Dissecting the total cost of ownership of fully electric cars in Italy: The impact of annual distance travelled, home charging and urban driving

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A B S T R A C T

The paper quantifies the importance for cost competitiveness of fully electric cars (BEVs) of three determinants of the total cost of ownership (TCO): the annual distance travelled (ADT), the percentage of urban trips, and the availability of a private parking space. The estimates are performed with reference to the Italian car market. We find that charging at home increases the break-even BEV manufacturer's suggested retail price (MSRP) relative to other propulsion systems by €2866-11,466, depending on the ADT. Driving in urban areas increases the break-even BEV MSRP by €910-10,314, depending on the ADT and on the referenced propulsion system. Taking into account the share of Italian drivers who own a garage and drive in urban areas, we find the cheapest BEVs are cost competitive without a subsidy with respect to the HEVs for 11.8% of the Italian drivers, but not with respect to the diesel and petrol cars, unless extremely high annual distances are driven. With the purchase subsidy recently introduced by the Italian government, the cheapest BEVs become competitive also with respect to the diesel cars, but not relative to the petrol cars, unless more than 12,500 km are annually driven.

1. Introduction

Battery Electric Vehicles[1] (BEVs) are characterized by higher initial costs than Hybrid Electric Vehicles (HEVs) and Internal Combustion Engine Vehicles (ICEVs), i.e. petrol and diesel ones. Such a characteristic hinders BEVs uptake, since some consumers tend to underestimate long-term savings due to their lower operating costs (Allcott and Wozny, 2014; Krause et al., 2013). The Total Cost of Ownership (TCO) concept, encompassing all present and future costs of a vehicle, is proposed as an alternative metric that a rational consumer should consider when deciding which vehicle to acquire.[2] Since the pioneering work by Delucchi and Lipman (2001), an abundant literature has developed models and presented estimates comparing vehicles with different propulsion systems. It is, however, still open to debate whether, and under which conditions, BEVs are cost competitive. To be true, estimating the TCO metric is fraught with difficulties concerning the distinction between private and social costs, the uncertainty connected to the future stream of costs, the impact of the regulatory and fiscal policies, the inherently vehicle-, country- and individual-specific nature of the estimates.

This paper focuses on the latter issue (country- and individual-specific TCO estimates). Given the high heterogeneity among drivers in terms, among other things, of annual distance travelled, home charging availability and percentage of urban travel, this paper aims at dissecting the importance of these three cost determinants on the BEV TCO[3] and, consequently, on BEV competitiveness. The annual distance travelled is a very important determinant of the BEV competitiveness since BEVs' variable costs are much lower that the ICEVs' ones. The home charging availability, linked to the ownership of a parking space (in a private garage or multi-unit dwelling) entails the possibility of

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[1] Throughout the paper, we will use the acronyms BEV and HEV, although we will estimate the TCO model only with respect to passenger cars.

[2] Various sources (educational websites, governments, utilities, environmental groups, automakers, and universities) have presented cost calculators (Breetz & Salon, 2018) in order to help consumers make rational decisions, and some scholars have suggested the introduction of standardized vehicle TCO labels (Dumortier et al., 2015; Wu et al., 2015).

[3] Please note that these variables are not the most important ones in terms of impact on the TCO, hence they are not derived from a sensitivity analysis. Rather, they are selected because they are likely to be differentiated among individuals and our interest is in identifying how much they impact BEV competitiveness for given individuals. The estimates we produce will be used to segment the market as reported in Section 6.

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charging at night at cheaper hourly rates than those at public chargers. The percentage of trips made in urban traffic conditions (where BEVs outperform conventional cars in terms of fuel/energy efficiency[4]) implies lower operating costs. All these factors strengthen BEV competitiveness. Hence, drivers who enjoy such conditions are the ones who could benefit the most from buying a BEV. While the impact of the distance travelled is often studied in the literature via sensitivity analyses, the other two determinants, to the best of our knowledge, have been less researched (an exception being De Clerck et al. (2018) and Breetz and Salon (2018) for urban driving). Yet, we believe that they are very important in order to estimate the BEV potential market and to identify the proper marketing and public policies.

We develop a TCO model that makes explicit the role played by the specific characteristics of BEVs and perform the estimates for the Italian car market. We compare among 4 propulsion systems: BEV, HEV, petrol and diesel, and estimate the TCO for 36 best-selling car models belonging to the small to medium car segment. The selected models represent a large share of the total car sales. We use the break-even BEV manufacturer's suggested retail price (MSRP) metric in order to identify by how much a BEV MSRP should be reduced (by the car manufacturers or by the policy maker via a purchase subsidy) in order to help BEVs penetrate the market. Finally, segmenting the Italian car drivers on the basis of the three abovementioned cost determinants, we estimate the share of Italian drivers who would find it cost convenient to buy a given electric car model in a scenario with or without purchase subsidies.

Our results are useful for a more detailed understanding of the determinants of the BEV TCO and of how they affect the overall BEV market potential. They can be of interest to car buyers, guiding their decision on which propulsion system to select for their car from a solely private monetary point of view. They can also be useful to car manufacturers to develop more focused BEVs' marketing strategies, as well as to transport policy decision makers to tailor spatially and temporally their policies (e.g. purchase subsidies), targeting specific market segments without risking an excessive or insufficient use of public resources.

2. Related literature

Many papers stress that BEVs competitiveness is highly dependent on political support (Hao, Ou, Du, Wang, & Ouyang, 2014; Diao, Sun, Yuan, Li, & Zheng, 2016; Zhao, Doering, & Tyner, 2015; Lévay, Drossinos, & Thiel, 2017). Breetz and Salon (2018), analyzing the TCO of the Nissan Leaf (BEV), Toyota Prius (HEV), and Toyota Corolla (ICEV) in 14 U.S. cities from 2011 to 2015, find that in almost all cities BEV's higher purchase price and rapid depreciation outweigh its fuel savings, and conclude that both federal and state incentives are necessary for BEVs to be cost competitive. Similar findings are reported by other authors comparing different vehicles (Fulton, 2018; Palmer, Tate, Wadud, & Nellthorp, 2018; Weldon, Morrissey, & O'Mahony, 2018).[5] On the contrary, Nian, Hari, and Yuan (2017) find that in Singapore BEVs are on parity with ICEVs even in the absence of policy incentives. However, policy support is deemed needed to compensate for obstacles such as the lack of a sufficient network of charging infrastructures, clustered living in high rise buildings, perceived range limits, and the higher upfront purchase price. In order to shed light on future developments, van Velzen, Annema, van de Kaa, and van Wee (2019) combine the TCO and the technology selection literature making use of field interviews. They conclude that even in a future with large learning and scale effects, the TCO of BEVs might not be lower than that of the ICEVs, especially if BEV producers will try to recoup their investment costs. They warn that financial incentives will still be needed for some time. A much brighter image of the TCO of BEVs is instead presented in some websites.[6]

A point of debate in estimating the TCO metric is the distinction between private and social costs. Letmathe and Suares (2017) propose to use two TCO specifications: the consumer-oriented TCO, including all the costs borne by the car user, and the society-oriented TCO, including also the costs borne by society. Yet, some of the societal costs are passed on to private users when the government imposes a tax on CO_2 via fuel prices. A private benefit is also generated when BEVs are subsidized, registration taxes are reduced or circulation taxes or parking fees are cancelled. Hence, the distinction between consumer-oriented and society-oriented TCO is blurred.

A further difficulty has to do with the uncertainty connected to the future stream of costs. Uncertainty exists at three levels: technical, economic, and political. In the case of BEVs, which are a relatively new technology, subject to continuous technological improvements, a major technical uncertainty concerns battery degradation, with implications on the substitution costs and the vehicle's resale value. Moreover, there is still a lot of uncertainty regarding BEV efficiency in real traffic, at different speeds and in different weather conditions, as well as the actual maintenance and repair costs. Of course, as more experience with BEVs is gained, technical uncertainty reduces, although technological and software improvements do alter continuously BEV efficiency. Economic uncertainty is linked mainly with future fuel and energy prices since especially the former are subject to high fluctuations, given the oligopolistic nature of the markets where they are determined. Political uncertainty plays also a very relevant role. Political decisions regarding traffic regulation (tolls, access restrictions, parking tariffs) and incentives' mechanisms (e.g. purchase subsidies and circulation tax exemptions) largely affect the relative cost advantages of the different propulsion systems. In the existing literature, the uncertainty aspect has been incorporated using probabilistic TCO models (Danielis, Giansoldati, & Rotaris, 2018; Wu, Inderbitzin, & Bening, 2015). The economic uncertainty connected with future prices has been studied by Weldon et al. (2018) using an assortment of future cost scenarios, or by van Velzen et al. (2019) combining tools from the TCO and technology selection literature.

