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Total Cost of Ownership Model Development for Electric Cars

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Abstract Higher market-share of electric cars can be facilitated by several incentives. Our aim was to elaborate a cost model and a calculation method for total cost of ownership (TCO) pertaining to electric vehicles (EVs), as well as an information application, to support new vehicle purchase. Purchase, operation, maintenance, and other cost elements were considered. Based on this method, we developed an information application for customers and other stakeholders. Thus, several vehicle types and operational cases may be compared based on specific and aggregated costs. Findings and Originality: We found that question as 'Under what operating conditions is it worth to buy an EV?' can be answered by our calculation method. Customers' most typical questions, as 'Which vehicle type's TCO is the most favourable?' and 'How much less emission do EVs produce?', can be also answered. We found that above app. 21000 km/year covered distance it is worth to buy an 'average' EV with general features for private use. Our results substantiate further research activities and practical applications. During the research, the novelty and quick development of the EV technology (e.g., lacking operational experiences), the availability, dynamism and reliability of data, and the forecast of cost elements (e.g., future depreciation or specific energy costs) were the most relevant challenges. Consumers and companies may use our decision support tool. We are going to address the following issues: support company fleet purchase, investigation of typical vehicle types, estimation of maintenance and repair costs, sensitivity analysis of variables.

Keywords: • Electric Car Purchase • Decision Support • Total Cost Of Ownership • Technological Change

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INTRODUCTION

Operation of electric road vehicles differs from that of conventional ones. It implies novel decision-making situations for users and other stakeholders of electromobility system. At Department of Transportation Technology and Economics in Budapest University of Technology and Economics (BME), we have been performing research with wide scope regarding planning and operation of transportation systems based on electric vehicles for many years and provide scientific solutions, which are well applicable in practice too.

Price of electric cars are still rather high. All cost elements, their correspondences, their values, and future changes are not transparent for and known by users. Accordingly, they make non-rational decisions in many cases. Further hurdle, that impacts of technological development cannot be clearly forecasted. Therefore, beside purchase price, the Total Cost of Ownership (TCO) is also to be investigated. Our research objective is to elaborate a cost calculation method to facilitate spread of electromobility and aid users' decisions, as well as to develop a user-friendly information application.

LITERATURE REVIEW

Market of electric cars are influenced by both costs and incentives. We have summarized literature results accordingly.

Total cost of ownership

Literature pertaining to TCO deals mainly with calculation of costs and CO_2 emission. Besides, user preferences are investigated and forecasts regarding future vehicle market shares are provided in several research papers. Spatial validity and forecast time horizons are various in these papers. The most detailed research results are available for the USA, European Union, Germany, UK, France, the Netherlands, and Norway. In general, timespan 2030-2050 is applied in forecasts. Most of the studies focus on passenger cars; vans are mentioned only in some cases. Number (and size) of vehicle types varies between 1 and 6 (e.g., small, compact, medium, executive, SUV, minivan); while number of usage types is typically 3 according to rate of urban and long-distance travels. Generally, the following propulsion modes are involved in the investigations: Internal Combustion Engine Vehicle (ICEV), Hybrid Electric Vehicle (HEV), Plug-in Hybrid Electric Vehicle (PHEV), Battery Electric Vehicle (BEV) and Fuel Cell Electric Vehicle (FCEV). During emission calculation, the wider, so called Well-To-Wheel (WTW) approach is more common; but the narrower, so called Tank-To-Wheel (TTW) approaches are also often applied. In the case of emphasizing sustainability, external cost elements are also to be involved into the cost model. In consumer-oriented total cost of ownership (TCOC) calculations the latter ones are not considered. Cost models to support decisions of vehicle manufacturers are related to consumer models through purchase price.

Value of TCO is influenced by many (app. 30-40) factors either directly or indirectly, having impact with different strengths [1]. Besides, future values of cost elements may be calculated only with significant uncertainties. Therefore, scenarios are created in many cases and the total cost is derived from the parameters fixed in them. The scenarios are typically determined according to maturity of EV market; namely, rate of EVs within newly purchased vehicles. For instance, it has been stated that vehicle purchase promotions significantly facilitate market share increase of EVs according to market model based on the Germany, 2030 scenario [2].

