Parametric Modelling of Cost arising from the Production, the Operation and the Recycling of Vehicles

Conference on Future Automotive Technology: Focus Energy Storage

Stephan Fuchs[1], Jonas Laubmann[2], Markus Lienkamp[1]
[1]Institute of Automotive Technology, Technische Universität München
[2]Student at the Technische Universität München

***Abstract*—The production costs of battery electric vehicles (BEV) determine their success or failure on the market. Even for conventional internal combustion engine vehicles (ICEV), vehicle costs are becoming increasingly important due to higher cost pressure. With rising fuel prices over the years, the operating costs of vehicles have been increasing. But so did the cost sensitivity of the customer at the same time. The real costs of BEV and ICEV can be compared only by examining the life cycle of the vehicle, since the production costs of BEV are, due to the currently high battery costs, significantly more expensive than those of ICEV.**

In order to evaluate vehicle designs already in the early stage of the development process, a parametric weight model [1] was developed. A supplementary cost analysis tool (CAT), which is presented in this article, enables to estimate the production, operation and recycling costs and to include them in a design assessment. By linking the CAT to the weight model, it can account for secondary mass effects of lightweight construction measures. Thereby, the CAT allows us to determine the effects of lightweight construction on the vehicle production costs, usually increasing costs. However, in case of consumption savings, the CAT enables us to compare the life-cycle costs as well.

Keywords—Total Cost of Ownership, Battery Electric Vehicle, BEV, Internal Combustion Engine Vehicle, ICEV, Life Cycle Costing, LCC

I. MOTIVATION

Most customers buying a vehicle primarily consider the acquisition costs and the fuel consumption for their purchase decision. Especially for mass-market vehicles, there is strong cost pressure. For those vehicles a positive profit margin is usually generated only through optional extras [2]. Independent of the type of vehicle and the vehicle segment, extras are very lucrative. In contrast, there are always vehicles that can only be offered at a competitive price by having a negative contribution margin. The Toyota Prius has only been sold profitably since the third generation model [3]. The Audi A2 with its costly aluminium body was sold at an estimated loss of 7,900 EUR per vehicle [4]. At the current price one can assume that BEVs cannot be sold for profit. Thus, the costs of new technologies lead to a negative profit margin, at least in the beginning. According to estimations of industry analysts and manufacturing experts, General Motors is selling the Chevrolet Volt with a loss of 49,000 USD per vehicle [3]. For the customer, nevertheless, a Volt is a costly purchase at 30,000 USD. To still be able to operate a BEV or hybrid electric vehicle economically, the high purchase cost must be amortized through lower operating costs.

Determining the costs of a vehicle over its life cycle requires a holistic analysis of all cost factors. Here the Total Cost of Ownership (TCO) is the right approach. However, there are very few customers who wonder about the true TCO of their future vehicle.

Not only for the consumer but also for the automotive manufacturer (OEM, Original Equipment Manufacturer), it would be beneficial to be able to calculate the costs of a vehicle quickly and easily. The methods OEMs use today to calculate the costs with high precision require a great deal of information and knowledge of various parameters. The "Clean Sheet Solution", as an example, can determine the manufacturing cost of a product very accurately. All parameters of the production costs, including each production step, are included in this calculation. This makes the modelling process very time intensive. Also, all parts must be known. The cost analysis tool (CAT) allows OEMs to assess the costs – especially the production costs – with far fewer parameters, even in the design exploration phase. Thus, CAT supports decision-making, especially a decision between different designs. In addition, the influence of design changes and lightweight design – including secondary mass effects – on the life-cycle costs can be estimated.

[5] presents a calculation tool for a vehicle body made from high-strength steel grades only. This model calculates the production costs of a vehicle structure at a very high level of detail. However, it is not possible to vary the body material or change the vehicle form.

Easier methods have their limitations when it comes to the entire vehicle costs and the general application of the method. A holistic methodology to estimate the life-cycle costs of a vehicle with only a few parameters is not known by the authors at the present time.

II. APPROACH OF TOTAL COST OF OWNERSHIP

The term Total Cost of Ownership was originally introduced by the management consultancy Gartner Group, who were commissioned by Microsoft to determine the life-cycle costs of a computer system [6].

To calculate TCO, all costs incurred by the user over the life of the product are taken into account. In the world of cars, the TCO can differ from the perspective of the user or of the product itself. In the user perspective, a resale of the vehicle occurs after a certain holding period. The resale value will be credited to the customer. The product perspective includes the user perspective of all users and also entails the recycling of the vehicle. In the case of a vehicle purchase and a holding period until the disposal of the vehicle, the product and the user perspectives are identical.

The approach of TCO provides the user with one key figure, a monetary value. By comparing this figure across various vehicle designs, life-cycle costs can be accounted for in design decisions in the development process.

III. APPROACH OF PARAMETRIC COST ESTIMATION

Figure 1 illustrates the structure of the CAT. The TCO of a vehicle is split into the costs of production, operation and recycling. In the case of a vehicle resale, the residual vehicle value is taken into account instead of the recycling costs.

FIGURE 1

The cost of each vehicle component depends on its weight and material. For example, the structure of a larger vehicle requires more material, and the type of material determines a large part of the cost. Material prices, in turn, depend on market developments. Parts become larger with increasing vehicle size, requiring bigger and more expensive machines and tools. The number of welding spots and joints also increases with the size of a vehicle. Therefore, like the material cost, the costs of processing and joining are scaled by weight. Thus, the weight of the vehicle is a central aspect in the calculation of production costs.

The CAT calculates the operating costs of the vehicle from the energy consumption of the BEV or the fuel consumption of the ICEV and takes the energy prices from [7] as a basis. According to [8], the driving resistance increases proportionally by the weight of the vehicle. This directly affects the energy consumption, and thus the weight of the vehicle also plays a central role in the calculation of operating costs. The costs of maintenance as well as insurance and road tax charges of the vehicle are calculated by a database with values taken from [7] and [9].

The calculation of the recycling costs differentiates between the user perspective and the product perspective, as mentioned previously. In the user perspective, the vehicle is resold for its residual value. The product perspective is rounded out with the recycling of the vehicle. In both cases, the proceeds will be considered positively in the TCO. Potential revenue from the sale of spare parts is intentionally not taken into account.

IV. WEIGHT AND MATERIAL COMPOSITION OF COMPONENTS

The parametric weight model [1] calculates the weight of the components and the entire vehicle as well as the energy consumption. *Figure 2* shows the basic parameters of a vehicle, which will be used later on as an example to illustrate how the CAT works. Parameter variations are indicated at the appropriate place.

FIGURE 2

Compared to [1], the weight model has been extended to allow for the calculation of ICEV as well. The key parameters defining the vehicle design include the main dimensions, like wheelbase and height, the desired driving range and the acceleration potential of the vehicle. Figure 3 shows the simulation results for several driving ranges of a BEV. The weight of the vehicle rises with the range.

FIGURE 3

In order to determine the costs of the vehicle components as described before, it is necessary to have information about their material composition. The material composition is derived from a benchmark study of 24 vehicles [10].

The benchmark data distinguishes between steel, aluminum, CFRP, various plastics, glass, textiles, etc.

FIGURE 4

The material compositions are average values. Because of specific requirements regarding design or technology, the material composition may vary for a specific vehicle. Due to the lack of benchmark data for BEV-specific components, the material composition of them has been determined separately [10].

V. PRODUCTION

The costs of the vehicle production can be split into raw material, processing and joining costs. All of them are calculated for each individual component group, as they are determined with [1].

For the calculation of a vehicle body, for example, the weight of the body and the raw material costs must be known. OEM are using more and more high- and ultrahigh-strength steel grades [11]; furthermore, the purchase prices of various steel grades differ widely. In order to reflect these circumstances as precisely as possible, the steel structure in the CAT is also calculated from steels of different strength grades. The composition of the structure is based on [12]. The strength of the steel grades vary between 250 and 1,200 MPa; thus the material prices vary by strength.