Moreover, it is obvious that the TCO is inherently vehicle-, region- and individual-specific. Cost competitiveness among propulsion systems differs according to the market segment (small, medium or large cars, SUVs, light commercial vehicles, trucks, etc.). Up to now, car manufacturers such as Tesla Motors, Audi and Jaguar, have focused on the richer, high-performance, luxury segment of the market. Others, such as Nissan, Volkswagen and BMW, proposed BEVs in the medium segment, and only Renault and Daimler Smart have so far attempted the

[4] For instance, Braun and Rid (2017a) find that the BEV's relative consumption advantages increase to 77% for urban driving, with respect to 68% in the baseline scenario. They also document the importance of driving patterns and regenerative braking for energy efficiency (Braun & Rid, 2017b).

[5] Weldon et al. (2018), with a focus on Ireland and with reference to the year 2016, compare three electric passenger cars (Nissan Leaf, BMW i3, Tesla Model S) and an electric van (Renault Kangoo Z.E. Maxi) with the corresponding ICEVs (Nissan Note, BMW Series 1, Lexus GS 450 h and Renault Kangoo Maxi). Palmer et al. (2018) present a comprehensive intertemporal (1997–2015) and international comparison (Japan, California, Texas, UK), comparing the Toyota Prius (HEV), the Toyota Prius plugin (PHEV), the Nissan Leaf (BEV), and the Toyota Corolla. Fulton (2018) compares BEVs and HEVs and finds that the six smallest ownership costs are split evenly between HEVs (Toyota Prius c, Hyundai Ioniq, Hyundai Ioniq Blue) and BEVs (Hyundai Ioniq Electric, Ford Focus Electric, Nissan Leaf).

[6] For example, ADAC (Allgemeiner Deutscher Automobil-Club) argues that 4 out of 8 BEVs are cheaper compared to comparable models from the same manufacturer (https://www.adac.de/rund-ums-fahrzeug/e-mobilitaet/kaufen/elektroauto-kostenvergleich/, accessed on May 10th, 2019). The International Council on Clean Transport (ICCT) concludes that in France, Germany, Norway, Netherlands and the UK, the BEV and PHEV VW Golf are cheaper to own when taking into account the operating costs (https://thedriven.io/2019/02/13/electric-vehicles-now-cheaper-to-own-than-petrol-diesel-cars-in-europe/, accessed on May 10th, 2019).

production of BEVs in the small car segment. Consequently, competitive conditions and consumers' willingness to pay for an innovative technology vary largely across car segments. Country and regional specificities are connected with policy choices regarding vehicles' and fuel taxation. Much of the current disparity among BEV uptake (Norway with 20.9% and Italy with 0.3%[7]) might be due to these two aspects,[8] other factors being income level and cultural differences. Finally, TCO is highly individual specific depending on driving style, travelling and charging habits/needs and vehicle use intensity (measured by the average annual distance travelled). Several papers have explored TCO differences among segments[9] and, over the years, several propulsion systems have been subject to comparative evaluations[10]. With regard to regional specificities, most contributions deal with a specific country or region, although some studies have performed cross-country (Lévay et al., 2017; McKinsey, 2011; Palmer et al., 2018) or cross-city (Breetz & Salon, 2018) comparisons. Most of these studies present aggregate estimates, but some studies attempted to provide disaggregated or individual-specific estimates, clarifying the role played by the various cost components. For instance, Propfe, Redelbach, Santini, and Friedrich (2012) and Plötz, Gnann, Kühn, and Wietschel (2013) consider whether the car is used as first or second family car. Windisch (2013) differentiates her estimates by residential density. De Clerck et al. (2018) adopt a persona-based approach to represent six diverse driver profiles with different mobility patterns in Flanders. Frequently, authors use sensitivity analyses to explore the impact of changes in the model parameters, including the annual distance travelled assumption on the TCO.

3. Total cost of ownership model and break-even BEV MSRP

The private TCO of a vehicle covers all costs occurring over its lifetime. It includes one-time costs, i.e. the lump-sum initial costs (IC), the annual operating costs (AOC) during the period of use minus the residual value (RV) of the vehicle at time T, when it is sold or scrapped.

Initial costs (IC) include all the upfront expenses to acquire a vehicle. In addition to the MSRP, they encompass possible retailer's discounts (RD), government subsidies (SUB), registration costs (RC) and, in the case of BEVs, the costs for acquiring and installing the home charging equipment (e.g., wall-box) (HCE):

$$IC = MSRP - RD - SUB + RC + HCE \quad (1)$$

AOC includes all the costs incurred during the period of ownership T of the vehicle. For every year $t \in [1, T]$, AOC is equal to:

$$AOC_t(ADT) = CT_t + INS_t + MAINT_t(ADT) + FE_t(ADT) \quad (2)$$

where CT is the circulation tax, INS is the insurance premium, MAINT is the repair and maintenance cost depending on the annual distance travelled (ADT), and FE stands for the fuel/electricity cost to run the car for a given ADT.

FE is equal to:

$$FE(ADT) = \frac{FE\_E}{100} \cdot FE\_P \cdot ADT \quad (3)$$

where FE_E is the fuel/energy efficiency (i.e. fuel/energy consumption in liters or kWh per 100 km) and FE_P is fuel/electricity price (i.e. its average price in € per litre or kWh).

We distinguish between urban and extra-urban cycles. Moreover, since extreme temperatures affect BEV FE_E, we specify FE_E as follows:

$$FE\_E = \gamma \cdot (\alpha \cdot FE_{urb} + (1-\alpha) \cdot FE_{exturb}) \quad (4)$$

where γ is the weather-adjustment factor, FE_{urb} and FE_{exturb} the fuel/energy efficiency in urban and in extra-urban roads, respectively, and α is the percentage of trips driven in an urban area.

As FE_P is concerned, the electricity price depends on whether BEV charging takes place at home or at public chargers. Therefore, we compute the weighted average of the electricity price paid at home, EP_{home}, and that at the public charger, EP_{public}, denoting with β the percentage of electricity charged at home. For diesel and petrol cars (including petrol-electric HEVs), we consider the average price paid. Hence, we specify FE_P as:

$$FE\_P = \begin{cases} \beta \cdot EP_{home} + (1-\beta) \cdot EP_{public} & for\ BEVs \\ average\ price\ of\ diesel/petrol & for\ HEVs, diesel\ and\ petrol\ cars \end{cases} \quad (5)$$

The abovementioned costs, however, have different timelines. Part of the initial costs are subject to an Annual Percentage Rate (APR)[11] if financed with borrowed money, another part is fully paid when the vehicle is purchased, the operating costs are incurred annually during the ownership period, and the residual value is gained at the vehicle's resale. In order to obtain an estimate of the annualized TCO of the vehicle to be compared among different propulsion systems given an ADT, we need to make these costs comparable through discounting and annualization adjustments, as described in what follows.

The total amount to be paid to the retailer when purchasing the vehicle is equal to MSRP-RD-SUB. If financed with borrowed money at a given APR for the ownership period T of the vehicle, the annual constant installments are equal to:

$$\frac{(MSRP - RD - SUB) \cdot APR}{1-(1+APR)^{-T}} \quad (6)$$

Initial costs include also RC and HCE. Their annualized value is obtained multiplying them by the CRF,[12] i.e. the capital recovery factor equal to $(i(1+i)^T)/((1+i)^T - 1)$:

$$(RC + HCE) \cdot CRF \quad (7)$$

The Annualized Initial Cost (AIC), hence, can be computed as:

$$AIC = \frac{(MSRP - RD - SUB) \cdot APR}{1-(1+APR)^{-T}} + (RC + HCE) \cdot CRF \quad (8)$$

[7] ACEA (2019), New passenger car registrations by fuel type in the European Union, (available at: https://www.acea.be/uploads/press_releases_files/20190207_PRPC_fuel_Q4_2018_FINAL.xlsx).

