EFFECTIVENESS OF MONETARY AND NON-MONETARY INCENTIVES ON THE PURCHASE OF PLUG-IN ELECTRIC VEHICLES CONSIDERING NATIONAL AND REGIONAL FRAMEWORKS WITHIN THE EUROPEAN UNION

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1 Introduction

Municipalities and national governments struggle to meet the ever increasing challenges for the road transport system posed by climate change and urbanisation. One possible response to these challenges is electric mobility, which is expected to reduce local emissions of noise, air pollutants and greenhouse gases and is, thus, promoted by measures differing across nations and regions in the European Union. The effectiveness of these incentives with respect to their impact on the uptake of electric mobility, however, is yet not fully understood: In the past some countries with rather limited incentives showed a larger EV market growth than other countries with strong incentives, cf. Mock & Yang (2014). Thus, the installed incentive measures exhibit heterogeneous effects on electric vehicle registrations in the European countries, cf. Fearnley et al. (2015). The lack of understanding hampers the identification of best practise measures and their transfer to other regions and countries, cf. Davies et al. (2014).

Input and outcomes of this work are based on the project “Incentives for Cleaner Vehicles in Urban Europe” (I-CVUE), which addresses these open questions regarding the effectiveness of monetary and non-monetary incentives, and, at the same time, aims to identify current use-cases for the replacement of conventional powered vehicles with plug-in electric ones in Europe[1]. Within this project an advanced model to calculate total cost of vehicle ownership (TCO) and vehicle utility was developed and condensed in a publicly accessible web-tool[2]. Compared to various previous TCO calculations of, e.g., Al-Alawi & Bradley (2013); Rousseau et al. (2015); Wu et al. (2015), this comprehensive and refined calculation model includes purchase cost and resale values, profit tax reliefs, maintenance and repair cost, fuel and energy cost, motor vehicle taxes as well as purchase taxes and monetary incentives. Additionally, cost due to range limitations are considered for battery electric vehicles, as well as national taxation and incentive schemes for Austria, Germany, Spain, the Netherlands and the United Kingdom. Furthermore, different new-vehicle sizes and customer types, e.g. private customers or commercial fleet operators are taken into account. Non-monetary aspects of car ownership, i.e. well-to-wheel CO_2 emissions and driving dynamics, are considered via a utility function, as are third party cost items, e.g. benefit in kind taxes for employees that privately use a company car. The reader is encouraged to inspect the given data sets, to reproduce the results presented here and to issue own calculations.

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[1] http://icvue.eu
[2] http://dsm.icvue.eu

Based on this powerful tool, the present study aims to provide insights on the impact of incentives upon EV-uptake as well as to assess the current potential of plug-in electric vehicles for important new-vehicle markets in Europe. This work is structured as follows: Chapter 2 is dedicated to the TCO model description as well as the explanation of fleet-specific costs and the employed data sets. In Chapter 3 considered non-monetary aspects and the calculation of vehicle utility will be addressed. Results for vehicle TCO and integrated vehicle utility will be given in Chapter 4. Chapter 5 will provide country-specific and fleet-type specific policy recommendations for national decision-makers.

2 Total cost of ownership

The literature comprises numerous total cost of ownership calculations comparing conventional vehicles to such with electric powertrains – for an overview of recent studies refer to, e.g., Bubeck et al. (2016); Redelbach (2016); Wu et al. (2015). Most studies, however, focus on a single country only. Due to often different approaches taken in different studies, it is hard to compare TCO frameworks among countries. A further complication for a consistent comparison of TCO calculations stems from the assumed vehicle user type and associated vehicle usage behaviour. Regarding this point, many studies only consider country-specific average usage behaviour and either private or corporate car ownership. As a remedy, this paper covers not only five different countries (Austria, Germany, Spain, the Netherlands and the United Kingdom) but also three different types of corporate car ownership as well as private vehicle ownership, in the following referred to as “fleet type”. Each fleet type exhibits a different cost structure, see Section 2.2, and is thus investigated separately.

2.1 Model approach

The TCO presented in this paper are calculated according to the following approach: A vehicle is purchased at the beginning of the first year of the ownership period. The total investment cost I are calculated as sum of purchase price P, purchase taxes T_{p} and other onetime cost O_{o}, which refer to e.g. registration cost. Purchase incentives D are subtracted from this sum, resulting in:

$$I = P + T_{\mathrm{p}} + O_{\mathrm{o}} - D \tag{1}$$

Purchase prices may (partially) include value added tax (VAT) and are calculated according to

$$P = P_{\mathrm{N}} * (1 + p_{\mathrm{V}} * VAT) \tag{2}$$

Here, P_{N} corresponds to the vehicle net price, p_{V} is a prefactor ranging from 0 to 1, depending on country and fleet type, see Subsection 2.3.2, whereas VAT equals the country’s VAT-percentage at the date of purchase.

Annual costs A^t of a year t of vehicle ownership are accounted for at the end of the corresponding time period. These costs are calculated as sum of fixed annual cost

A_{f}^{t}, variable annual cost A_{v}^{t}, and, for battery electric vehicles (BEV) only, rental cost C_{R} for substitute conventional vehicles on days with long-range trips, see Subsection 2.3.7, i.e. $A^{t} = A_{\mathrm{f}}^{t} + A_{\mathrm{v}}^{t} + C_{\mathrm{R}}$. Fixed annual costs are the sum of motor Tax T_{M}^{t}, fully comprehensive insurance premiums C_{I} and company car corporate cost C_{4}^{t}, see Subsection 2.3.4, in the year of interest, resulting in $A_{\mathrm{f}} = T_{\mathrm{M}}^{t} + C_{\mathrm{I}} + C_{4}^{t}$.

Variable annual costs represent the sum of fuel and energy cost E^{t} and maintenance and repair cost M, see Propfe et al. (2012). For corporate fleets it is assumed, that the vehicle owning company makes enough profit to fully reduce the fiscal burden according to all expenses associated with vehicle ownership. Note that vehicle value loss is calculated according to country-specific depreciation rules for the book value, including additional and faster-than-normal depreciation for EVs in the Netherlands, cf. Agentschap NL (2012). The profit tax reduction θ^{t} is subtracted from the previous sum of cost, resulting in

$$A_{\mathrm{v}}^{t} = E^{t} + M - \theta^{t} \tag{3}$$

The effective tax reduction is calculated as sum of all deductible expenses connected to the vehicle ownership in the corresponding year multiplied with the company profit tax factor. For Austria, the share of deductible expenses is reduced in case of high vehicle list prices, according to BMF (2004).

