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Consumer- and society-oriented cost of ownership of electric and conventional cars in Italy

Romeo Danielis*[1], Marco Giansoldati*, Mariangela Scorrano*

* *Dipartimento di Scienze Economiche, Aziendali, Matematiche e Statistiche "Bruno de Finetti"*
Università degli Studi di Trieste, Via dell'Università, 1 – 34123 Trieste, Italy.

Abstract

The paper presents a total cost of ownership (TCO) model, implemented with data on Italian cars with different propulsion systems. The model is applied to three case studies: a) a comparison between the best-selling (battery electric vehicles (BEVs) and internal combustion engine vehicles (ICEVs); b) a pairwise comparison between comparable BEVs and ICEVs of the same brand; c) the impact of urban parking and access policies favoring the BEVs. We find that in Italy the purchasing cost of the BEVs is about 15,000 euro higher than the 10 best-selling ICEVs. Such a gap is not compensated by the lower variable costs unless a very high annual distance (20,579 km per year for 10 years) is driven, which is much above the current Italian average. Such a finding helps explaining the low BEVs' market share in Italy. The difference between the consumer-oriented TCO and the society-oriented TCO, which represents the amount of the subsidy economically justifiable on the basis of the social costs, varies between €315 and €581. If the social costs are internalized, the overall (consumer-oriented and society-oriented) TCO would be still lower for the ICEVs than the BEVs. The pairwise comparison suggests that at least a 4,000-6,000 euro subsidy would be needed to balance the BEVs' unfavorable TCO. Finally, we find that parking and access fees favoring BEVs at the urban level could have a significant impact on reducing the distance driven needed to reach the consumer-oriented TCO break-even point.

Keywords: total cost of ownership, passenger cars, electric vehicles, internal combustion engine vehicles

1. Introduction

Italy is one of the countries with the lowest uptake of BEVs in Europe. Many factors play a role (Berkeley et al., 2017; Giansoldati et al. 2018). The *total cost of ownership* (henceforth, TCO) is most likely one of these. TCO has been defined as a purchasing tool and philosophy, aimed at understanding the true cost of buying a specific good such as a car (Ellram, 1995). This paper illustrates a model used to estimate the TCO for cars (Letmathe and Suares, 2017) with different propulsion systems. The model is used to compare the ICEVs to BEVs, at aggregate and disaggregate level, under different scenarios.

TCO can be divided into two cost components: the consumer-oriented cost ($_C$TCO) including all the cost born by the vehicle user (purchasing price, fuel consumption, vehicle tax, maintenance, repairs, depreciation and so on), and the society-oriented cost ($_S$TCO) including the cost born by the society at large of building and using a vehicle such as global and local air pollution, and noise.

Building and estimating a TCO model presents difficult computational challenges. In fact, as the number of car types grows and as new propulsions systems come to the market (Hybrid Electric Vehicles, HEVs, Plug-in Hybrid Electric Vehicles, PHEVS, BEVs), it becomes more and more

[1] Corresponding author: Romeo Danielis (romeo.danielis@deams.units.it). Tel.: +39 040 5587076; fax: +39 040 567543

difficult to process all available information. Nonetheless, acquiring a better knowledge of the TCO of a car is useful for consumers, fleet managers, original equipment manufacturers (OEMs) and the public policy decision maker.

As argued by Hagman et al. (2016), the tools available to consumers have so far been limited. Consequently, one might suspect that private consumers (and to a lesser extend fleet managers) have limited knowledge regarding the TCO metric, potentially leading to economically irrational purchase decisions. Stated differently, consumers might suffer from the ‘‘energy-efficiency paradox’’ (Gillingham and Palmer, 2013) because of imperfect information, bounded rationality, and limited mathematical skills. One strategy to address consumer 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. Similar results are found by Kaenzig (2010) regarding eco-innovations.

This paper puts a special emphasis on discussing the potential implication of the diffusion of BEVs. Comparative information on the BEV's $_C$TCO and $_S$TCO is important also for the OEMs and for public policy. 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 excess or insufficient use of public resources.