[8] The radical intervention of the Norwegian government in favor of electric vehicles is well explained by Haugneland, Lorentzen, Bu, and Hauge (2017) who compare the prices of an Audi A7 and a Tesla Model S in Norway. They report that the import prices for the two models are NOK 319,464 and NOK 636,000, respectively. After CO_2 tax, VolkNOx tax, Weight Tax, Scrapping fee and 25% VAT are factored in, the corresponding prices become NOK 697,300 (€73,000) and NOK 638,400 (€67,000). Similarly, the VW Golf starts with NOK 180,634 and ends up at NOK 289,300 (€31,000), while the VW e-Golf starts at NOK 258,900 and ends up at NOK 262,300 (€27,000). On the contrary, the Italian government adopted a much less differentiated vehicle tax and a purchase subsidy which amounts to €6000 only in the case of scrapping an old polluting car.

[9] For instance, Wu et al. (2015) consider five of the nine European classes, then grouped into the A/B (small vehicles), C/D (medium vehicles), and J (large vehicles), while Scorrano, Danielis, and Giansoldati (2019a) focus on light commercial vehicles.

[10] The list includes petrol, diesel, HEV, PHEV (Plug-in Hybrid Electric Vehicle), BEV, FCEV (Fuel Cell Electric Vehicle), LPG, methane. However, some of these technologies (notably, the most recent ones such as the BEV, PHEV, FCEV) constantly evolve, changing their cost structure. Hence, they require to be newly evaluated.

[11] APR represents the actual yearly cost of funds over the term of a loan. This includes any fees or additional costs associated with the transaction but does not take compounding into account.

[12] The capital recovery factor represents the amount of equal payments to be received for T years such that the total present value of all these equal payments is equivalent to a payment of one euro at present, if interest rate is *i*.

AOC takes place during the lifetime of the vehicle. We discount each annual cost component, we sum these values and compute the average value, obtaining the average annual operating cost (AAOC):

$$AAOC\ (ADT) = \frac{1}{T}\sum_{t=1}^{T}\frac{AOC_t\ (ADT)}{(1+i)^t} \tag{9}$$

Finally, we consider the discounted and annualized residual value (DARV):

$$DARV = \frac{RV}{(1+i)^T}\cdot CRF \tag{10}$$

where RV can be expressed as a percentage η of the MSRP.

Therefore, the annualized TCO metric, given a specific ADT, is the following:

$$ATCO(ADT) = AIC\ +\ AAOC(ADT) - DARV \tag{11}$$

Dividing this sum by the ADT in kilometers, we finally obtain the metric TCO/km, which represents the average cost per kilometer of owning a given vehicle:

$$\frac{TCO}{km} = \frac{ATCO}{ADT} = \frac{1}{ADT}\left(\frac{(MSRP - RD - SUB\ )\cdot APR}{1-(1+APR)^{-T}} + \frac{1}{T}\sum_{t=1}^{T}\frac{AOC_t}{(1+i)^t} + (RC\ +\ HCE)\cdot CRF - \frac{\eta\cdot MSRP}{(1+i)^T}\cdot CRF\right) \tag{12}$$

Equation (12) can be used to compute the BEVs' MSRP that would make BEV's TCO/km equal to that of an alternative propulsion system (TCO_{APS}/km). We term this indicator as break-even BEV MSRP. We will use this metric to estimate by how much the current BEV MSRPs should decrease in order for BEVs to be cost competitive with the alternative propulsion system.

The TCO_{APS}/km for a given propulsion system is estimated as the average of the TCO/km of all car models considered for that specific propulsion system. Assuming the same ADT across propulsion systems, the break-even BEV MSRP relative to a given TCO_{APS}/km is equal to:

$$Break-even\ BEV\ MSRP = \frac{TCO_{APS} - AAOC + \frac{(RD+SUB)\cdot APR}{1-(1+APR)^{-T}} - (RC+HCE)\cdot CRF}{\frac{APR}{1-(1+APR)^{-T}} - \frac{\eta\cdot CRF}{(1+i)^T}} \tag{13}$$

4. Vehicle selection and model parameters

We apply the TCO model to Italian data relative to the cost structure of the best selling cars in the period January–April 2019 and belonging to the small to medium car segment.[13] We have selected 10 petrol and diesel cars, 9 HEVs, and 7 BEVs (i.e., Tesla Model 3, Nissan Leaf, Smart fortwo, Smart forfour EQ, Renault Zoe 41 kWh, BMW i3 and Hyundai Kona, while we have excluded the Tesla Model S and Model X, and the Jaguar I-Pace because they belong to a higher segment). The main characteristics of the selected models are reported in the Supplementary Material and an overview of the main statistics per propulsion system is reported in Fig. 1. The selected models represent a large share of the total sales: 44%, 29%, 81% and 92% of the total petrol, diesel, HEV and BEV sales, respectively.[14] BEVs have a much higher mean and median values, with an upper extreme represented by the Tesla Model 3 and a lower extreme represented by the Smart fortwo EQ Youngster. Note that Smart's MSRP is higher than the average MSRP of the diesel and petrol cars. HEVs have lower mean and median values, with an outlier represented by the Audi A6. Diesel and petrol cars have a much lower MSRP dispersion, with the VW T-Roc representing an outlier.

We apply the following baseline assumptions.

4.1. Initial costs

- Purchase price (MSRP): it varies by model type as listed in the Supplementary Material;
- Retailer's discount (RD): we assume the consumer pays exactly the MSRP proposed by the manufacturer without any dealers' discount;
- Registration cost (RC): it varies by model type and place of residency as listed in the Supplementary Material; we consider Trieste, in the North-East of Italy, as the reference location;
- Government subsidy (for BEVs only) (SUB): €0 or €6000;
- Wall-box and installation costs (for BEVs only) (HCE): €2000;
- Resale value (RV): while for conventional cars the depreciation rate is sufficiently known, the question for the BEVs is still controversial, given their recent appearance in the market. BEVs depreciate faster than ICEVs mainly because of technological advancements, e.g., battery cost reduction, that lead to a decrease in the resale value of earlier variants (Zhao et al., 2015).

4.2. Operational and use costs

- Maintenance (MAINT): we made the cautious assumption that BEV costs 30% less than the average of ICEVs for maintenance and repair costs, because of regenerative braking, no oil change, spark plugs, or transmission fluids. There is still uncertainty on this parameter, although there is a growing empirical evidence[15];
- Insurance premium (INS): it depends on many factors related to vehicle's features, driver's characteristics (e.g. past accidents history) and residential area, but also on the commercial strategy of the insurance company. In order to ensure comparability between cars with different propulsion systems, we keep constant some of these risk factors. In particular, we consider a 40-years-old man living in the Friuli Venezia Giulia Region. We use quotes obtained from "facile.it", a website comparing the most important Italian insurance companies. Insurance premiums vary by type of model and propulsion system;
- Circulation tax (CT): it varies among cars, depending on the engine power (in kW) of the vehicle (see the Supplementary Material);
- Ownership period (T): we assume that a user sells his/her car after 6 years, for example to take advantage of new technological developments;

[13] Alternatively, we could have compared among car pairs of the same size and brand, but with different propulsion systems, as in, e.g., Weldon et al. (2018) and Breetz and Salon (2018). Our choice has two advantages: 1) it accounts for the consumers' appreciation for a model within each propulsion system; 2) it overcomes the difficulty of finding equivalent models in terms of equipment, brand and size, but differing by propulsion system. The disadvantage is the heterogeneity within and between each group of models.

[14] Unrae (2019) - Top 10 per alimentazione Aprile 2019 http://www.unrae.it/files/06%20aprile%20Top%2010%20alimentazione_5ccb005f4ad89.pdf, accessed on August, 10th 2019.

[15] For instance, Propfe et al. (2012) reports a 49% annual savings, Alexander and Davis (2013) 61%, Mitropoulos, Prevedouros, and Kopelias (2017), 30%, and Logtenberg, Pawley, and Saxifrage (2018), 47%.