The processing costs are influenced by machine operating costs, labor costs and depreciation. The required investments and thereby the depreciation are scaled by vehicle weight. This can be justified by the fact that a heavy vehicle has both larger and more items. While larger parts require larger machines, additional parts demand more machines and tools. The investment calculation assumes a basic investment sum being independent of the vehicle weight. To obtain the total investment, the calculation adds a weight-dependent amount. If the required investments are known, they can be manually entered directly into the CAT as well. The investments are amortized over a defined period of time and the number of produced vehicles. In addition to the costs for processing, the joining cost of parts are taken into account as well. In case of a vehicle structure, there are welding spots and length of seams – both are assumed to depend on vehicle size. By using these parameters together with the costs for energy, auxiliary materials and supplies, the CAT determines the costs of spot welds and adhesive seams. Thus, a distinction is made between spot and laser welding and adhesive bonding.

The costs of injection-molded parts is calculated with a separate model, as shown in *figure 5*. Here, the machine-hour rate is computed with the data of VDMA [13]. Subsequently, the model determines the process costs by using the cycle time, the number of units and the tool costs. The material and labor costs are added and the result is an estimation for the costs of injection-molded parts.

FIGURE 5

Because of today's high battery costs they are the main cost factor in the production of a BEV. [7] estimates costs of 200 EUR/kWh in 2013 and expects a decline to 100 EUR/kWh in 2020. Rising production capacity and decreasing rejection rates, as well as more aggressive pricing of OEMs are named as the reasons for the cost reduction.

For some components, such as the airbag, it is not practical to scale the production costs by component weight. Their costs depends rather on the market in which the product is to be distributed. For this reason, some components assume standard values from [7].

The CAT determines the assembly costs of the vehicle by the hourly wage and the required assembly time. [14] specifies an assembly time of 20 hours for the BMW i3. In contrast, the assembly time of a conventional vehicle is approximately 40 hours [14]. Since the assembly times of various vehicle models can vary widely, the CAT user can specify this parameter manually.

In addition to the manufacturing costs, other factors, like overhead and development costs, have to be considered. The development and overhead costs must be amortized over the number of vehicles sold. In order to cover warranty and distribution costs, a corresponding amount will be added to the production costs. In addition, the OEMs as well as the traders earn profits through margins, which are also added to the costs of production. These cost factors, in addition to the production costs, results to the net list price. To determine the gross list price, or purchase price of the customer, the value-added tax (VAT) must be included.

VI. OPERATION

The operating costs for a vehicle can be split into direct and indirect costs. The direct costs are incurred through daily use, while indirect costs are incurred independent of vehicle usage. *Figure 6* shows an overview of the vehicle operating costs.

FIGURE 6

The energy costs, which are direct costs, depend on the mileage and the holding period; they are the main part of the operation costs. To determine the energy costs, the energy consumption from [1] is multiplied by the energy price and the mileage of the vehicle. As energy prices have shown a significant fluctuation in the past and are likely to be sensitive to various influences, the standard prices of the CAT can be adjusted manually [7].

The maintenance and repair of a vehicle also lead to costs, which have to be considered in the TCO as well. According to [15], the average annual maintenance costs of BEV are up to 35 % lower than those of ICEV. Whereas the backup battery is more heavily stressed in BEV, time-consuming maintenance steps of ICEV, such as changing the tooth belt or engine oil, can be omitted for BEV. Furthermore, the BEV braking system is less stressed because of the recuperation. The average maintenance costs of a vehicle class are obtained by averaging across three exemplary.

Most indirect operating costs depend on the vehicle class. The CAT estimates the vehicle class by the empty weight of the vehicle. However, as the weight of ICEV and BEV of the same vehicle class may vary, the user can select the vehicle class manually to improve the accuracy.

In addition to the individual profile of the vehicle owner, vehicle class largely determines the insurance costs, which is estimated as previously described. The insurance contributions for each vehicle class were averaged over vehicles of these categories

In contrast to ICEV, BEV are excluded from the motor vehicle tax in Germany for the first five years after initial registration. ICEV are taxed right from the purchase based on their engine size and their CO_2 emissions levels. In the CAT, the amount of the motor vehicle tax is also calculated by the vehicle class. A mean value is deposited for each vehicle class in the CAT.

The value of the vehicle depreciates during the holding. This loss in value describes the amount of money that has to be saved monthly during the holding period in order to be able to buy a new, equivalent car with the resale value and without debt financing [9]. The residual value intentionally does not distinguish between ICEV and BEV. According to [15] the residual value development of BEV cannot be estimated at present.

VII. RESALE/RECYCLING

By recycling a vehicle at its end of life no costs are incurred to the customer, but rather he will receive a credit. According to [16] a homologation of a new vehicle is linked to a recycling rate of more than 85 %. The end-of-life-scenario considers the vehicle as mixed-scrap in the CAT.

If the user sells the vehicle after the holding period, the residual value of the vehicle will be credited. The residual value results from the difference between the purchase price and the value loss.

VIII. ESTIMATION OF COST FACTORS

Calculating the TCO of a vehicle design requires assumptions regarding production and material parameters.

The costs for steel coils are taken from price lists [17]. The material costs of aluminium is determined by a ratio calculation according to [18]. *Figure 7* shows the most important material parameters.

FIGURE 7

The assumptions for development and overhead costs were made on the basis of balance sheets of OEMs. The investments for production can be derived from [5]. For some components, it is not possible to scale the costs by the weight as previously mentioned; they are accounted for with standard values based on databases and expert discussion.

IX. VALIDATION

In order to verify the functionality of the CAT, a plausibility check of the simulation results is performed in this section. Section 11 discusses the results later on.

As a first vehicle, a 4-door, C-Segment ICEV with seating for 5 passengers is simulated. The manufacturer's tag price is ~ 21,000 EUR. The CAT calculates the tag price to an amount of ~ 19,000 EUR; this corresponds to a deviation of ~ 10 %. Depending on the mileage and holding period the differences for the costs per kilometer vary between 4 % and 14 %.

A second ICEV vehicle belongs to the E-segment and also offers 5 seats and 4 doors. The manufacturer’s tag price is ~ 40,000 EUR. The calculated tag price is ~ 30,000; that implies a difference of ~ 25 % in this example. The results are shown in *figure 8*.

FIGURE 8

Figure 9 shows the simulation results for the BEV reference vehicles. The battery prices has a very high influence on the simulation result. The exact battery prices of the OEMs are not known here. For the following calculations, battery costs of 200 EUR/kWh and motor cost of 30 EUR/kW are assumed. For a C-segment BEV with 5 seats and 4 doors, the CAT calculates a tag price of ~ 28,000 EUR. This corresponds to a deviation of 6 % compared to the manufacturer's tag price of ~ 29,700 EUR. The costs per kilometer differ between 1 % and 15 %.

For a B-segment BEV, equipped with 4 doors and room for 4 passengers, CAT calculates a tag price of ~ 27,900 EUR – with the same assumptions from above. This implies a difference of ~ 5 % compared to the manufacturer´s tag price of 29,300 EUR.

FIGURE 9

X. EXAMPLES OF APPLICATION

A. *Variation of Body material*

Figure 10 compares the TCO of vehicle designs with different body materials. The only variation with respect to the reference design is the structure material; the exterior is made of steel in each case. For the simulation, battery costs of 200 EUR/kWh, motor cost of 30 EUR/kW, a holding period of 6 years and an annual mileage of 20,000 km are assumed.

The calculated tag price of the steel-BEV is ~ 31,400 EUR and the tag price of the aluminium-BEV is also ~ 31,400 EUR. Even though aluminium is more expensive, the increased costs for the structure are balanced by cheaper battery costs. The CAT calculates the tag price of the CFRP-BEV to ~ 38,800 EUR. In comparison, a diesel-ICEV with the same dimensions is calculated at a tag price of ~ 21,400 EUR. Thus, the ICEV would be more reasonable to purchase than a comparable BEV.

The energy consumption of the aluminum-BEV is 13.3 kWh per 100 km; in comparison, the energy consumption of the steel-BEV is 13.8 kWh per 100 km. As a result, the operating costs of steel and aluminum-BEV differ by around 200 EUR over the entire mileage, which is equivalent to ~ 1.6 %. Compared to the steel-BEV, the CFRP-BEV saves about 400 EUR during the operation. The amount of the operating costs of the diesel-ICEV (4.1 L/100 km) are 18,500 EUR and thus, it is significantly more expensive in operation (~ 45 % vs. steel-BEV) than the BEVs.

Among BEV, the aluminium-BEV shows the lowest TCO, which can be explained by the favorable production and operating costs. The CFRP-BEV has the lowest operating costs due to the lowest weight, but it is very expensive in production, because the high production and processing costs of the CFRP structure. Even though the diesel-ICEV has the highest operating costs, it is still the best in overall consideration, which can be explained by the cheapest production costs.