Environmental and health impacts caused by shift from combustion engine powered vehicles to EVs were assessed as external costs using the ExternE method [3]. In this Europe-wide research, the different raw-materials and the technological features of energy generation were also considered, which vary country to country and change time by time.

Profit rate of car manufacturers is usually underestimated in the TCO-related literature, while they are aiming at payback of their investments. Consequently, TCO of EVs is expectedly not significantly lower than that of ICEVs. It also means that some measures should be applied to increase TCO of ICEVs (e.g., introduction of new taxes) [4]. Additionally, several prohibitions and restrictions with various spatial, temporal etc. extent can be applied for conventional vehicles to lessen their popularity.

One part of the applied models is based on so-called techno-economic approach. In these models, technological correspondences are validated using results coming from measurements performed under real driving conditions. The cost calculation uses these correspondences. In this way, more reliable values can be calculated than in the case of TCO models based on theoretical values provided by car manufacturers, as theoretical values differ from real ones, because they usually slightly tend towards combustion engine cars. Besides, it was also found that effect of economic variables on TCO is more significant than that of technical ones [5].

TCO calculations regarding vehicles with hydrogen fuel cells have several peculiarities, which is the consequence of the new and specific technology and its less matured characteristics. Further difficulty, that only little experience, as well as few operational and usage data are available. These TCO models also contain complex forecasting procedures to determine values of cost elements. It is one of the peculiarities that travel cost to the nearest charging facility is also considered, as the charging network is significantly rarer in the case of this new technology. Furthermore, calculation of maintenance and repair costs is more difficult (e.g., failure rates are considered), as well as specific costs of energy resources are to be forecasted only with uncertainties [6].

Cost calculations consider total life cycle of vehicles only in some cases. Therefore, in some studies, life cycle cost models were elaborated that include indirect costs (externalities), emission values (e.g., global, and local air pollution) etc. These models can be applied in the case of several vehicle technologies and fuels; both analyses and comparisons can be produced. These calculation results significantly contribute to the more efficient decisions and measures [7].

Incentives

Literature regarding incentives answer the questions that, which measures can facilitate and accelerate shift from conventional vehicles to EVs and related energy management solutions (e.g., vehicle to grid technology) and, which impacts are expected accordingly. Incentives can be categorized as monetary and non-monetary incentives. Several incentives facilitate higher EV market share through impact on TCO.

It was found in many studies, that high purchase price does not hold back growth of market share in the case of most hybrid vehicles, while significant subsidization is needed to increase competitiveness of plug-in hybrid and pure battery EVs [8].

Questionnaire surveys and deep interviews are widely used to identify incentives and estimate their impacts. For the latter case, transport, and energetics experts, as well as decision makers are involved usually. Analyses show that views and opinions regarding measures' advantages and disadvantages often significantly vary according to countries, regions, and cities, as well as maturity of EV market. It is stated that stabile and consistently managed target values and purchase discounts are needed in each country, which are to be combined with campaigns to enhance consciousness [9]. The national measures may be supplemented by regional or local incentives. Analyses of cities cover building regulations, facilities to connect to the energy network, issues related to social equity etc. in the context of EVs. It was found that significant differences can be observed regarding urban incentives from the lack of regulatory tools to very detailed and extended regulations. More emphasis is placed on incentives related to urban vehicle fleets, while less attention is paid to building regulations [10]. Not only the advantages and challenges of EVs were identified according to the respondents' answers in questionnaire survey, but the typical knowledge gaps and misbelieves were also revealed among the potential users. For example, users often do not know the exact environmental benefits because the lack of transparency due to varying energy-mix country by country.

STATE OF ELECTROMOBILITY

The most relevant indicators to characterize state of electromobility of certain countries (regions) are:

- number and rate of different EV types sold in the given period,
- size, composition, and attributes of EV fleet,
- extension and characteristics of charging facility network (spatial coverage,

quantity, power, capacity, tariff, standardization),

- characteristics of information system and services aiding electromobility,
- existence of political targets, governmental subsidies, and incentives.

