

# An Overview of Costs for Vehicle Components, Fuels, Greenhouse Gas Emissions and Total Cost of Ownership Update 2017

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## Abstract

This paper gives an overview of prices for components of both conventional and electric vehicles, including energy storage, drivetrain as well as interior and exterior vehicle body components. In particular, prices for electric vehicle traction battery packs are analysed, which are estimated to drop remarkably until 2030. In addition, fuel and electricity prices with projections until 2030 are given for important automotive markets. Furthermore passenger cars and commercial vehicles are taken into account. The calculation assumptions for a TCO calculation in the long haul sector are displayed in a showcase for a diesel semi-trailer tractor unit.

All costs are based on data found in various literature sources, including experts' opinions. The purpose is to provide a common data basis as a reference point of discussion which is subject to continuous adjustments and improvement. The data itself can be used in order to perform calculations for passenger vehicles and to produce comparable cost estimations.

## 1. Introduction

Cost data for vehicles and vehicle components is essential for various research activities in the field of automotive technology. For example, in order to roughly calculate the manufacturing costs of an electric vehicle – which is the basis for an estimation of the purchase price and Total Cost of Ownership (TCO) of a vehicle – cost data in terms of costs for the car manufacturer (Original Equipment Manufacturer, OEM) has to be available at least for the main components like the vehicle body, the powertrain and the energy storage system. However, costs are usually part of the business secret of any company, so that cost data is not widely available. Hence, the results presented in this paper are mainly based on data from scientific publications, reports, experts' opinions and on own research results.

The conditions under which the given values are true are a major challenge. For example, costs of vehicle components highly depend on costs of manpower in the manufacturing countries, on margins of the OEM and its suppliers, on the production volume and on sales policies. Moreover, varying exchange and inflation rates make cost values less transparent and comparable.

Considering these challenges, this paper focuses on giving general approximate values for costs of vehicle components. In addition, results of estimations about costs for fuels and electricity are given for important car markets. Finally, price ranges for greenhouse gas (GHG) emissions (CO<sub>2</sub> costs) are given. The purpose is to provide a basis for estimating the vehicle costs on a rough estimation level, without having to go into more detail. This paper also provides a basis for comparing the costs of vehicles in the future. Projections are given for the costs of major vehicle components and for fuel and electricity prices.

## 2. Overview and Background

### Cost-Influencing Factors

Costs of vehicle components depend on a wide range of factors, which include for example the region where components are manufactured, the volume of production or the markets the components are sold in. Mostly, these factors are not clearly stated together with the cost values found in literature, which make a comparison between cost values from different sources difficult. [Table 1](#) contains a list of some important factors.

Table 1: Ranking of some factors affecting the comparability of cost values [FTM14a]

Influence of manufacturing costs		Influence of retail prices	
1	Material costs	1	Margins of the retailer and OEM
2	Energy costs	2	Regional / local taxes
3	Labour costs	3	Sales policies / managerial decisions
4	Production volume	...	
5	Margins of the suppliers		
6	Shipping costs		
7	Learning curves		
8	Matureness of technology		
9	Productivity / efficiency		
...			

### Comparability of Cost Data

In addition to the above-mentioned cost-influencing factors, the cost values found in different sources are often not directly comparable due to the assumptions made.

First, costs are found in different currencies in the literature, mostly in Euros (EUR) or US dollars (USD). As exchange rates are not always stated within the sources, average 2009 to 2012 have been used to compare the cost values (most sources are from this range of dates). All values have been converted into EUR ([Table 2](#)). We assume purchase power parity and Europe as reference region.

Table 2: Approximate exchange rate used for sources since 1/1/2015 [OAN15]

1 EUR → USD	1 EUR → GBP	1 EUR → SGD	1 EUR → CNY
1.11	0.73	1.53	6.93

Average annual midpoint rates 2015. (sources are mainly from this range of dates)

EUR: Euro, USD: US Dollar, GBP: British Pound, SGD: Singapore Dollar, CNY: Chinese Yuan Renminbi

Second, the devaluation of money over time (inflation) has to be taken into account. For example, cost values stated for 2010 cannot be directly compared to cost values stated for 2030, as nominal prices in 2030 may have changed in comparison to 2010, depending on the inflation in the respective region or country. As only some sources [e.g. [CON12](#)] indicate the time reference of the prices, it is assumed that the prices indicated in a source are at the price level of the time of publication of this source (real prices).

Third, some sources do not indicate their cost estimations as costs for the OEM who does the final assembly of a car. However, considering the type of sources, it can be assumed that the prices found for battery packs, vehicle components and materials are OEM purchase prices, whereas the prices for fuel and electricity are retail prices for the final consumer.

## Structure of Sources

Considering the variety of cost information existing for vehicle components etc., the sources can be structured into three categories. The categories roughly represent different scientific levels, ranging from reports and scientific publications to press releases and expert's opinions (Table 3).

Table 3: Classification of sources

Category	1	2	3
Description	report / book / scientific publication	press release	expert's opinion
Scientific level	very high	low	medium
Reliability	medium	low	high

Most sources for this paper are reports or scientific publications. They generally give an overall cost estimation, which often includes the costs at a point of time and one or more cost projections (scenarios). They can be regarded as a good option to get an overall idea of component costs. Press releases and expert's opinions have to be considered as less scientific as they may have a particular mind-set (press release) or only reflect a single person's point of view (expert's opinion). These types of sources were mainly used to get a first idea about the price levels, or when reference values from scientific publications were not available.

## Definitions

In order to provide consistent cost estimations, the results presented in this paper are purchase costs for the OEM, which are equal to supplier retail prices. Approximate values for distribution costs, margins etc. are given in order to derive consumers' prices from the costs for the OEM. The only exception are the energy costs for fossil fuels, hydrogen and electricity which are retail prices and include all taxes in the respective countries. Moreover, as costs change over time, the cost values are given as estimations for "today" and for selected future points of time until 2030. "Today" is defined to be year 2017. The cost values have to be considered as estimations for large volume production, except for some new technologies today, which include battery pack and battery pack component costs, electric drivetrain component cost, fuel cell, hydrogen tank and CFRP costs. Finally, prices are considered as real (inflation-adjusted) prices on today's price level. In order to convert the different currencies of the sources into Euros, we used the exchange rates according to [OAN13] (Table 2).