The construction and implementation of the model requires the identification and calculation of the multiple components of both private and social cost. Some components have uncertain values (i.e. real consumption in real driving conditions, repairs, residual value), others 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 nonmonetary incentives or fees for parking or for accessing to reserved areas). Moreover, the estimation requires to take into account the annual distance driven, the type of trips (urban/suburban), the ownership period (with implications for the residual value), and the appropriate discount rates.

As some authors underlined (Windisch, 2013; Hagman et al., 2016; Wu et al., 2015), the TCO evaluation needs to be:

- *Country specific,* taking into account electricity and fuel price, car price, vehicle excise tax, insurance;
- *Time-specific*, since fuel\electricity prices, the electricity mix and the battery costs change over time;
- *Vehicle type-specific,* with reference to the segment\brand\vehicle type;
- *Location-specific*, since the owner's place of residence and trip type determine the fuel efficiency and social costs.

It should also be stressed that the TCO model comprises only monetary variables. However, the choice of a vehicle is determined by other relevant non-monetary variables either a) time related, such as charging times or the car range; b) socio-psychological, such as knowledge, environmental concerns, attitude towards technological innovation, or driving style; and c) infrastructural, e.g. the density of the battery charging stations. The impact of these variables on the consumers' purchasing behavior is usually studied via discrete choice models (Liao et al., 2017).

We contribute to the literature by developing a TCO model for Italy, including both $_C$TCO and $_S$TCO, for cars with different propulsion systems. The $_S$TCO considers CO_2 emissions, local pollution and noise. To the best of our knowledge, no TCO model has been developed for Italy, with the exception of Scorrano et al. (2017) and Lévay et al. (2017) who includes some Italian cars in a cross-country comparison. The case of Italy is interesting because, among the European countries, Italy is one of the countries with the lowest BEVs' uptake. This is due to several reasons, including the lack of BEV-specific subsidies, a fiscal taxation favoring diesel vehicles, the lack of charging infrastructure and the lack of interest on BEVs of the major Italian OEM. Yet, air pollution levels in the northern Italian towns is a serious health issue and the political interest for the BEVs is growing. A TCO model is useful to quantify the financial gap between BEVs and ICEVs, to calculate the amount of the subsidy that would be needed to close the gap, and to evaluate whether such a subsidy is economically justifiable considering the externality cost savings.

The database developed for the model includes more than 90 car types of different propulsion systems (petrol ICEV, diesel ICEVs, HEV, PHEVs, BEVs with leased-battery and BEVs with purchased battery). In this paper we present applications related only to the comparison between ICEVs and BEVs. In order to draw conclusions on what could trigger BEVs' uptake in significant numbers, the 10 best-selling cars among the ICEVs and the BEVs are compared. The TCO model is based on current prices and allows us to analyze the status quo. It is part of our research agenda to use the model to forecast future scenarios.

The paper has the following structure. Section 2 introduces the related literature. Section 3 illustrates the TCO model. Section 4 presents three applications of the TCO model to compare: a) the top-selling BEVs and ICEVs in Italy; b) specific BEVs with equivalent ICEVs; c) the impact of urban policy favoring the BEVs. Section 5 concludes.

2. Related literature

The literature on the TCO of cars is rapidly growing. Comprehensive literature reviews have been compiled by Wu et al. (2015) and by Bubeck et al. (2016). We update their reviews, considering papers which compare across propulsion technologies and include BEVs, since our special interest is to discuss the potential penetration of the BEVs in the Italian car market. The surveyed contributions are listed in Table 12.

The propulsion systems considered include ICEVs, HEVs, PHEVs, BEVs and sometimes FCEVs. Not all studies include both cost components, $_{C}$TCO and $_{S}$TCO. Some studies, assuming that the alternative propulsion systems have the potential of reducing energy use and CO_2 emissions, focus on only the $_{C}$TCO. However, the pioneering study by Kromer and Heywood (2007) invites not to overestimate the environmental benefits connected with the BEVs, due to the large carbon content in the US electricity mix. They see 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 have excess costs above 10,000 euro, granting very small CO_2 gains. They conclude that unless massive cost and efficiency improvements are achieved, BEVs will require enormous subsidies.