FIGURE 10

As shown in *figure 11*, the break-even point between ICEV and BEV is around 70,000 to 170,000 km, depending on the structure material. For this calculation only the yearly mileage has been varied; the holding period remains unchanged at 6 years.

FIGURE 11

If the battery costs would be assumed to be 100 EUR/kWh, the break-even point can be located at a mileage of 30 – 130 thousand kilometers as shown in *figure 12*.

FIGURE 12

BEV that are currently offered on the market are potentially cross-subsidized within the company. This means that the purchase price is less than shown in *figure 11*. As a result, the break-even point with the ICEV is reached earlier and a BEV is be amortized for the customer at a lower mileage.

B. Variation of Battery Position

In the following example, two vehicle designs, which differ in the positioning of the traction battery, are compared regarding their TCO. In vehicle A, the batteries are installed behind the backseats, leading to an additional wheelbase of +250 mm. In vehicle B, the batteries are placed in the underside, increasing the height of B by 200 mm [20]. But does the position of the batteries also have an influence on the production and operating costs?

As shown in *figure 13*, the vehicle A is 200 EUR cheaper to produce as the vehicle B. The main reason for this is that the batteries in vehicle B have to be designed larger due to the higher c_w-value of vehicle B, and thus they are more expensive. This cancels the effect of a compact and thus more favorable structure of vehicle B, which is in the end just a few kilograms lighter.

The higher c_w-value affects the operating costs of vehicle B in a negative way. They are about 200 EUR higher compared to vehicle A over the entire holding period. The overall TCO after 120,000 km of vehicle B are 34,500 EUR and of vehicle A 34,100 EUR.

FIGURE 13

XI. DISCUSSION

Cost data in the automotive industry are highly sensitive and kept secret within companies. Thus, the cost structures of OEMs are unknown. During the preparation of the CAT, the cost data had to be largely estimated. In addition, the pricing policy depends on many non-technical factors.

Because of the uncertainties, calculating a tag price of a specific vehicle leads to a quite substantial difference of the simulation results and the real data. However, calculating real prices is – given the current cost base – not the intention of CAT. Real component and material cost factors, which are readily available at the OEMs, would be required to improve the absolute calculation result.

However, CAT in its current version can be used to compare vehicle concepts, as all simulated vehicles will have the same underlying assumptions.

In order to improve the accuracy of the CAT, sources of errors and influencing factors must be analyzed. The following approaches can be used to explain the deviations of the calculated production costs – primarily the all require more accurate cost data.

- The manufacturing quality and the quality of the interior in premium class vehicles are higher compared to mass-market vehicles. Especially with plastics, a higher-finish quality leads to higher processing costs. However, these features do not necessarily have an effect on the vehicle weight, and thus the costs cannot be calculated. Additional factors are required to consider the influence of the finish quality on the costs.
- For some exceptions, costs do not always correlate with weight. Multi-link suspension systems are more comfortable in contrast to McPherson suspension systems. However, in the development and production, multi-link suspension systems are much more complex to manufacture and thus more expensive. Although McPherson suspension systems are more favorable regarding the weight, the reason behind the different costs is the intricacy. This contradicts the linear approach of the CAT. By introducing a suitable correction factor or a finer distinction of components in CAT, the resulting deviations could be minimized.
- The warranty surcharges of high-end vehicles are higher, as many repairs are handled through fair dealing; potential warranty repairs are more expensive. Due to the lack of data, an appropriate parametric account is not possible.
- The overhead costs were estimated from balances of various car manufacturers. However the vary largely between OEMs, and even within one OEM across the offered cars.
- Development costs of a vehicle will usually not be communicated externally by the OEMs, making it difficult to estimate the development costs of a vehicle design. Furthermore, the development costs depend on the innovation level and the segment of the vehicle. Under certain circumstances, components may also be taken from other vehicle models, which results in lower development costs (e.g., the modular platforms of the VW group). The development costs are also related to the number of special equipment variants. Thus, the development costs of different vehicles can deviate significantly, resulting in uncertainties in the CAT.
- The costs of the software are not considered sufficiently. These systems are not reflected in the vehicle weight, but may carry a large part of the vehicle costs. The software is taken into account with a lump sum in the CAT, which does not correspond to reality under certain circumstances.
- For a reliable calculation of the costs of a BEV, knowledge about the exact battery costs is an important factor. However, the calculation prices of the OEMs are difficult to estimate, and an incorrect estimation of the battery costs can result in severe variation in the overall costs.

In addition to the production costs, the operating costs also show differences to the reference values. In order to improve the calculation of the operation costs, the following approaches could be used:

- The cost of vehicle insurance primarily depends on the insurance classification. This may vary widely even within a vehicle class, and thus the calculation of an average value may lead to errors.
- The loss in value of a vehicle depends not only on the holding period, the mileage and the maintenance state, but also on the image of the brand. Many factors cannot be considered when determining the loss in value.

XII. SUMMARY & OUTLOOK

This conference contribution describes a cost analysis tool to asses cost of different vehicle concepts and designs. The method is based on the vehicle component weights, derived with a weight model [1].

Given the accessible cost data from outside an OEM CAT gives satisfactory results for compact-car ICEVs, with deviations up to 10 % of the manufacturer´s tag price. For upper-class ICEVs the deviation is 25 %. The high divergence can partly be explained by the large scope of the CAT and unknown pricing policy for different vehicle models.

The accuracy of the costs of BEV rises and falls with the battery costs. The deviations of the production costs are – based on the assumptions – between 5 % and 6 %.

Different BEV structure materials are assessed using CAT, and compared to a steel ICEV. Then the break-even points of the respective designs were determined. The key results are:

- Although the vehicle with CFRP structure has the lowest operating costs, it is much more expensive in production compared to the steel and aluminium structures.
- The vehicles with aluminum and steel structure hardly differ in the amount of production costs; however, the vehicle with aluminium structure is more favorable in the operation.
- The ICEV has the lowest production costs but the highest operation costs in comparison to the BEVs.
- The break-even point between ICEVs and BEVs can be located at a mileage of 30 – 170 thousand kilometers – depending on the structural material and the battery costs.

Another design comparison examines the positioning of the traction batteries in the vehicle – behind the seats or in the underfloor. The positioning of the batteries affects other parameters as the drag coefficient of the vehicle and thus the weight and costs. The CAT indicates for the chosen parameters that a battery placed behind the seats leads to lower production as well as lower operating costs.

The methodology for calculating costs as a function of vehicle weight is shown by the values determined by CAT. The quality of the results crucially depends on the cost assumptions, whose quality can only be ensured by the OEMs. The results of the model can still be significantly improved with detailed cost knowledge.

The CAT was, as mentioned, not designed for an accurate cost prediction of vehicles – for this, more suitable software tools exist. The motivation was rather to be able to compare vehicle designs and design variations quickly and easily based on a few parameters. Thus, the methodology of the cost model – in conjunction with the sensitive cost data of the OEM – has the potential to fundamentally revolutionize cost considerations in vehicle development.

