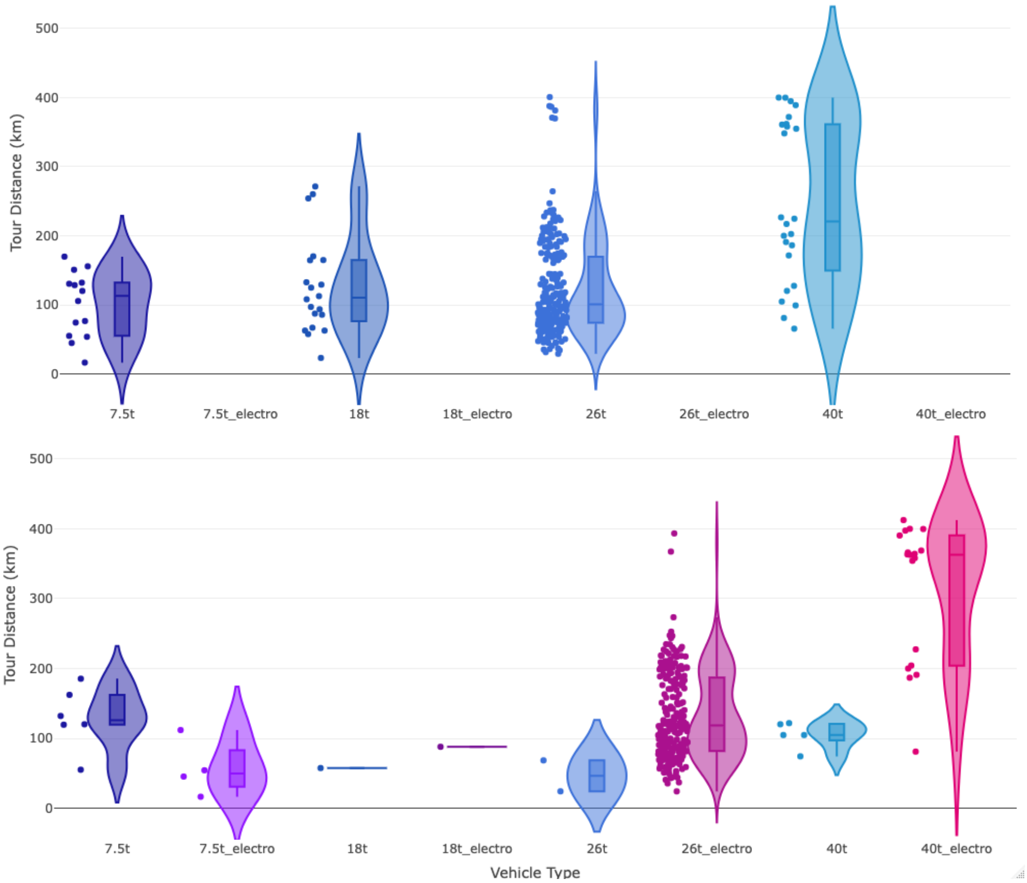


Fig. 1: Vehicle kilometers travelled per vehicle tour differentiated by vehicle type. Each dot stands for one vehicle tour; TOP: Base case with only ICEVs available. BOTTOM: Policy case with ICEVs and range restricted BEVs.

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. The distances and traffic conditions as well as the road categories for the individual vehicles on the individual links were taken into account for the calculation. The traffic states on the individual links were determined by means of the vehicle-specific travel time on the links. The calculation method itself for HBEFA emissions with MATSim is described in detail in Kickhöfer (2016); Hülsmann et al. (2011). For an improved calculation of Heavy Goods Vehicles (HGV) emissions, see also Gable et al. (2022). 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 particulate matter $< 10\mu m$ (PM_{10}), particulate 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,

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. Electricity generation is assumed to be CO_2-free, but some CO_2 emissions remain because some of the tours are still undertaken by ICEVs.

Emissions component		Base: only ICEV	Policy: ICEV and additional BEV
particulate matter < 10μm (PM_{10})	(kg/year)	1 445	1 164 (- 19.4%)
particulate matter < 2.5μm ($PM_{2.5}$)	(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%)

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.

4.3. Well to wheel emissions

To analyze the environmental impact of the 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, as of now it is not possible to base a meaningful W2W analysis on HBEFA. 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 the year of 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 2021, 251 g CO_2eq/kWh in 2030, and 94 g CO_2eq/kWh in 2050. For *diesel* 3 170 g CO_2eq/l diesel is assumed (DIN EN 16258:2012, 2013).