The studies carried out up to the year 2012 are rather pessimistic over the potential penetration of the BEVs, less so for the HEV. They saw a potential $_{C}$TCO convergence only after the period 2025-2030 (McKinsey & Company, 2011; Douglas and Stewart, 2011). However, in 2010 and 2012 two successful BEVs, the Nissan Leaf and the Tesla Model S, were introduced in the market. Propfe et al. (2012) argue more optimistically that $_{C}$TCO gaps for alternative drivetrains will decrease significantly by 2020. In a very detailed report, Plötz et al. (2013) state, among other things, that BEVs' share in 2020 is highly dependent on external factors and that they 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 $_{C}$TCO to ICEVs. BEVs could be competitive for users driving 20,000 miles per year for over 12 years, and tax credits are crucial in supporting the BEVs' diffusion. Bubeck et al. (2016) also find the HEVs are competitive in Germany since 2015, whereas the BEVs need a premium ranging from 8,600 to 32,400 euro. They forecast that BEVs will be economically viable in 2030.

Various authors (Hao et al., 2014; Diao et al., 2015; Zhao et al., 2015; Lévay et al.; 2017) stress the role of policies. Since BEVs have higher $_{C}$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' $_{C}$TCO is 2.5 times higher than IVEVs' and that the payback period is 13 years. Mitropoulos et al. (2017) carry out a $_C$TCO and externality ($_S$TCO) study comparing the ICEVs, HEVs and EVs in the USA. They find the HEVs have the lowest $_C$TCO and $_S$TCO, the EVs have intermediate values and the ICEVs have the worse values both in terms of $_S$TCO and $_C$TCO. On the contrary, Bickert 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 a financial advantage.

Wu et al. (2015) propose a probabilistic simulation model, able to estimate $_C$TCO accounting for the uncertainty in some model parameters. They distinguish by propulsion systems and among 5 car segments, estimating the $_C$TCO in the years 2014, 2020, and 2025. They find that the $_C$TCO metric does not reflect how consumers make their purchase decision today, and that cost efficiency of EV increases with the consumer's driving distance and is higher for small than for large vehicles. Danielis et al. (2018) develop a probabilistic TCO model for Italy, comparing cars with different powertrain technologies. Their model includes stochastic and non-stochastic variables, vehicle usage and contextual assumptions. They show that with incentivizing policies electric cars are cost competitive with respect to hybrid electric ones and are expected to gain market share in 2025 without subsidies.

Very recently, Palmer et al. (2018) publish a cross-country historical analysis of the $_C$TCO estimates, finding a clear connection between HEVs' $_C$TCO and their market share.

As can be seen from Table 12, studies focused on different vehicle classes, since each of them has its own peculiarities. The vehicle types selected for each vehicle class are either conceptual models, whose characteristics are defined selecting 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 representative models selected 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.

In the following Sections we will introduce our model and underline its main characteristics relative to the previous ones.

3. The total cost of ownership model

The TCO model of a car comprises all monetary expenses to be paid in order to use a car for a given number of years and a given number of kilometers. Costs can be distinguished between fixed and variable costs. Fixed costs include the one-time cost incurred to purchase and register a car, and the annual fixed costs such as the vehicle excise duty (also known as "vehicle tax", "car tax" or "road tax"), the insurance premium, and the maintenance costs. Variable costs that vary on the basis of distance traveled include fuel costs and oil consumption. A group of costs is partly fixed and partly variable such as extraordinary repairs, tire costs, and starting-lighting-ignition SLI battery. Finally, there are costs such as access or parking fees associated with trips in urban center, differentiated by propulsion system and the engine technology of the car (EURO class).

The abovementioned costs are born by the user of the car. They are private in nature and are labelled “consumer-oriented costs” in the TCO literature.

A different group of costs are generated by the emission of air pollutants and noise. These are social or external in nature and are labelled “society-oriented costs” in the TCO literature.

To summarize, a TCO model comprises the following costs:

Total cost of ownership = Consumer-oriented costs + Society-oriented costs

where:

Consumer-oriented cost = *Initial fixed costs* + *Annual fixed costs* + *Other fixed costs* + *Variable costs depending on distance traveled* + *Other variable costs* – *Residual value*

- Initial fixed costs: retail price + state registration and licensing fees;
- Annual fixed costs: insurance + vehicle excise duty + preventive care and maintenance costs;
- Other fixed costs: extraordinary repair, cost of the replacement of the batteries;
- Variable cost per km: fuel cost*annual distance traveled;
- Other variable costs: access and parking costs to urban areas differentiated by propulsion system;
- Residual value: the value of the car after the given years of use.