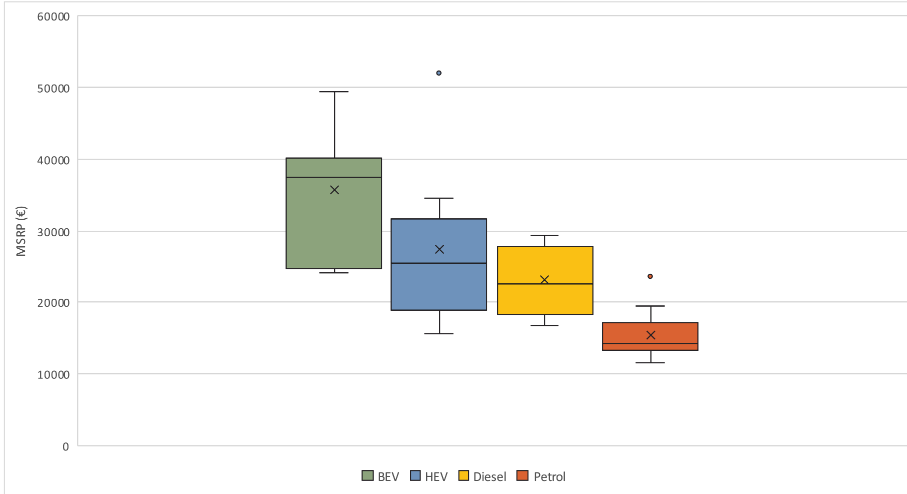

Fig. 1. Main statistics of the selected cars per propulsion system.

- Fuel efficiency (FE_E): fuel and energy efficiency values are derived from the EPA database (when available) and from the, although controversial, European NEDC (see the Supplementary Material)[16];
- Diesel price: 1.49 €/litre (the average price in Italy in 2018)[17]; the value is kept constant over the vehicle lifetime;
- Petrol price: 1.60 €/litre (the average national price observed in 2018); the value is kept constant over the vehicle lifetime;
- Electricity price, when charging at home (EP_{home}): 0.22 €/kWh[18]; the value is kept constant over the vehicle lifetime;
- Electricity price, when charging at public stations (EP_{public}): 0.45 €/kWh; the value is kept constant over the vehicle lifetime;
- Weather-adjustment factor (γ): we assume for BEVs a 30% decrease in energy efficiency when driving at very high (in summer) or very low (in winter) temperatures. This entails an adjustment γ in the electricity consumption of 1.15 (no adjustment, i.e. $\gamma = 1$, is needed for ICEVs). The assumption is based on the evidence we gathered in field study concerning Italian BEV drivers (Scorrano, Danielis, & Giansoldati, 2019b), previous literature (American Automobile Association, 2019; Yuksel & Michalek, 2015) and social media data.[19]

4.3. Financial costs

- Discount rate (i): 1%, that is the current interest rate of Italian treasury bonds with a residual maturity of 6 years[20];
- Annual Percentage Rate (APR): even if traditionally, in Italy, it was common to pay cash, recently more and more people finance their car purchases with borrowed money. Therefore, we assume that the car buyer finances the purchase with a loan, paying an average APR equal to 7%.[21]

5. Results

In this section we present the TCO/km and break-even BEV MSRP's estimates under the baseline assumptions and then considering the scenarios illustrated in Table 1.

They allow us to estimate: a) the impact of monetary BEV incentivizing policies, introducing the €6000 "Ecobonus" purchase subsidy; b) the impact of urban driving, varying the percentage of trips driven in an urban area (α); c) the impact of home charging, varying the percentage of electricity charged at home (β); and d) the joint impact of urban driving and home charging in four polar cases, both without and with the €6000 "Ecobonus".

5.1. Baseline estimates

We illustrate in Fig. 2 the TCO/km of each selected vehicle in relation with its MSRP. The estimates are obtained under the following baseline assumptions: ADT: 10,250 km (i.e. the average distance travelled by Italian drivers in 2018); home charging: 90%, urban trips: 50%; no subsidy (as it was the case in Italy up to April 1st, 2019, although there were sporadic subsidies at regional level). There is an almost perfectly linear relationship between the MSRP and the TCO/km (y = 2E-05x + 0.1585, with an R-squared value of 0.9524). BEVs are mostly at the top right of Fig. 2, but for the two Smart BEVs (fortwo and forfour), which enjoy a lower MSRP, and hence TCO/km metric, than some of the HEVs and diesel cars. Petrol cars are mostly in the bottom-left corner, diesel ones to their right, and HEVs in between the diesel and the HEVs.

In the following section we will modify the assumptions of the baseline scenario in order to analyze how monetary and energy efficiency-related variables affect the break-even BEV MSRP.

5.2. The break-even BEV MSRP without and with subsidy

The break-even BEV MSRP metric provides an indication of what

[16] Danielis et al. (2018) argue that the data on fuel efficiency entail a considerable degree of uncertainty, associated with the difference between test and real fuel consumption, and with the testing cycles used. Test fuel consumption is measured through predefined driving cycles such as the American EPA and the European NECD and WLTP driving cycles. The EPA cycle usually leads to about 43% and 12% higher estimated consumption levels than the NECD and WLTP ones, respectively (https://insideevs.com/features/343231/heres-how-to-calculate-conflicting-ev-range-test-cycles-epa-wltp-nedc/). Further areas of uncertainty, not accounted for in the conventional EPA cycles, are associated with aggressive, high speed and/or high acceleration driving behavior, use of air conditioning units, and cold temperature cycles.

[17] https://dgsaie.mise.gov.it/prezzi_carburanti_mensili.php?prodcod=2&anno=2018.

[18] https://www.statista.com/statistics/881421/household-electricity-price-in-italy/. Massi Pavan, Lughi, and Scorrano (2019) find that the levelized cost of electricity is even lower when charging from a renewable-based microgrid.

[19] We consulted the following website: https://electrek.co/2019/02/07/study-electric-cars-lose-range-temperature-tesla-disputes/(accessed on April 2nd, 2019).

[20] https://www.ilsole24ore.com/finanza-e-mercati.shtml.

[21] Each financial institution or retailer charges a different APR; we considered one of the most common value, proposed for example by https://www.findomestic.it/prestiti-personali/rata-verde.shtml.

Table 1
Analyzed scenarios.

Baseline assumptions: % home charging: 90%, % urban trips: 50%, ADT: 10,250 km	Subsidy: €0
	Subsidy: €6000
The impact of urban driving	% urban trips (α): 0%; varying ADT
	% urban trips (α): 100%; varying ADT
The impact of home charging	% home charging (β): 0%; varying ADT
	% home charging (β): 100%; varying ADT
The joint impact of home charging and urban driving: four polar cases without subsidy	Case 1: α = 100%, β = 100%; with varying ADT
	Case 2: α = 100%, β = 0%; with varying ADT
	Case 3: α = 0%, β = 100%; with varying ADT
	Case 4: α = 0%, β = 0%; with varying ADT
The joint impact of home charging and urban driving: four polar cases with subsidy	Case 1: α = 100%, β = 100%; with varying ADT
	Case 2: α = 100%, β = 0%; with varying ADT
	Case 3: α = 0%, β = 100%; with varying ADT
	Case 4: α = 0%, β = 0%; with varying ADT

should be the BEV MSRP to break-even in terms of TCO with an alternative technology. Fig. 3 illustrates the results we obtained when setting the percentage of urban trips to 50%, the percentage of home charging to 100%, no subsidy and varying ADT. It turns out that BEVs, to be competitive with the average HEVs, should cost less than €28,352 when the ADT is equal to 5000 km, less than €29,273 when the ADT is equal to 10,000 km and so on. To be competitive with respect to the average diesel cars, BEVs should cost between €18,844 and €25,684, depending on the ADT. With respect to the average petrol cars, their MSRP should be even lower, between €12,578 and €24,463. Of the 7 best-selling BEVs in Italy, only the Smart fortwo and forfour (the Renault Zoe only for a very high ADT) are cost competitive with the average HEVs. Compared with the average petrol and diesel cars, no BEV is competitive (apart from the two Smart but for an unrealistically high ADT).