Price of EVs decreased significantly in the last years, while the new models are getting to be more and more developed and equipped and the manufacturers provide longer and wider guarantee. Quick spread of electromobility is only possible if consumers accept the new technology and make rational monetary decisions.

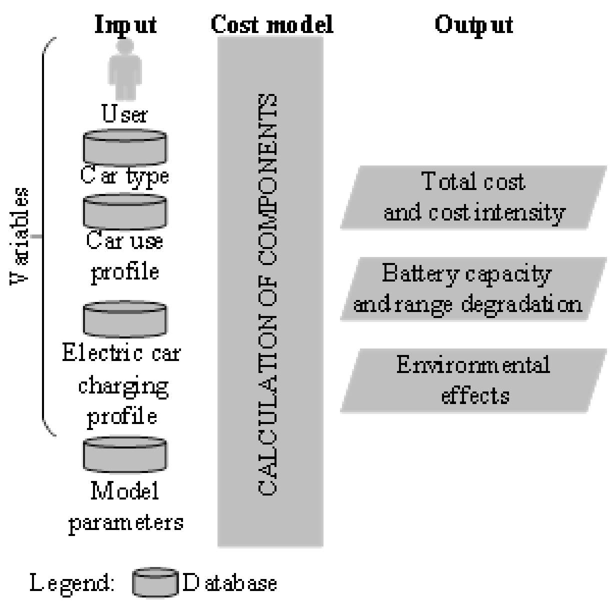
COST MODEL

The following model limitations were applied:

- The cost calculation may be performed for new vehicles for a maximum period of 15 years.
- The average fuel and electric energy prices over a period were considered.
- Car amortization is a function of time and mileage. Vehicle categories were not considered.
- Obligatory tax and fees were determined based on the Hungarian legislation.
- The car is sold at the end of the investigated period. The selling price is the original purchase price minus amortization.

The cost model is summarized in Figure 1.

Figure 1. Cost model



Input data were categorized into the following groups:

- Variables: the user may modify them.
- Model parameters: stable values that are may be modified by the operator. Model parameter values may be reviewed periodically.

Variables

To support manual data entry, some variable values are stored in databases. For instance, the attributes of an electric car may be stored in a database. The variables related to car purchase, maintenance and use are summarized in Table 1. The variables covering energy consumption, charging and pollution are given in Table 2.

Table 1. Model variables – purchase, maintenance, use

Cat.	Sign	Name
Purchase	B	Battery capacity
	C_v	Purchase price
	I	Highest own contribution, regardless of the purchase price
	P	Power
	$r_{\%}$	Interest
	APR	APR of a loan
	T_{APR}	Loan maturity
	T_0	Ownership period
Maintenance	C_{CASCO}	Annual fee of CASCO insurance
	C_{ITP}	Annual fee of third-party liability insurance
	C_{SE}	Cost of planned service
	C_{ST}	Cost of summer tyre set
	C_{WT}	Cost of winter tyre set
	C_{12V}	Cost of 12V car battery
	f_M	Frequency of planned service
	T_{ST}	Expected lifetime of a summer tyre set
	T_{WT}	Expected lifetime of a winter tyre set
	T_{12V}	Expected lifetime of a 12V car battery
Use	C_P	Parking cost
	C_R	Road toll
	M	Annual mileage
	$r_{E,L}$	Share of electric drivetrain on highways
	$r_{E,M}$	Share of electric drivetrain on main roads
	$r_{E,S}$	Share of electric drivetrain in urban areas
	$r_{T,L}$	Share of highway use based on mileage
	$r_{T,M}$	Share of main road use based on mileage
	$r_{T,S}$	Share of urban road use based on mileage

We considered road toll; however, drivetrain dependent road toll is not typical, but it may be introduced in the future. The following road categories were distinguished from the point of car use:

- highway,
- main road, and
- urban road.

The share of road use per category is based on the mileage. The share of electric drivetrain use (rE,x), electric energy and fuel consumption ($c_{E,x}$ and $c_{F,y}$), and pollution ($e_{E,x}$) may be different for each road category.

