A probabilistic total cost of ownership model to evaluate the current and future prospects of electric cars uptake in Italy

Romeo Danielis*, Marco Giansoldati, Lucia Rotaris

Dipartimento di Scienze Economiche, Aziendali, Matematiche e Statistiche “Bruno de Finetti” Università degli Studi di Trieste, Via dell’Università, 1, 34123 Trieste, Italy

ARTICLE INFO

Keywords:
Total cost of ownership
Passenger cars
Electric cars
Conventional cars

ABSTRACT

In order to evaluate the current and future prospects of electric cars’ in Italy, we develop a probabilistic total cost of ownership (TCO) model, which includes stochastic and non-stochastic variables, vehicle usage and contextual assumptions. We find that electric cars are currently not cost-competitive in Italy with the conventional petrol or diesel cars. However, they are cost-competitive with the hybrid electric cars when more than 10,000 km are annually traveled. With incentivizing policies (a €5,000 subsidy and a €400 parking and access fee annual savings), currently in place in a limited number of Italian Regions and cities, electric cars perform in monetary terms better than hybrid electric cars and some diesel cars, especially if they are charged at home. However, electric cars are expected to gain market share in the year 2025 if fuel prices follow past trends, even without subsidies. The driving force could be a drop in their retail price, thanks to declining battery pack costs, and a possible revision of the taxes on diesel.

1. Introduction

Italy is one of the countries with the lowest uptake of electric cars (BEVs)[1] in Europe, equal in 2017 to 0.01% of the total new car sales, while in neighboring countries, such as Austria, France, Switzerland or Germany, BEVs have a market share ranging from 1.5% to 3%, and growing. Many factors play a role in the consumers’ car purchase decision (Coffman et al., 2017; Berkeley et al., 2017; Liao et al., 2017; Biresselioglu et al., 2018). They are both monetary (e.g., purchase price, excise taxes, operational costs, parking fees) and non-monetary (e.g., driving range, car size and segment, brand, attitudes,[2] charging time and charging infrastructure). The former group of costs are captured by the *total cost of ownership* (henceforth, TCO) concept. TCO is defined both as a purchasing tool and a philosophy, aimed at understanding the true financial cost of buying a specific good such as a car (Ellram, 1995). This paper develops and applies a probabilistic TCO model to evaluate the prospects for BEVs’ diffusion in Italy.

Using the terminology proposed by Letmathe and Suares (2017), TCO can be divided into two cost components: the consumer-oriented TCO, including all the cost born by the car user, and the society-oriented TCO. This paper focuses on the former, whereas Danielis and Giansoldati (2017) deal with both types of TCO.[3]

Estimating the TCO of a car presents difficult computational challenges. Nonetheless, TCO provides a useful information for consumers, fleet managers, original equipment manufacturers (OEMs) and policy makers. As argued by Hagman et al. (2016), the informational tools available to consumers have so far been limited. Consequently, one might suspect that private consumers (and to a lesser extent fleet managers) have limited knowledge on the TCO metric and its components, potentially leading to economically irrational purchase decisions.[4] OEMs could use this information to develop more focused BEVs’ marketing strategies and transport policy decision makers might tailor spatially and temporally their policies, eventually targeting specific market segments without risking an excessive or insufficient use of public resources.

The construction and implementation of a TCO model requires the

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* Corresponding author.
E-mail address: danielis@units.it (R. Danielis).

[1] Hereafter, we shall use the conventional acronym BEVs, battery electric vehicles, although we will restrict our analysis to cars without considering light- and heavy-duty vehicles, two- or three-wheelers, pick-up trucks and vans. In addition, in our paper BEVs refers only to pure battery electric cars and do not include plug-in cars.

[2] Zhang (2007) stresses the importance of the “familiarity” in car adoption. As suggested by the reviewer, in Italy BEV uptake might be helped by the large presence of e-car sharing schemes (about 30% of the share cars) that allow for a personal experience of electric car by a population orders of magnitude larger than actual current purchasers.

[3] A recent evaluation of the CO_2 emission of the different propulsion systems for all European countries is presented by Cavallaro et al. (forthcoming).

[4] Gillingham and Palmer (2013) argue that consumers might suffer from the “energy-efficiency paradox” because of imperfect information, bounded rationality, and limited mathematical skills. One strategy to address consumers’ misconception is to supply information on the TCO. Dumortier et al. (2015) find that providing such information would affect the stated preferences of consumers to purchase more energy efficient cars. Kaenzig and Wüstenhagen (2010) find similar results regarding eco-innovations.

https://doi.org/10.1016/j.enpol.2018.04.024
Accepted 12 April 2018

identification of the multiple private and social cost components. Some of them have uncertain values (i.e. real consumption in real driving conditions, preventive maintenance, residual value), some have a subjective nature (e.g. insurance premiums, driving styles), or vary over time (e.g. fuel or electricity cost). Some others are scientifically controversial (e.g. external costs of environmental or noise pollution), or stem from political decisions (e.g. monetary or non-monetary incentives, fees for parking or accessing reserved areas). Moreover, the estimation requires to take into account the driving habits (e.g., annual distance driven, the percentage of urban/suburban trips), the ownership period (with implications for the residual value), and the appropriate discount rates.

In order to deal with parameters' uncertainty, this paper develops a probabilistic TCO model along the lines suggested by Wu et al. (2015). The model is used to evaluate the current and future prospects of a BEV's diffusion in Italy in different scenarios, assuming that there is a relationship among the monetary cost of a car and the consumers' buying decision, although we acknowledge that non-monetary variables play also a relevant role.

To the best of our knowledge, no probabilistic TCO model has been so far developed for Italy. Previous non-probabilistic TCO models with Italian data are developed by Rusich and Danielis (2015), Danielis and Giansoldati (2017) who estimate consumer- and society-oriented TCO, and Lévay et al. (2017) who publish a comparison among European countries which includes Italy. The Italian case is characterized by the lack of BEV-specific national subsidies and an insufficient charging infrastructure, a fiscal taxation favoring diesel vehicles, and poor interest on BEVs from the major Italian OEMs. Yet, air pollution level in the northern Italian towns is a serious health issue and the political interest for BEVs is growing. An additional peculiar characteristic of the Italian market is that customers buy mostly small-to-medium sized cars, which require capital investments that are quite smaller than the average current BEVs price.[5]

The TCO model proposed in this paper is useful to quantify the financial gap between BEVs and internal combustion engine vehicles (ICEVs), in the present conditions and taking into account future price and technology developments. Differently from other studies (e.g., Wu et al., 2015; Letmathe and Suares, 2017), but similarly to Lévay et al. (2017), we implement the TCO model considering the 10 best-selling cars instead of relying on conceptual car models. Four propulsion systems are considered: petrol-fueled ICEVs (P-ICEV), diesel-fueled ICEVs (D-ICEV), petrol-fueled hybrid electric vehicles (HEVs), and BEVs. The appeal of this approach is that it allows us to understand which are the actual competitors of the BEVs, as they try to gain market share.

The paper has the following structure. Section 2 introduces the related literature. Section 3 illustrates the probabilistic TCO model. Section 4 presents the main findings: a) in the current cost scenario without BEVs' incentivizing policies; b) in the current cost scenario with BEVs' incentivizing policies; c) in two future scenarios. Section 5 compares our results with those reported in previous studies and Section 6 concludes.

2. Related literature

The literature on the TCO of cars is rapidly growing as recent reviews indicate (Wu et al., 2015; Bubeck et al., 2016; Danielis and Giansoldati, 2017). Since the pioneering work by Delucchi and Lipman (2001), numerous contributions followed on the TCO of BEVs (Appendix, Table 15). Some of them deal with both consumer- and society-oriented costs, considering the costs caused by CO_2 emissions (Kromer and Heywood, 2007; Thiel et al., 2010; Element Energy, 2011; Prud'homme and Koning, 2012; Bikert et al., 2015; Liu and Santos, 2015; Bubeck et al., 2016; Falcão et al., 2017) or those caused by local pollutants and noise (Prud'homme and Koning, 2012; Tseng et al., 2013; Zhao et al., 2015; Rusich and Danielis, 2015; Mitropoulos et al., 2017; Danielis and Giansoldati, 2017). Obviously, including the social costs in the TCO model makes the task more challenging and adds uncertainty to the results, since it involves monetizing nonmarket goods and services.

All the propulsion systems available in the market have been subject to comparative evaluations: P-ICEV, D-ICEV, HEV, PHEV (Plug-in Hybrid Electric Vehicle), BEV, FCEV (Fuel Cell Electric Vehicle), LPG, methane. Some of these technologies (notably, the most recent ones such as the BEV, PHEV, FCEV) constantly evolve, changing their cost structure.

The TCO evaluations have been carried out with reference to many countries (McKinsey and Company, 2011; Lévay et al., 2017; Palmer et al., 2018). As each country is characterized by specific cost structures, due to different fuel/electricity prices (linked to different excise taxes), insurance premiums, and subsidies, results differ among countries. It has been also pointed out that the TCO greatly depends on the vehicle usage patterns. Determining factors are trip type (urban vs highway), residential density (Windisch, 2013; Wu et al., 2015), user segments, as well as whether the car is used as first or second family car (Propfe and Redelbach, 2012; Plötz et al., 2013).

TCO models include many cost components such as vehicle price, vehicle excise duty, insurance, preventive maintenance, tire substitution, car's resale value, fuel consumption, etc. BEVs pose an additional challenge connected with the need to include the cost of battery substitution, recycle or reuse (Letmathe and Suares, 2017). Such an inclusion raises difficult questions both regarding when a battery substitution is needed and on how much it would cost or what one would gain from recycling or reusing the battery. Since BEVs are a recent product, not enough experience or data exists on these issues.