We now consider the impact on the break-even BEV MSRP of the so-called "Ecobonus" (https://ecobonus.mise.gov.it/), a purchase subsidy that has been enacted from April 1st, 2019 by the Italian ministry for infrastructures and transportation in cooperation with the Italian ministry for economic development. According to this measure, BEVs and HEVs buyers are entitled to benefit from the maximum amount of the subsidy equal to €6000 when the purchase of a new car is associated to the scrapping of an old one. The new car must have a MSRP lower than €50,000 VAT excluded. With such a subsidy, BEVs' prospects improve (Fig. 4). The Smart fortwo and forfour, the Renault Zoe, and the Hyundai Kona are cheaper than the average HEV for a reasonable ADT. The Smart fortwo and forfour are convenient also relative to the average diesel car, while they cost compete with petrol cars only when the ADT is higher than 17,000 km.

5.3. *The impact of urban driving on the break-even BEV MSRP*

We quantify the importance of travelling in urban areas rather than in suburban roads by estimating the break-even BEV MSRP relative to other propulsion systems in the two polar cases: 0% or 100% urban trips, with varying ADT, and 100% home charging (Table 2).

The "Diff." column reports the difference between the two break-even BEV MSRPs. In the case of HEVs, when the ADT is equal to 10,000 km, the difference is equal to €910, growing to €3639 when the ADT is 40,000 km. In the case of diesel cars, the difference is larger, ranging from €1700 to €6799 and even larger for petrol ones (€2579 to €10,314). This is due to the fact the fuel/energy efficiency differential between BEVs and ICEVs (petrol and diesel) in urban traffic is higher than in the case of HEVs. Higher ADT leads to higher BEVs competitiveness.

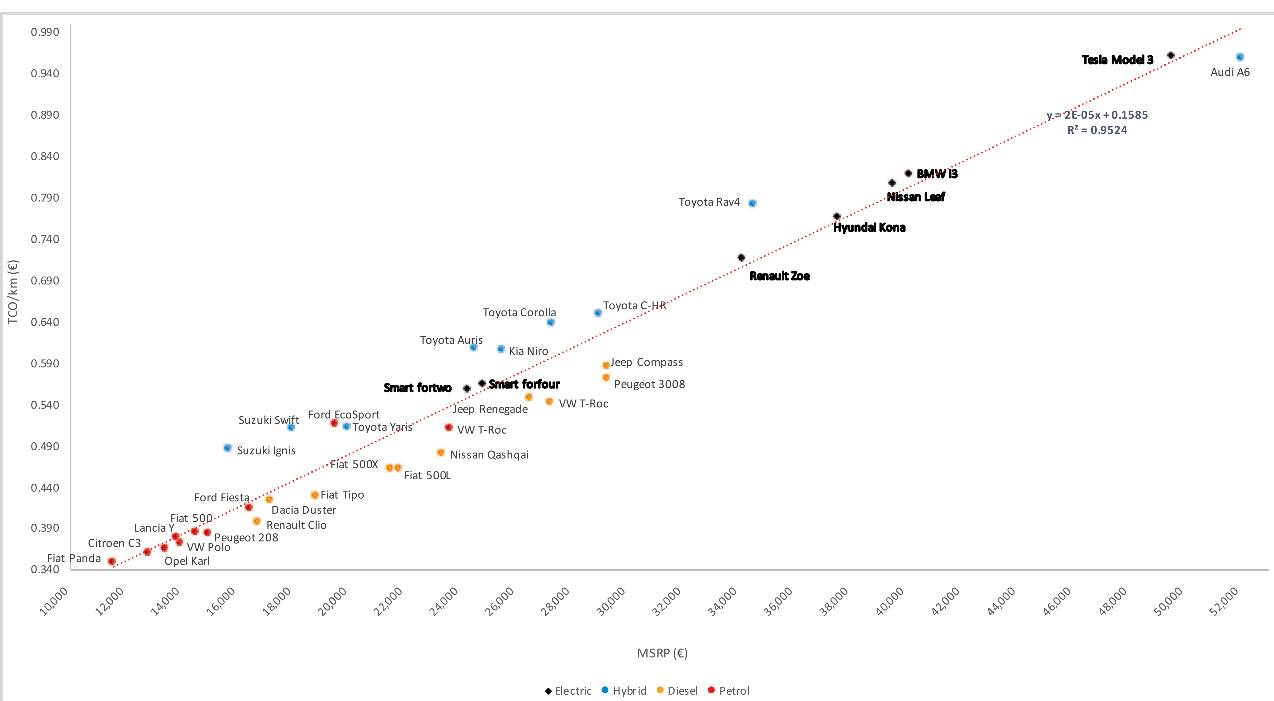

Fig. 2. Relation between MSRP and TCO/km for the 36 vehicles considered.

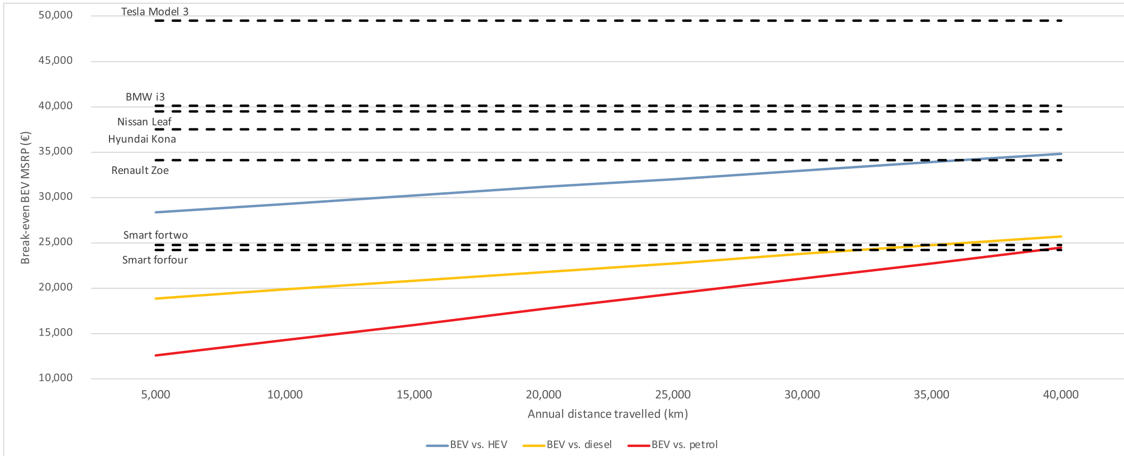

Fig. 3. Break-even BEV MSRP (50% urban trips, 100% home charging) without subsidies.

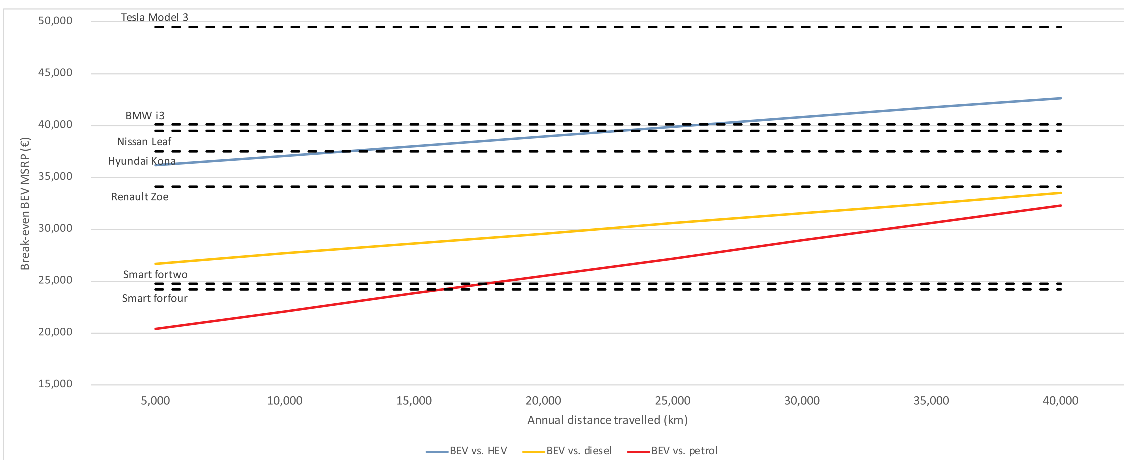

Fig. 4. Break-even BEV MSRP (50% urban trips, 100% home charging) with subsidies.

Table 2
The impact of urban driving on the break-even BEV MSRP (home charging β = 100%, without subsidies).