## 3. Vehicle Costs

In this chapter, cost estimations are given for the most important components of passenger cars of different powertrains. This includes costs for vehicle body materials and components, conventional and electric powertrain components as well as fuel and energy storage components. In addition, typical values for manpower costs and margins are given. Table 4 contains a structured list of these components. The estimated cost values are summarised in Tables A1 to A4 in the appendix.

Table 4: Structure of vehicle cost data

Component group	Component / specification	Time range (Today = 2017)	Units	Vehicle types
Energy storage	High voltage traction battery	Today to 2030	EUR or EUR/kWh	BEV PHEV FCEV
	Fuel tank CNG tank LNG tank Hydrogen tank	Today to 2030	EUR or EUR/kg fuel	ICEV FCEV
Powertrain	Power electronics Charger Converter	Today to 2030	EUR or EUR/kW	BEV PHEV FCEV
	Electric motor Fuel cell ICE & ICE parts	Today to 2030	EUR or EUR/kW	All
Vehicle body	Interior parts Exterior parts Electronics and systems	Today	EUR or EUR/kg	All
Materials	Metals CFRP Plastics	Today	EUR/kg	All
Manufacturing and additional costs	Vehicle assembly Manpower Distribution costs, margins	Today	EUR or EUR/h	All

BEV: battery electric vehicle with a battery capacity of 20 to 40 kWh  
 PHEV: plug-in hybrid electric vehicle with a battery capacity of 5 to 10 kWh  
 FCEV: fuel cell electric vehicle  
 ICE: internal combustion engine; ICEV: internal combustion engine vehicle  
 CNG: compressed natural gas  
 LNG liquefied natural gas

[KAM13] provides estimations about the costs of components and component groups as a percentage of the costs of the complete vehicle (Figure 1). The portion of costs of the drivetrain in comparison to the costs of the entire vehicle is at least 4% lower for BEVs than for conventional ones with ICE. This is mainly due to the smaller number of parts in the electric drivetrain. However, at current battery costs, the battery pack costs for BEVs are estimated to be responsible for up to 50% of the entire vehicle costs [KAM13]. This number is supposed to decline in the next years with falling battery costs (Figure 3), which will reduce today's price difference between ICEVs and BEVs.

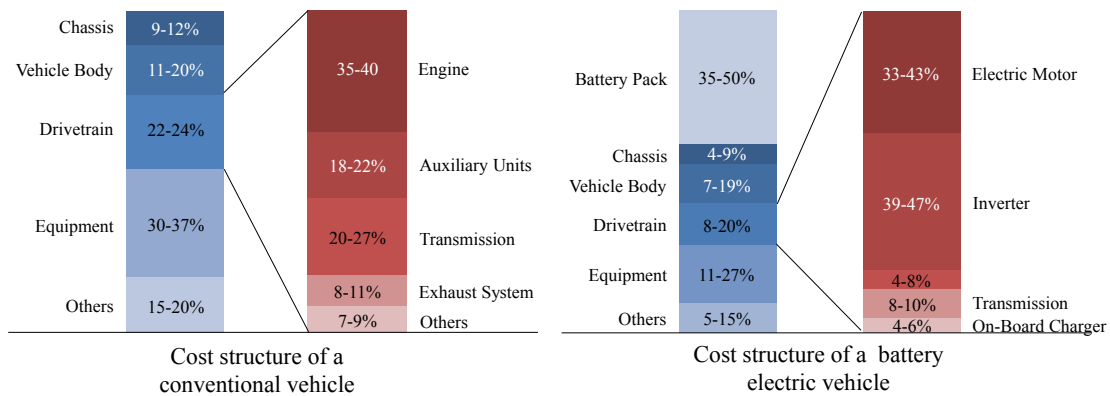


Figure 1: Cost structure of an ICEV and a BEV [KAM13]

[Fri17a] provides estimations about the costs of components and component groups as a percentage of the costs of a 40 t semi-tractor trailer unit (Figure 2). The portion of costs of the drivetrain in comparison to the costs of the entire vehicle is at least 12% lower for the diesel engine vehicle than for the PHEV.

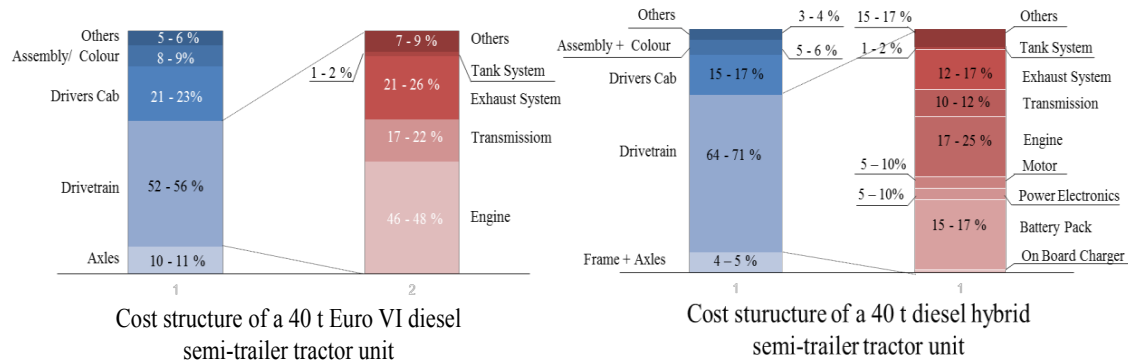


Figure 2: Cost structure of a diesel and diesel electric 40 t semi-trailer tractor unit [Fri17a]

### Example: Costs of Vehicle Traction Batteries

The costs for lithium ion batteries are of particular interest because the battery pack is the drive train's most expensive component. Since the breakthrough of electro mobility is closely linked to the battery costs, many cost models can be found in literature making battery price assessments. However, the focus of those cost models is always different.

Gaines et al. [Gai00] develop a cost model which focuses on cylindrical shaped 18650 battery cells, which were quit common in 2000. He investigated the influence of raw material prices on the battery price for both, high energy and high power cells. He concluded the cathode material prices are the dominating factors.

Amirault et al. [Ami09] developed a cost model based on a weight model for lithium ion batteries. Based on the selected cell chemistry the model calculates the material effort. Moreover he estimates the portion of the cost price to 75 % of the total price. Thus he takes no account for different production processes for different cell shapes, nor more or less technological mature processes.