Most TCO models have deterministic parameters, exception made for Element Energy (2011) and Wu et al. (2015), who develop a probabilistic simulation model which is able to account for the uncertainty in the TCO model's parameters. This paper adopts the same strategy since we are confronted with significant sources of uncertainty on both current and future variables.

The surveyed studies focus on different vehicle classes, since each of them has its own peculiarities. The selected vehicle types are conceptual models, whose characteristics are defined by the main components of a vehicle, or representative models, selected from the real world models offered in a country at a specific date. In most cases the number of selected representative models is rather small (especially for the BEVs, since only a few were available), usually choosing the most popular ones (e.g. Nissan Leaf, Zoe, BYD, depending on the country). Lévay et al. (2017), being a more recent contribution, is able to compare 10 vehicle types for each propulsion systems in 8 European countries.

For the abovementioned reasons, the prospects for BEVs' diffusion in the market are country-, vehicle class-, time-, and vehicle usage-specific. Consequently, it is no surprise that findings are not univocal. However, there appears to be an historical trend: from skepticism to moderate optimism.

The pioneering study by Kromer and Heywood (2007) shows no clear winner in the future competition among propulsion systems, unless strongly influenced by government policies. Prud'homme and Koning (2012) find that in the year 2010 in France BEVs had excess costs above €10,000, granting very small CO_2 gains. They conclude that unless massive cost and efficiency improvements are achieved, BEVs will require enormous subsidies. However, in the years 2010 and 2012 two BEVs, the Nissan Leaf and the Tesla Model S, were successfully introduced in the market.

Propfe and Redelbach (2012) argue more optimistically that the TCO gap for alternative drivetrains will decrease significantly by 2020. In a very detailed report, Plötz et al. (2013) state that BEVs' share in

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[5] Thiel et al. (2015) estimate that the share of small cars (A and B segments) in the total new vehicle registrations in 2014 was 23% in Germany and 48% in Italy.

2020 will be highly dependent on external factors and that BEVs might be more appealing for users driving an annual distance of 15,000 km. Similarly, Tseng et al. (2013) find that only HEVs have comparable TCO to ICEVs and that BEVs could be competitive for users driving 20,000 miles per year for over 12 years. Bubeck et al. (2016) also find that the HEVs are competitive in Germany since 2015, while BEVs need a premium ranging from €8,600 to €32,400 to be an appealing alternative to ICEVs. They forecast that BEVs will be economically viable in 2030.

Various authors (Hao et al., 2014; Diao et al., 2016; Zhao et al., 2015; Lévay et al., 2017) stress the role of policies. Since BEVs have higher TCO than ICEVs, policies are essential to support BEVs' diffusion and take advantage of their lower air pollutants in-use emissions. This is true in any country, including China.

Considering a different vehicle segment, minibuses for passenger transportation, Falcão et al. (2017) reach the conclusion that BEVs' TCO is 2.5 times higher than ICEVs' and that the their payback period is 13 years. Mitropoulos et al. (2017) carry out a consumer and society-oriented TCO study, comparing ICEVs, HEVs and BEVs in the USA. They find that HEVs have the lowest consumer and society-oriented TCO, BEVs have intermediate values and ICEVs have the worst values in terms of both consumer-oriented and society-oriented TCO. On the contrary, Bikert et al. (2015), analyzing the small car market segment in Germany, conclude that, even considering the external costs caused by CO_2 emissions, BEVs do not have an economic advantage.

In the next section, we will introduce our model and underline its main characteristics with respect to the previous ones.

3. A probabilistic TCO model

Following Wu et al. (2015), we estimate the metric TCO per km, computing the consumer-oriented TCO and dividing it by the annual kilometers traveled (AKT). Formally, the TCO model can be written as follows:

$$\frac{TCO}{km} = \frac{\left(MSRP - RV * PVF\right) * CRF + \frac{1}{N}\sum_{n=1}^{N} \frac{AOC}{(1+i)^n}}{AKT}$$

where MSRP is the manufacturer's suggested retail price, RV is the resale value, PVF is the present value factor, CRF is the capital recovery factor $= (i(1+i)^N)/((1+i)^N-1)$, AOC is the annual operating cost, i is the discount rate, and N is the vehicle holding period of the first owner.

3.1. Non-stochastic and stochastic cost parameters

Our model contains non-stochastic and stochastic cost variables. They are listed in Table 1.

Non-stochastic variables can be divided into two groups:

- *annual fixed cost variables* which are incurred on an annual basis, such as vehicle excise duty, insurance premium, preventive maintenance; and
- *other cost variables* that are costs incurred on a non-annual basis such as extraordinary repairs, replacement of the starting-lighting-ignition battery, and tires.

The estimation of such variables for the different propulsion systems is subject to data limitations and estimation uncertainties. However, having done our best to select the proper variable for each car type (for more information on the selected values see Appendix), we consider their value as non-stochastic in the model.

On the contrary, three variables are assumed to be stochastic: the manufacturer's suggested retail price (MSRP); the fuel economy; and the resale value. Monte Carlo simulation are used to analyze distributions and probabilities of outcomes.

Table 1
Non-stochastic and stochastic cost parameters.

Non–stochastic cost variables	Stochastic variables
Annual fixed costs: ● Vehicle excise duty ● Insurance ● Maintenance	Purchasing price: Stochastic variable to account for potential discounts or bundled services. Beta distribution (10,1)
Other costs: ● Repairs ● Starting-light ignition (SLI) battery ● Tires	Fuel economy: Stochastic variable to account for real traffic variability in urban and highway cycles. Beta distribution (1,10)
	Resale value: Depreciation rate is set to 20% for ICEVs and HEVs, and to 10% for BEVs in the year 2017 and reversed in the year 2025.[a] Normal distribution (estimated resale value, €1,000)

[a] We accepted the reviewer's suggestion to adopt these assumptions, since BEVs depreciate faster in their initial phase than ICEVs. On the contrary, in the year 2025, ICEVs will potentially be an old technology leading to faster depreciation rates than those of BEVs. The so-called "dieselgate" might be considered an example of rapid depreciation due to technological innovations and political decisions.

3.1.1. Purchasing price

Similarly to previous studies (Windisch, 2013; Hagman et al., 2016; Lévay et al., 2017), our TCO model is based on real-life prices.[6] OEMs recommend a MSRP to help standardizing prices among locations. MSRP usually varies considerably by country. However, car dealers apply discounts, defining the final price that the customer pays for the car. It is common practice to apply generous discounts, so that the MSRP is nothing but a starting point. In order to capture such a variability, the MSRP is defined as a stochastic variable having a Beta distribution (10,1) with the MSRP as the upper boundary, implying that 90% of the times the discount is less than 10%.

3.1.2. Fuel economy

Fuel economy is an important cost component in a comparison across propulsion systems. Its value, however, is uncertain. A first issue concerns the difference between test and real fuel consumption. Real consumption depends on many factors linked to traffic conditions (congestion levels), type of road (flat or steep), weather conditions, and driving style. The latter has a particular influence on BEVs, which are endowed with regenerative breaking. Test fuel consumption is measured through predefined driving cycles such as the American Environmental Protection Agency (EPA) and the New European Driving Cycle (NECD). The EPA cycle usually leads to higher estimated consumption levels than the NECD one, and is commonly considered closer to real-world consumption. The uncertainty connected with real life fuel economy lead us to define it as a stochastic variable characterized by Beta distribution (1,10), implying that 70% of the times the real fuel consumption in real traffic is twice as much as that reported in the NECD test.

3.1.3. Resale value

The residual value of the car is not easy to be predicted. Age and the total distance driven are certainly leading parameters. However, other factors play a role such as driving habits, color, brand, size, specific market demand and so on. A crucial question for our comparisons is to evaluate whether cars with different propulsion systems depreciate differently. If for conventional cars the depreciation rate is sufficiently known, for BEVs it is

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[6] An alternative approach adopted in some studies (Al-Alawi and Bradley, 2013; Wu et al., 2015; Bubeck et al., 2016), is to model the retail price (labelled retail price equivalent) by summing up the car's components. The disadvantage of this approach is its inability to capture the OEMs' market strategies.

highly uncertain (Lévay et al., 2017). In our TCO model we assume that a car is held by the first owner for 6 years. In addition, as a baseline, we assume that ICEVs and HEVs retain 20% of their initial value, whereas BEVs hold only 10%, because, being a new technology, is subject to rapid technological depreciation. However, such assumption is reversed in the year 2025,[7] as in the year 2025, ICEVs will probably be an old technology subject to many limitations (e.g., inner-city access restriction), leading to faster depreciation rates than those of BEVs. In order to capture the uncertainty connected with these parameters we treat the resale value as a normally distributed stochastic variable with mean equal to the estimated resale value and a €1,000 variance.

3.2. Vehicle usage and contextual assumptions

The TCO model is also based on the vehicle usage and the contextual assumptions illustrated in Table 2.

Vehicle usage assumptions concern the type of trips made and the annual distance driven. Fuel economy depends on whether the car is driven in an urban environment or in a highway. In Italy, urban areas are highly congested and cause frequent start-stops. In this respect, ICEVs' fuel economy might be seriously affected by urban driving, a non-negligible aspect as we assume, based on ISFORT (2017), that 60% of the distance driven takes place in urban areas.

The AKT are assumed to be 5,000; 10,000; 15,000 km which enable us to derive three sets of results. Considering that the average distance of an Italian car driver is about 11,200 km per year (www.facile.it), the first assumption corresponds to a situation where the car is used mostly for short distances, as a second car, or by a person who does not work (e.g., pensioner), or who does not commute by car. The two other assumptions are compatible with a daily traveled distance of about 30 and 50 km, respectively.