	BEV vs. HEV (€)			BEV vs. diesel (€)			BEV vs. petrol (€)		
ADT (km)	α = 0%	α = 100%	Diff.	α = 0%	α = 100%	Diff.	α = 0%	α = 100%	Diff.
10,000	28,818	29,728	910	18,971	20,671	1700	12,987	15,565	2579
20,000	30,206	32,025	1819	20,076	23,475	3400	15,093	20,250	5157
30,000	31,593	34,322	2729	21,180	26,280	5099	17,199	24,935	7736
40,000	32,980	36,619	3639	22,285	29,084	6799	19,306	29,620	10,314

5.4. The impact of home charging on the break-even BEV MSRP

Table 3 reports the break-even BEV MSRP when the percentage of home charging is set equal to 0% or 100%, with varying the ADT and assuming 50% urban trips. The "Diff." column is an estimate of the importance of having the possibility to charge at home rather than in public charging stations. It is higher than in the previous case, varying from €2866 to €11,466, depending on the ADT. The same values apply across propulsion systems since only BEVs are affected by charging savings.

To summarize the two cases, since the electric propulsion system due to its technical properties performs at best in terms of efficiency in an urban environment, BEVs cost competitiveness is enhanced if a user drives only (or mostly) in an urban area. The increase in competitiveness between fully-urban and fully-suburban driving can be valued between €910 and €10,314, depending on ADT and on the propulsion system to which the BEV is compared. The ability to charge at home at cheaper rates instead of charging at public chargers at higher rates is also very relevant. It is valued between €2866 and €11,466, depending on ADT irrespective of the propulsion system to which the BEV is compared.

5.5. The joint impact of home charging and urban driving: four polar cases

As the previous results confirm, the TCO/km estimate varies across individuals, depending on the ADT, the percentage of trips driven in an urban area (α) and the percentage of electricity charged at home (β). We will consider below the following polar cases:

Table 3
The impact of home charging on the break-even BEV MSRP (urban driving α = 50%, without subsidies).

	BEV vs. HEV (€)			BEV vs. diesel (€)			BEV vs. petrol (€)		
ADT (km)	β = 0%	β = 100%	Diff.	β = 0%	β = 100%	Diff.	β = 0%	β = 100%	Diff.
10,000	26,407	29,273	2866	16,955	19,821	2866	11,410	14,276	2866
20,000	25,382	31,115	5733	16,043	21,776	5733	11,939	17,672	5733
30,000	24,358	32,957	8599	15,131	23,730	8599	12,468	21,067	8599
40,000	23,333	34,799	11,466	14,218	25,684	11,466	12,997	24,463	11,466

- Case 1: α = 100%, β = 100% (with varying ADT): it represents the situation of an individual who drives only in a city and has the possibility to charge always at home;
- Case 2: α = 100%, β = 0% (with varying ADT): it represents the situation of an individual who drives only in a city but does not have the possibility to charge at home;
- Case 3: α = 0%, β = 100% (with varying ADT): it represents the situation of an individual who drives only outside urban areas and has the possibility to charge always at home;
- Case 4: α = 0%, β = 0% (with varying ADT): it represents the situation of an individual who drives only outside urban areas and does not have the possibility to charge at home.

We will examine the break-even BEV MSRP in two scenarios: A) without a BEV purchase subsidy and B) with a BEV purchase subsidy.

5.5.1. *Without the subsidy*

If charging takes place entirely at public stations (HC = 0%) at the current charging prices, BEV competitiveness is limited. In the most favorable situation (Fig. 5 – Case 2A), when all trips take place in an urban area, the break-even BEV MSRP, relative to that of the average HEVs, declines since BEVs' variable costs with respect to the ADT are higher than HEVs' ones. Only the two cheapest BEVs (Smart fortwo and Smart forfour) are cost competitive with the average HEV, but they are never competitive with the diesel and petrol cars. In the least favorable situation (Fig. 5 – Case 4A), when all trips take place in extra-urban areas, the break-even BEV MSRP declines with respect to all the other propulsion systems, meaning that the combination of charging at public stations and using the BEV in the least favorable traffic conditions makes their variable costs always higher. Even the less expensive BEVs are hardly competitive relative to their counterparts. They become competitive only with respect to the average HEV when less than 17,000 km are yearly travelled.

If charging takes place always at home (HC = 100%) at the Italian electricity prices, BEV competitiveness improves. When all trips are made in urban areas (Fig. 5 – Case 1A), the cheapest BEVs become cost competitive even with the diesel cars when at least 23,000 km are yearly travelled, and are always convenient when compared with the average HEV. Relative to the petrol cars, however, they are not competitive unless high urban-only ADTs are assumed (more than 29,000 km). This is unlikely in the case of private drivers, but it could be the case of a taxi driver, as documented by Scorrano et al. (2019b) for the city of Florence. When all trips take place in extra-urban areas (Fig. 5 – Case 3A), the break-even BEV MSRP increases with ADT when compared to all the other propulsion systems as in the Case 1A, meaning that the availability of home charging at lower prices is important for BEV operating cost-related savings. The competitiveness of the cheapest BEVs is confirmed with respect to HEVs.

5.5.2. *With the subsidy*

Let us now examine the impact of the BEV "Ecobonus" purchase subsidy. In the worst case scenario, when charging takes place entirely at public stations at the current charging prices (Fig. 6 – Cases 2B and 4B), BEVs are still hardly competitive with the other propulsion systems. Only the two cheapest BEVs are competitive not only with the HEVs (regardless of the ADT) but also with the diesel when considering urban-only trips. In this case (Fig. 6 – Case 2B), the cheapest BEVs are competitive with petrol cars only with a high ADT (more than 25,000 km). For intercity trips (Fig. 6 – Case 4B), characterised by lower congestion and less frequent stop-and-go, petrol cars remain the cheapest alternative.

In the best-case scenario, when charging takes place entirely at home and all trips take place in urban areas (Fig. 6 – Case 1B), three BEVs (Smart fortwo, Smart forfour and Renault Zoe) are competitive with

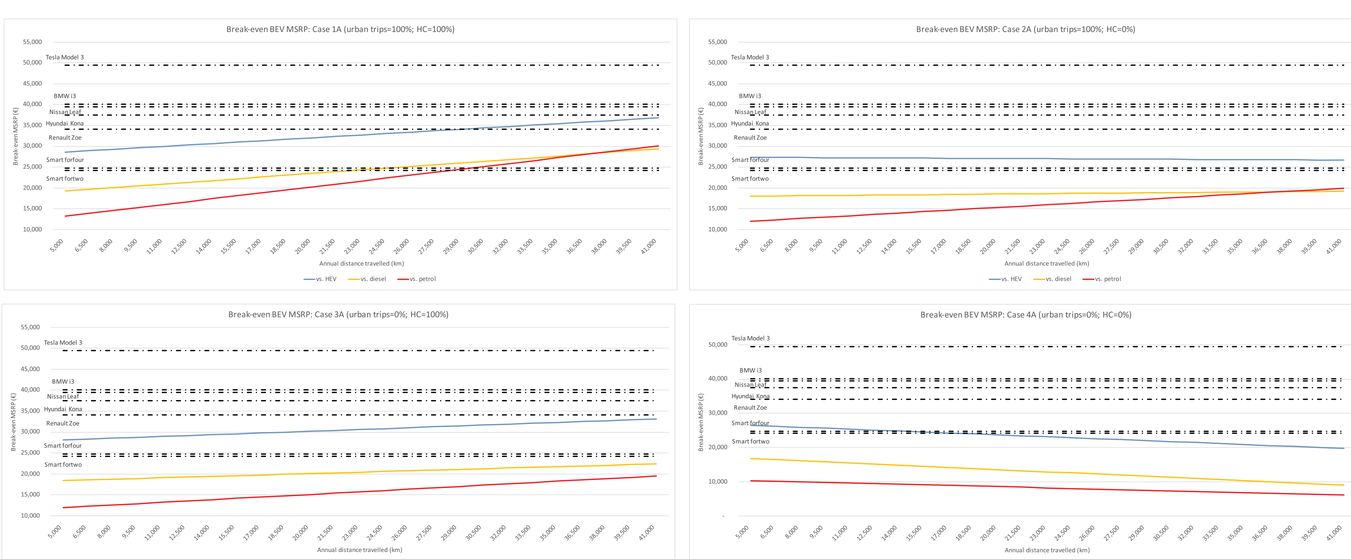

Fig. 5. Break-even BEV MSRP with respect to HEVs, diesel and petrol cars varying urban trips (0%–100%) and home charging (0%–100%) when no subsidy is considered.