At the end of the last year of ownership the vehicle’s residual value R is estimated based on the relative formula given by Propfe et al. (2012), i.e.

$$R = P \times (c - 1.5 \times 10^{-6} \times VMT) \tag{4}$$

Here, VMT corresponds to the total travelled vehicle mileage at the end of the ownership period of 4 years and c is a constant of either $c = 0.476$ or $c = 0.404$ for conventional vehicles or electric powertrains, respectively. The reduced offset for BEVs takes into account the large uncertainty regarding the lifetime of current traction batteries. In case VAT was considered during purchase, the same VAT share is assumed during vehicle sale. Differences between estimated residual value and book value are also taken into account at this point.

Finally, to calculate the present value of total cost for vehicle ownership, the expected real discount rate r, averaged over the ownership period n, is considered, yielding

$$TCO = I + \sum_{t=1}^{n} \left[\frac{A^{t}}{(1+r)^{t}} \right] - \frac{R}{(1+r)^{n}} \tag{5}$$

2.2 Fleet-types and specific cost allocation

According to KBA (2013), new vehicle registrations in Germany are dominated by corporate car owners. Therefore, in addition to the commonly investigated private vehicle ownership, 3 different corporate fleet ownership and usage types are considered in this work. The “car rental” fleet type refers to vehicles purchased for the purpose of lending them to a customer. This is to be distinguished from car sharing, which is in this work assigned to the second fleet type, “commercial”. This type covers also taxi fleets, company car pool fleets and, logistics fleets, where all transportation tasks are solely business-related. The third fleet type “company car” relates to only those vehicles with additional private usage for the employee.

In dependence of the fleet type, some cost items are not paid for by the company owning the car but the actual user of the vehicle, e.g. fuel cost are paid for by a vehicle rentee but not the car rental company. If so, the cost are not accounted for in the TCO, but instead added to the sum of total cost for the user, which we will abbreviate TCU. It is indicated in Table 1 which cost items (energy cost, insurance premiums and substitute rental cost for BEV) are allocated to the owner or user of the vehicle, respectively. Here, only cost items are shown whose allocation differs among fleet types. In accordance to the majority of company cars in the UK energy cost of company cars are paid for by the vehicle user.

Table 1: Distribution of cost items among vehicle owner and vehicle user corresponding to fleet type; for private vehicle ownership owner and user are assumed to be the same person

Fleet type	Energy cost	Insurance premiums	Subst. rental cost
car rental	user	user	-
commercial	owner	owner	-
company car	user	owner	user
private ownership	owner	owner	owner

2.3 Data basis

The following paragraphs aim to provide the reader with details to assess the data basis of this work. Furthermore, the following assumptions apply: All calculations begin with 2016 as first year with a fixed ownership period of 4 years. The time resolution is set to one year, thus, changes in legislation that come into force in the first half of the year are applied in full for the current year, whereas changes that come into force in the second half of the year are applied to the following year. All monetary values are given in $€_{2016}$, unless indicated otherwise. British pound were converted to Euro with a fixed conversion factor of 1.3 €/£ for convenience. Due to currently low inflation and interest rates, see, e.g. Eurostat (2016), the annual real discount rate is set to about 1.7% per annum.

2.3.1 Vehicle data collection

Purchase prices, technical features and motorisation vary strongly among vehicle sizes, manufacturers and vehicle model. Additionally, many of the fiscal cost items mentioned above depend on vehicle CO_2 emission, energy consumption or engine displacement, as well as vehicle type and country. In order to yield specific TCO results, six different vehicle sizes, cf. EEC (1999), are considered, ranging from segment A: mini cars to segment E: executive car plus segment N1: light commercial vehicles. Vehicle data were collected at the beginning of 2015 according to the following scheme: The three to five most popular vehicle models were selected, for every considered country, vehicle size and considered powertrain, i.e. petrol, diesel and battery electric. For each of these vehicle models, technical and economic data were obtained from original equipment manufacturer websites, whereby only the basic trim level was considered. Derived stats for the TCO analysis, e.g. annual motor tax rates, were evaluated for each vehicle model and afterwards averaged over all models per country, vehicle size and powertrain type.

2.3.2 Legislation regarding vehicle purchase

For private vehicle ownership VAT is included in purchase prices, whereas for corporate fleets VAT is excluded, with the following exceptions: in Austria input tax deduction applies only to corporate battery electric vehicles (BEV), cf. *UStG* (2016); in Spain only half of the VAT is deducted, cf. fleetnews.co.uk (2003), i.e. $p_{\mathrm{V}} = 0.5$ in Eq. (2), if company cars are also used for private purpose; in the UK, VAT may not be deducted for company cars that include private use, cf. HM Revenue & Customs (2014). Vehicle purchase taxes are considered for Austria, Spain and the Netherlands, cf. *IVTM* (2016), *NoVAG* (2015), *BPM* (2016). Purchase incentives are taken into account for Germany, Spain and the United Kingdom, see e.g. 'Plug-in car and van grants' (2016); Scheremet (2016).

2.3.3 Energy cost

For each of the considered countries individual fuel price scenarios are used, based on an oil price scenario common to all countries. To identify country-specific correlations between fuel price and crude oil price, regression analyses on historic data between 2013 and 2015 were executed, which compared price developments for Brent crude oil to those for gasoline and diesel, without VAT and excise duty. Fuel prices, VAT and excise duty were obtained from EEA (2016a). The oil price scenario is based on the assumption that the crude oil price will rise linearly from the current level to about $80\,USD_{2016}$ at the end of 2020, cf. IEA (2015). Resulting expected average gross prices in the time period 2016 to 2019 for gasoline and diesel are shown in Table 2.

Table 2: Average gross fuel and electricity prices in selected countries between 2016 and 2019, own calculation

	AT	DE	ES	NL	UK
Gasoline	1.166 €/l	1.344 €/l	1.201 €/l	1.536 €/l	5.046 £/gal
Diesel	1.083 €/l	1.149 €/l	1.074 €/l	1.188 €/l	5.195 £/gal
Electricity	0.231 €/kWh	0.332 €/kWh	0.251 €/kWh	0.238 €/kWh	0.180 £/kWh

Historic data on electricity prices demonstrate that those, contrary to fuel prices, are less volatile and have a strong correlation with national energy policies. Therefore, electricity prices were modelled independently from a supranational parameter. Instead, for each country a ten-year historic trend from average national electricity prices was modelled linearly and continued until 2020, yielding moderate electricity price increases in that timeframe, see also Table 2.