Petri et al. [Pet15] focuses on the assessment of different cell chemistries. Therefore he also focuses on raw material prices. The production process of lithium ion cells is not considered in this model.

Rempel et al. [Rem13] introduces the TIAX cost model. Based on a 5.5 kWh battery pack, consisting of 18650 high power battery cells, the cost price is calculated. Different cell chemistries can be evaluated (NCA, NMC, LMO, LFP) but the model is restricted to high power cells. However the model also considers uncertainties regarding the input values.

The United States Advanced Battery Consortium (USABC) published their cost model in 2015 [Usa15].

However this model is designed as a template for cost calculations and the user has to enter the according data. When everything is set up, the model calculates the individual production costs and general expense.

The Battery Performance and Cost Model (BatPac) developed by the Argonne National Laboratory (ANL) is a public available cost model for lithium ion pouch battery packs [Nel12]. It calculates the costs for a battery pack depending on the selected cell chemistry, cell capacity, coating thickness of electrodes or the amount of cells in the year 2020 on the basis of pouch cells with 40 Ah.

Looking more closely at today's BEV market, a bright variety (shape and capacity) of cells installed in BEV's battery packs can be found [Tob16]. Existing, public available cost models cannot assess the costs for today's BEV market due to this variety. Therefore a cost model is necessary which is capable of:

- Calculating the cost price for all three different cell shapes (cylindrical, prismatic hard case and pouch cells)

- Consideration of different production processes depending on the cell shape
- Consideration of the maturity level of production processes
- Consideration of the error rate of a production process depending on the maturity level
- Consideration of common cell chemistries, and future technological improvement of materials
- Cost prognosis prediction for future prices

Based on the cost model BatPac we modified the model to fulfill the above mentioned requirements.

- Parametric capacity cell models were added to the model to calculate the cell properties depending on the cell shape and geometry. The models are based on [Ker15].
- The production process for cylindrical and prismatic cells were analyzed and added to the model. Based on Heimes, Korthauer, Kampker and Tagawa [Hei14, Kam14, Kor13, Tag09] necessary data was generated and correlated to data from Batpac.
- The maturity level of the production processes were taken from Heimes [Hei14] and were correlated to existing data from BatPac
- Error rates from BatPac's pouch cell were correlated with the technological maturity level of the production processes
- Few additional cell chemistries were added to the model with all necessary data
- Raw material cost model were added, which predicts raw material prices until 2030

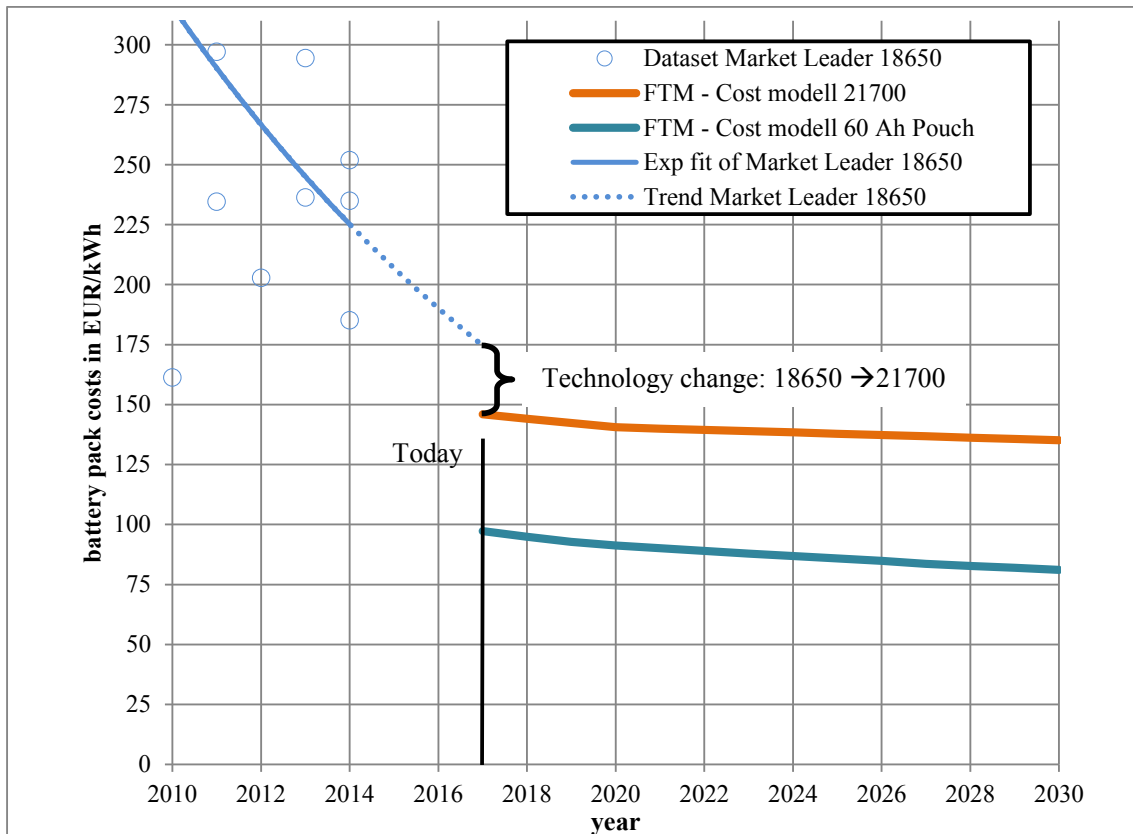


Figure 3: Cost trends for electric vehicle traction battery packs [Nyk15 and own calculations based in on a 90 kWh battery, cell chemistry NMC611]

As displayed in Figure 3, prices for 18650 cells (from 2010 to 2014) from Nykvist et al. are taken which are fitted, and calculations from our cost model beginning from 2017 on are brought face to face. The gap in 2017

between the *Trend Market Leader 18650* and the *21700 price prognosis* is due to the technology change from the 18650 cylindrical cell to 21700, with the delivery of first Tesla Model 3 BEVs. Cost calculations are based on a 90 kWh battery pack. Estimated production volume in 2015 is 30.000 battery packs with an annual growth rate of 10%.