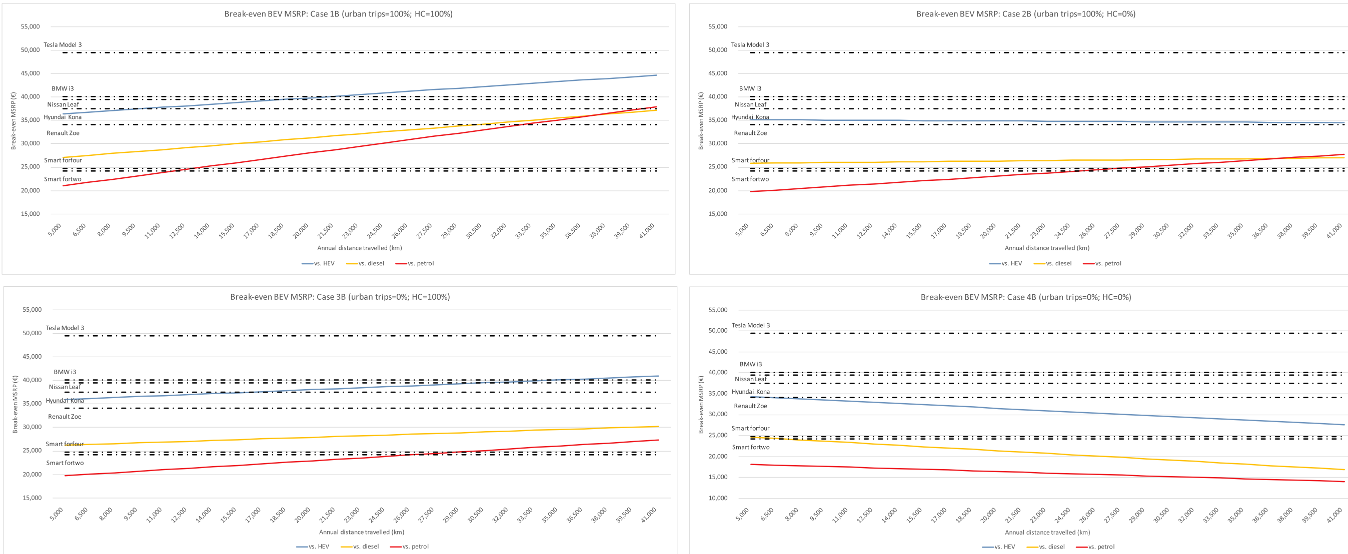

Fig. 6. Break-even BEV MSRP with respect to HEVs, diesel and petrol cars varying urban trips (0%–100%) and home charging (0%–100%) when the €6000 "Ecobonus" purchase subsidy is considered.

HEVs irrespective of ADT. The Hyundai Kona, the Nissan Leaf and the BMW i3 are competitive for realistically high ADTs, while with respect to the diesel cars, only the two Smart cars are competitive. The cheapest BEVs compete with the petrol cars for an ADT higher than 12,500 km. If all trips are extra-urban (Fig. 6 – Case 3B), only three BEVs are always competitive with HEVs and the two cheapest BEVs are competitive with the diesel cars (regardless of the ADT). The petrol cars remain the cheapest solution up to 27,000 km ADT.

6. How big is the potential BEV market in Italy?

Having examined the interplay between ADT, percentage of home charging and percentage of urban trips, it is worth discussing the implications of our findings for BEV market diffusion in Italy. An exact estimation of the potential market BEV uptake would require a detailed information on drivers' ADT, home charging availability and urban/intercity travel mobility habits. Unfortunately, such data is not available for Italy. The available information is the following:

- ADT of Italian car drivers: 18.8% of the drivers travel less than 5000 km; 57.6% between 5000 km and 10,000 km; 12.1% between 10,000 km and 15,000 km; 9% between 15,000 km and 25,000 km; and only 2.5% more than 25,000 km[22];
- private parking space (Istat, 2011): 81% of the car drivers in towns with less than 10,000 inhabitants have a private parking space for their car; the number increases to 85% for the towns with 10,000 to 100,000 inhabitants; and decreases to 51% in the cities with more than 100,000 inhabitants;
- number of driving licence holders: 33% of the Italian driving licence holders live in towns with less than 10,000 inhabitants; 44% in towns between 10,000 and 100,000 inhabitants; and 23% in cities with more than 100,000 inhabitants.[23]

Using such information, we can estimate the number of car drivers potentially benefitting from a BEV in terms of TCO/km, by making the following assumptions: a) car drivers living in cities with more than 100,000 inhabitants make mostly urban trips; b) car drivers living in towns between 10,000 and 100,000 inhabitants make 50% of their trips in an urban environment; and c) car drivers living in towns with less than 10,000 inhabitants make only extra-urban trips.

The results are described in Table 4. The number of drivers owning a private parking space is equal to 75.7%. Of these, 11.8% drive mostly in urban areas. They are the ones who would benefit the most from owning a BEV, with limited requirements in terms of ADT. As described above, it results that with a €6000 BEV subsidy (Case 1B), they would find three BEVs (Smart fortwo, Smart forfour, and Renault Zoe) always more convenient than average HEVs, and two BEVs (Smart fortwo, Smart forfour) always competitive with diesel, while to compete with petrol cars a 12,000 ADT is needed.

The situation is certainly more complex for the 11.5% of the Italian drivers living and travelling in urban areas but not owning a parking space. Even if they enjoy a subsidy (Case 2B), they find BEVs on average more expensive than the other propulsion systems. Only cheaper BEVs are convenient. However, they have to rely on a public charging infrastructure, which charges them higher fees and reduces the relative BEV cost competitiveness. In fact, they do not find BEVs competitive with the petrol cars unless at high ADT. Hence, for this segment of the population petrol cars are likely to remain the best choice.

Conversely, we estimate that a mere 6.1% of the Italian car drivers drive only outside urban areas without having the possibility to charge at home. These drivers do not benefit from owning a BEV, even if there is a BEV subsidy and they drive very high ADT (Case 4B). The proportion of drivers driving outside urban areas and having the possibility to charge at home is quite large, equal to 26.6%. In case of a BEV subsidy (Case 3B), BEVs are on average convenient relative to the HEVs but not relative to the other conventional cars. Cheaper BEVs are, however, cost competitive relative to the diesel but not to the petrol cars (unless very high ADT). Petrol cars are consequently the most likely choice for this segment.

Table 4
Estimated distribution of drivers by mobility and charging habits.

	100% Home charging	0% Home charging	Row total
100% urban trips	11.8%	11.5%	23.2%
0% urban trips	26.6%	6.1%	32.7%
50% urban trips	37.3%	6.8%	44.1%
Column total	75.7%	24.3%	100%

[22] http://www.intermediachannel.it/wp-content/uploads/2016/06/Osservatorio-auto-giugno2016.pdf.
[23] Our estimates based on: Istat - Popolazione residente per classe di ampiezza demografica dei comuni - Italia (dettaglio regionale) - Censimento 2011.

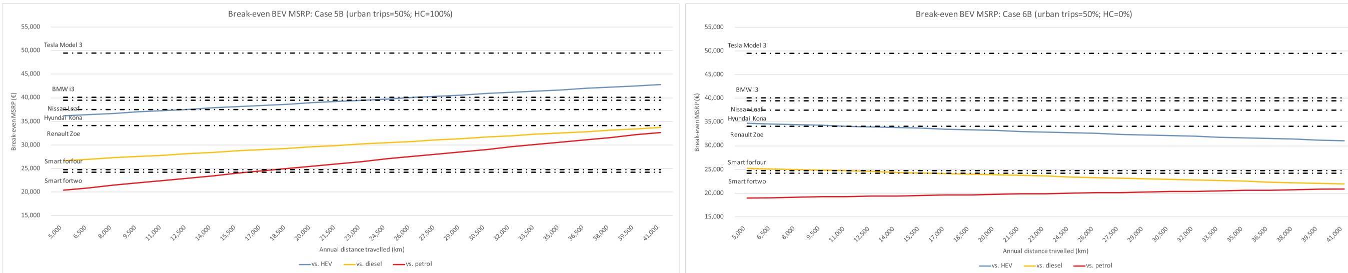

Fig. 7. Break-even BEV MSRP with respect to HEVs, diesel and petrol cars in two intermediate situations when the €6000 "Ecobonus" purchase subsidy is considered.