2.3.4 Cost for private usage of company cars

In case an employee is granted private usage of a company car, the employer and its employee need to pay additional taxes on benefit in kind (BIK). Note that Eq. (3) includes only the corporate cost part, but not the employees' cost for BIK. Latter ones are calculated separately, added to the TCU and then accounted for during utility calculations, see Chapter 3. The rules on how to calculate the employer's cost for the private usage of company cars differ strongly among countries, and are considered accordingly. In a nutshell, VAT on benefit in kind tax values as well as employer contributions on payroll taxes of BIK values are considered here, where applicable.

The calculation of BIK cost is based on the raised tax burdens of an employee, which in turn depends on the employee's marginal income tax rate. The corresponding reduction of net income depends on the taxable base value of the company car as well as the employee's income tax rate. The BIK base value is calculated according to the laws effective in 2016 and depends in most countries on the list price and CO_2 emissions of the vehicle. Regarding the income tax rate, it is assumed in this work that those employees, who are granted a company car for private use, have an above average annual income. An arbitrary gross income of 55,000 € per year was chosen to determine the income tax rate per country. Table 3 gives country-specific rates used in this work regarding employee income tax and company profit tax.

Table 3: Assumed rates on company profit tax, cf. BMF (2014a), and employee income tax

Country	Company profit tax rate	Employee income tax rate
AT	25%	43%
DE	30%	52%
ES	25%	37%
NL	25%	42%
UK	23%	40%

2.3.5 Insurance premium

For each of the investigated vehicle models described in subsection 2.3.1 an average from 5 quotes for a full comprehensive insurance were obtained utilising an online insurance comparison website. Identical specifications for the driver were used for each quote. Due to the strong correlation between list price and insurance premium, a linear regression analyses was executed for each powertrain in question, which allows estimating annual insurance premiums based on the vehicle net list price. Resulting net insurance premiums range from about 580 €/a to about 1000 €/a for mini- to executive-sized vehicles, respectively. Country-specific insurance tax rates were applied, and, for Austria only, engine-related insurance tax was considered, see BMF (2014b).

2.3.6 Motor vehicle tax

Taxes on ownership of motor vehicles differ significantly among the considered countries, not only regarding height, but also with respect to the calculation scheme. Common to all countries is, however, that plug-in electric vehicles are either exempt or pay strongly reduced fees, with the exception of N1 vehicles in the UK, where the full tax applies also to EVs. Figure 1 shows average annual motor tax rates, calculated according to the technical vehicle data obtained as explained in subsection 2.3.1, for each country, vehicle size and powertrain of interest.

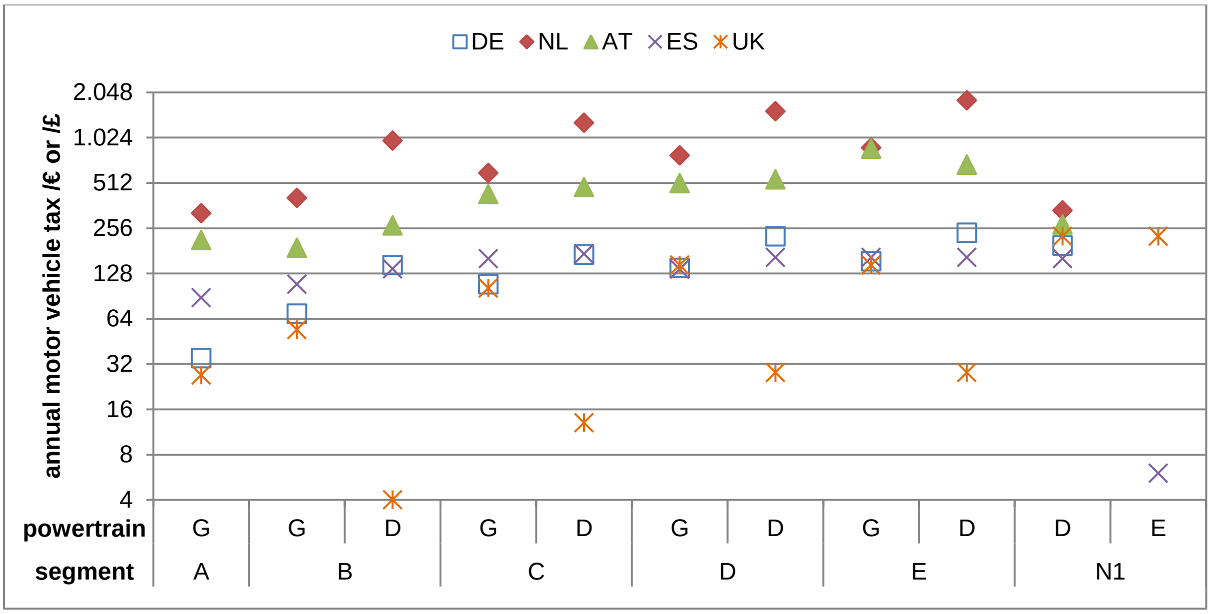

Figure 1: Annual motor vehicle tax rates (logarithmic axis) by vehicle size and powertrain as used in this work. All values given are in $€_{2016}$, except for the UK ($£_{2016}$). Powertrain labels (above) refer to G: gasoline, D: diesel, E: battery-electric powertrains. Vehicle size labels (below) correspond to EEC classification. For sizes A-E tax rates are not shown for BEVs as those rates are negligible.

2.3.7 Rental cost for substitute conventional vehicles

One of the major hurdles for the uptake of electric mobility is the restricted single-charge driving range of battery electric vehicles currently on the market, cf. Götz et al. (2012). This driving range is, considering real-world energy consumptions, see e.g. Wolfram & Lutsey (2016), for most BEVs below 150 km. Note that the second generation BEVs currently pushing into the market will have an extended range of up to 300 km. It is assumed in this work that BEVs are only charged once per day, although multiple charges per day would be possible. Instead, a rental car with conventional powertrain is used on days where the total daily driving distance exceeds the real-world single-charge driving range of the vehicle, see also Jakobsson et al. (2014). Net rental cost daily rates by vehicle size were obtained as averages over online rental offers from SilverTours (2016) and are shown in Table 4.