Own cost calculations consider raw material cost (constant price scenario with raw material prices from 2016), purchase items costs and direct labor costs for electrode processing, cell assembly and for formation, cycling, testing and sealing. Despite being calculated by the cost model, costs for capital equipment, buildings, land and utilities, Sales, General and Administration (SG&A), Research and Development (R&D), as well as taxes and warranty costs are disregarded. Reasons are uncertainties due to privileges granted by the countries of production, regarding taxes, subsidies etc.

Table 5 also provides a value for fixed battery costs (which are independent from the battery size), as well as a ratio which gives an approximate relationship between battery cell costs and the battery pack costs.

Table 5: Costs for traction battery packs and battery cells today until 2030 (own calculations)

Cell Specs	Vehicle Type	2017	2020	Potential (2030)	Unit	
Battery cells	Large cell (60 Ah)	92	86	76	EUR/kWh	
	Small Cell (4.5 Ah)	110	103	92	EUR/kWh	
Ratio battery pack costs to cell costs <sup>1</sup>		1.35	1.30	1.25		
Battery pack	Large cell (60 Ah)	BEV <sup>2</sup>	124	112	95	EUR/kWh
	Small cell (4.5 Ah)		148	130	115	EUR/kWh
	Large cell	PHEV <sup>3</sup>	176	165	141	EUR/kWh
	Ratio PHEV to BEV battery pack costs <sup>3</sup>		1.42	1.47	1.48	
Additional fixed costs per battery pack <sup>4</sup>		200			EUR	

VDA: German Association of the Automotive Industry (Verband der Automobilindustrie)

<sup>1</sup> The ratio takes into consideration cost for cell contacting technology, battery cooling, slave BMSs (one slave for 10-12 battery cell connected in series) etc. [FTM14a].

<sup>2</sup> BEVs with a battery capacity of 60 to 90 kWh.

<sup>3</sup> PHEVs with a battery capacity of 5 to 10 kWh.

<sup>4</sup> The fixed battery costs have to be added on top of the battery pack costs, which can be calculated using the EUR/kWh values. In particular, these costs should be taken into consideration for smaller battery packs where the fixed cost components are responsible for a larger part of the battery pack costs. Fixed and partly fixed cost components of battery packs include contactors, fuses, insulation monitoring unit, BMS master unit, plugs and battery housing (depends on battery design and mounting inside the vehicle) [FTM14a].

In various interviews with former members of the management board of german truck manufacturers and CEOs of long haul companies an estimation about the costs of commercial vehicle components and component groups as a percentage of the costs of the complete semi-trailer tractor vehicle is set up in Figure 3.

## 4. Energy Costs

Cost estimations for energy costs include prices for fossil fuels (diesel, gasoline and CNG) and electricity. In addition, hydrogen prices for Germany are given. However, hydrogen is not widely available today. Hence, it is probably too early to give reasonably correct future hydrogen price estimations.

All energy prices are retail prices (electricity: household tariffs), including the taxes in the respective regions. Price projections for diesel, gasoline and CNG are based on oil and CNG price projections respectively according to [CON12]. For the electricity price projections, the country-specific energy mixes were taken into consideration by using plausible values for the future electricity price developments based on different sources. It is worth noting that the electricity price data in different sources allows to make a range of plausible future price projections (depending on the scenarios, assumptions or time range), which makes it difficult to provide general estimation values. Political and regulatory decisions have a strong influence on the electricity tariffs. Hence, more detailed projections which, for example, analyse different scenarios should be used for more in-depth analyses.

The energy prices are summarised in Table A5 in the appendix.

## 5. Costs for Greenhouse Gas Emissions

Various regional systems exist in which allowances for GHG emissions can be traded between the participants such as electricity producers or industries [ECC13c]. The biggest of these is the European Union Emission Trading Scheme (EU ETS), which consists of several phases. The first phase started operation in 2005 and served as a learning period for phase two (from 2008 to 2012) which coincided with the start of the commitment period of the Kyoto Protocol. The penalty for non-compliance rose from 40 EUR/t CO<sub>2</sub> in the first phase to 100 EUR/t CO<sub>2</sub> in the second phase [ECC13a]. In 2013, the third phase of the emission trading scheme has started taking into consideration further GHGs and industrial sectors [ECC13b].

As the amount of allowances often exceeded the demand in the past, the price for GHG emissions rather declined than increased as one might have expected. For example, the International Energy Agency (IEA) predicted prices of 18 to 20 EUR/ton CO<sub>2</sub> for today, and 30 to 70 EUR/ton CO<sub>2</sub> in 2030 for different policy scenarios and regions [IEA10]. In contrast, prices for CO<sub>2</sub> emission allowances at the European Energy Exchange in fact dropped from 15 EUR/ton CO<sub>2</sub> to around 5 EUR/ton CO<sub>2</sub> today [EEX13] (Figure 4). [FEL13] mentions that energy production is strongly subsidized, which translates into subsidies of about 75 EUR/ton CO<sub>2</sub> (100 USD/ton CO<sub>2</sub>). This leads to an equal amount of costs if the subsidization would stop.



Figure 4. Price development of EU emission allowances (Spot) - primary market auction [EEX13]

Hence, the future price for GHG emission allowances strongly depends on the stipulated emission cap, the economic and industrial growth, efficiency improvements among the large GHG emitters, cost development for CO<sub>2</sub> reducing measures, the linking of various global trading schemes and the overall development of the regulatory framework. For these reasons, the future cost development is hard to predict. However, if a penalty cost for non-compliance exists as in the EU ETS, this forms an upper price limit which will certainly not be exceeded by the future cost development.

In addition, [BMU09] describes European policies designed to lower direct CO<sub>2</sub> emissions of passenger vehicles. In the future, an OEM has to pay a penalty payment of up to 95 EUR for one vehicle sold which exceeds its individual limit by 1 g CO<sub>2</sub>/km. In order to compare this value to the prices for usual emission allowances, a total lifetime mileage of the vehicles has to be assumed. For example, a total mileage of 150,000 km leads to an emission price of 633 EUR/ton CO<sub>2</sub> (at 95 EUR/g CO<sub>2</sub> and exceeding the limit by of 1g CO<sub>2</sub>/km), which is a lot higher than the price for the emission allowances. However, such regulations are subject



to frequent changes. The start of this regulation, which was initially scheduled for 2020, has recently been postponed to 2024 [SPI13].