As for the contextual variables, we assume that the first owner keeps the car for 6 years. There are no Italian official data on this parameter. Wu et al. (2015) choose this value based on German data, supposedly not very different from the Italian one. Depending on vehicle use, such an assumption amounts to a maximum total distance driven of 90,000 km, which is feasible also for a BEV without much battery degradation.[8] For this reason, the costs of battery substitution or the gains from battery reuse/recycle will not be included in our model.

For the calculation of CRF and PVF, we use a real interest rate of 4%, based on the annual nominal interest of a car loan of six years to buy a car (www.prestitionline.it) net of the forecasted inflation interest rate. Finally, as explained at length in Section 4.1, we will assume in a scenario that monetary costs saving for the BEVs might result from incentivizing policies such as a purchasing subsidy and parking and access fee exemptions, as currently in place in some Italian Regions and cities.

4. Results

We illustrate results relative to current and future scenarios. The current scenario comprises two parts: without and with policies. The future scenarios regard the year 2025 and 2 alternative sets of assumptions.

We choose to compare the TCO of the 10 best-selling cars in Italy in the year 2017 for each propulsion system, reported in Appendix in Table 17–20. The advantage of this approach is that one can gain a good idea of which are the actual competitors of the BEVs when they strive to gain market share. The best-selling cars with the largest market share are petrol- or diesel- fueled cars. In Italy, they are small or compact-sized (e.g., the best-selling Fiat Panda), they are easy to use in the narrow lanes of the Italian city centers and, at the same time, allow intercity trips, and they are relatively inexpensive. Since monetary costs represent an important factor for car choice (see Valeri and Danielis, 2015, for an Italian case study), a non-marginal BEVs' market share could be achieved if BEVs are reasonably cost competitive with the best-selling conventional models. Alternatively, one could compare cars with identical or similar characteristics in terms of size, engine displacement and so on or belonging to same Euro market segment (e.g., city-cars, sedans, SUVs, etc.). In order to allow the reader to better appreciate our results, we will present both aggregate and disaggregate tables, the former reporting the average TCO/km and the latter reporting the TCO/km for each BEV and for the best P-ICEV, D-ICEV and HEV. The interested reader would thus be able to make also model-specific comparisons.

Table 2
Vehicle usage and contextual parameters.

Vehicle usage assumptions:	Contextual assumptions:
• % of city vs. intercity trips: 60% and 40% • fuel/electricity costs (base values): petrol (€1.579/l), diesel (€1.427/l), electricity at home (€0.18/kW h) and public chargers (€0.40/kW h). • AKT: 5,000; 10,000; 15,000 km	• Years of first ownership: N = 6 • Real interest rate: 4% • Purchasing subsidy: €5,000 • Parking and access BEV-incentivizing measures: €400 annually

4.1. Current scenario

4.1.1. Current scenario without policies

By applying the probabilistic TCO model with 10,000 Monte Carlo simulation draws, we obtain the average TCO/km values for each of the four propulsion systems reported in Table 3.

The first row shows the average MSRP. It can be seen that in Italy the 10 best-selling ICEVs have a much lower market price than the 10 best-selling BEVs. BEVs cost 2.44, 1.52, and 1.30 times more than P-ICEVs, D-ICEVs, and HEVs, respectively. Variable cost savings make up some of these capital cost differences. The remaining rows present the TCO/km according to the annual distance traveled. BEVs have always the highest average TCO/km, exception made when 15,000 km are driven annually and only with respect to HEVs.

As BEVs are characterized by high initial fixed cost and low variable costs, we have increased the assumed AKT. It results that BEVs break-even with P-ICEVs, D-ICEVs, and HEVs only when AKT are assumed to be about km 35,000, 30,000 and 22,000, respectively.

Having developed a probabilistic model that accounts for the uncertainty implied by the stochastic variables, we are able to report the distribution of the TCO/km metric for every propulsion system. A graphical representation is provided in Fig. 1.

In a stochastic model the TCO/km distributions for the different propulsion systems may overlap, depending on which values are drawn from the assumed distributions of the stochastic variables. We have estimated the probability that a BEV has a lower average TCO/km relative to a car with a different propulsion system over the 10,000 draws (Table 4). We compare two BEV charging assumptions: always charging at home at a cost of 0.18 €/kW h and using 50% of the times public chargers at a cost of 0.40 €/kW h. These cost assumptions are based on the current electricity costs in Italy.[9]

We find that when AKT are equal to 5,000 km, BEVs have always an

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[7] We thank the reviewer's suggestion to adopt these assumptions, since BEVs are likely to depreciate faster in their initial phase than ICEVs. On the contrary, in the year 2025, ICEVs will potentially be an old technology leading to faster depreciation rates than the BEVs. The so-called "dieselgate" might be considered an example of rapid depreciation due to technological innovations and political decisions.

[8] The question of how long will a battery last is not an easy one. It depends on many factors (https://cleantechnica.com/2016/05/31/battery-lifetime-long-can-electric-vehicle-batteries-last/). Since BEVs are relatively recent, only anecdotal evidence is available.

[9] The main source for these assumptions are the website: www.eneldrive.it and https://luce-gas.it/faq/auto-elettriche/ricarica-colonnina-elettrica-aperta-pubblico#Costi (0.40 €/kW h is the Enel Drive tariff).

Table 3
Average TCO/km for different AKT assumptions.

	P-ICEVs	D-ICEVs	HEVs	BEVs
MSRP (€)	13,717	20,227	25,744	33,440
AKT: 5,000 km	0.77	0.96	1.19	1.32
AKT: 10,000 km	0.46	0.55	0.68	0.70
AKT: 15,000 km	0.36	0.41	0.51	0.49

Table 4
Probability that a BEV has a lower average TCO/km in the current scenario without policies.

	BEV vs P-ICEV		BEV vs D-ICEV		BEV vs HEV	
AKT	100% home charging	50% home charging	100% home charging	50% home charging	100% home charging	50% home charging
5,000	0%	0%	0%	0%	0%	0%
10,000	0%	0%	0%	0%	14%	4%
15,000	0%	0%	0%	0%	76%	31%

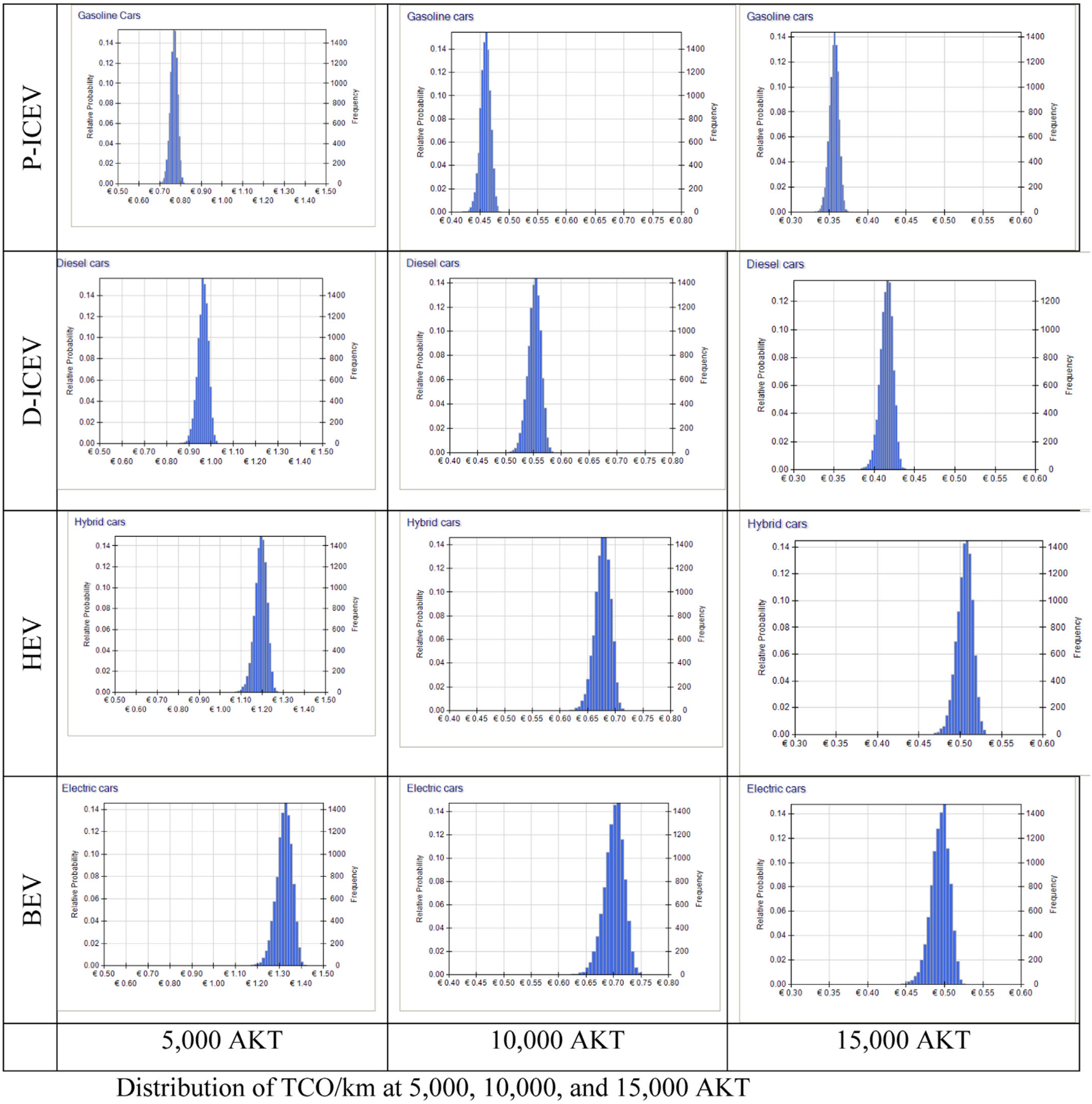

Fig. 1. Distribution of TCO/km at 5,000, 10,000, and 15,000 AKT.