To obtain the total rental cost per year for substitute conventional vehicles, it is necessary to find a reasonable estimate for the number of days per year where a rental vehicle would be necessary. Therefore, data sets of the large travel behaviour survey “Mobility in Germany”, DLR & Infas (2010), was analysed. Daily driving distance distributions were investigated for each annual mileage cluster from 1,000 km/year to 30,000 km/year, where for each of these clusters the total amount of driving days was normalised such that the sum of daily driving distances per year match the total annual mileage. For daily driving distances that exceeded a given effective electric range, the corresponding amount of days was added to the sum of car rental days. An example result of this procedure is depicted in Figure 2.

Table 4: Net rental cost per day by vehicle size

Vehicle size by EEC classification	Net rental cost per day /$€_{2016}$
A: mini cars	48
B: small cars	50
C: medium cars	55
D: large cars	65
E: executive cars	78
N1: light commercial vehicles	45

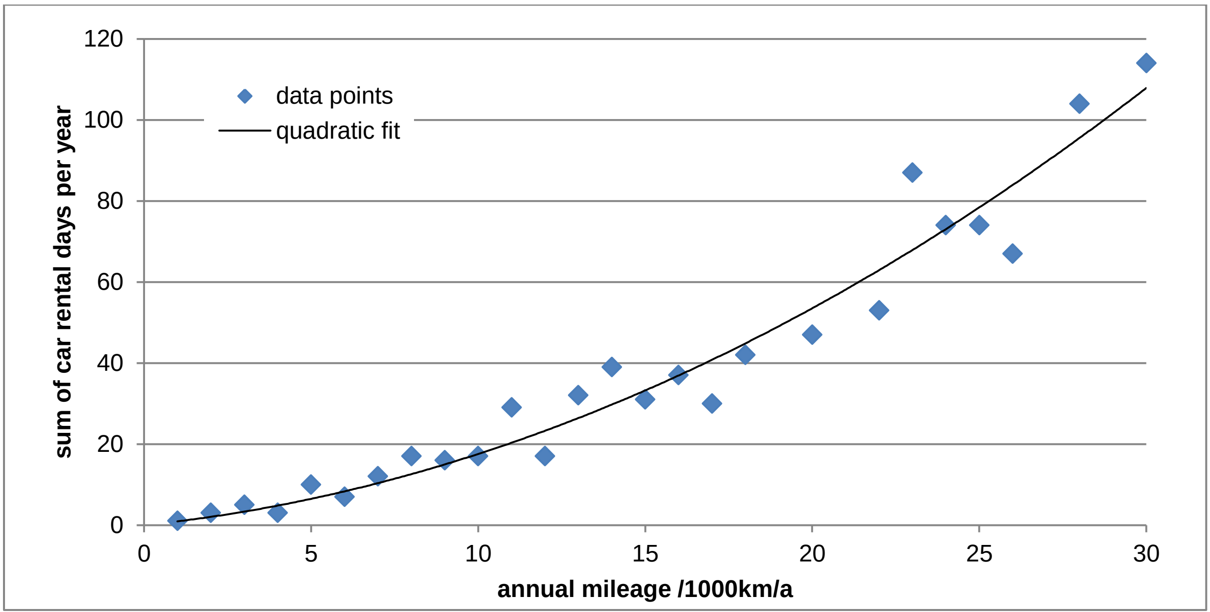

Figure 2: Total sum of days per year requiring a rental car as function of annual mileage for a BEV; exemplary result for 90 km effective single-charge electric range in Germany, based on data from DLR & Infas (2010)

The figure also includes a quadratic fit function, which seems reasonably appropriate, and was thus used to calculate the rental day cost, thereby smoothing the rather coarse data. Similar quadratic fit functions could be obtained for effective electric vehicle ranges from 50 km to 300 km. Since comparable statistics could not be obtained for all countries of interest, it is assumed that the daily driving distance distribution at a given annual mileage is similar for all countries. BEV substitute rental costs are considered only for private vehicle ownership TCO as well as TCU of company cars with private usage. For fleet types “car rental” and “commercial” substitute rental costs are not included in TCO since these vehicles are not assigned to an individual person and, instead, will most likely instead be assigned to a transport task matching the BEVs electric range and charging pattern.

3 Consideration of non-monetary aspects

Total cost of ownership for a vehicle is one of the most influential factors considered for the purchase decision, see e.g. Power (2015). However, there are also further, non-monetary aspects considered by customers, thus influencing the market penetration of electric vehicles. Important non-monetary aspects included in this analysis are well-to-wheel (WTW) CO_2 emissions, vehicle acceleration and total cost for the vehicle user (TCU).

At vehicle data collection only basic trim levels were considered, see Subsection 2.3.1, thus the motorisation of included conventional vehicles is lower than those of corresponding BEVs since for most vehicle sizes BEV models are offered only with a single but powerful motorisation option, whereas for conventional vehicle models customers may choose from a variety of different motorisation options. To balance this inequality vehicle acceleration is considered as a measure for driving dynamics. We take into account well-to-wheel instead of tailpipe CO_2 emissions since the environmental benefit of BEV usage is reduced when combined with a CO_2 intensive electricity mix. This effect has been discussed in the media, especially in Germany, for several years, see, e.g., Dünnes (2015).

In order to take the TCO as well as non-monetary aspects into account, following Specht & Balderjahn (2001), their combined utility $U(x_1, x_2, \ldots, x_k)$ is evaluated for the given set of commodities x_k. For each vehicle i the utility value is calculated, based on Redelbach (2016), as follows:

$$\frac{1}{U_i} = \beta_{\mathrm{TCO}} \times TCO_i + \beta_{\mathrm{TCU}} \times TCU_i + \beta_{\mathrm{Acc}} \times \left(t_{\mathrm{Acc},i} - 10\mathrm{s}\right) + \beta_{\mathrm{CO_2}} \times m_{\mathrm{CO_2},i} \qquad (6)$$

Here, β_k is the willingness-to-pay coefficient for criterion k, t_{Acc} refers to the time to accelerate from [0-100km/h] in seconds, $m_{\mathrm{CO_2}}$ equals the sum of well-to-wheel CO_2 emissions during the ownership period in tons and TCU is the total cost for the vehicle user during in the same time period. Note that a typical vehicle acceleration time of 10s is used to match the assumptions made by Redelbach (2016), leading to an increased utility for acceleration times shorter than that. Thus, utilities obtained from Eq. (6) are the inverse of total monetarised detriments during vehicle ownership.