In summary, we do not give a specific estimation for GHG emissions in this paper. GHG emission costs should be taken into consideration by analyzing scenarios with different cost assumptions, which are in the range of the values mentioned above. However, the assumption is that the cost per ton CO<sub>2</sub> for fossil fuels in the transport sector will be higher than 100 EUR/ton CO<sub>2</sub> at long term.

## 6. TCO Calculation in the commercial vehicle operation

The main cost types in the vehicle total cost-of-ownership calculation are based on four cost types. Variable, kilometer-dependent costs, personnel costs, time-dependent (fixed) costs and overhead costs, as displayed in Fig. 4. A simplified version of this comprehensive cost model can be used for the calculation of passenger cars.

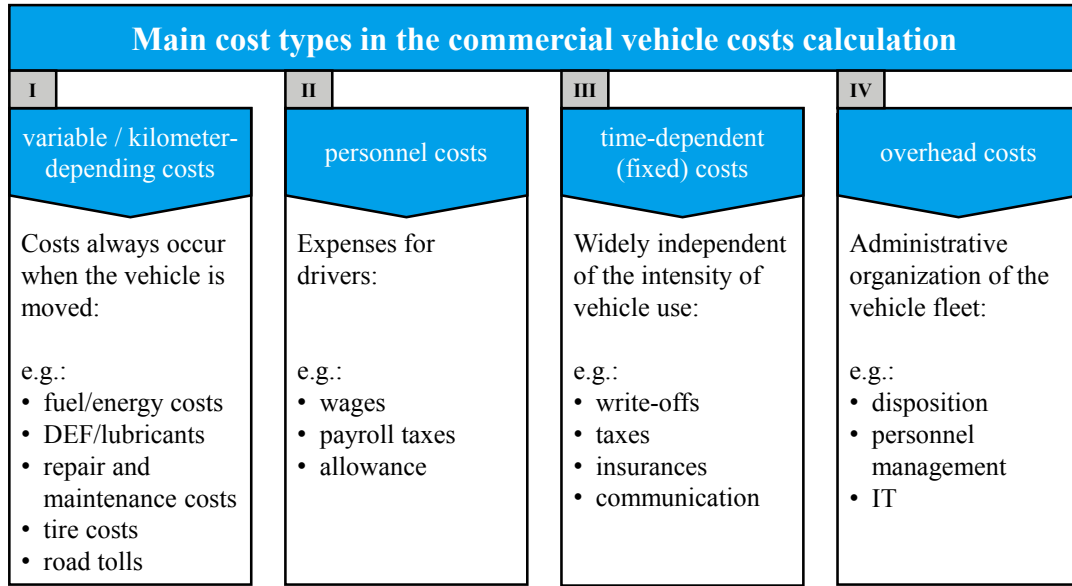


Figure 4: Main Cost Types in the vehicle cost calculation [Wit14]

For a precise derivation of the annual mileage in a pre-calculation for specific commercial vehicle applications the following calculation scheme is proposed. This can be used for a TCO calculation on a €/km basis with consideration of the specific routing and the vehicle specifications e.g. the engine power.

The truck driver's working day typically consists of driving time  $t_{drive,day}$ , supervising or executing the loading/unloading procedures  $t_{load/unload,day}$  and spending time  $t_{other work,day}$  doing other jobs, e.g. refuelling.

$$t_{work,day} = t_{drive,day} + t_{load/unload,day} + t_{other work,day} \quad (6.1)$$

The daily time spent for loading/unloading depends on the amount of loaded rides, that is calculated by the share of dry runs  $p_{dry run}$ , the time needed for loading  $t_{load}$  and unloading  $t_{unload}$  the vehicle combination and the number of rides per day. The latter depends on the vehicle's average speed  $v_{avg}$ , the daily driving time  $t_{drive,day}$  and the average distance  $s_{load/unload}$  between the loading and unloading points.

$$t_{load/unload,day} = (1 - p_{dry run})(t_{load} + t_{unload}) \frac{v_{avg} t_{drive,day}}{s_{load/unload}} \quad (6.2)$$

Inserting eq. (6.2) in (6.1) and solving for daily driving time:

$$t_{drive,day} = \frac{t_{work,day} - t_{other\ work,day}}{1 + (1 - p_{dry\ run})(t_{load} + t_{unload}) \frac{v_{avg}}{s_{load/unload}}} \quad (6.3)$$

The annual mileage  $s_{year}$  calculates from the average speed, the daily driving time and the number of workdays  $d_{work}$  per year.

$$s_{year} = v_{avg} t_{drive,day} d_{work} \quad (6.4)$$

Figure 5 shows a typical TCO distribution of a 40 t semi-trailer tractor unit in a long-haul application, with an assumed annual mileage of 130,000 km and a calculated usage of 5 years. A 324 kW Euro VI diesel engine and a gearbox with 12 levels drive the vehicle. The ratio of fuel costs to vehicle purchase costs is around 7:1 in such an application. The fuel costs represent approx. one third of the TCO.

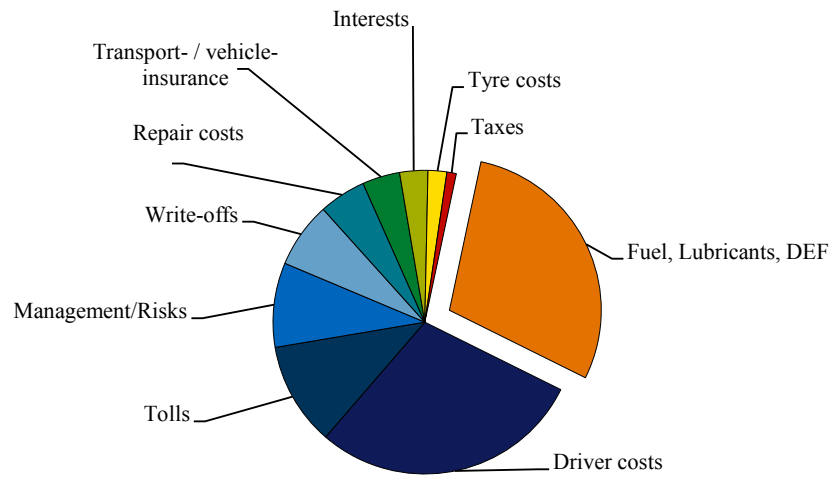


Figure 5: TCO Distribution of a 40 t semi-trailer tractor unit with 5 years of usage and an annual mileage of 130,000 km [Wit14]

## 7. Conclusion

The cost estimations given in this paper are reasonable values for the vehicle components, fuels and GHG emissions. They are supposed to be a common basis for general cost calculations for commercial and passenger vehicles, which allow performing comparable cost estimations.