Table 2. Model variables – energy consumption, charging, pollution

Cat.	Sign	Name
Energy consumption	$c_{E,L}$	Electric energy consumption on highways
	$c_{F,M}$	Electric energy consumption on main roads
	$c_{E,S}$	Electric energy consumption on urban roads
	$c_{F,L}$	Fuel consumption on highways
	$c_{F,M}$	Fuel consumption on main roads
	$c_{F,S}$	Fuel consumption on urban roads
	$C_{CH,H}$	Cost of home charging
	$C_{CH,W}$	Cost of charging at workplace
	$C_{CH,AC}$	Cost of public charging at non-free normal chargers
	$C_{CH,DC}$	Cost of public charging at non-free superchargers
	$C_{CH,O}$	Cost of charging at other non-free locations
	C_F	Fuel cost
	$r_{CH,H}$	Share of home charging based on charged energy
	$r_{CH,W}$	Share of charging at workplace based on charged energy
	$r_{CH,AC}$	Share of public charging at non-free normal chargers based on charged energy
	$r_{CH,DC}$	Share of public charging at non-free superchargers based on charged energy
	$r_{CH,O}$	Share of charging at other non-free locations based on charged energy
	$r_{CH,FREE}$	Share of free charging based on charged energy
Pollution	$e_{CH,H}$	Emission intensity of home charging
	$e_{CH,W}$	Emission intensity of charging at workplace
	$e_{CH,O}$	Emission intensity of charging at other non-free locations
	$e_{CH,FREE}$	Emission intensity of free charging
	$e_{E,L}$	Emission intensity on highways
	$e_{F,M}$	Emission intensity on main roads
	$e_{E,S}$	Emission intensity on urban roads

The share of the electric drivetrain is 0 % for conventional cars, 100 % for pure electric cars and between 0 and 100 % for plug-in hybrid cars. The following charging station location types were distinguished:

- home,
- workplace,
- public non-free, normal charger,
- public non-free, supercharger,
- other non-free public,
- free charging.

The share of charging per location type is based on the charged energy. The cost of charging (CCH,x) and the emission intensity of electricity generation (eCH,x) may be different for each charging station location type.

The following databases support the manual data entry:

- Car type: the following variables may be given per car type: B, C_V, P, F, r_E, i, $c_{E,j}$, $c_{F,k}$, $e_{F,l}$.
- Car use profile: the following profiles may be given per car use profile: M, $r_{T,x}$.
- Electric car charging profile: the following variables may be given per charging profile: $r_{CH,y}$.

The set of variables were indicated using general indexes in subscript. For instance, $r_{E,i}$ indicates the share of electric drivetrain on highways ($r_{E,L}$), main roads ($r_{E,M}$) and urban roads ($r_{E,S}$). Based on the literature review and previous surveys, we determined car use (Table 3) and electric car charging profiles (Table 4). The car use profiles differ on the mileage and the share of road category use. We considered that the access to private charging and car use effect significantly the charging behavior. Therefore, the following electric car charging profiles were determined:

- charging at home is typical,
- short journeys, charging at the destination is typical,
- long journeys, charging interrupting journeys is typical.

Table 3. Car use profiles

Variable		Urban traveller	Commuter	Travelling salesman
M	[km]	13000	19000	25000
$r_{T,L}$	[%]	10	25	60
$r_{T,M}$		10	25	20
$r_{T,S}$		80	50	20

Table 4. Electric car charging profiles

Variable		Home	Destination	En-route
$r_{CH,H}$	[%]	70	0	0
$r_{CH,W}$		0	0	0
$r_{CH,AC}$		5	65	25
$r_{CH,DC}$		10	20	70
$r_{CH,O}$		0	0	0
$r_{CH,FREE}$		15	15	5

Furthermore, default values and the integration of existing calculators, such as loan and insurance cost calculators, may also support the manual data entry.

Model parameters

The amortisation was recorded as a time and mileage-dependent parameter (Table 5). Above-average mileage increases amortisation, and lower than average mileage decreases it. The amortisation rate and average mileage were based on conventional car use. The amortisation rate is the value loss compared to the original purchase price.