Although well-to-tank CO_2 emissions of plug-in electric vehicles depend strongly on the electricity mix of corresponding energy suppliers, country-specific average CO_2 intensities for the electricity mix, cf. Nitsch et al. (2012) and EEA (2012), were used for the calculation of total WTW CO_2 emissions of BEVs. For an evidence-based analysis of CO_2 emissions from electric vehicles in corporate fleets in conjunction with renewable energy production, please refer to Dittus et al. (2016).

Table 5: Willingness-to-pay coefficients for given criteria k in the calculation vehicle utility, cf. Redelbach (2016)

k	TCO	TCU	Acc	CO_2
β	1	1	468 €/s	213 €/t

Table 5 lists willingness-to-pay coefficient values used for the calculation of vehicle utilities. Coefficients for acceleration and CO_2 emission are adopted from Redelbach (2016). In contrast to this work, however, the limited range of BEVs was not included via a willingness-to-pay ansatz, but instead directly monetarised via car rental cost of supplement conventional vehicles, see Subsection 2.3.7. The total costs of the user are considered to be equally important with respect to the purchase decision as the total costs of the vehicle owning company, cf. Gnann (2015).

4 EV opportunity analysis

4.1 Total cost of ownership

Figure 3 provides a comprehensive overview for the TCO of BEVs compared to the TCO of conventional vehicles, according to the assumptions and formulae explained in Chapter 2. Red to blue fields mark higher or lower TCO for BEVs, respectively.

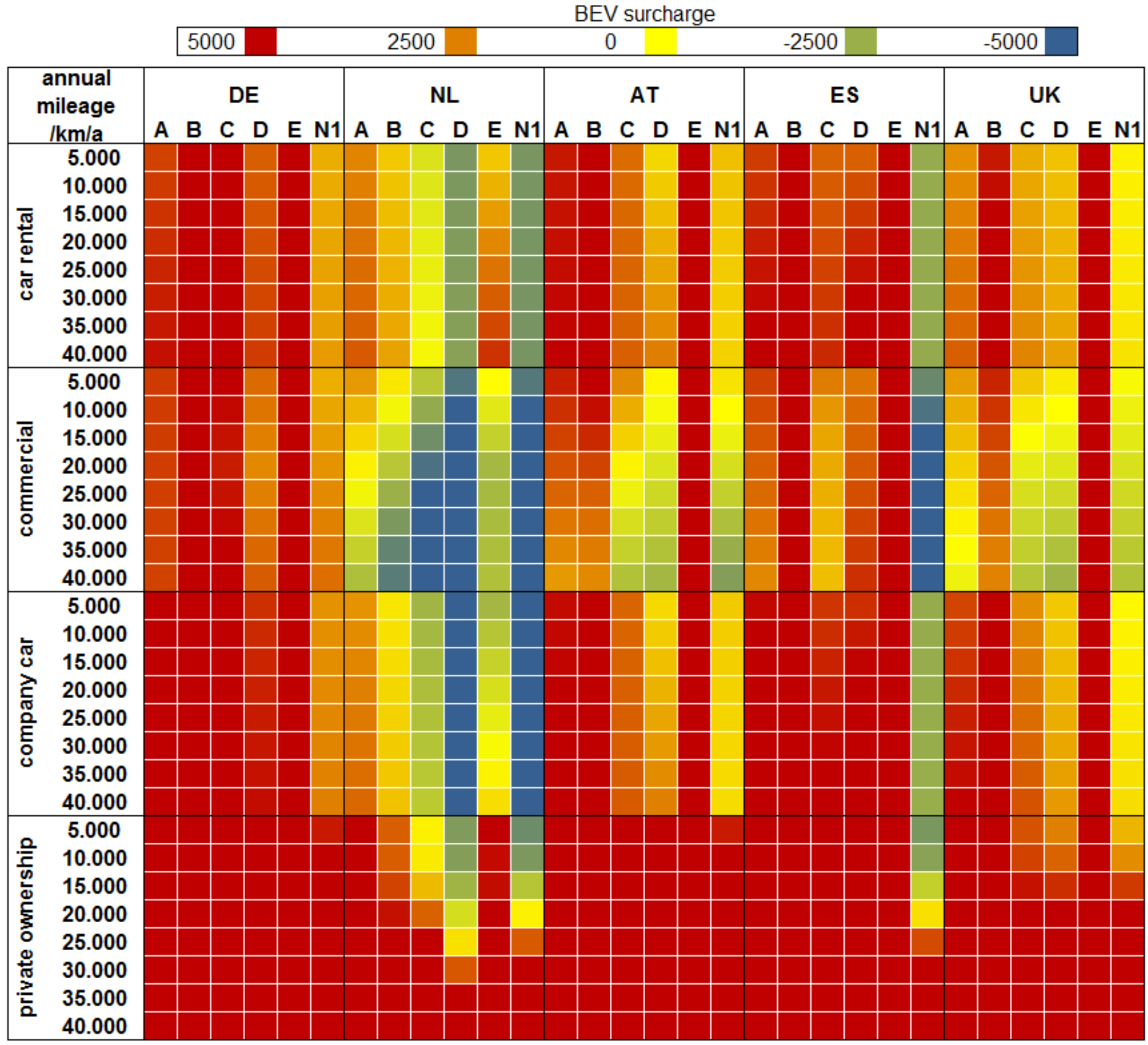

Figure 3: BEV surcharge in $€_{2016}$ compared to the conventional vehicle with lowest TCO in dependence of fleet type and annual mileage (rows) as well as vehicle size and country (columns); blue to green fields indicate lower TCO for BEV, whereas red and orange fields mark lower TCO for conventional vehicles.

In every country, except Germany, there is savings potential by replacing conventional vehicles with BEVs. The most favourable conditions for BEVs can be found for commercial fleets in the Netherlands. There, electric vehicles profit from significant savings regarding registration tax and motor tax plus an above standard depreciation. The resulting absolute TCO differences between BEVs and conventional vehicles are shown in Figure 4. Due to relatively high fuel prices and, at the same time, low electricity prices in the Netherlands, TCO savings for BEVs improve with increasing annual mileage. Inflections on some graphs in Figure 4 are the result of transitions from gasoline to diesel vehicles on the conventional side, which have lower operating costs at high annual mileages.