Society-oriented cost = *Cost associated to CO_2 emissions* + *Cost of local atmospheric pollution* + *Cost of noise pollution*

- Social cost associated to CO_2 emissions: direct and indirect CO_2 emission*cost of CO_2 per km driven;
- Cost of local atmospheric pollution: emission of local pollutants*cost for local pollution per car-km;
- Cost of noise pollution: emissions of local noise pollution *cost of local noise per km driven.

The TCO model can be used to compare two types of car with different propulsion systems, computing the break-even in terms of either: a) the distance to be annually driven for a given number of years to generate the same amount of TCO or b) the payback period, that is the number of years needed, given an annual mileage, in order to equalize TCO (e.g., Al-Alawi and Bradley, 2013). The former approach will be taken in this paper, since we want to estimate the vehicle use which makes a BEV cost convenient.

To estimate the model, we have built a database containing information on the most common cars on sale in Italy. All propulsion systems are included. To date, the database contains about 90 models. For each of them, the information gathered relates to:

- Technical variables such as type of model, accessories, battery size, car size, trunk size, fuel economy (urban, highway and combined);
- Economic variables such as retail price, state registration and licensing fee, vehicle excise duty, insurance premiums, fuel\electricity price, maintenance and repair costs, ordinary and extraordinary maintenance, vehicle depreciation, main battery replacement (in the case of an EV), access and parking cost in protected areas, financing;
- Environmental variables such as direct and indirect CO_2 and local pollutants emissions, noise level and their monetary evaluation.

Some of these costs are rather problematic to estimate. In the following Section, the main data issues and assumptions made will be described. More details are described in the Appendix.

4. Definition of the variables

Our main purpose is to compare among propulsion systems with specific focus on the BEVs. The comparison will be made:

- estimating the total cost of owning the car for a given number of years (the economic life of a car) and travelling a given number of kilometers;
- assuming a driver of 40 years of age and living in the Italian Region of Friuli Venezia Giulia;
- assuming a driving pattern of 60% urban and 40% highway trips;

The model could be used for simulation. Sensitivity analysis can be easily performed but it is not reported in this paper.

4.1 Technical variables

Vehicle type

A specific feature of our approach to modelling TCO is to rely on real cars with the largest sales in the Italian market, instead of developing conceptual car types (Al-Alawi and Bradley, 2013; Wu et al., 2015) or using a limited number of representative vehicle type (Lèvay et al., 2017; Mitropoulos et al., 2017). The advantage of the conceptual car approach is to control for car components so that two cars might differ only on the desired features. The advantage of our approach is to base the comparison on the vehicle types currently available to the customers. However, it is difficult to select among the numerous variants within each vehicle type (for instance, the Nissan Leaf is available in Italy in 3 trims: Visia, Visia Plus, Acenta, Tekna). Price and horsepower\kilowatts may vary substantially on the basis of different configurations. Color, software endowment, safety equipment or autonomous drive, and comfort equipment might further determine the final price of the car. We have made an effort to choose for our comparisons cars similar regarding size, acceleration, power and engine displacement, trunk size, number of seats.

Fuel economy

Fuel economy represents an important aspect in a comparison across propulsion systems. This information, however, is problematic. A first issue concerns the difference between test and real fuel consumption. Real consumption depends from many factors linked to traffic conditions (congestion levels), type of road (flat or steep), weather conditions, and driving style. The latter aspect 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 EPA and the European NECD driving cycles. The EPA one usually leads to higher estimated consumption levels than NECD one, and is commonly considered closer to real-world consumption. When available (i.e. only for the cars sold in the US), we opted for the EPA estimates.