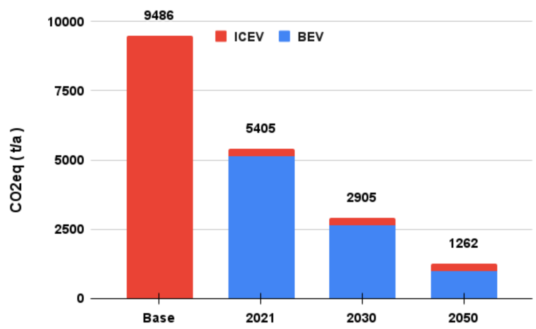


Fig. 2: Calculated Well-to-Wheel (W2W) emissions per year. For the policy case with the BEVs, three different electricity mixes are assumed (year 2021, 2030, and 2050).

Table 4: Well-to-Wheel (W2W) emissions per 100 vehicle kilometer (*vkm*). For the BEVs, three different values are computed, based on the (assumed) electricity production in 2021, 2030 and 2050.

	W2W emissions [kg CO_2eq / 100 km]			
Vehicle type	ICEV	BEV 2021	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

Combining these factors leads to the type-specific W2W emission factors (in CO_2 equivalents (CO_2eq)) 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.

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 2021. 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 studies above were run with constant diesel and electricity prices of € 1.55/l and € 0.18/kWh. This leads to savings through the electrification of € 1988 per day (cf. Table 2), or € 497,000 per year, or approx. € 13 millions from 2024 until 2050. This result is also shown in Figure 3 as the comparison of the scenarios "ICEVs - constant diesel price (2024)" and "ICEVs, BEVs - constant energy prices (2024)". We now first consider how this changes if diesel prices increase over time, as might be expected from carbon pricing (2024: € 1.55; 2030: € 1.78; 2050: € 3.2 (Gnann et al., 2024), and linearly interpolated in between. The results can be seen under "ICEVs - diesel price increase" compared to "ICEVs, BEVs - low energy price" ("ICEVs, BEV" = BEVs allowed) in Figures 3 and 4; also in the "ICEVs, BEVs - low energy price" case, annual costs increase over time because of the few remaining diesel tours. The resulting savings through electrification are now approx. € 645 mio – € 574 mio = € 71 mio. The costs for charging infrastructure for the BEVs are included, but its share to the total costs is only marginal (see Figure 4). As a final test, we also consider higher electricity prices (2024: € 0.24; 2030: € 0.21; 2050: 0.21) (Gnann et al., 2024). The results are the "ICEVs, BEVs - high energy price" curves in Figures 3 and 4. If at the same time, diesel prices remained constant, the ICEV-only and the BEV-allowed case ("ICEVs, BEVs - constant energy prices (2024)") would end up with the same cumulated costs; if diesel prices increase over time as assumed above, the BEV-allowed case would save approx. € 645 mio – € 588 mio = € 57 mio. For all of these computations, the fleet composition remains the same as decided in the initial year.

A second analysis recomputes the optimal fleet composition in the years 2024, 2030 and 2050 under the influence of dynamic prices. The results are shown in Figures 5a and 5b. All cases contain the increasing diesel prices as defined above; the "ICEVs - diesel price increase" corresponds to ICEVs-only, the "ICEVs, BEVs - low energy price" to BEVs-allowed, and the third case "ICEVs, BEVs - high energy price" has BEVs-allowed but higher electricity prices. One finds in particular that the increasing diesel prices drive out the remaining ICEVs from the fleet, but that higher electricity prices delay this process. In terms of daily total costs (Figure 5b), the dynamic diesel prices mean that in 2050 the electrification has a clear cost advantage, while in 2024 and 2030 the differences are less pronounced.

The cost advantages of electrification were already present, but only minimal in the results (see Section 4). The sensitivity analysis clearly shows that the advantages of electrification become significant and relevant to the decision as soon as a) the electricity price becomes cheaper or b) the diesel price becomes more expensive over time.

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 already today can achieve cost benefits when compared to 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.

However, the study also highlights some restrictions that need to be addressed. In particular, the limited range of BEVs, although improving, still poses restraints for longer routes; also, the difficult-to-predict development of energy prices is a challenge, in particular given the much larger initial investment cost for BEVs.

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.