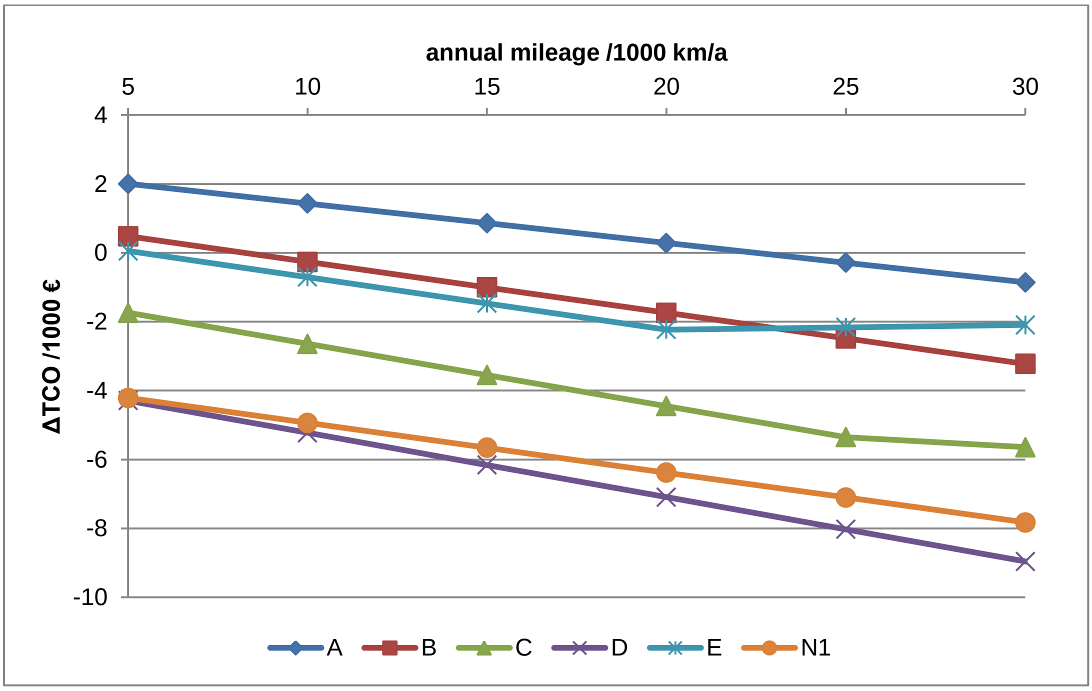

Figure 4: BEV surcharge compared with the conventional vehicle with lowest TCO by vehicle size over annual mileage for commercial fleets in the Netherlands

The situation in Germany is, however, less attractive regarding the TCO of BEV. This can be seen in Figure 5 where specific TCO per vehicle distance in Germany are shown (solid lines). Due to lower acquisition cost for conventional vehicles, moderate fuel prices but very high electricity prices in Germany, the TCO for privately owned medium-sized conventional vehicles are significantly below those for BEVs at any annual mileage investigated. This holds also true for battery electric LCVs in commercial fleets, although those have the least surcharge for replacing conventional vehicles with electric ones in Germany. Note that these calculations included the new German incentives for electric vehicles. Our results are in accordance with recent values from Wu et al. (2015). Those found TCO of 0.65 €/km and 0.42 €/km at annual mileages of about 7,500 km/a and 15,200 km/a, respectively, corresponding to our findings at these annual mileages of 0.68 €/km and 0.42 €/km.

Dashed lines in Figure 5 depict absolute TCO values for private vehicle ownership. From this presentation it becomes apparent that the TCO surcharge for BEV ownership in Germany is massive and is even increasing with higher annual mileages. This is caused by rental cost for substitute conventional vehicles, which, as is shown in Subsection 2.3.7, increase quadratically with rising annual mileage.

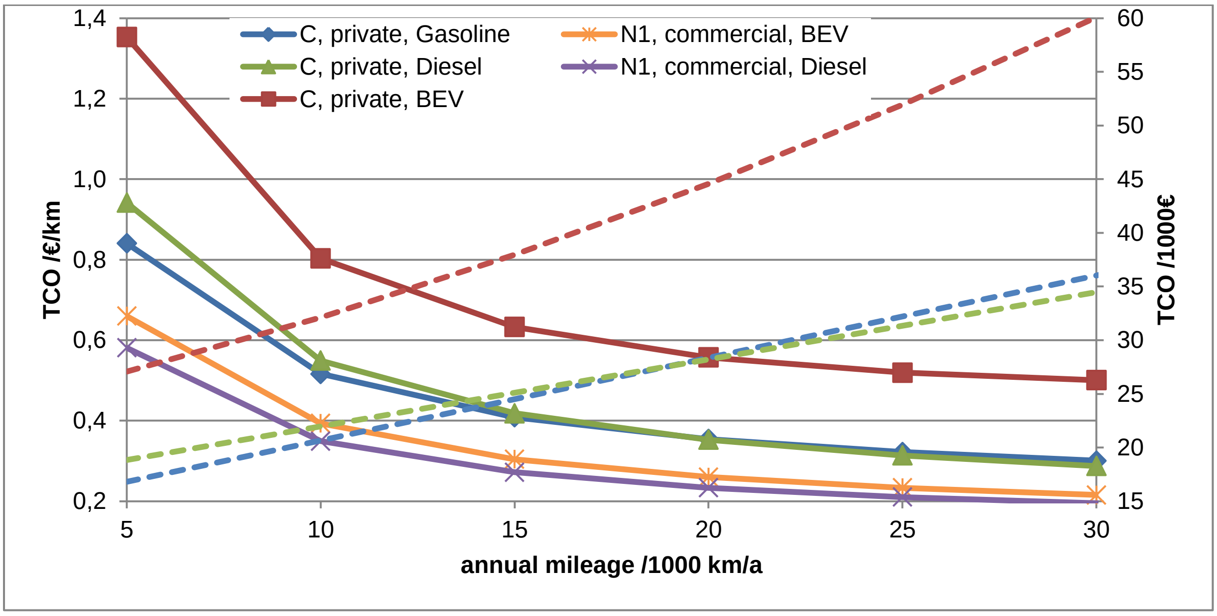

Figure 5: TCO in € (dashed lines) and €/km (solid lines) for medium-sized (C) vehicles with private ownership as well TCO in €/km for LCVs (N1) in German commercial fleets over annual mileage.