For a couple of vehicle components and systems, little information about costs can be found. One reason is that costs are a very sensitive topic for companies, so that detailed cost information is mostly not released. Moreover, costs always need to be considered in their context, as they depend on inflation and exchange rates, production volume, technology used or managerial decisions. It has to be pointed out that the estimated values given in this paper have to be used with care, having in mind the different aspects which have an influence on the costs. If necessary, one can adapt the cost estimations accordingly.

**Acknowledgement**

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## Appendix

Table A1: Energy storage costs (OEM purchase price)

Component group	Component / specification	2017	2020	Potential (2030)	Unit	References used for value estimation
Energy storage	Large cell (60 Ah)	92	86	76	EUR/kWh	[KER17]
	Small cell (4.5 Ah)	110	103	92	EUR/kWh	[KER17]
	Ratio battery pack costs to cell costs <sup>1</sup>	1.35	1.30	1.25		[KER17]
	Battery pack Large cell (60 Ah)	300	112	95	EUR/kWh	
	Battery pack Small cell (4.5 Ah)	148	130	115	EUR/kWh	[KER17]
	Battery pack Large cell PHEV	176	165	141	EUR/kWh	
	Ratio PHEV to BEV battery pack costs	1.42	1.47	1.48		[[KER17]
	Additional battery pack fixed cost components <sup>2</sup>	200	200	200	EUR	[KER17]]
	Fuel tank (gasoline or diesel tank)	1			EUR/kg diesel	[FR117], [FTM17]
	CNG tank <sup>3</sup>	19.5			EUR/kg CNG	[FR117], [FTM17]
LNG tank <sup>3</sup>	22			EUR/kg LNG	[FR117], [FTM17]	
Hydrogen gas tank <sup>3</sup>	1000	700	300	EUR/kg hyd.	[BES09, DOU11, EDW11, KAL07, WIE10, BEU16]	

Remark: values are estimated values based on the stated sources

<sup>1</sup> The ratio takes into consideration battery cooling, slave BMSs (one slave for 10-12 battery cell connected in series), cell contacting etc. [FTM14a].

<sup>2</sup> The fixed battery costs have to be added on top of the battery pack costs, which can be calculated using the EUR/kWh values. In particular, these costs should be taken into consideration for smaller battery packs where the fixed cost components are responsible for a larger part of the battery pack costs. Fixed and partly fixed cost components of battery packs include contactors, fuses, insulation monitoring unit, BMS master unit, plugs and battery housing (depends on battery design and mounting inside the vehicle).

<sup>3</sup> The cost in EUR/kg hydrogen or CNG may not be linear across all tank sizes. Tank prices are for standard size tanks with an approx. capacity of 40 kg CNG/LNG or 5 kg hydrogen.

Table A2: Powertrain costs (OEM purchase price)

Component group	Component / specification	2017	2020	Potential (2030)	Unit	References used for value estimation
Powertrain	Permanent synchronous motor (nominal power) <sup>1</sup> Ratio peak power to nominal power: 2.0 Asynchronous motor (nominal power) <sup>1</sup> Ratio peak power to nominal power: 3.0 Power electronics <sup>2</sup> Ratio peak power to nominal power: 1.35   1.2   1.0	12.9	10	10	EUR/kW	[BES09, DOU11, EDW11, ENE10, FTM14a, BWe15]
		10.3	8	8	EUR/kW	[DOU11, EDW11, ENE10, FTM14a, BWe15]
		4.5	3	3	EUR/kW	[ORN15a, ORN15b, ORN15c]
	DC-DC step-down converter On-board charger	250	190		EUR	[BES09, ENE10, WAL10]
		500		300	EUR	[BES09, WAL10, BEU16]
	Gasoline ICE (including transmission) <sup>3</sup>	35			EUR/kW	[BES09, DOU11, EDW11]
		50			EUR/kW	[BES09, EDW11]
	Diesel ICE (including transmission) <sup>3</sup>	120			EUR/kW	[Fri17a]
	Diesel ICE (including transmission+ Interarder) <sup>4</sup>	125			EUR/kW	[FTM17], [Fri17a], [Fri17b], [Fri17c]
	Natural Gas Engine (spark ignition) <sup>4</sup>	180			EUR/kW	[FTM17], [Fri17a], [Fri17b], [Fri17c]
HPDI Engine (self ignition) <sup>4</sup>	200			EUR	[EDW11]	
Stop & go system (for gasoline ICE)	300			EUR	[EDW11]	
Stop & go system (for diesel ICE)	300			EUR	[EDW11]	
Exhaust treatment (for gasoline ICE)	700			EUR	[EDW11]	
Exhaust treatment (for diesel ICE)	6300			EUR	[PAR16], [Fri17a], [Fri17b], [Fri17c]	
Exhaust treatment (3-Way-Catalyser for trucks)	1600			EUR	[FTM17], [Fri17a], [Fri17b], [Fri17c]	
Fuel cell system	600	100	60	EUR/kW	[BES09, DOU11, EDW11, MCK10, WIE10, BEU16]	

Remark: values are estimated values based on the stated sources

<sup>1</sup> The electric motor costs are without power electronics (inverter) and including transmission. The values given are for a mid-sized motor with approx. 90 kW nominal power. The electric motor costs are expected to reduce by one third by 2020, and to remain approximately constant after that.

<sup>2</sup> The power electronics costs (including inverter) in EUR/kW are for nominal motor power. Traditional IGBT first, then the double side cooling Si IGBT, and in the end SiC.

<sup>3</sup> ICE passenger car costs include transmission, but exclude stop & go systems and exhaust treatment. The ICEs are with direct fuel injection technology. The values given are for a mid-sized engine with approx. 70 kW power.

<sup>4</sup> The engine is sized for long-haul trucks. The values given are for European 40 t trucks.