4.2 Economic variables

Retail price

Similarly to previous studies (Windisch, 2013; Hagman et al., 2016; Lévay et al., 2017), we use real-life prices. However, it is common practice for OEMs to recommend a retail price (known as manufacturer's suggested retail price, MSRP) to help standardizing prices among locations. MSRP usually varies, sometimes considerably, by country. 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. As our database is not able to incorporate such variability, we rely on the MSRP in Italy in the year 2017, although it might lead to an overestimation of the TCO. However, if the overestimation is similar across models and propulsion systems, the comparison is not seriously distorted. An alternative, adopted in some studies (Al-Alawi and Bradley, 2013; Wu et al., 2015; Bubeck et al., 2016), would be to model the retail price (termed retail price equivalent) by summing up the car's components. The disadvantage of the latter being its inability to capture the OEMs' market strategies.

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, we keep constant the components b), c), d). At the moment, referring to a 40 years old driver living in the Friuli Venezia Giulia Region. Presently, in

Italy major insurance companies apply a 50% discount on BEVs' insurance premiums. Quotations for every model are derived from internet websites.

Fuel\electricity price

Fuel\electricity prices have a market component (oil and energy mix price) and a fiscal component (fuel taxes). The results presented below are based on the observed prices in Italy, kept constant in real terms over the years.

Vehicle excise duty

In Italy, such a tax is defined and managed at regional level. It is commonly differentiated by engine displacement, by EURO class and by fuel type. More information in the Appendix.

Years of use of the car, battery replacement and the residual value

A crucial aspect in the comparison between ICEVs and BEVs concerns the years of use, the replacement of the battery and the residual value.

It is well-known that, in an ICEV, the engine is the part that ages most quickly. Technological improvements, however, made it possible for internal combustion engines to last several years, subject only to preventive care and maintenance. As a result, ICEVs are sold with a long warranty period[2] (3 to 6 years).

BEVs do not have an endothermic engine and have much fewer moving parts, but the battery degrades (it loses range) over time and needs to be replaced after a certain number of years. Some car manufacturers dealt with this issue (Renault, for example) through the sale of BEVs with leased batteries, so that the risks are born by the manufacturer. However, it was not a commercial success. Since BEVs are a relatively new product and the continuous technological improvements, it is difficult to make assumption about the length of battery life[3]. And It is problematic to quantify the cost of its substitution. These challenges make the comparison amongst cars with different propulsion systems quite uncertain.

Such uncertainties are passed on the residual value of the car. If for conventional cars, the depreciation rate is sufficiently known, for BEVs it is highly uncertain (Lèvay et al., 2017). The empirical evidence seems to show a very rapid initial depreciation but converging to the ICEVs in the medium term.

In our calculations, since the average owning time in Italy is 10 years, the uncertainty will be solved by setting the resale value of both ICEVs and BEVs to zero. According to most sources, we consulted, after 10 years, the resale value of any car is close to zero[4]. This is a strong assumption which might not be true for all ICEVs, especially the ones with highly-reputed brands, or for the Tesla Motors' luxury models. The car use selected for our comparison, however, do not belong to the luxury segment.

Two scenario will be evaluated: an annual distance driven equal to 5,000 km and to 10,000 km. Both scenarios appear to be compatible with the forecasted battery lifetime, so that there is no need for substituting the battery for the BEVs[5]. The first scenario is representative of a BEV used as a second car, mainly for urban trips. The second scenario is representative of a BEV used as the only

[2] Three years or 36,000 miles (always calculated by whichever comes first, and often referred to as 3/36) seems to be the de facto bumper-to-bumper warranty coverage, but most luxury cars have a 4/50 warranty and still some other cars have 5/60. American and Japanese vehicles offer an additional powertrain warranty to as long as 10/100 – covering the engine and transmission only. However, European luxury brands do not extend powertrain coverage beyond the basic warranty period.

[3] 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/). As the BEVs are relatively recent, only anecdotal evidence is available.

[4] Diao et al. (2015) estimate for China a resale value of 10% of the MSRP after 10 years. Zhao et al. (201) assume a resale value of 15% of its MSRP for an ICEV and 10% for a BEV.

[5] Mitropoulos et al. (2017) makes the same assumption.

car for urban and intercity trips. The combination 10 years and 10,000 km per year is representative of the Italian average[6]. An alternative approach, adopted in the literature (Windisch, 2013; Wu et al, 2015; Hagman et al., 2016) would be to consider only the TCO of the first owner and estimate the resale value of the car. As it is more common in Italy to keep the car for its entire lifetime, we did not opt for this latter approach.