The strong impact of this term on the TCO of BEVs with private vehicle ownership leads to cost disadvantages for BEV at higher annual mileages in all countries, as can be seen in Figure 3. This, however, fits to results of Frenzel et al. (2015), who found that purchased BEVs in Germany show a significantly lower annual mileage than conventional vehicles and are often used as secondary vehicle in multi-car households, which, to a large extent, negates the need for a substitute conventional vehicle in those households.

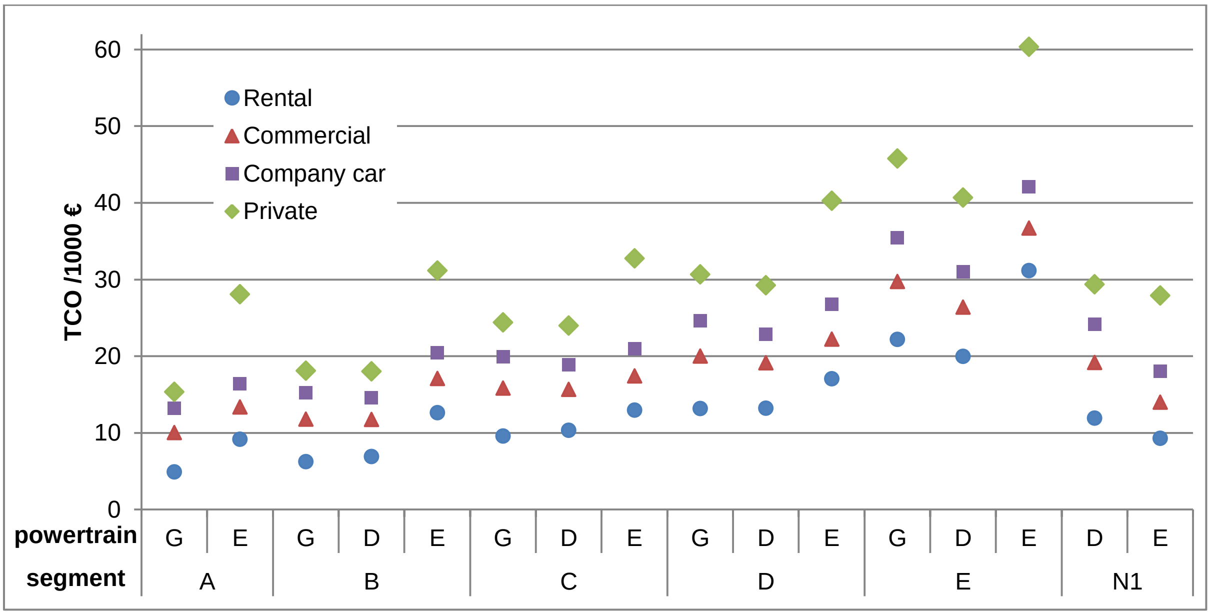

Figure 6: TCO by fleet type over different vehicle sizes and powertrains in Spain for a fixed annual mileage of 15,000 km/a; powertrain labels (above) refer to G: gasoline, D: diesel, E: battery-electric powertrains. Vehicle size labels (below) correspond to EEC classification.

A TCO comparison in Spain for different fleet types is given in Figure 6. Although these results relate to Spain, the general findings are valid for all investigated countries: Ordered by TCO, private and company car ownership TCO always exceed those for commercial fleets and car rental vehicles. This is mainly caused by additional taxes applied to private use or private ownership of vehicles. Following the TCO for different vehicle sizes and any given powertrain, it can be seen that the conventional vehicle TCO increase about linearly per vehicle size segment, whereas the TCO increment per vehicle size for BEVs varies strongly between neighbouring vehicle sizes. We attribute these TCO fluctuations to the reduced model assortment for BEVs per vehicle size, i.e. BEVs are not available from all important car manufacturers for every vehicle size.

4.2 Vehicle utility

Utility results for BEV are depicted in Figure 7, distinguished by country, fleet type, vehicle size and mileage. Values are given relative to the conventional vehicle with best utility (diesel or gasoline), whose utility is set to 100 for convenience.