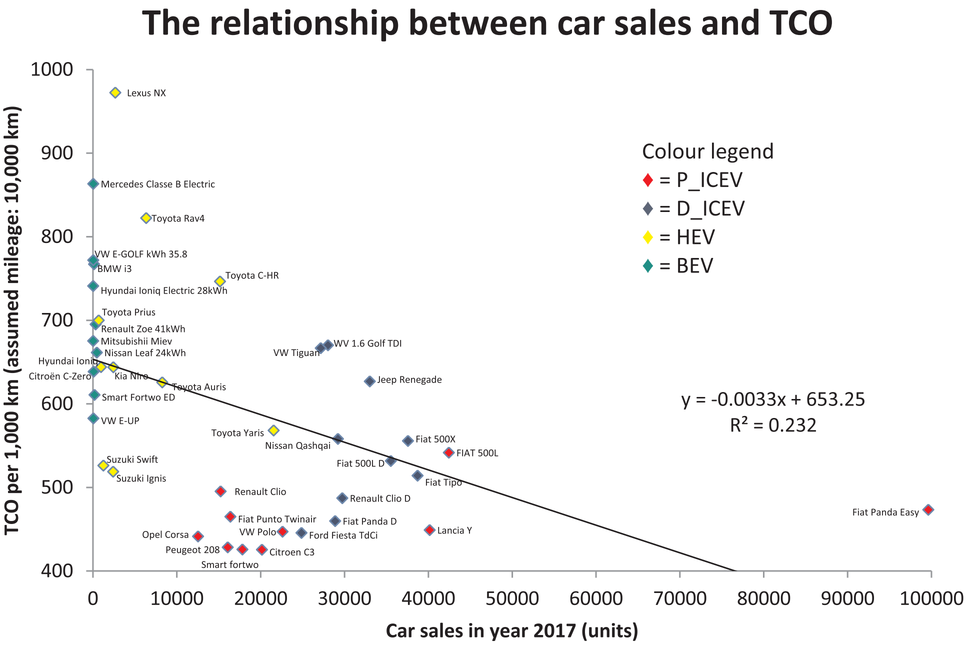

Fig. 2. Correlation among TCO/1,000 km estimates and 2017 sales. Note: The labels "Fiat Panda D", "Renault Clio D", and "Fiat 500L D" are presented with the additional letter "D" to stress they are Diesel models and avoid potential confusion with the corresponding or similar gasoline version.

Table 5
Ranking of BEVs in terms of TCO/km out of 40 cars.

Model Types	TCO/km and ranking (5,000 km)		TCO/km and ranking (10,000 km)		TCO/km and ranking (15,000 km)	
Nissan Leaf 24 kW h	1.24	30	0.66	28	0.47	26
Smart Fortwo ED	1.14	24	0.61	22	0.44	21
Mitsubishii Miev	1.27	32	0.68	31	0.48	29
Mercedes Classe B Electric	1.63	39	0.86	39	0.61	38
BMW i3	1.45	36	0.77	36	0.54	35
Hyundai Ioniq Electric 28 kW h	1.40	35	0.74	34	0.52	34
Renault Zoe 41 kW h	1.31	34	0.70	32	0.49	31
VW E-GOLF kW h 35.8	1.46	38	0.77	37	0.54	36
VW E-UP	1.09	21	0.58	21	0.41	17
Citroën C-Zero	1.20	28	0.64	25	0.45	23

average TCO/km higher than the other propulsion systems. With 10,000 AKT, BEVs have an average TCO/km lower than HEVs 14% and 4% of the times, depending on the charging habits. With 15,000 AKT, BEVs are still not competitive with the petrol or diesel cars, but they can be 76% of the times more convenient than HEVs when they are charge at home.

A more detailed and informative picture can be derived from observing the results for each of the 40 car models considered. Table 21 reports the estimates obtained under the assumption of 10,000 AKT, which is correspondent to the Italian average and Fig. 2 illustrates them. It can be seen that BEVs rank mainly in forth group, with the expectations of VW E-UP (21 out of 40), Smart Fortwo ED (22), Citroën C-Zero (25) and Nissan Leaf 24 kW h (28), the first three being small cars, all with a limited driving range. Table 21 reports also the 2017 sales for each car model and their ranking. It is interesting to test whether there is a correlation among TCO/km values and 2017 sales.[10]

The analysis can be performed directly on the absolute values or on the ranking. In Fig. 2 we graph the former data.

It can be noted that there is an inverse correlation (Spearman's rho: −0.5699, p-value: 0.0001), but the explicative power of the TCO/km we have estimated and the number of cars sold for each model is not too strong.[11] Specifically, the Fiat Panda Easy is by far the best-selling car, although its TCO is not the lowest. P-ICEVs have the lowest TCO, while some D-ICEVs have quite high TCO metrics, although they enjoy large sale numbers. HEVs have relatively high TCOs, apart from the two Suzuki car models. BEVs have very low sale numbers and still high TCO. Several factors explain the only partial link between TCO and sales. We believe the main ones are the following. First, the consumers have bounded rationality; they consider mainly the MSRP and they are not willing or capable of fully estimating the operating cost savings connected with the BEVs. Second, factors other than the monetary variables play a role (Sierzchula et al., 2014; Coffman et al., 2017; Berkeley et al., 2017; Liao et al., 2017): most notably driving range, car size, brand (in Italy, Fiat) or other attitudinal or psychological variables. With specific reference to the BEVs, Italy still lacks the collective willingness to switch to this alternative propulsion system. The necessary monetary, regulatory and infrastructural preconditions are not in place, yet. Hence, consumers' choice still favor the diesel engine, which is strongly questioned in other non-European and European countries.

In order to test how the AKT assumption affects the BEVs ranking we have estimated the model under our three assumptions. The results are reported in Table 5.

As expected the best BEVs' ranking are obtained when 15,000 AKT are assumed, especially the VW E-UP (17) and the Smart Fortwo ED (21). A 15,000 AKT assumption, equivalent to 50 km/day for 300 days is, however, not only higher than the Italian average but also at odds with the limited driving range of these car models who do not allow long trips, especially in Italy due to the still insufficient charging infrastructure.

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[10] We thank an anonymous reviewer for the suggestion.

[11] The issue of the relationship between TCO and sales is discussed in depth by Lévay et al. (2017). They compare among countries and account the different car segments and models. They find that big cars have a fairly strong cost-sales relationship, whilst medium-sized and small cars have weaker one.

Table 6
Average TCO/km for different AKT assumptions with BEVs-incentivizing policies.

	P-ICEVs	P-ICEVs	HEVs	BEVs
MSRP (€)	13,717	20,227	25,744	28,440
AKT: 5,000 km	0.77	0.96	1.19	1.08
AKT: 10,000 km	0.46	0.55	0.68	0.58
AKT: 15,000 km	0.36	0.41	0.51	0.41

4.1.2. Current scenario with BEV-incentivizing policies

Next, we consider the impact of two policies favoring BEVs: a) a €5,000 direct subsidy; and b) a €400 annual saving due to lower parking or access fees in urban centers. Currently, in Italy, there are no subsidies on BEVs at the national level. Yet, recently, some Italian Regions (Trentino Alto Adige, Friuli Venezia Giulia and Veneto) have introduced a subsidy of about €5,000. In this scenario, we assume that such a policy would be enacted for all Regions. The second assumption reflects the common practice of many urban administrations (e.g., Rome, Milan, Turin, and Florence) of granting free parking and free access to the inner city to alternative fuel vehicles in order to foster their diffusion and improve urban air quality.[12] The monetary savings for the car owner of such policies are, however, difficult to quantify (Diao et al., 2016, terms them "intangible costs"). We assume an annual saving of €400 relative to the other propulsion systems. The impact that implementing both policies would have on the TCO/km is illustrated in Table 6.

BEVs' average price decreases by the amount of the subsidy. In this manner, BEVs' TCO/km would be lower than HEVs,[13] and slightly higher than that of D-ICEVs'. BEVs break-even with P-ICEVs, D-ICEVs and HEVs when AKT is about 23,000, 15,000 and 25,000, respectively.

These results prove that national and local policies could greatly impact BEVs' diffusion as already reported in the literature (Sierzchula et al., 2014; Lieven, 2015; Diao et al., 2016; Lévay et al., 2017). The distribution of the TCO/km metric for every propulsion system is illustrated in Fig. 3.

With 5,000 AKT, BEVs have always an average TCO/km higher than P-ICEVs and D-ICEVs but they are always less costly than HEVs (Table 7). With 15,000 AKT, they are on average cost-competitive compared to D-ICEVs 55% of the times when charged only at home. The ranking for each single BEV model is reported in Table 8. The cheapest BEVs (VW E-UP and Smart Fortwo) make it to the second group of ten cars, and are always more expensive than P-ICEVs. Two very popular cars, such as the Nissan Leaf 24 kW h and the Renault Zoe 41 kW h, gain the 16 and 22 position, respectively.

4.2. Future scenario

In order to test the prospects for BEVs' market penetration, we develop two future scenarios as depicted in Table 9. As illustrated by Newbery and Strbac (2016), forecasting fuel prices and BEV's battery costs is fraught with difficulties. The former do not depend only on market forces, since they are highly determined also by fuel excise taxes. In Italy, in the years 2008–2017, the producer's price of petrol ranged between 28% and 47% of the consumer's petrol price, the remaining being excise duties and VAT. Similarly, the producer's price of diesel ranged between 30% and 56% of the consumer's price. The average excise duty on petrol and on diesel were 44% and 38%, respectively, indicating that in Italy as in Germany, diesel has been politically favored on industrial and environmental grounds.