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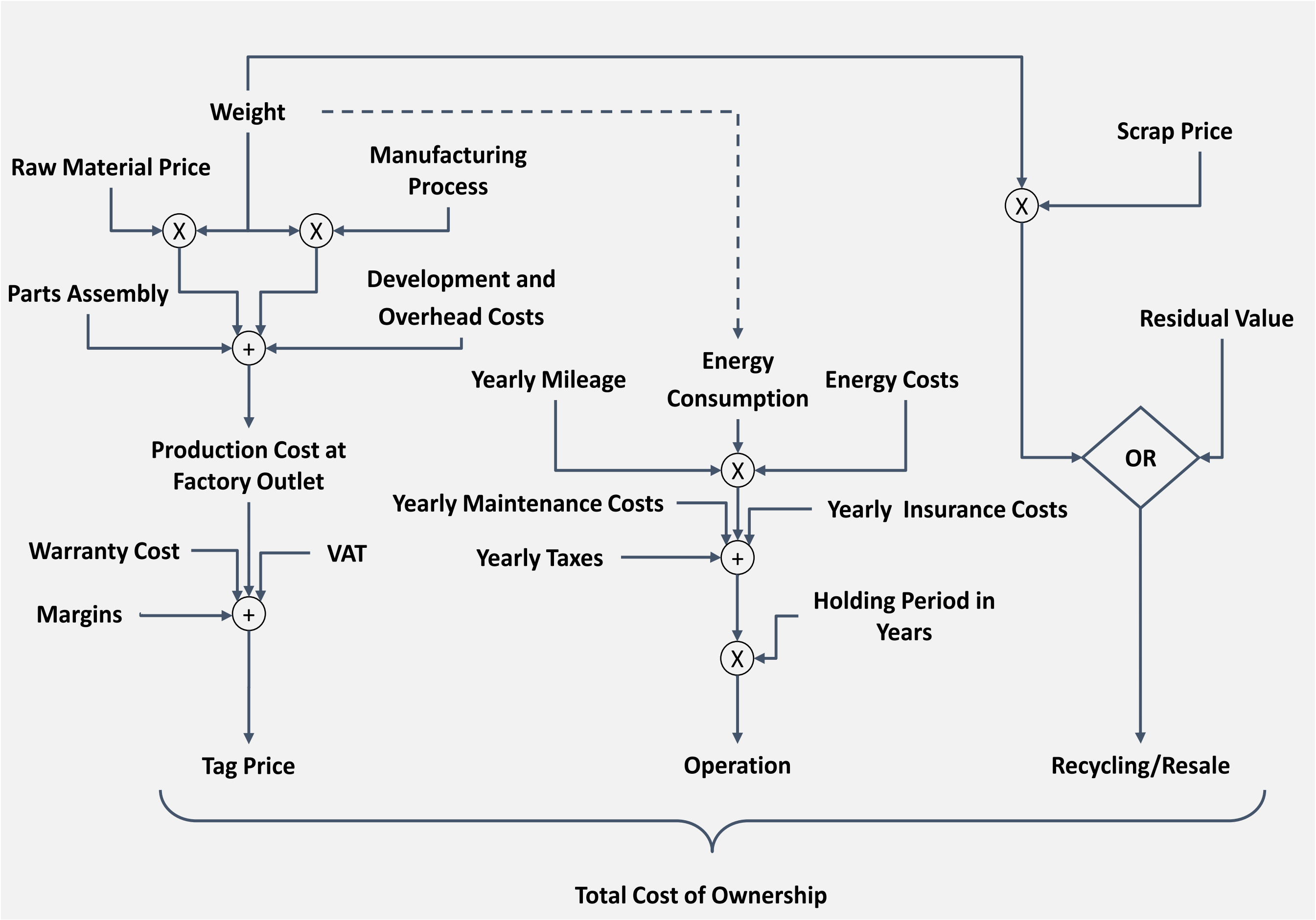
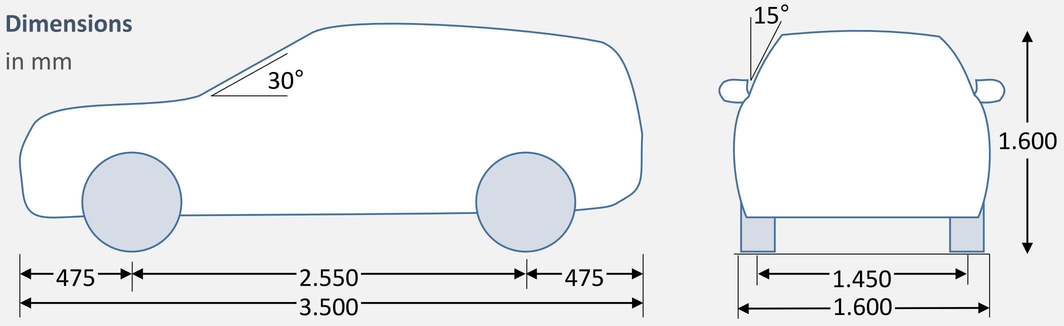


Fig. 1. General structure of the cost analysis tool



General vehicle specifications	
Vehicle form	Station wagon
Payload (incl. driver)	350 kg
Number of passengers	5
Number of doors	4
Driving cycle	NEDC

Specific parameters	BEV	ICEV
Energy density of battery in Wh/kg	150	n/a
Acceleration 0 – 100 km/h in sec	15	10
Driving range in km	150	900
Analyzed body materials	Alu, Steel, CFK	Steel
Weight determined with [1] in kg	1,037	1,146

Fig. 2. Basic parameters of simulated vehicle

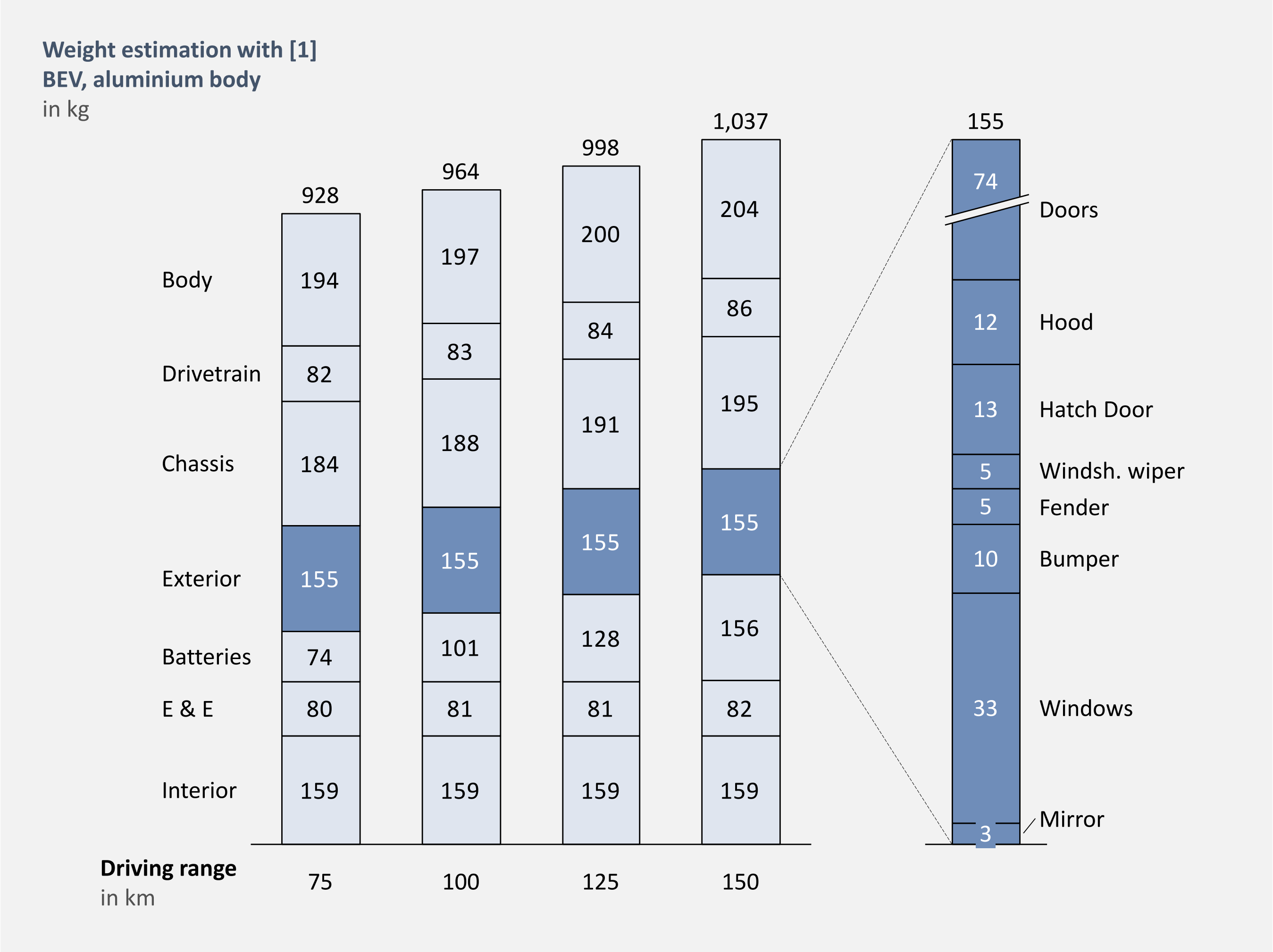


Fig. 3. Weight split of the vehicle simulated with [1]