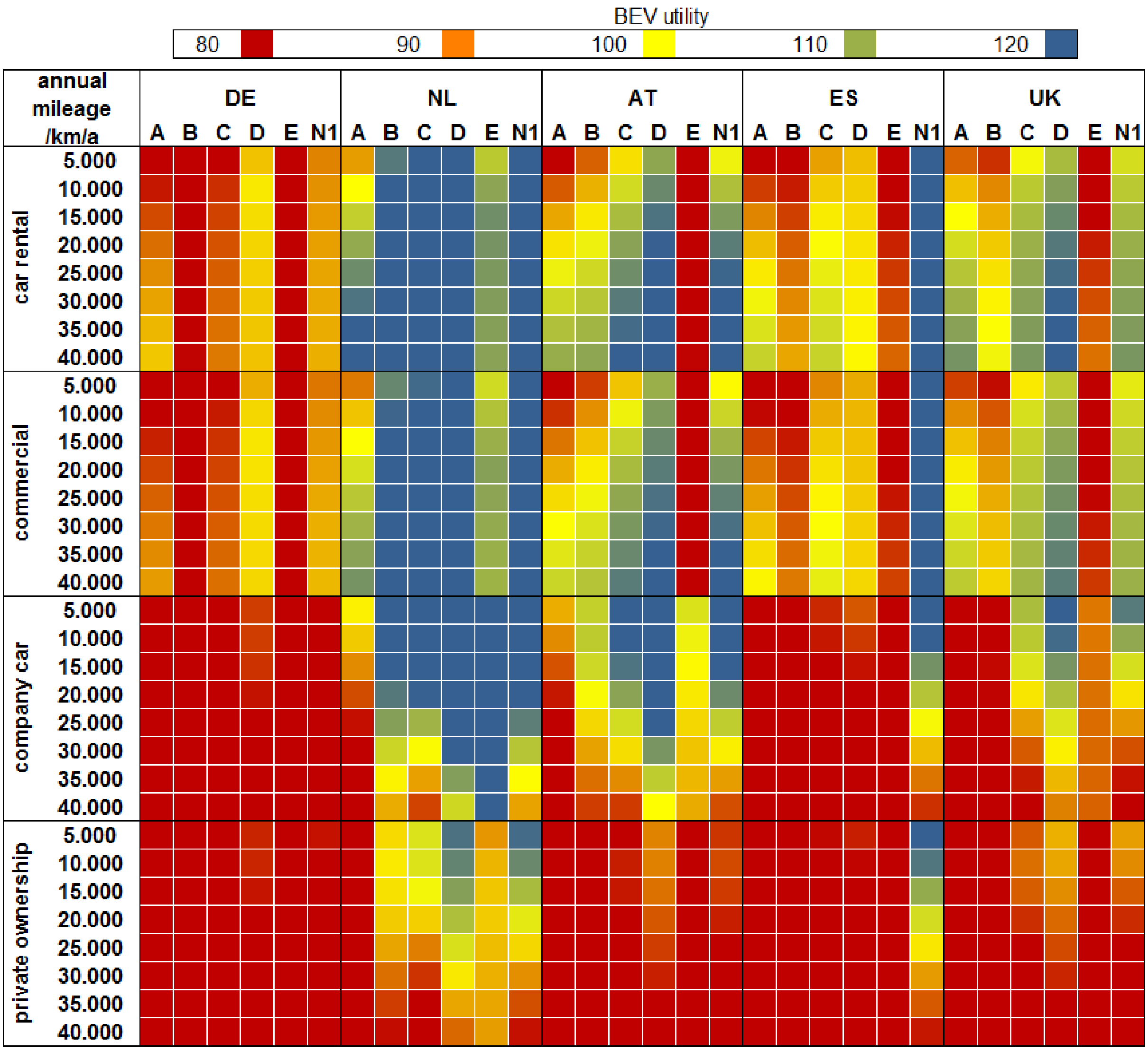

Figure 7: BEV utility values relative to the conventional vehicle with best utility result, which is set to 100 for convenience. Thus, utility values lower than (red - orange) or higher than (green - blue) 100 correspond to reduced or increased utility, respectively, for BEV in comparison to the conventional vehicle with best utility value.

The comparison of the results in Figure 3 and Figure 7 reveals the influence of user cost and environmental care on the utility of the considered vehicles. It becomes apparent that in Germany the only potential for the market uptake of BEVs can be identified for upper-medium sized vehicles in commercial or car rental fleets. The positive situation for BEVs in the Netherlands, which was already found during TCO analysis, is confirmed also with this utility analysis. Significant changes in the assessment of BEV potential due to the consideration of non-monetary aspects can be seen in Austria, Spain and the United Kingdom. Especially medium-sized company cars with annual mileages up to 20,000 km/a show a significantly higher BEV utility compared to conventional vehicles in Austria and the UK. For vehicles of this size a utility above 90% compared to conventional cars can be found in Spain for commercial and car rental fleets. It is also striking that BEVs of size A, B or E show a reduced utility compared to medium-sized BEVs. Although this contradicts to some extend the current sales figures, since the most prominent BEVs in Europe are from the B and E segment (i.e. Renault Zoe and Tesla Model S, cf. Pontes (2016)), it is to be expected that a large-scale market uptake of BEVs in these vehicle segments will required significant price reductions for corresponding BEV models.

5 Conclusions and policy recommendations

In this work the total cost of ownership and total vehicle utility were analysed for corporate and private vehicle ownership in five European countries. In order to identify as many use-cases as possible for the application of electric vehicles, different vehicle sizes and annual mileages were considered and evaluated individually. Based on this assessment, we draw the following conclusions:

Although the new incentives for BEVs were considered in these calculations, BEV ownership in Germany causes higher costs for any investigated vehicle size, annual mileage or fleet type. In order to achieve a strong market uptake for electric vehicles in Germany as desired by the current government, cf. Bundesregierung (2009), the current monetary disadvantages for BEV ownership, of about 5000 € per vehicle need to be compensated. An important contribution to this could be to widen the yet narrow gap between fuel and electricity cost, necessary for the compensation of higher BEV investment cost, for example by exempting EV charging electricity from VAT and EEG levy, cf. ‘EEG’ (2014), especially since BEVs can contribute to the energy grid stabilisation, see eCG et al. (2016), a necessary requirement for the success of the German energy revolution.

A different situation can be found in the Netherlands. Here, BEVs provide a solid savings potential with respect to TCO for types of vehicle use in corporate fleets. These findings are in accordance to the plug-in electric vehicle sales in the Netherlands, which were in the order of 10% of all new vehicles sales in 2015, compared to less than 1% in Germany according to EEA (2016b).

Although current BEV new vehicle sales in Austria and the United Kingdom are significantly below 1%, see EEA (2016b), our utility analysis revealed high potential for BEVs, predominantly for medium-sized fleet vehicles. Especially the reduced benefit in kind taxes for BEVs contribute to their overall utility. However, in order to accelerate the BEV market uptake with respect to private vehicle ownership in these countries the overall utility of BEVs needs to increase compared to those of conventional vehicles. This need holds true also for Spain. There we found significantly reduced BEV utilities for company cars and private vehicle ownership.

A further drop of traction battery production cost, cf. Nykvist & Nilsson (2015); Thielmann et al. (2015), and an assumed associated reduction of BEV prices in the future will contribute to the competitiveness of small-sized BEVs, which have currently the least utility across all countries investigated. This technological evolution of traction batteries and thereby increased driving ranges for BEVs will be necessary to support an extensive market uptake for privately-used BEVs. The current range limitations of BEVs lead to rather high additional cost for private vehicle users, especially those in single-car households, which currently cannot be compensated for by monetary or non-monetary benefits of BEV ownership. Extended electric vehicle ranges would also help to overcome range anxiety and increase convenience during long-range trips.

In summary, we found that especially for private vehicle ownership BEVs cannot yet compete with conventional powered vehicles with respect to TCO. The investigated non-monetary incentives for BEVs provided only a rather small increase for the utility of these vehicles. Thus, the reduction of investment cost for privately owned BEVs should be prioritised by policy makers in Austria, Germany, Spain and the United Kingdom, since non-monetary incentives will currently not suffice to close the cost- and utility-gap between conventional and electric vehicles in these countries. Additionally, further research is required to uncover the influence of other non-monetary incentives for electric mobility, e.g. bus lane usage or zone entrance restrictions, on the utility and market uptake of EVs.

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