Table A3: Material and vehicle component costs (OEM purchase price)

Component group	Component / specification	2013	2020	Potential (2030)	Unit	References used for value estimation
Vehicle body	Windows	2			EUR/kg	[FTM14a]
	Window lifter	7			EUR	[FTM14a]
	Exterior lights	200			EUR	[FTM14a]
	All electronics (mid-range car; excludes wiring harnesses and high voltage system) <sup>1</sup>	500			EUR/vehicle	[FTM14a]
	Wiring harnesses (small / subcompact car) <sup>1</sup>	100			EUR/vehicle	[FTM14a]
	Wiring harnesses (mid-range / large car) <sup>1</sup>	200			EUR/vehicle	[FTM14a]
	ESP	150			EUR	[FTM14a]
	ACC	180			EUR	[FTM14a]
	Steering system (wheel to steering wheel) <sup>1</sup>	200			EUR/system	[FTM14a]
	4 airbags	100			EUR	[FTM14a]
	Basic front seat	50			EUR	[FTM14a]
	HVEC (heating without AC) <sup>1</sup>	50			EUR/system	[FTM14a]
	Outer mounting parts (e.g. mirrors, wipers)	50			EUR/vehicle	[FTM14a]
Materials <sup>2</sup>	Aluminium	8			EUR/kg	[FTM14b, VDI98]
	High-strength steel	3			EUR/kg	[HUS12, FTM14b, LAE12, THY13a, THY13b, THY13c, WOR13]
	CFRP	50	30		EUR/kg	[FTM14a, FTM14b, KAMI3, LAE12]
	Plastics (PP)	3.5			EUR/kg	[FTM14b]
	Plastics (ABS)	4			EUR/kg	[FTM14b]

Remark: values are estimated values based on the stated sources

Abbreviations: ABS: acrylonitrile butadiene styrene; PP: polypropylene; ESP: electronic stability programme; ACC: adaptive cruise control; HVAC: heating ventilation air conditioning; AC: air conditioning; CFRP: carbon fibre reinforced polymer

<sup>1</sup> Costs have to be considered for ICEVs.

<sup>2</sup> All material costs are processed material costs.

Table A4: Manpower and additional vehicle costs

Component group	Component / specification	2013	2020	Potential (2030)	Unit	References used for value estimation
Vehicle assembly <sup>1</sup>	Sub-compact car (conventional ICEV)	25			HPV	[FTM14a, OWY08]
	Mid-range car (conventional ICEV)	40			HPV	[FTM14a, OWY08]
	Large car (conventional ICEV)	50			HPV	[FTM14a, OWY08]
Labour	Germany	46			EUR/h	[BLS13, DUD10, HEN05, SBA13, SCH08, SCH12, VDM13]
	Japan	38			EUR/h	[BLS13, DUD10, HEN05]
	USA	33			EUR/h	[BLS13, DUD10, HEN05]
	Spain	23			EUR/h	[BLS13, HEN05, SBA13, SCH12]
	Eastern Europe	11			EUR/h	[BLS13, SBA13, SCH08, SCH12]
	China		3		EUR/h	[SCH08]
Additional costs	Distribution cost <sup>2</sup>		5% ... 15%			[CUE99, DOU11, IKA12, MCK12]
	Manufacturer's margin (standard cars) <sup>2</sup>		-5% ... 9%			[CAR13, DOU11, IKA12]
	Manufacturer's margin (premium cars) <sup>2</sup>		5.8% ... 12.5%			[CAR13, DOU11, IKA12]
	Retailer margin <sup>2</sup>		5% ... 15%			[CUE99, DOU11, IKA12, MCK12]
	Overall ratios					
	Ratio vehicle list price to OEM purchase price in Germany <sup>3</sup> (low cost and mid-range cars)		1.7 (all years)			[CAR13, CUE99, IKA12, MCK12]
	Ratio vehicle list price to OEM purchase price in Germany <sup>3</sup> (upper mid-range and premium cars)		2.0 (all years)			[CAR13, CUE99, IKA12, MCK12]

Remark: values are estimated values based on the stated sources

Abbreviations: HPV: hours per vehicle

<sup>1</sup> Increased productivity and reduction of the HPV can be expected in the future.

<sup>2</sup> Additional cost have to be considered as a percentage of the total OEM costs per vehicle.

<sup>3</sup> The ratios includes OEM margins, distribution costs, retailer margins and German value added tax (19%).

Table A5: Fossil fuel, electricity and hydrogen prices in major car markets (consumer price)

Country	Type of fuel	2015	2020 (low-oil-price scenario)	2020 (high-oil-price scenario)	Unit	Sources
Argentina	Electricity	0.05			EUR/kWh	[CAM14]
	Gasoline	1.20	1.32	1.72	EUR/l	[GLO16]
	Diesel	1.09	1.21	1.57	EUR/l	[GLO16]
Brazil	Electricity	0.07			EUR/kWh	[Bra13]
	Gasoline	0.91	1.11	1.31	EUR/l	[GLO16]
	Diesel	0.77	0.86	1.01	EUR/l	[GLO16]
Canada	Electricity	0.08			EUR/kWh	[NUS14]
	Gasoline	0.85	0.94	1.22	EUR/l	[GLO16]
	Diesel	0.77	0.86	1.02	EUR/l	[GLO16]
China	Electricity	0.10			EUR/kWh	[Sha15]
	Gasoline	0.95	1.05	1.36	EUR/l	[GLO16]
	Diesel	0.84	0.93	1.20	EUR/l	[GLO16]
	CNG	0.68	0.79	0.98	EUR/kg	[CON12, IEA10, INFI4, NGV13b]
China - Hong Kong	Electricity	0.14			EUR/kWh	[HKE15]
	Gasoline	1.72	1.90	2.47	EUR/l	[GLO16]
	Diesel	1.26	1.40	1.81	EUR/l	[GLO16]
Colombia	Electricity	0.12			EUR/kWh	[Cod15]
	Gasoline	0.69	0.77	1.00	EUR/l	[GLO16]
	Diesel	0.68	0.75	0.97	EUR/l	[GLO16]
France	Electricity	0.15			EUR/kWh	[EIA15a]
	Gasoline	1.36	0.77	1.00	EUR/l	[GLO16]
	Diesel	1.16	0.75	0.97	EUR/l	[GLO16]
Germany	Electricity	0.23			EUR/kWh	[EON15]
	Gasoline	1.40	1.54	2.00	EUR/l	[GLO16]
	Diesel	1.19	1.32	1.71	EUR/l	[GLO16]
	<sup>1</sup> CNG	1.08		1.26	EUR/kg	[CON12, IEA10, NGV13a]
	<sup>2</sup> LNG	0.92	1.04	1.28	EUR/kg	[Dem16], [Alb13], [BUN17]
	Hydrogen	10.00	8.00	8.00	EUR/kg	[DIE10]
India	Electricity	0.09			EUR/kWh	[Bij15]
	Gasoline	0.93	1.02	1.32	EUR/l	[GLO16]
	Diesel	0.72	1.06	1.38	EUR/l	[GLO16]
Indonesia	Electricity	0.10			EUR/kWh	[Per15]
	Gasoline	0.61	0.68	0.87	EUR/l	[GLO16]
	Diesel	0.73	0.81	1.05	EUR/l	[GLO16]
Japan	Electricity	0.23			EUR/kWh	[Tep15]
	Gasoline	0.98	0.91	1.09	EUR/l	[GLO16]
	Diesel	0.82	1.18	1.41	EUR/l	[GLO16]
Mexico	Electricity	0.14			EUR/kWh	[IEA14]