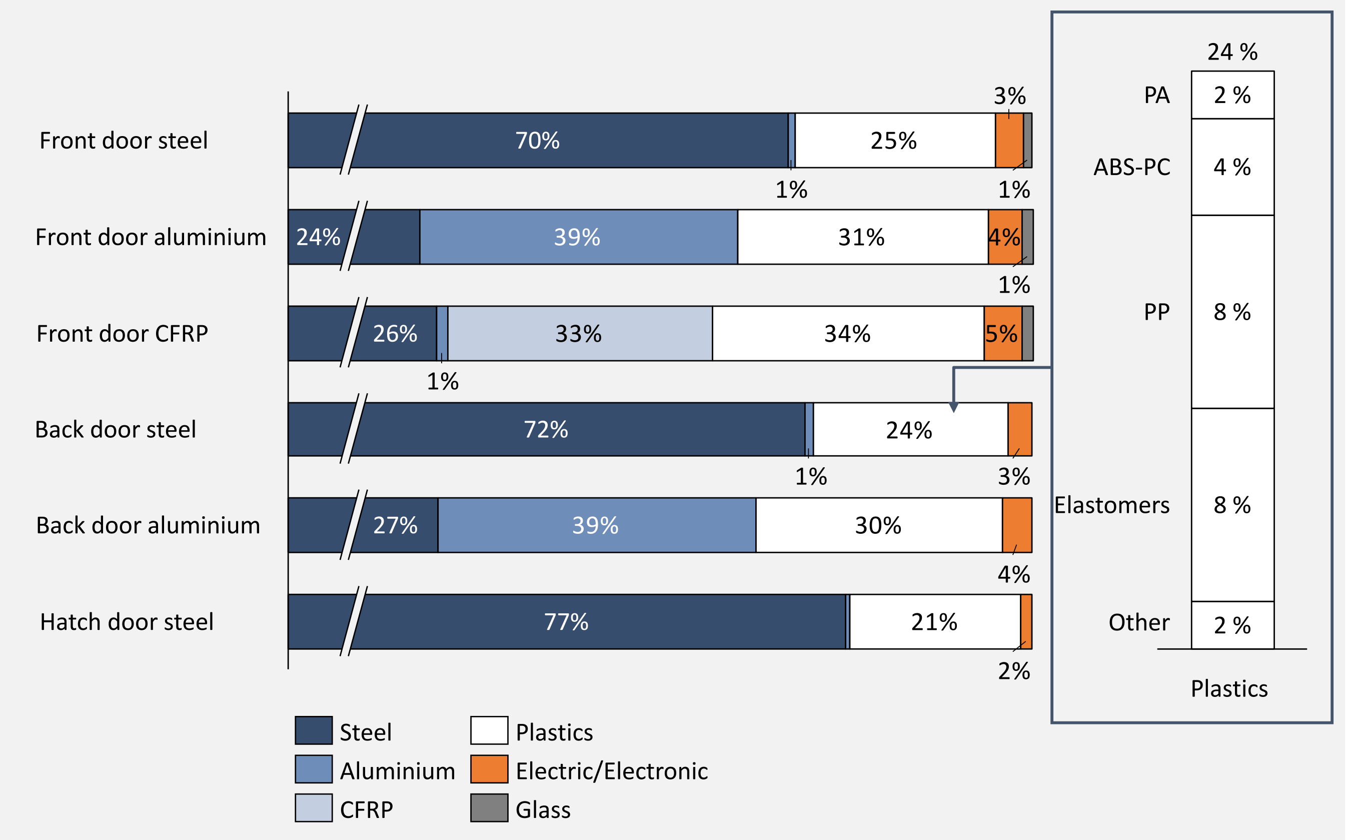


Fig. 4. Material composition of exterior parts of a BEV

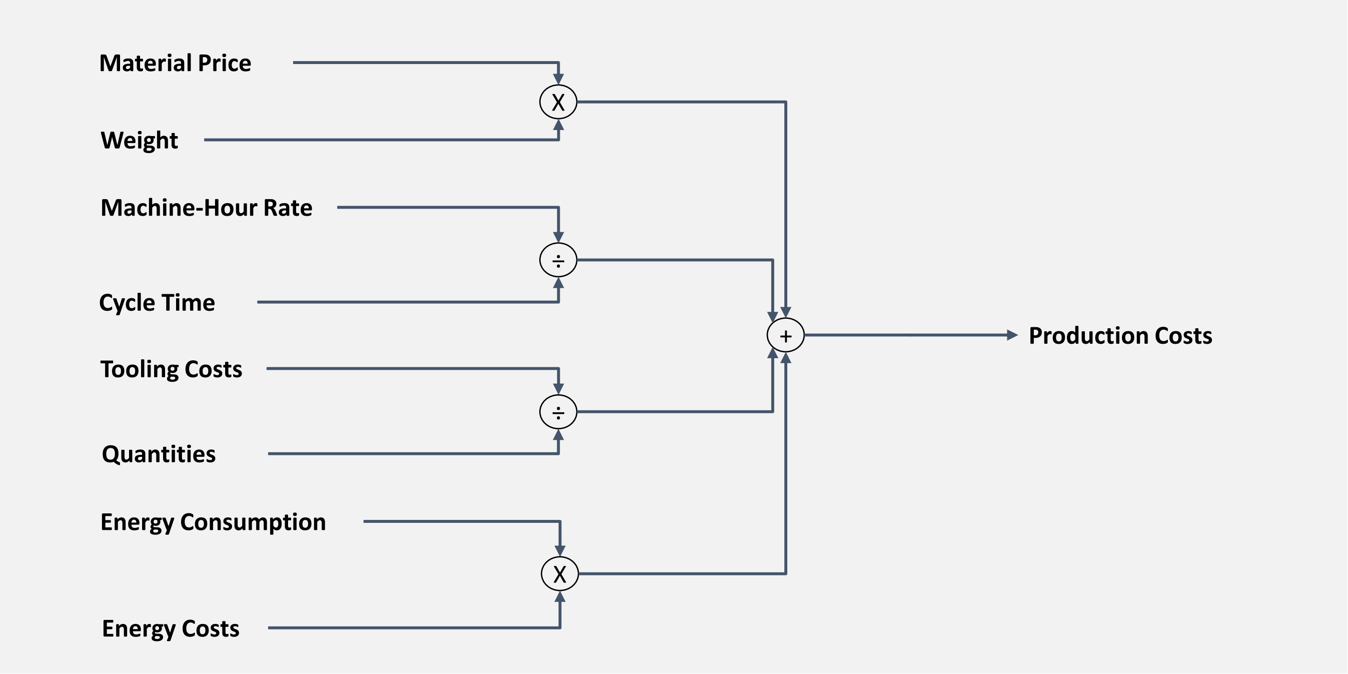


Fig. 5. Calculation of manufacturing costs of injection-molded components

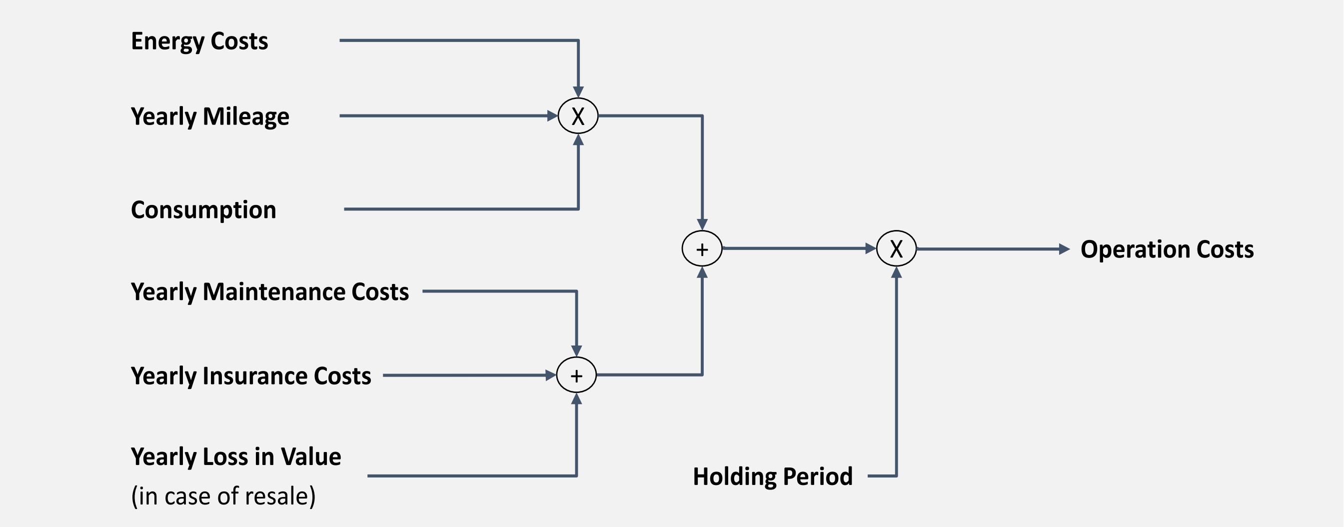


Fig. 6. Overview of vehicle operation costs

Material Costs

Material/Components	Information	Costs in EUR/kg	References
Steel	DP1000, raw material	1.08	[17]
Steel	HF1500, raw material	0.93	[17]
Steel	further steel, different strength	0.81….1.39	[17]
Aluminium	raw material	3.5	[18]
Plastics	PP, with processing	3.45	industry, model shown in figure 5
Plastics	ABS, with processing	4.05	industry, model shown in figure 5
Airbag	Driver and passenger airbags	100 EUR	[7]