Cost of parking or access to reserved areas

Some Italian cities allow BEVs to access the city center and park for free. As such savings might be an important motivation for buying a BEV, these potential savings are included in the our TCO model.

4.3 Environmental variables

As listed in Table 12, all studies evaluating $_S$TCO include CO_2 emissions, some include also local pollutants, only Prud'homme and Koning (2012) include noise. Mitropoulos et al. (2017) include time losses. Our model includes CO_2 emissions, local pollutants and noise.

The social cost of CO_2

CO_2 emissions are linked to fuel consumption. Information on CO_2 emissions during vehicle use is provided on the basis of NECD or EPA driving cycles. It needs to integrated by the so called "well-to-tank" emissions generated during fuel extraction, production, distribution and the manufacturing and disposal of the car. The Italian values, taking into account the Italian electricity mix, are drawn from Rusich e Danielis (2015) and Danielis et al. (2019).

The monetary value to be attributed to CO_2 is quite uncertain. A detailed discussion of this issue is provided by Nocera et al. (2015) who reports 699 estimates stemming from 60 studies published on scientific journals between 2010 and 2014. The values range from -2 to 1.48 euro per ton. The average value is €56/tCO_2eq (with a standard deviation equal to 137). The median value is 17.5 euro per ton. We use such a value as a starting point for our estimations. See the Appendix for more details.

The social cost of local environmental pollution

The emission of local pollutants such as CO, NOx, PM and O_3 is differentiated by engine technology. Traffic conditions impact the performance of the car: urban driving, characterized by frequent stop-and-go requirements, is less efficient than highway driving. The damage connected with the exhaust emissions depends on many factors including geomorphological and seasonal ones. Moreover, the estimation of the damages to human health and historical buildings can be performed with different methods. These complexities and uncertainties are analyzed and discussed in the publication by the DG MOVE (2014). See the Appendix for more details.

The social cost of noise

The estimation of the external cost of noise is also quite problematic. BEVs are less noisy than ICEVs given the absence of an endothermic engine, but they are not exempt from the noise generated by the rolling of the tires. We rely on the values presented in the publication titled "Update of the Handbook on External Costs of Transport (2014)" by the DG MOVE (2014). The values are differentiated for type of vehicle, day and night, traffic conditions and area (rural, suburban, and rural). See the Appendix for more details.

[6] Mitropoulos et al. (2017) for the US selects these values: 11,300 miles and lifetime of 10.6 years.

5. Three applications of the TCO model

The model allows us to perform several types of estimations. We have chosen to report:

a) a comparison between the 10 best-selling BEVs and ICEVs;
b) a pairwise comparison between BEVs and ICEVs of the same brand with similar characteristics;
c) as in b) but with urban policies incentivizing BEVs;

A comparison between the 10 best-selling BEVs and gasoline cars in Italy

We selected the 10 best-selling ICEVs in Italy (

Table 1). According to UNRAE statistics in 2017 (up to November 2017), they are three petrol cars and 7 diesel cars.

Table 1 – Techno-economic characteristics of the best-selling ICEVs

Brand	Fuel	Vehicle type	Engine displ. (cc)	Size	HP	Accele-ration*	CO_2 (g/km)	MSRP	Quantity sold 2017
Fiat Panda	P	1.2 Easy	1242	365/164/155	69	14.2	120	11,600	94,732
Lancia Y	P	1.2 Silver	1242	384/168/152	69	14.5	120	13,350	38,128
FIAT 500L	P	1.4 Pop Star	1368	415/178/166	95	12.8	143	18,150	40.324
Fiat 500L	D	1.3 Multijet 95 CV Easy	1248	365/164/155	95	12.8	94	15,540	33,174
Fiat 500X	D	1.3 Multijet 95 CV Pop 4x2	1598	425/180/160	95	12.9	107	19,250	35,177
Jeep Renegade	D	1.6 Multijet 95 CV Sport	1598	424/180/167	95	10.2	115	22,800	30,854
Renault Clio	D	1.5 dCi 75 CV Life	1461	406/173/145	75	14.3	85	15,000	28,124
Fiat Tipo	D	1.3 Multijet Easy	1248	453/179/150	95	11.7	108	17,600	36,868
Nissan Qashqai	D	1.2 DIG-T Visia	1197	438/181/159	116	11.3	129	20,830	27.400
Fiat Panda	D	1.3 Multijet 95 CV Easy	1248	365/164/155	95	12.8	94	16,500	27,166

P= Petrol, D= Diesel ; *Acceleration (0-100 km/h in sec.)