Obligatory tax, fee and cost elements regulated by legislation were recorded as parameters. Parameters related to battery degradation and pollution are summarized in Table 6.

Table 5. Amortization parameters

Parameter	Value
Value loss in the 1st year	30 %
Value loss in the 2nd year	15 %
Value loss in the 3rd year	10 %
Annual value loss between 4th and 6th year	4 %
Annual value loss between 7th and 10th year	3 %
Annual value loss between 11th and 15th year	2 %
Average mileage	15 000 km
Above-average mileage correction	0,5 %/5000 km
Lower than average mileage correction	0,3 %/5000 km

Table 6. Battery degradation and pollution parameters

Parameter	Value
Emission intensity of battery manufacturing	120 kgCO_2eq /kWh
Battery capacity degradation	3 %/100 charges
Average used battery capacity	60 %
Efficient battery capacity for range calculation	90 %
Emission intensity of electricity generation at public non-free normal and superchargers	200 gCO_2eq /kWh
Energy content of petrol	8,7 kWh/litre
Energy content of diesel	9,9 kWh/litre
CO_2 absorption of a tree	22 kg/year

Cost model

The cost model supports decision making through the following outputs:

- TCO calculation.
- Battery capacity and range calculation.
- Environmental effect calculation.

The cost elements are categorised into the following groups:

- Purchase: amortisation, loan, and losing capital income because of vehicle purchase.

- Maintenance: insurance, planned service, tax, and obligatory costs.
- Use: parking fee, road toll, and energy cost.

We assumed that the purchase price includes the cost of one summer tyre set. Planned service may depend on time and mileage. Thus, service is partly related to car use because above-average mileage may increase service costs. We applied a simplification and assigned the total service cost to the maintenance.

The TCO is the sum of purchase, maintenance and use related costs. We determined the TCO intensity based on time [€/month] and mileage [€/km] to support decision making. Namely, the TCO was divided by the number of months and mileage.

The remaining battery capacity is calculated according to eq. (1). We applied the battery capacity degradation (3 %/100 charging session) and the average used battery capacity (60 %) parameters.

$$B' = B \cdot (0.97)^{\frac{E'_E}{60B}} \tag{1}$$

Where B' is remaining battery capacity, and E'_E is total charged energy during the investigated period.

A range is calculated based on the remaining battery capacity and energy consumption, assuming a 90 % battery capacity utilisation.

The pollution was determined considering the emission of battery manufacturing, electricity generation and fuel consumption. Recycling and reuse (in static energy storage systems) of batteries were not considered because they may not increase the emission of battery manufacturing in the long term. Furthermore, we estimated the number of trees that may eliminate the environmental effects of vehicle use.

CASE STUDY

Theoretical conventional petrol, plug-in hybrid, and pure battery electric vehicles were compared based on the cost model. The vehicle characteristics are summarized in Table 7.

Table 7. Vehicle characteristics

Variable	Petrol	Plug-in hybrid	Electric
B	0	15	40
C_V	22 200	26 400	33 300
P	100	100	100
$r_{E,L}$	0	10	100
$r_{E,M}$	0	25	100
$r_{E,S}$	0	90	100
$c_{E,L}$	0	24	23
$c_{E,M}$	0	18	19
$c_{E,S}$	0	15	16
$c_{F,L}$	7	7	0
$c_{F,M}$	6	5,5	0
$c_{F,S}$	7	3	0
$e_{F,L}$	150	155	0
$e_{F,M}$	130	110	0
$e_{F,S}$	150	60	0
C_{SE}	275	250	165
f_M	1	1	1

The estimated annual planned service fee of a conventional petrol car was 275 €. The planned service fees of plug-in hybrid and pure electric battery cars were estimated based on our experiences. The commuter car use profile and home charging profile were selected. The cost of charging and emission intensity of electricity generation are summarised in Table 8. We assumed that local renewable power generation at home (e.g., solar panels) might reduce the cost of charging at home. We applied the typical Hungarian electricity prices and emission intensity (electricitymap.org).