Material and Component Costs with different Scenarios

	Costs in EUR/…			
Component	Present	Middle-term	Long-term	References
Battery-system	200 (kWh)	150 (kWh)	100 (kWh)	[7]
Electric motor incl. Power electronics	30 (kW)		20 (kW)	[7]
CFRP, with processing	50 (kg)	35 (kg)	20 (kg)	[19]

Production Parameters

Parameter	Costs	References
Overhead	1,000 – 6,000 EUR/vehicle	Estimated by balance sheets of OEMs
Development	200 – 6,000 EUR/vehicle	Estimation based on [7]
Margin Distributor	5 % of Production Price	Estimation based on [7]

Fig. 7. Cost assumptions and material parameters

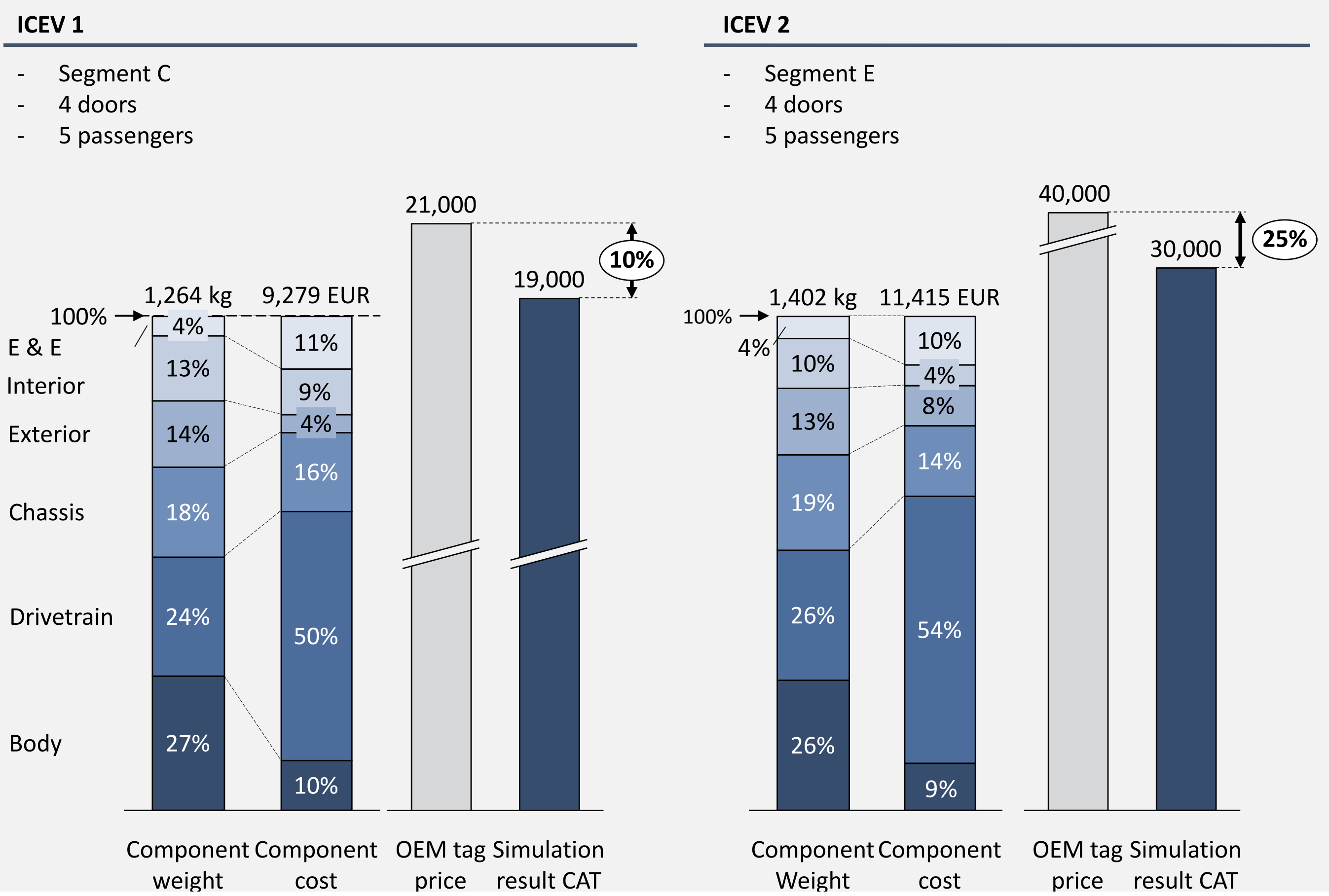


Fig. 8. Cost comparison between OEM tag price and simulation results for ICEV

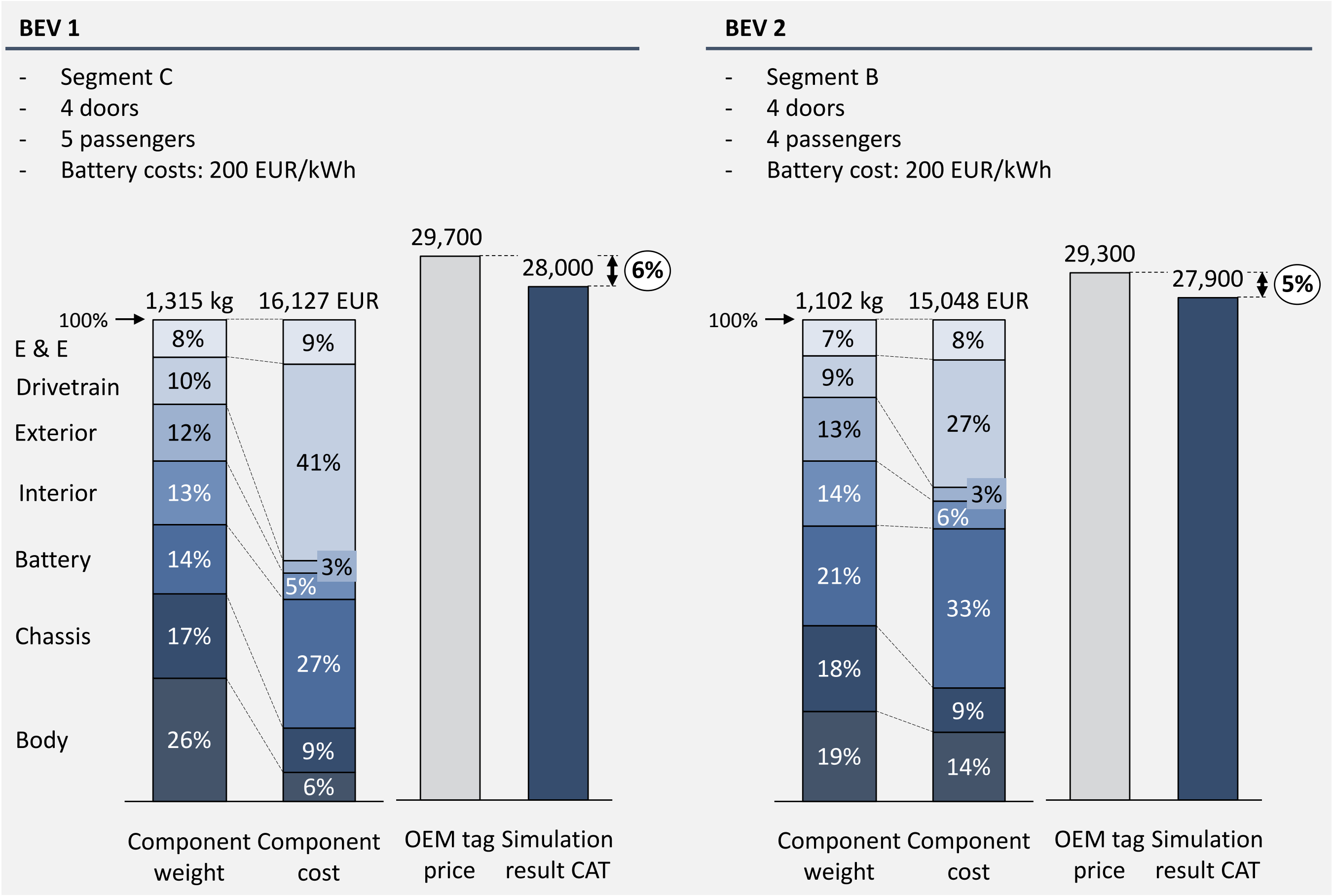


Fig. 9. Cost comparison between OEM tag price and simulation results for BEV

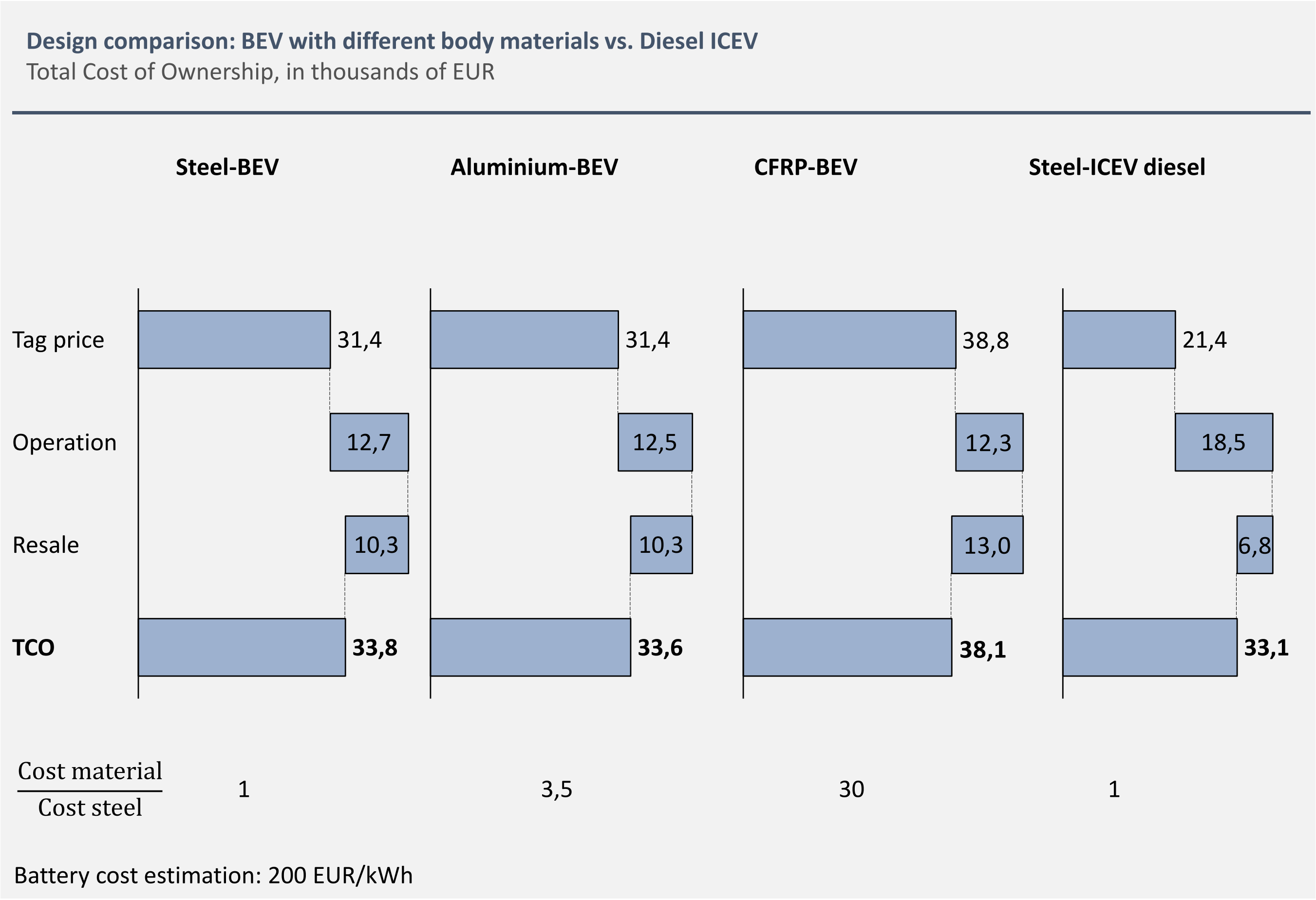


Fig. 10. Comparison of body materials for BEV

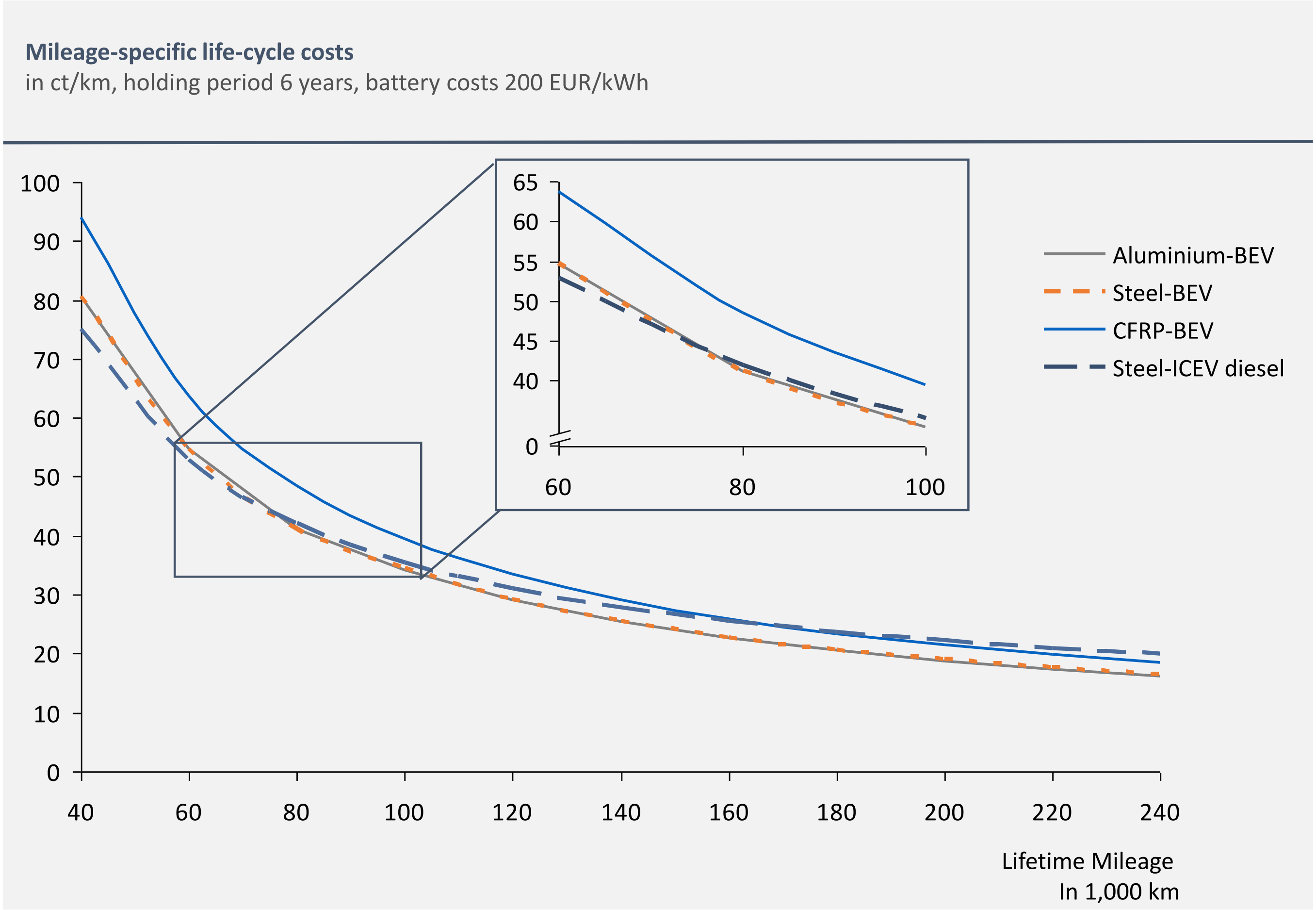


Fig. 11. Mileage specific costs of BEV with different body material and battery costs of 200 EUR/kWh