	Gasoline	0.82	0.90	1.17	EUR/l	[GLO16]
	Diesel	0.81	0.89	1.16	EUR/l	[GLO16]
Singapore	Electricity	0.18			EUR/kWh	[EMA14]
	Gasoline	1.33	1.68	2.23	EUR/l	[GLO16]
	Diesel	0.85	1.29	1.71	EUR/l	[GLO16]
Thailand	Electricity	0.11			EUR/kWh	[MEA15]
	Gasoline	0.90	1.00	1.30	EUR/l	[GLO16]
	Diesel	0.65	0.71	0.93	EUR/l	[GLO16]
Turkey	Electricity	0.17			EUR/kWh	[IEA14]
	Gasoline	1.49	1.64	2.14	EUR/l	[GLO16]
	Diesel	1.27	1.40	1.82	EUR/l	[GLO16]
UK	Electricity	0.22			EUR/kWh	[DEC14]
	Gasoline	1.54	1.69	2.21	EUR/l	[AAD16]
	Diesel	1.59	1.75	2.27	EUR/l	[AAD16]
USA	Electricity	0.14			EUR/kWh	[EIA15a]
	Gasoline	0.63	0.69	0.90	EUR/l	[GLO16]
	Diesel	0.65	0.71	0.93	EUR/l	[GLO16]
USA - Chicago	Electricity	0.10			EUR/kWh	[EIA15a]
	Gasoline	0.62	0.68	0.89	EUR/l	[EIA15b]
	Diesel	0.63	0.69	0.90	EUR/l	[Gas15]
USA - Houston	Electricity	0.11			EUR/kWh	[EIA15a]
	Gasoline	0.50	0.56	0.72	EUR/l	[EIA15b]
	Diesel	0.61	0.68	0.88	EUR/l	[EIA15b]
USA - New York	Electricity	0.18			EUR/kWh	[EIA15a]
	Gasoline	0.57	0.63	0.81	EUR/l	[EIA15b]
	Diesel	0.69	0.77	1.00	EUR/l	[NYS15]
USA - Los Angeles	Electricity	0.14			EUR/kWh	[EIA15a]
	Gasoline	0.78	0.86	1.13	EUR/l	[EIA15b]
	Diesel	0.72	0.79	1.04	EUR/l	[EIA15b]

Remarks:

- All values are rounded.
- The price projection for gasoline and diesel is based on prices from the year 2015 and is done for two oil-price scenarios. The baseline of 2015 is around 50 USD per barrel
- The low-oil-price scenario assumes oil-price increases of 2.0% per year for all countries [CON12, IEA10].
- The values for the high-oil-price scenario are 30% higher than those in the low-oil-price scenario.
- <sup>1), 2)</sup> Natural gas prices according to [BUN17] until 2026.

Table A6: Energymix

Country / State	Year	Coal	Oil	Natural Gas	Nuclear	Hydro	Other Renewables	Others/Waste	Sources
Argentina	2013	2 %	14 %	54 %	5 %	22 %	2 %	0 %	[Wor16]
Brazil	2013	4 %	5 %	12 %	3 %	69 %	8 %	0 %	[Wor16]
Canada	2014	10 %	1 %	10 %	17 %	59 %	3 %	0 %	[Wor16]
China	2014	75 %	0 %	2 %	2 %	17 %	4 %	0 %	[Wor16]
Colombia	2013	10 %	1 %	18 %	0 %	69 %	3 %	0 %	[Wor16]
France	2014	2 %	0 %	3 %	78 %	11 %	5 %	1 %	[Wor16]
Germany	2014	45 %	1 %	10 %	16 %	3 %	23 %	1 %	[Wor16]
Hong Kong	2013	75 %	0 %	25 %	0 %	0 %	0 %	0 %	[Wor16]
India	2013	73 %	2 %	6 %	3 %	12 %	5 %	0 %	[Wor16]
Indonesia	2013	51 %	12 %	24 %	0 %	8 %	5 %	0 %	[Wor16]
Japan	2014	33 %	9 %	41 %	0 %	8 %	7 %	3 %	[Wor16]
Mexico	2014	11 %	11 %	57 %	3 %	13 %	5 %	0 %	[Wor16]
Singapore	2015	0 %	1 %	96 %	0 %	0 %	0 %	3 %	[EMA15]
Thailand	2013	20 %	1 %	71 %	0 %	4 %	5 %	0 %	[Wor16]
Turkey	2014	30 %	1 %	48 %	0 %	16 %	5 %	0 %	[Wor16]
UK	2014	30 %	1 %	30 %	19 %	2 %	18 %	1 %	[Wor16]
USA									
California	2014	0 %	0 %	61 %	9 %	8 %	20 %	2 %	[EIA15a]
Illinois	2014	42 %	0 %	3 %	48 %	0 %	5 %	0 %	[EIA15a]
New York	2014	3 %	2 %	40 %	31 %	19 %	3 %	2 %	[EIA15a]
Texas	2014	34 %	0 %	47 %	9 %	0 %	9 %	0 %	[EIA15a]

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