The Status Quo scenario consists of the 2017 petrol, diesel and electricity prices used in the TCO model. According to Bloomberg (2017), which collected data from more than 50 companies, the current average battery pack cost for an electric car is 209 $/kW h. Scenario 1–2025 adopts fuel prices forecasted with an ARIMA time series model on Italian data. For detailed description, see the Appendix. An assumption is made that the average BEV's MSRP drops by 24%. Such an assumption is based on the prediction, made by different sources (Blomberg, 2017; Berckmans et al., 2017, and newspaper news[14]), that the average BEV's MSRP will drop in 2025 to 100 $/kW h. We infer, admittedly based on limited information on the relationship between BEV's battery pack cost and MSRP, that when battery pack cost drops to 100 $/kWh, a 24% MSRP reduction will take place.[15]

Scenario 2–2025 assumes a larger BEVs' MSRP reduction, equal to 35%; and an increase in the diesel price, equalizing the petrol price, assuming that the diesel's favorable fiscal treatment is cancelled, as currently debated in Germany. As for the incentivizing policies, we assume that there are no direct subsidies on buying a BEV, but the annual savings on parking and access fees are preserved.

The Scenario 1–2025 leads to the results presented in Table 10 and Table 11. The starting point is that BEVs' average MSRP is slightly lower than HEVs' and higher than D-ICEVs'. As a result, BEVs' average TCO/km is lower than HEVs' and close to the D-ICEVs. Assuming higher than 5,000 AKT, BEVs are cost-competitive with D-ICEVs and HEVs but not with P-ICEVs.

Under the assumptions of the Scenario 2–2025, BEVs' average MSRP is lower than both HEVs' and D-ICEVs', but still much higher than P-ICEVs. As a result, BEVs' average TCO/km is lower than HEVs' and D-ICEVs'. Assuming 15,000 AKT, BEVs are also cost-competitive with P-ICEVs' (Table 12 and Table 13).

Looking at the specific models' ranking reported in Table 14 and Table 15, the VW E-UP and the Peugeot iOn have quite good rankings also at 5,000 AKT, to become to cheapest cars if 15,000 AKT are assumed. Obviously, such a long distance is at odds with the small battery/range of these models, which is the main reason for their low MSRP. Focusing on the more popular medium-sized cars such as the Nissan Leaf 24 kW h, the Renault Zoe 41 kW h, the VW E-GOLF kW h 35.8 and the BMW i3, which have a bigger battery and a larger range, their ranking is relatively good at 10,000 AKT, which is close to the Italian average AKT. The charging infrastructure plays, obviously, an important role in accompanying such a development.

5. Comparison with previous studies

The two sets of results we have produced, relative to the year 2017 and 2025, can be compared with results from previous studies. Whereas for some recent contributions we were not able to find the necessary comparable results (Letmathe and Suares, 2017; Lévay et al., 2017), a useful comparison can be made with Wu et al. (2015). They provide estimates for Germany, for four propulsion systems (BEV; ICEV; HEV, PHEV), three segments (A/B, C/D, J) and for the years 2014, 2020, and

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[12] Milan charges residents €2 to access the inner city (Area C) and 1.20 €/h for parking. BEVs are exempted. Rome grants also free parking (ranging from 1.20 to 0.50 €/h) and inner city access to BEVs. BEVs' owners are not even required to display any sticker on their cars (https://romamobilita.it/it/servizi/strisce-blu). Turin allows electric cars and hybrid cars emitting less than 50 g/km to CO_2 free parking in the Venaria area and that surrounding the Soccer Stadium (http://www.comune.torino.it/trasporti/ztl/permessi-4.shtml). Florence grants fee parking to hybrid and BEV cars owned by residents in some areas of the city and access to the limited traffic zone. A complete list of Regions and cities that offer free access to parking to either BEV or HEV is supplied here: https://www.panorama-auto.it/info-utili/ibride-elettriche-agevolazioni-2017.

[13] This result holds true provided that no incentives are placed on HEVs. In fact, some Italian Regions (e.g., Friuli Venezia Giulia and Veneto) do subsidies HEVs as well due to their low CO_2 emissions.

[14] We thank an anonymous reviewer for indicating us these recent sources: https://seekingalpha.com/article/4156050-lower-cost-tesla-volkswagens-new-battery-cell-costs-100-euro-per-kwh, https://www.volkswagenag.com/en/events/2018/JPK2018.html.

[15] There is not enough statistical evidence on the relationship between battery pack costs and MSRP. However, there is some evidence that newer BEV models are offered with larger battery packs and constant MSRP, e.g., the 2018 Nissan Leaf vs. the previous models.

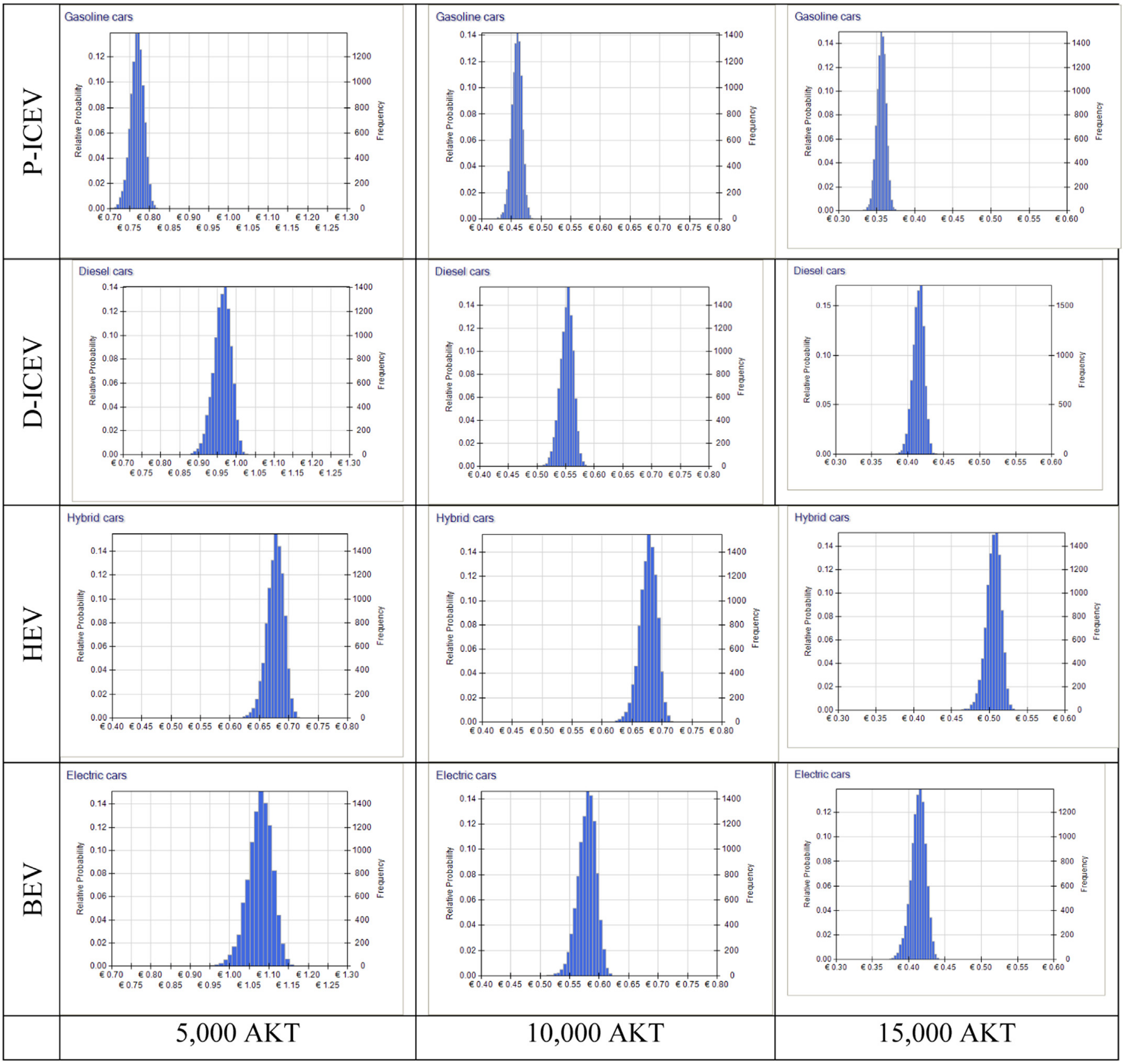

Fig. 3. Distribution of TCO/km at 5,000, 10,000, and 15,000 AKT with policies incentivizing BEVs.

Table 7
Probability that a BEV has a lower average TCO/km in the current scenario with policies.

AKT	BEV vs P-ICEV		BEV vs D-ICEV		BEV vs HEV	
	100% home charging	50% home charging	100% home charging	50% home charging	100% home charging	50% home charging
5,000	0%	0%	0%	0%	100%	99%
10,000	0%	0%	8%	1%	100%	100%
15,000	0%	0%	55%	10%	100%	100%

2025, adopting the conceptual approach in defining their car types. As for AKT, they define three distances (7,483, 15,184, and 28,434 km), making the comparison only partially possible. Since we have used different AKT (5,000, 10,000, and 15,000), we restrict the comparison to the 15,000 AKT assumption. Their averaged-among-segments TCO/km for the three propulsion systems we have in common are the following in the year 2014: ICEV (0.39 €/km), HEV (0.43 €/km), BEV (0.52 €/km). Our estimates for the year 2017 are: P-ICEV (0.36 €/km), D-ICEV (0.41 €/km), HEV (0.51 €/km), BEV without incentivizing policies (0.49 €/km), BEV with incentivizing policies (0.41 €/km). Hence, our estimates are very similar for ICEVs, while those for HEVs are higher and for BEVs are lower when incentives are taken into account. This proves the importance of adopting BEV-promoting policies in their initial phase of uptake.