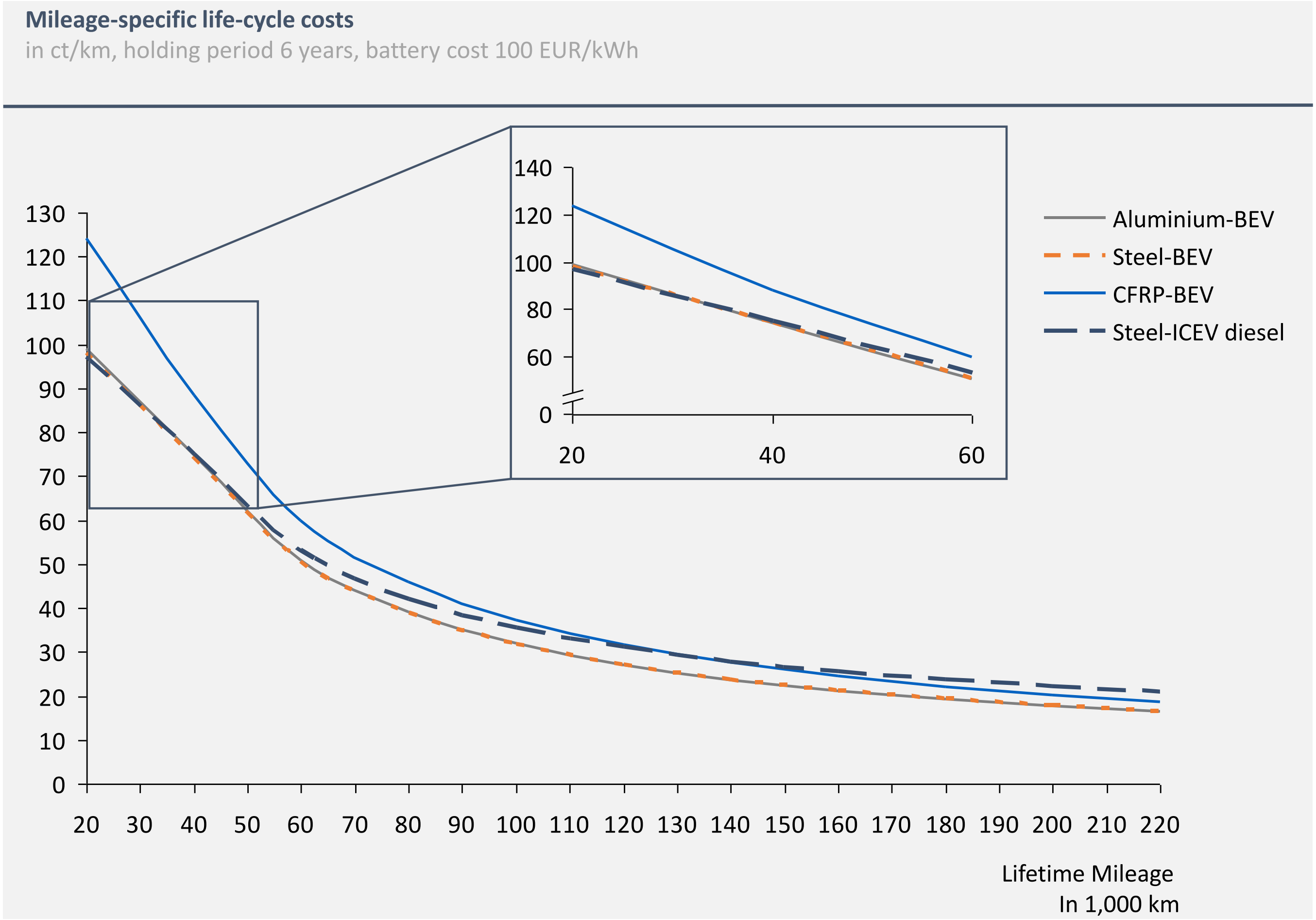


Fig. 12. Mileage specific cost for BEV with different body material and battery costs of 100 EU/kWh

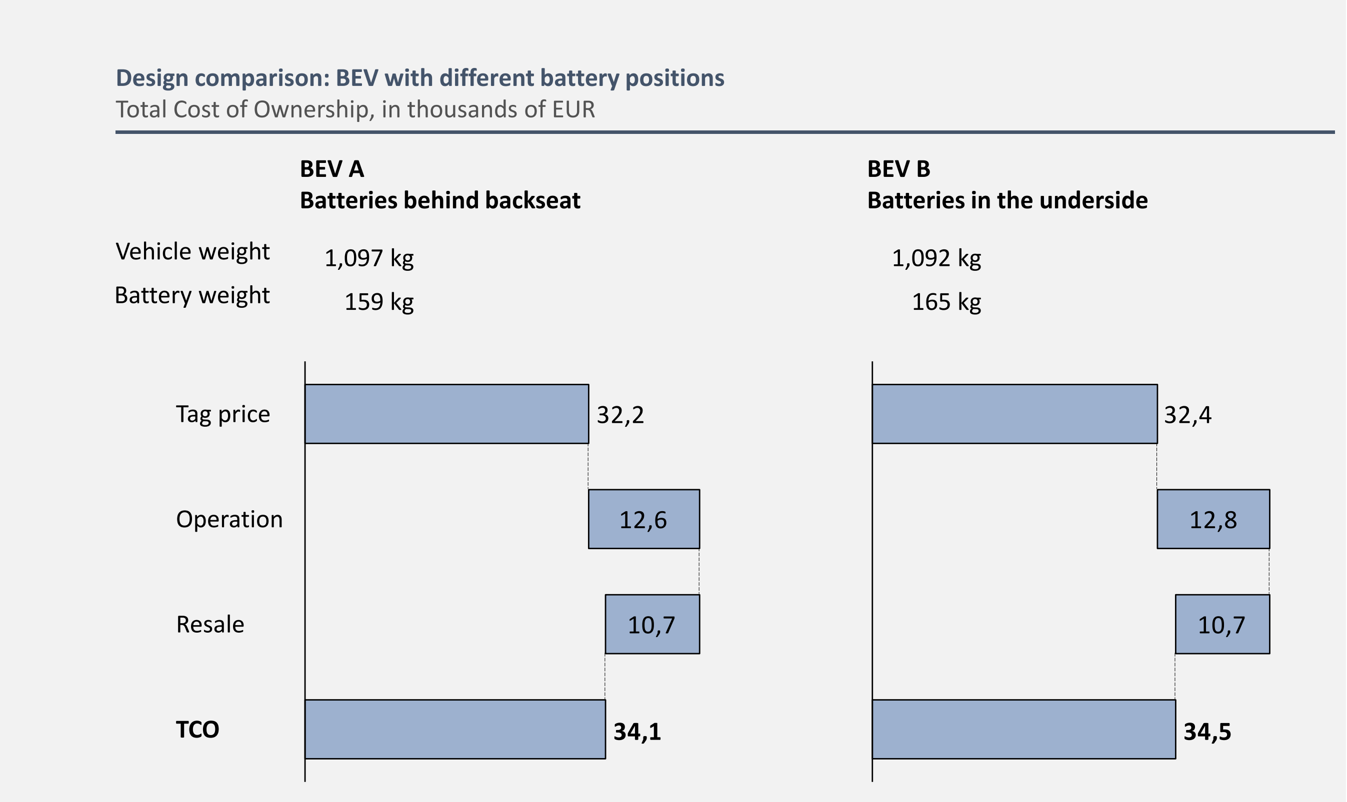


Fig. 13. TCO Comparison of BEV with different battery positions