Case 5B in Fig. 7 describes a common situation (37.3% of the Italian drivers) where 50% of the trips are made in urban areas and charging takes place always at home. With the subsidy, BEVs are on average cost competitive with respect to HEVs, but not to diesel and petrol cars. However, cheaper BEVs are always cost competitive. Relative to the petrol cars, an ADT of about 16,500 km is needed. The remaining 6.8% of the drivers who cannot charge at home and drive 50% of urban trips (Fig. 7 - Case 6B) do not find on average BEVs convenient, unless they buy a cheap BEV but only relative to the HEVs and diesel ones.

7. Conclusions and policy implications

We have developed a TCO model and analyzed the role played by ADT, home charging and the percentage of urban trips on the BEV competitiveness relative to HEVs, diesel and petrol cars. As a metric, we used the break-even BEV MSRP, that is the BEV MSRP that would equalize the TCO/km of BEVs relative to other propulsion systems. We applied the model to Italian data on the cost structure of a group of up to 10 best-selling cars for each propulsion system in the car segment "small-medium sized cars". We find that not only the ADT plays a crucial role, but also the possibility of charging at home at cheaper rates and, to a minor extent, the percentage of urban trips determine to a large extent BEV competitiveness. Charging at home instead of at public chargers increases the break-even BEV MSRP from €2866 to €11,466, depending on the ADT and irrespective of the propulsion system considered. Travelling in urban areas instead of in rural areas increases the break-even BEV MSRP from €910 to €10,314, depending on the ADT and on the propulsion system considered. In the most favorable scenario, charging at home and driving in urban areas generate TCO savings that are much larger than the subsidy. They indicate that some drivers might find it convenient to buy a BEV at current prices, even in the absence of a purchase subsidy. To the best of our knowledge, no similar estimates have been provided so far in the literature.

Having identified four polar cases plus two intermediate cases, and estimated the number of Italian drivers belonging to each case, we have discussed the BEV potential in the Italian market. Since home charging largely increases BEV cost competitiveness, one should expect that BEVs will be initially acquired mostly by drivers who are able to charge at home. Luckily, in Italy, the percentage of such drivers is about 76%. The most favorable case for the BEV competitiveness is, obviously, when a driver is able to charge at home and travels mostly in urban areas. In our estimates, this amounts to 11.8% of the Italian drivers. We find that without subsidies they are better off when buying a cheaper BEV instead of a HEV, but not with respect to diesel and petrol cars, unless high ADT is considered (ADT higher than 23,000 km and 29,000 km, respectively). Given that the BEV uptake in Italy is lower than 1%, an implication of our result is that there is still a large market potential. Reasons other than monetary factors might, hence, explain why such a market potential is not yet realized. These include: the widely discussed BEVs range limitations (Giansoldati, Danielis, Rotaris, & Scorrano, 2018), psychological factors (concerns about battery degradation or about charging issues; Patt, Aplyn, Weyrich, & van Vliet, 2019), informational factors (lack of knowledge about BEVs; e.g. Wang, Wang, Li, Wang, & Liang, 2018) or short-sightedness (focus on initial costs; e.g. Allcott & Wozny, 2014; Krause et al., 2013), which determine car choice together with monetary variables (e.g., Giansoldati et al., 2018).

For drivers enjoying less favorable conditions, as already pointed out in the recent literature (Breetz & Salon, 2018; Weldon et al., 2018), we confirm that purchase subsidies are important for BEVs to be cost competitive. The recent introduction of the "Ecobonus" in Italy is going to help BEV penetration. With subsidies, BEV competitiveness is much stronger even if the MSRP is about €35,000. Cheaper BEVs are competitive with both HEVs and diesel cars and, in some cases, also with petrol cars. Conversely, drivers who live and use the car mostly in an urban setting but are not able to charge at home do not find BEVs competitive since they have to pay the higher public charging tariffs. Consequently, we argue that for the majority of Italian drivers the interplay between four factors determines BEV competitiveness: home charging availability, urban travelling, ADT and purchase subsidy.

These findings lead to the following suggestions to car manufactures and to policy makers. Firstly, in order to facilitate BEV uptake, at least in Italy, financial incentives, possibly in the form of purchase subsidies, given the current price structure, are generally needed for large segments of the drivers population. Subsequently, as BEVs enter the market in larger numbers, drivers' knowledge not only about BEVs' technical performance (e.g., battery degradation, charging issues) but also about their cost structure and medium to long run savings, including the resale value, is likely to increase, leading to a more informed car choice decision.

Secondly, home charging is important for not only energy management reasons (i.e., peak shaving, distributed consumption) but also to improve BEV cost competitiveness. In the case of private house owners with a private garage, the challenges are limited. In the case of drivers living in multi-unit dwellings with shared parking facilities, in many countries including Italy, the current technical and legal regulations present significant barriers[24] that do not encourage building owners to retrofit existing buildings with charging points. Given the home charging relevance for BEV cost competitiveness, these barriers should be overcome for the BEVs to gain market acceptance in order to make overnight charging available to as many BEV owners as possible. In the case of drivers without a private or shared parking facility, charging in public areas is the only possibility. So far, to the best of our knowledge, very few cities succeeded in developing a network of slow, medium or fast charging stations sufficiently dense to satisfy the needs of the growing number of BEV users who do not have access to home charging. This issue represents a challenge for both the energy providers and policy makers (Guo, Yang, & Yang, 2018; Vazifeh, Zhang, Santi, & Ratti, 2019). Energy and infrastructure providers face various technical and economic issues, including the need to develop a robust business model.

[24] The issues are linked to the need to add electrical loads on the buildings' existing power systems, to the lack of support from non-BEV drivers, and to the lack of a clear regulation concerning the rights and obligations of drivers and landlords.

Policy makers are faced with the task of supporting such a development, but within the limits of competition law and of their political mandate.

Thirdly, we have noticed that the current BEV cost competitiveness in Italy suffer from the very large differential in initial costs between BEVs and the conventional propulsions systems. One reason for the MSRP differential is certainly the cost of the battery. Luckily, according to many sources (e.g., https://www.bloomberg.com/opinion/articles/2019-04-12/electric-vehicle-battery-shrinks-and-so-does-the-total-cost), this cost component is rapidly declining and will probably decline in the future thanks to technological progress and to the economies of scale connected with the fast growing battery production. However, a second reason for the MSRP differential is that so far BEVs are in many cases high trim, luxury sedans, with sophisticated technological and software equipment (e.g., fast acceleration, heated seats, adaptive cruise control, lane assist, autonomous driving, dual motors, fancy monitors, glass roof). Probably for image and economic reasons, BEV car manufacturers focused initially on the higher end of the market, proving that BEVs are able to provide superior performance and incorporate highly innovative solutions. Very few BEV car manufacturers produced BEVs for the lower end of the market. Consequently, our analysis of the up to 10 best-selling cars in the Italian market finds that BEVs are only rarely cost competitive. Recently, however, several car manufacturers have planned to bring to the international and Italian market small, cheap and modestly equipped BEVs (e.g., the PSA 208e, the Opel Corsa, the VW Skoda Citigo-e iV, the Fiat 500e), that will be better able to compete with the existing diesel and petrol cars in the popular small-to-medium car segment.

The methodology presented in this paper proved capable of isolating BEV cost components relevant for BEV competitiveness. The main limitations of the results presented relate to the uncertainty characterizing some of the model parameters, notably the resale value in a rapidly changing technological environment and the future variations in the fuel and energy prices. Interesting research developments include: a) dissecting the impact on the BEV TCO of other individual-specific parameters, for instance the financing needs implying different APRs and the available insurance premium; b) comparing among countries characterized by different regulatory and financial policies, cost structures, fleet composition and urbanization levels, and analyze the relationship between BEV TCO and BEV penetration levels; c) extending the TCO model, including future cost trends and account for uncertainty.

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