Falcão et al. (2017)'s conclusion that the TCO of electric vehicle is 2.5 times higher than diesel vehicle is not confirmed by our estimates. We find that with 5,000 AKT and no promoting policies (the worst-case scenario), BEVs' TCO is 39% higher than D-ICEVs, which is instead consistent with the results by Zhao et al. (2015). Our results confirm the conclusion of Tseng et al. (2013), and Rusich and Danielis (2015) that

Table 8
Ranking of BEVs in terms of TCO/km out of 40 cars (with incentives).

Model Types	TCO/km and ranking (5,000 km)		TCO/km and ranking (10,000 km)		TCO/km and ranking (15,000 km)	
Nissan Leaf 24 kW h	1.00	24	0.54	20	0.39	16
Smart Fortwo ED	0.89	16	0.49	13	0.35	10
Mitsubishii Miev	1.02	25	0.55	22	0.40	19
Mercedes Classe B Electric	1.39	38	0.74	37	0.53	37
BMW i3	1.21	33	0.65	32	0.46	28
Hyundai Ioniq Electric 28 kW h	1.16	31	0.62	27	0.44	27
Renault Zoe 41kWh	1.07	26	0.57	26	0.41	22
VW E-GOLF kW h 35.8	1.22	34	0.65	33	0.46	30
VW E-UP	0.85	13	0.46	9	0.33	3
Citroën C-Zero	0.96	21	0.52	16	0.37	12

Table 9
Summary of scenario assumptions. *Source*: *our assumptions and **Bloomberg (2017).

Variables	Status Quo 2017	S1–2025*	S2–2025*
Petrol price (€/l)	1.58	1.68	1.68
Diesel price (€/l)	1.42	1.52	1.68
Electricity price (€/kW h)	0.18	0.23	0.23
Resale value	BEV = 10% Non-BEV = 20%	BEV = 20% Non-BEV = 10%	BEV = 20% Non-BEV = 10%
Battery pack cost ($/kW h)	209**	100	75
MSRP BEVs	2017	24% reduction of 2017 MSRP	35% reduction of 2017 MSRP
BEV Subsidies	no	no	no
Annual saving for parking and access fees (€)	400	400	400

Table 10
Average TCO/km for different AKT assumptions (Scenario 1–2025).

	P-ICEVs	D-ICEVs	HEVs	BEVs
MSRP (€)	13,717	20,227	25,744	25,414
AKT: 5,000 km	0.82	1,03	1.27	0.88
AKT: 10,000 km	0.49	0.59	0.72	0.48
AKT: 15,000 km	0.38	0.44	0.54	0.35

Table 11
Probability that a BEV has a lower average TCO/km (Scenario 1–2025).

	BEV vs Gasoline	BEV vs Diesel	BEV vs HEV
5,000	3%	100%	100%
10,000	51%	100%	100%
15,000	98%	100%	100%

Table 12
Average TCO/km for different AKT assumptions (Scenario 2–2025).

	P-ICEVs	D-ICEVs	HEVs	BEVs
MSRP (€)	13,717	20,227	25,744	21,736
AKT: 5,000 km	0.82	1.03	1.27	0.76
AKT: 10,000 km	0.49	0.59	0.72	0.43
AKT: 15,000 km	0.38	0.44	0.54	0.32

Table 13
Probability that a BEV has a lower average TCO/km (Scenario 2–2025).

	BEV vs Gasoline	BEV vs Diesel	BEV vs HEV
5,000	98%	100%	100%
10,000	100%	100%	100%
15,000	100%	100%	100%

Table 14
Forecasted ranking with Scenario 1–2025 of annual average TCO per km for the BEVs.

Model Types	TCO/km and ranking (5,000 km)		TCO/km and ranking (10,000 km)		TCO/km and ranking (15,000 km)	
Nissan Leaf 24 kW h	0.83	13	0.46	7	0.34	4
Smart Fortwo ED	0.76	3	0.43	2	0.32	2
Mitsubishii Miev	0.84	14	0.47	9	0.34	5
Mercedes Classe B Electric	1.10	30	0.61	30	0.44	26
BMW i3	0.98	25	0.53	21	0.39	18
Hyundai Ioniq Electric 28 kW h	0.93	20	0.51	17	0.37	14
Renault Zoe 41 kW h	0.87	16	0.48	13	0.35	8
VW E-GOLF kW h 35.8	0.98	24	0.53	20	0.39	17
VW E-UP	0.72	1	0.40	1	0.29	1
Citroën C-Zero	0.79	7	0.44	3	0.32	3

Table 15
Forecasted ranking with Scenario 2–2025 of annual average TCO per km for the BEVs.

Model Types	TCO/km and ranking (5,000 km)		TCO/km and ranking (10,000 km)		TCO/km and ranking (15,000 km)	
Nissan Leaf 24 kW h	0.72	4	0.41	4	0.30	4
Smart Fortwo ED	0.66	2	0.38	2	0.28	3
Mitsubishii Miev	0.72	5	0.41	5	0.31	5
Mercedes Classe B Electric	0.95	24	0.53	22	0.39	20
BMW i3	0.84	18	0.47	13	0.34	10
Hyundai Ioniq Electric 28 kW h	0.79	11	0.44	7	0.32	7
Renault Zoe 41 kW h	0.75	6	0.42	6	0.31	6
VW E-GOLF kW h 35.8	0.84	17	0.47	11	0.34	8
VW E-UP	0.62	1	0.35	1	0.26	1
Citroën C-Zero	0.68	3	0.38	3	0.28	2

high AKT and car holding time are needed to make BEVs cost-competitive.

As for the year 2025, our estimates are more optimistic than the ones presented by Wu et al. (2015). We estimated that the BEVs TCO with 15,000 AKT would be equal to 0.32–0.35 €/km, depending on the scenario, while they compute a value of 0.51 €/km. Concerning the other propulsion systems, our estimate for P-ICEVs is 0.38 €/km, for D-ICEVs is 0.44 €/km, and for HEVs is 0.54 €/km, respectively. Wu et al. (2015)'s average results for ICEVs are higher than our estimate (0.49 €/km), whereas those for HEVs (0.48 €/km) are more optimistic. Consequently, we predict a brighter future for the BEVs than Wu et al. (2015)'s, mostly because of the drop in battery prices and, consequently lower MSRP, which would make them cost-competitive with conventional cars even without the €5,000 subsidy.

Bubeck et al. (2016)'s conclusion that BEVs need premium ranging from €8,600 to €32,400 and will be economically viable in 2030 seems rather pessimistic, while Propfe and Redelbach (2012)'s statement that

TCO gaps for alternative drivetrains will decrease significantly by 2020 seems excessively optimistic.

6. Conclusions

Since the TCO metric influences the individual and firm decision regarding car purchasing and manufacturing, we developed a probabilistic TCO model to evaluate the current and future prospects of BEVs' diffusion in Italy under different scenarios. The model comprises stochastic and non-stochastic variables, vehicle usage and contextual assumptions. The model is applied: a) at current costs; b) at current costs altered by BEVs' incentivizing policies; c) at 2025 costs forecasted applying two trend scenarios.

The main conclusions can be summarized as follows. In the current scenario without incentivizing policies, BEVs are currently not cost-competitive in Italy with the P-ICEVs and D-ICEVs. However, they could be cost-competitive with the HEVs for AKT higher than 10,000. With incentivizing policies (a €5,000 subsidy and a €400 parking and access fee annual savings), currently in place in a limited number of Italian Regions and cities, BEVs perform in monetary terms better than the HEVs, and, with high AKTs, of some D-ICEVs, especially when they are charged at home.

Considering the non-monetary limitations characterizing BEVs (i.e., limited range, long charging times, and still insufficient infrastructure in Italy), it is to be expected that the BEVs' market share would remain quite small. Considering the Italians' preference for small-sized, cheap cars, BEVs' MSRP needs to drop considerably in order to make them attractive to a large proportion of customers.

However, BEVs are expected to gain market share in the year 2025 if fuel prices follow past trends, even if no subsidies are in place. The main driving force would be a drop in their MSRP, thanks to declining battery pack costs. Such a scenario is not unlikely, given the current pace of technological improvements and the growing economies of scale in battery production. It is also quite likely that the diesel fiscal advantages will fade away as the new technology gains acceptance and the auto industry switches to the new propulsion system. Our model predicts that the market would be shared between ICEVs (especially petrol cars) and BEVs, with an increase share of BEVs for high AKT, provided, of course, that charging times are reduced and a dense charging network is put in place.

The estimates presented above suffer from the common data uncertainties, related to technological, economic and political factors. Their development over time needs to be closely monitored. The probabilistic TCO model could be easily adapted to estimate the impact of any such changes. Our future research agenda includes a finer territorial application of the model, taking into account urban density and geomorphological or climate characteristics, as these influence the BEVs performance. Furthermore, we would like to focus on specific vehicle usage types (intercity commuting vs. urban trips) or professions (taxi drivers, or sale persons). An even more challenging extension would be to merge a TCO mobility model with a renewable energy production model in a fleet or household context.

Appendix

Variable definitions

Vehicle Excise Tax

See Tables 16–21 and Fig. 5.