The highest own contribution was 27 800 €. The APR and loan maturity were 5,75 % and 60 months, respectively. We assumed the customer does not invest the remaining own contribution after the purchase. The total annual insurance cost was 830€ for each car. The cost of summer and winter tyre set, and car battery were 235 €, 210 € and 95 €, respectively.

Table 8. Charging cost and emission intensity of electricity generation

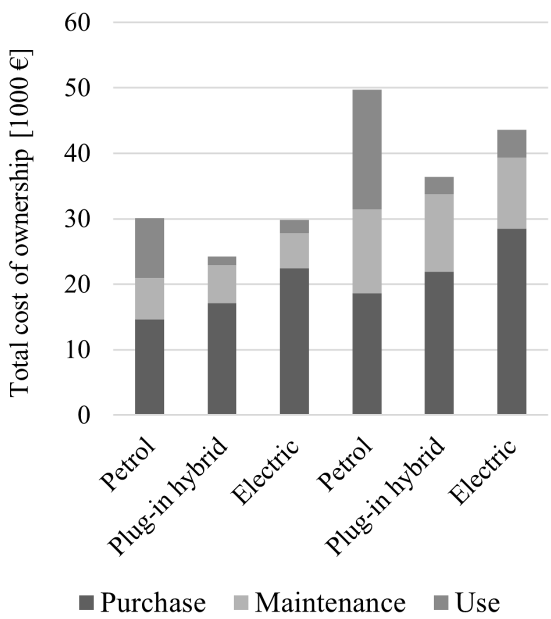
Location type	$C_{CH,x}$ [€/kWh]	$e_{CH,x}$ [gCO$_2$eq/kWh]
Home	0,028	45
Workplace	0	200
Public non-free, normal charger	0,375	200
Public non-free, supercharger	0,375	200
Other non-free	0,42	200
Free charging	0	200

The estimated lifetime of a tyre set, and car battery were 7 and 8 years. The monthly parking cost was 8 € for the petrol car, and 0 € for plug-in and pure electric cars. The annual road toll was 125 € for each car. The cost of petrol was 1,25 €. The TCO analysis was performed for 5- and 10-year long periods.

RESULTS AND DISCUSSION

The purchase, maintenance, and use related costs are given in Figure 2.

Figure 2. Total cost of ownership after 5 and 10 years



The purchase cost is different after 5 and 10 years because of the amortisation. It was noted that the plug-in hybrid car has the lowest TCO for both periods. However, the car use behaviour and access to the charging infrastructure may significantly influence the result. For a 5-year long period, the conventional petrol car is 25 % more expensive than the plug-in hybrid. Despite the significantly higher purchase cost of pure electric battery cars, there is no significant difference between petrol and pure electric battery cars. In the case of a petrol car, it was noted that only half of the TCO is the purchase cost. After 10 years, the TCO of the petrol car is 35 % and 15 % higher than the TCO of plug-in hybrid and pure electric battery cars. In other words, the higher purchase cost of electric cars may pay off after 5 years. The pure electric battery car is more expensive than the plug-in hybrid car because of the lower purchase and use related costs. The higher share of urban road use may decrease the TCO of pure electric battery cars. Accordingly, a pure electric battery car fits urban use, and a plug-in hybrid car is suitable for regular commuting. For long journeys, the conventional petrol car may be the most suitable. Further results are summarized in Table 9.

Table 9. Main results

	After 5 years			**After 10 years**		
	Petrol	**Plug-in hybrid**	**Electric**	**Petrol**	**Plug-in hybrid**	**Electric**
Amortization [1000 €]	14,45	17,2	21,7	18,45	21,9	27,7
Mileage based TCO intensity [€/km]	,32	,26	,31	,26	,19	,23
Remaining battery capacity [kWh]	0	11	31	0	8	23
Pollution [eqCO_2t]	14	8	6	28	14	8

The TCO intensity of cars is between 0,26-0,32 €/km after 5 years, and between 0,19-0,26 after 10 years. Namely, the extended operation of cars decreases the TCO intensity. It was noted that the remaining battery capacity is 77 % and 57 % after 5 and 10 years. The pollution of the conventional car was the greatest, and the pollution of the pure electric battery car was the lowest for both periods. Namely, the low pollution of electricity generation may eliminate the pollution of battery manufacturing after 5 years. After 10 years, the pollution of the petrol car is approximately three times higher than the pollution of the pure electric battery car and double of the plug-in hybrid car's pollution.