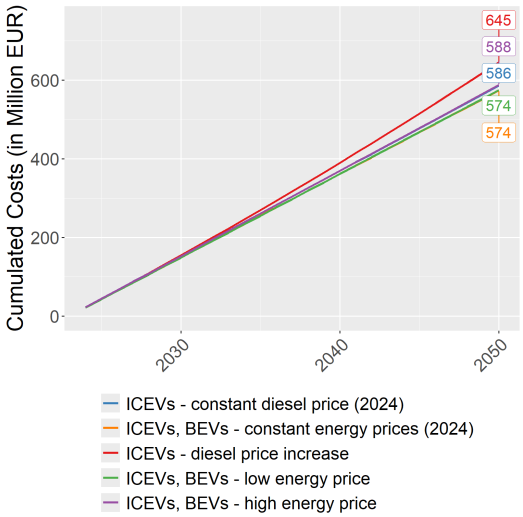


Fig. 3: Cumulated costs per scenario until 2050. The results are based on the most cost-effective solution fleet for a scenario in year 2024. For the scenario with constant energy prices with a mixed fleet the low electricity price for 2024 is assmued.

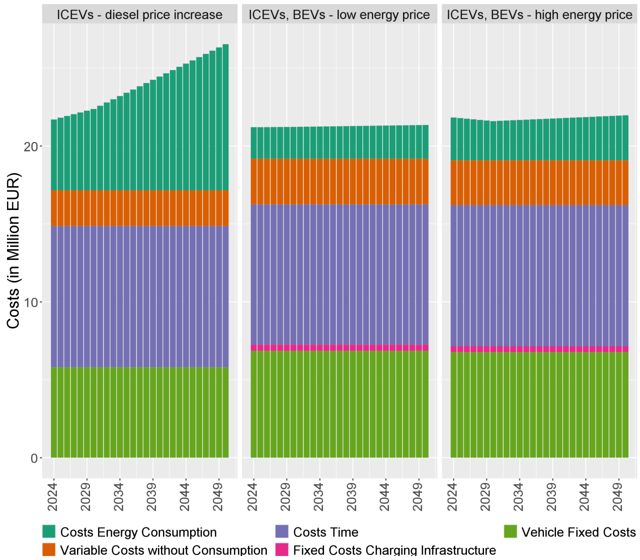
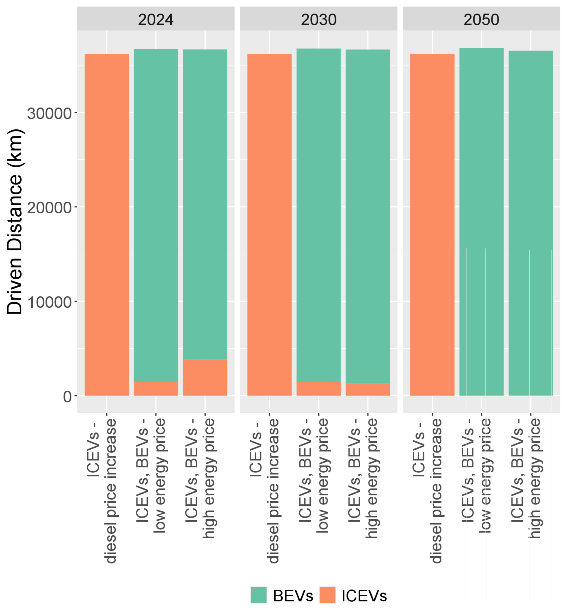
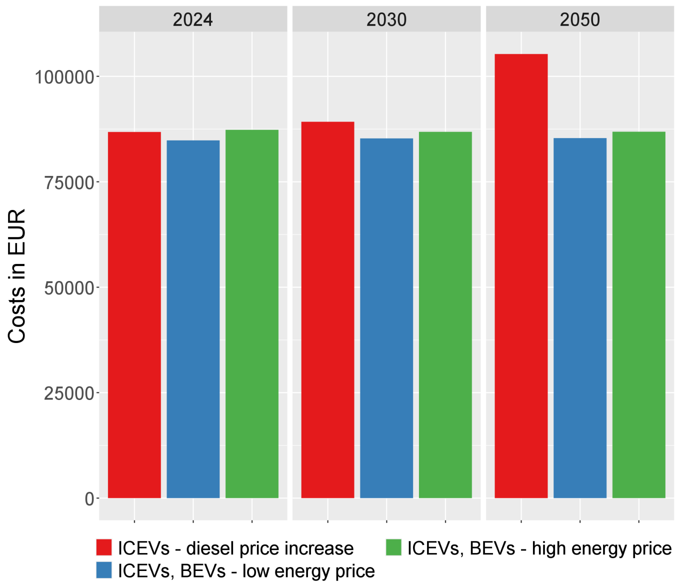


Fig. 4: Annual costs per cost type. The results are based on the most cost-effective solution fleet for a scenario in year 2024 and an assumed energy price for the following years.



(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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