The vehicle excise tax is a local tax to be paid on vehicles and motorcycles registered in Italy. The tax is differentiated by Region of residency and is computed taking into account the engine displacement and the EURO class. Some propulsion systems enjoy specific exemptions. Electric cars are exempted from its payment for the first five years. Afterwards, in some Regions the tax exemption is maintained (Lombardy and Piedmont), in others is partially reduced or cancelled. LPG- or methane-fueled cars are also tax exempted. ICEVs might pay the "superbollo", an add-on tax if the engine displacement exceeds 185 kW (€20 for each exceeding kW).

Insurance

The insurance premium depends on: a) vehicle's characteristics, b) driver's characteristics and past accident history, c) place of residency, and e) the commercial strategy of the insurance company. In order to ensure the comparability among propulsion systems, we keep constant the components b), c), d). In this study we refer to a 40 years old driver living in the Friuli Venezia Giulia Region. Currently, in Italy, major insurance companies apply a 50% discount on BEVs' insurance premiums. Quotations for every model are derived from internet websites.

Maintenance and repair

On the basis of available information (Diez, 2014), BEVs are estimated to incur in 35% less maintenance and repair costs than the average of ICEVs. Similarly, Mitropoulos et al. (2017) assume a 30% lower maintenance costs.[16] This reduction is attributable to the reduced number of car components and fluids.

Scenarios for the year 2025

For the year 2025 we develop two trend scenarios including assumptions on petrol, diesel and electricity prices and reduction of the MSRP of the BEVs.

Petrol and diesel prices

Petrol and diesel prices varied cyclically in the past decade (Fig. 3). It is very hard to predict what will happen in the future. On the one hand, worldwide demand might decline due to the competition of natural gas and renewable sources in electricity production as it happened in the recent years. On the other hand, the increase in car ownership, predominantly ICEVs, will further rise conventional fuel demand.

We develop our scenarios estimating a time series ARIMA model using weekly Italian data for the period 2008–2017. An ARIMA (1,1,0) model proved to be the best fit according to the results of the Akaike Information Criterion. We used the model to estimate the out-of-sample 2025 value. Due to the cyclicality of the data interval and the distant prediction, the confidence intervals are quite large. We choose the mean values equal to 1.683 €/l and 1.516 €/l for petrol and diesel, respectively, as assumption for the Scenario 1–2025.

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[16] As we are interested in difference between TCOs, the assumption is made that accidents and their cost can be assumed equal across different vehicles.

Table 16
Related TCO literature.

Authors	Propulsion systems	Vehicle classes	Vehicle type	societal TCO	Reference country	Main findings
Kromer and Heywood (2007)	P-ICEV, D-ICEV, HEV, PHEV, BEV	One reference model per technology	Representative model (1)	GHG, energy	USA	No clear winner
Thiel et al. (2010)	P-ICEV, D-ICEV, HEV, PHEV, BEV	Midsize	Representative model (1)	CO_2	EU-27	electrification can reduce CO_2 significantly
Contestabile et al. (2011)	D-ICEV, HEV, PHEV, BEV, FCEV	Super-mini, Lower-medium, Multipurpose, Luxury	Representative model (1)	no	UK	BEVs have an advantage on short distances and light vehicles
Element Energy (2011)	P-ICEV, HEV, REEV, BEV	A/B, C/D, E/H	Conceptual vehicle	CO_2	UK	ICEV will have lower TCO than BEVs up to 2030
McKinsey and Company (2011)	P-ICEV, D-ICEV, PHEV, BEV, FCEV	A/B, C/D, SUV	Conceptual vehicle	no	EU-27, CH, NO	After 2025, the TCO of all the power-trains converge
Prud'homme and Koning (2012)	D-ICEV, BEV	A/B	Representative model (1)	CO_2, Local pollutants, noise	FR	BEVs have excess costs much above €10,000 for very small CO2 gains
Propfe and Redelbach (2012)	P-ICEV, HEV, PHEV, REEV, BEV, FCEV	Midsize	Conceptual vehicle	no	DE	TCO gaps for alternative drivetrains will decrease significantly by 2020
Plötz et al. (2013)	P-ICEV, D-ICEV, PHEV, REEV, BEV	Small, Medium, Large	Representative model (3)	no	DE	The BEVs share in 2020 is highly dependent on external factors. More potential for users travelling above 15,000 km
Tseng et al. (2013)	P-ICEV, HEV, PHEV, BEV	Midsize	Representative model (1)	energy, CO_2 and local air pollutants	USA	Only HEVs have TCO comparable to ICEVs. BEVs are competitive with 20,000 miles over 12 years. Tax credits are crucial
Windisch (2013)	ICEV, PHEV, BEV	Compact, Sedan	Representative models	no	F	BEVs with leased-battery are competitive (with annual driven distance of 18,000 km). BEVs with purchased battery have higher payback period, require longer distances and financial incentives
Wu et al. (2015)	P-ICEV, D-ICEV, HEV, PHEV, BEV	A/B, C/D, SUV	Conceptual vehicle	no	DE	TCO does not reflect how consumers make their purchase decision today; cost efficiency of EV increases with the consumer's driving distance and is higher for small than for large vehicles
Diao et al. (2016)	ICEV, BEV	Medium	Representative models	no	CN	The intangible costs of traffic policies (purchasing and driving restrictions) have significant effects on BEVs' diffusion. They are higher in mega-cities.
Zhao et al. (2015)	ICEV, BEV	Compact, multi-purpose	representative models (5 ICEVs, 1 BEV)	CO_2 and local air pollutants	CN	BEVs have 1.4 higher TCO than ICEVs
Rusich and Danielis (2015)	ICEV, HEV, BEV, LPG, CNG	Small, Medium	Representative models	CO_2, Local air pollution, noise, energy	I	BEVs become convenient only when the annual distance traveled is at least 20,000 km
Bikert et al. (2015)	ICEV, BEV	Compact, Subcompact, Micro	Representative models (1)	CO_2	D	External cost are high but do not gives BEVs a financial advantage
Bubeck et al. (2016)	P-ICEV, D-ICEV, HEV, PHEV, BEV, FCEV	Small, Compact, Medium, Executive, SUV, Minivan	Conceptual vehicle	CO_2, energy	D	BEVs needed premium range from €8,600 to €32,400. BEVs will be economically viable in 2030.
Falcão et al. (2017)	D-ICEV, BEV	Medium-duty vehicle	Representative models	CO_2	undefined	Total cost of ownership of electric vehicle is 2.5 times higher than diesel vehicle. Payback of electric vehicle occur after 13 years operation
Lévay et al. (2017)	ICEV, BEV	Small, Medium	Representative model (10)	no	NO, NL, FR, UK, DE, HU, IT, PL	Big EVs have lower TCO, higher sales, and seem to be less price responsive than small EVs.
Mitropoulos et al. (2017)	ICEV, HEV, EV	unclear	Representative models	Local air pollution, GHG, time losses	USA	The HEVs are cleaner in terms of GHGs. EVs in terms of VOC, NOx, CO, but dirtier for Sox. Total externalities are lower for EVs. TCO are lower for HEVs, then EV and ICEV.
Danielis and Giansoldati (2017)	ICEV, HEV, EV	Small, Medium	Representative model (10)	CO_2, Local air pollution, noise	I	The difference between the consumer-oriented TCO and the society-oriented TCO varies between €315 and €581. If the social costs are internalized, the overall TCO would be still lower for the ICEVs than the BEVs.
Letmathe and Suares (2017)	ICEV, HEV, BEV	Small, medium, large	Representative models	no	D	Subsidies support the competitiveness of BEVs, but fail to lead to favorable TCO within several vehicle segments and several tested annual mileages.
Palmer et al. (2018)	ICEV, HEV, PHEV, BEV	Small, medium	Representative models (1)	no	UK, USA, JP	At current low fuel prices in the UK, hybrids reach cost parity at 16,000 miles.

Table 17
Tech-economic characteristics of the 10 best-selling P-ICEVs.

Brand	Type	Size	Acceleration*	Range (km)	KW	CO_2	MSRP (€)	Sales**
Fiat Panda	Fiat Panda 1.2 Easy	365/164/155	14.2	419	51	120	11,600	99,621
FIAT 500	1.4 Pop Star	415/178/166	12.8	729	70	143	18,150	42,442
Lancia Y	1.2 Silver	384/168/152	14.5	719	51	120	13,350	40,159
VW Polo	1.0 MPI 65 CV Trendline BMT	405/175/145	15.5	763	48	108	13,600	22,609
Citroen C3	1.2 PureTech 68 CV Live	400/175/147	14	889	50	108	12,250	20,154
Smart fortwo	70 youngster	270/166/156	14.4	633	52	93	12,910	17,824
Fiat Punto Twinair	1.2 Easy 3 doors Start&Stop	406/169/149	12.7	753	51	124	13,900	16,392
Peugeot 208	1.2 PureTech 68 CV Access 3p	397/174/146	14	988	50	108	12,450	16,075
Renault Clio	1.2 Intens −2017	406/173/145	12	714	55	127	16,350	15,226
Opel Corsa	1.2 70 CV 3 doors	402/174/148	16	781	51	124	12,610	12,535

*Acceleration (0–100 km in sec.); ** N° of cars sold in 2017. Source: unrae.it and www.alvolante.it (accessed on April 5th, 2018).

Table 18
Tech-economic characteristics of the 10 best-selling D-ICEVs.