CONCLUSION

The developed cost model and cost comparison of drivetrains contribute to the literature in the field of electromobility and support decision making. Developing a future-proof cost model was the most significant challenge because of the rapid technology development and the complexity of electromobility systems.

According to our results, pure electric battery cars are the best fur urban roads, plug-in hybrid cars fit commuting, and conventional petrol cars are suitable for frequent long journeys from the TCO point of view. It was noted that the low emission intensity of electricity generation could outweigh the emission of battery manufacturing in 5 years. Since electric cars are not widespread yet, we lack information on the service and amortisation. Furthermore, the oil price significantly fluctuates and increases, which influences the pay-off of electric cars. Therefore, the reliability of the cost model may be improved by updating the parameters in the future.

We plan to extend the cost model to fleet cars and analyse the effect of charging infrastructure, electricity network and car use profile on the TCO. Additionally, we are going to involve alternative drivetrains (e.g., hydrogen) and vehicle types (e.g., bus, truck).

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REFERENCES

[1] Letmathe, P., Suares, M. (2020). Understanding the impact that potential driving bans on conventional vehicles and the total cost of ownership have on electric vehicle choice in Germany. Sustainable Futures 2: 100018. doi: 10.1016/j.sftr.2020.100018.

[2] Bühne, J-A., Gruschwitz, D., Hölscher, J., Klötzke, M., Kugler, U., Schimeczek, C. (2015). How to promote electromobility for European car drivers? Obstacles to overcome for a broad market penetration. European Transport Research Review, 7(3). doi: 10.1007/s12544-015-0178-0.

[3] Buekers, J., Holderbeke, M. V., Bierkens, J., Panis. L. I. (2014) Health and environmental benefits related to electric vehicle introduction in EU countries. Transportation Research Part D: Transport and Environment, 33: 26-38. doi: 10.1016/j.trd.2014.09.002.

[4] Velzen, A., Annema, J. A., Kaa, G., Wee, B. (2019). Proposing a more comprehensive future total cost of ownership estimation framework for electric vehicles. Energy Policy 129: 1034–1046. doi: 10.1016/j.enpol.2019.02.071.

[5] Desreveaux, A., Hittinger, E., Bouscayrol, A., Castex, E., Sirbu, G. M. (2020). Techno-Economic Comparison of Total Cost of Ownership of Electric and Diesel Vehicles. IEEE Access, 8: 195752-195762. doi: 10.1109/ACCESS.2020.3033500.

[6] Wróblewski, P.; Lewicki W.; Drożdż, W.; Dowejko, J. (2021). Total cost of ownership and its potential consequences for the development of the hydrogen fuel cell powered vehicle market in Poland. Energies 14(8), 2131; doi: 10.3390/en14082131.

[7] Mitropoulos L., K., Prevedouros, P. D., Kopelias P. (2017). Total cost of ownership and externalities of conventional, hybrid and electric vehicle. Transportation Research Procedia 24C: 267–274. doi: 10.1016/j.trpro.2017.05.117.

[8] Bubeck, S., Tomaschek, J., Fahl, U. (2016). Perspectives of electric mobility: Total cost of ownership of electric vehicles in Germany. Transport Policy 50: 63–77. doi: 10.1016/j.tranpol.2016.05.012.

[9] Kestera, J., Noel, L., De Rubens, G. Z., Sovacool, B. K. (2018). Policy mechanisms to accelerate electric vehicle adoption: A qualitative review from the Nordic region. Renewable and Sustainable Energy Reviews. 94: 719–731. doi: 10.1016/j.rser.2018.05.067.

[10] Wood, J., Jain, A. (2020). Raceways, rebates, and retrofits: an exploration of several American cities' policies to facilitate electric vehicle purchase and usage. International Journal of Urban Sustainable Development. doi: 10.1080/19463138.2020.1843467.