Brand	Type	Size	Acceleration*	Range (km)	KW	CO_2	MSRP (€)	Sales**
Fiat Tipo	1.3 Multijet Easy	453/179/150	11.7	996	70	108	17,600	38,711
Fiat 500 ×	1.3 Multijet 95 CV Pop 4 × 2	425/180/160	12.9	1121	70	107	19,250	37,568
Fiat 500 L	1.3 Multijet Pop Star	424/178/166	13.9	1142	70	107	21,020	35,524
Jeep Renegade	1.6 Multijet 95 CV Sport	424/180/167	10.2	1021	70	115	22,800	33,016
Renault Clio	1.5 dCi 75 CV Life	406/173/145	14.3	1347	55	85	15,000	29,735
Nissan Qashqai	1.5 dCi Visia	439/181/159	11.9	1389	81	99	22,850	29,215
Fiat Panda	1.3 Multijet 95 CV Easy	365/164/155	12.8	944	70	94	15,540	28,884
WV 1.6 Golf TDI	Golf 1.6 TDI 110CV DSG 5p. Executive BMT	460/179/145	10.5	1225	81	102	29,900	28,031
VW Tiguan	1.6 TDI Style BMT	449/184/163	10.9	1124	85	125	29,000	27,165
Ford Fiesta	1.5 TDCi 85 CV Plus 3 doors	404/173/148	12.5	1135	63	90	16,500	24,867

*Acceleration (0–100 km in sec.); ** N° of cars sold in 2017. Source: unrae.it and www.alvolante.it (accessed on April 5th, 2018).

Table 19
Tech-economic characteristics of the 10 best-selling HEVs.

Brand	Type	Size	Acceleration*	Range (km)	KW	CO_2	MSRP (€)	Sales**
Toyota Yaris	1.5 Active 5 doors	395/170/151	11	495	74	79	19,200	21,548
Toyota C-HR	1.8 H Active E-CVT	436/180/157	11	520	90	86	28,400	15,152
Toyota Auris	1.8 Hybrid Cool	433/176/148	10.9	1286	100	84	24,050	8264
Toyota Rav4	2.5 HV E-CVT Active	461/185/168	8.3	768	145	115	33,500	6350
Lexus NX	Hybrid 300 h 2WD	463/187/165	9.2	793	145	117	39,800	2666
Kia Niro	HEV 1.6 GDi Urban	436/181/155	11.5	1014	104	101	25,000	2430
Suzuki Ignis	1.2 Hybrid iTop 2WD	370/166/160	13	705	66	97	16,800	2409
Suzuki Swift	1.2 Top Hybrid	384/174/150	11.9	885	66	90	17,690	1245
Hyundai Ioniq	1.6 Hybrid DCT Classic	447/182/145	10.8	1044	104	79	25,150	963
Toyota Prius	1.8 Hybrid E-CVT	454/176/147	10.6	812	100	92	27,850	684

*Acceleration (0–100 km in sec.); ** N° of cars sold in 2017. Source: unrae.it and www.alvolante.it (accessed on April 5th, 2018).

Table 20
Tech-economic characteristics of the 10 best-selling BEVs.

Brand	Type	Size	Acceleration*	Battery size (kW h)	Range (km)	KW	MSRP	Sales**
Nissan Leaf	LEAF VISIA	445/177/155	11.5	24	199	80	30,690	464
Renault Zoe	Zoe Life, R90 41kWh	408/173/156	13.5	41	300	80	33,250	319
Smart	Fortwo	270/166/155	11.5	17.6	160	41	23,819	184
BMW i3	I3	400/178/160	7.5	22	190	125	36,500	132
Citroën C-Zero	Séduction	348/148/161	15.9	16	150	49	30,690	82
VW E-UP	e-up!	360/164/150	12.4	18.7	160	60	27,150	55
VW E-GOLF	2017	427/179/148	10.4	38.5	300	100	37,600	38
Mercedes Classe B Electric	B Electric	436/179/156	7.9	28	200	65	41,403	< 38
Mitsubishii Miev	i-MiEV	348/148/161	15.9	16	150	47	32,214	< 27
Hyundai Ioniq Electric	Comfort	447/182/145	10.2	28	200	88	36,750	< 27

*Acceleration (0–100 km in sec.); ** N° of cars sold in 2017. Source: unrae.it and www.alvolante.it (accessed on April 5th, 2018).

The Scenario 2–2025 sets both prices at 1.683 €/l. The assumption is that the fiscal advantage of the diesel relative to petrol is cancelled, a policy decision that is currently under discussion in Germany. In Italy, alike in Germany, the diesel fuel received a preferential treatment relative to petrol for a series of industrial and political motivations and for its lower CO_2 emissions per km. Currently, such a policy is under debate, also on the basis that diesel vehicles release very high NOx emission in the atmosphere.

Table 21
TCO/km, TCO/km ranking, 2017 sales, 2017 sale ranking (AKT = 10,000, without BEV incentivizing policy).

	TCO/km	Rank	2017 sales	Rank		TCO/km	Rank	2017 sales	Rank
BEV					D-ICEV				
Nissan Leaf 24kWh	0,66	28	464	31	Fiat Tipo	0,51	13	38711	5
Smart Fortwo ED	0,61	22	184	33	Fiat 500 ×	0,56	18	37568	6
Mitsubishii Miev	0,68	31	27	39	Fiat 500 L D	0,53	16	42442	2
Mercedes Cl. B Electric	0,86	39	38	37	Jeep Renegade	0,63	24	33016	7
BMW i3	0,77	36	132	34	Renault Clio D	0,49	11	15226	19
Hyundai Ioniq Electric	0,74	34	27	39	Nissan Qashqai	0,56	19	29215	8
Renault Zoe 41kWh	0,70	32	319	32	Fiat Panda	0,46	8	28884	9
VW E-GOLF	0,77	37	38	37	WV 1.6 Golf TDI	0,67	30	28031	10
VW E-UP	0,58	21	55	36	VW Tiguan	0,67	29	27165	11
Citroën C-Zero	0,64	25	82	35	Ford Fiesta TdCi	0,45	5	24867	12
P-ICEV					HEV				
Fiat Panda Easy	0,47	10	99621	1	Toyota Yaris	0,57	20	21548	14
FIAT 500 L	0,54	17	42442	2	Toyota C-HR	0,75	35	15152	21
Lancia Y	0,45	7	40159	4	Toyota Auris	0,63	23	8264	23
VW Polo	0,45	6	22609	13	Toyota Rav4	0,82	38	6350	24
Citroen C3	0,43	1	20154	15	Suzuki Ignis	0,52	14	2409	27
Smart fortwo	0,43	2	17824	16	Kia Niro	0,64	26	2430	26
Fiat Punto Twinair	0,47	9	16392	17	Lexus NX	0,97	40	2666	25
Peugeot 208	0,43	3	16075	18	Suzuki Swift	0,53	15	1245	28
Renault Clio	0,50	12	15226	19	Hyundai Ioniq	0,64	27	963	29
Opel Corsa	0,44	4	12535	22	Toyota Prius	0,70	33	684	30

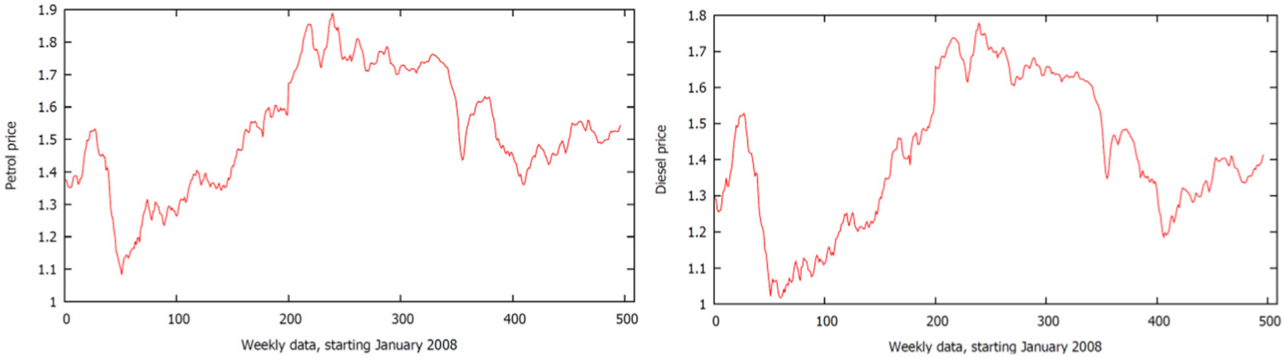

Fig. 4. Time series of petrol and diesel prices (€/liter) in Italy.

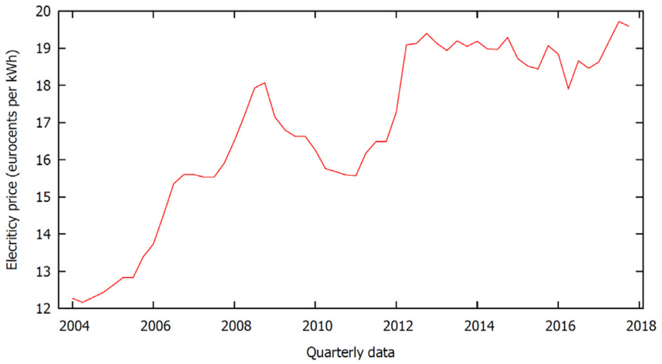

Fig. 5. Time series of electricity prices for domestic consumers in Italy (2004–2018, quarterly data).

Electricity prices

Similarly, we estimate the electricity prices for the final consumer using a time series ARIMA (1,1,0) model relying on quarterly Italian data for the period 2004–2017 (Fig. 4). Apart from the technical uncertainty connected with the out-of-sample prediction, a relevant component of electricity prices are the excise taxes, which increased over the years to finance investments in renewable energy sources (solar, wind and biomass). Recently, subsidies on renewable energy production have been limited considerably. For the two future scenarios, we choose the ARIMA prediction of 0.23 €/kWh.

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