By making use of the available data and the developed TCO model we obtain the values reported in Table 2:

Table 2 – TCO of the 10 best-selling cars in Italy

	Annual distance driven 5,000 km for 10 years			Annual distance driven 10,000 km for 10 years		
	average value	minimum value	maximum value	average value	minimum value	maximum value
MSRP	16,966	11,600	22,800	16,966	11,600	22,800
Annual operating cost	2,097	1,930	2,337	2,817	2,440	3,389
$_C$TCO	33,975	30,206	39,814	39,816	35,333	45,310
$_S$TCO	540	492	580	985	884	1,061
TCO = $_C$TCO + $_S$TCO	34,515	30,698	40,394	40,801	36,376	46,371

Taking into account the BEVs sold on the Italian market (Table 3), focusing only on the medium segment and excluding the Tesla Model S and Model X, we obtain the values reported in Table 4.

Table 3 – Techno-economic characteristics of the selected BEVs

Brand	Vehicle type	HP	Accele-ration*	Battery (kWh)	Size	MSRP	Quantity sold 2017
Nissan Leaf	LEAF VISIA	109	11.5	24	445/177/155	30,690	456
Renault Zoe	Zoe Life, R90	109	13.5	41	408/173/156	33,250	308
Smart Fortwo ED	Youngster	75	12.7	17.6	350/167/155	24,559	249
Citroën C-Zero	Séduction	67	15.9	16	348/148/161	30,690	81
VW E-UP	e-up!	82	12.4	18.7	360/164/150	27,150	52
VW E-GOLF	2017 model	116	10.4	24.2	427 /179/148	37,600	>27
Peugeot iOn	Active	67	15.9	16	348/148/161	28,151	>27
Mitsubishii Miev	i-MiEV	64	15.9	16	348/148/161	32,214	>27
BMW i3	I3	170	7.5	22	400/178/160	36,500	119
Hyundai Ioniq Electric	Comfort	120	10.2	28	447/182/145	36,750	>27

*Acceleration (0-100 km/h in sec.)

Table 4 – TCO of the BEVs sold in the Italian market

	Annual distance driven 5,000 km for 10 years			Annual distance driven 10,000 km for 10 years		
	average value	minimum value	maximum value	average value	minimum value	maximum value
MSRP	31,755	24,559	37,600	31,755	24,559	37,600
Annual operating cost	1,225	1,095	1,465	1,640	1,497	1,908
$_C$TCO	41,693	35,378	48,384	45,057	39,089	51,974
$_S$TCO	225	225	226	405	405	405
TCO = $_C$TCO + $_S$TCO	41,918	35,603	48,609	45,461	39,494	52,379

We observe the following.

- In Italy, the average MSRP of the BEVs is €14,789 higher than that of the 10 best-selling cars;
- The $_C$TCO of the ICEVs is €7,718 lower than the BEVs' one if the annual distance driven is 5,000 km for 10 years. It reduces to €5,241 if the annual distance driven is 10,000 km for 10 years.
- The average break-even kilometers for the best-selling ICEVs and BEVs in Italy is equal to 20,579 km. This means that if a driver travels such an average distance for 10 years, then BEVs is, on average, as convenient as the best-selling gasoline cars on the Italian market. Considering that an average passenger car in Italy travels about 11,200 km a year[7], it is no surprise that the market share for BEVs in Italy is currently very limited (equal to 0.1%).
- The difference between the $_C$TCO and the $_S$TCO is on average equal to about €581 (when the annual distance driven is 10,000) and €315 (when the annual distance driven is 5,000). That would be the amount of the subsidy economically justifiable on the basis of the social costs. It can be noted the overall TCO is lower for the ICEVs than for the BEVs.

It should be emphasized that the above results are country-specific. Compared to other European countries such as Germany, the UK or the Scandinavian countries, Italy has a fleet mainly comprising small\medium cars (segment A\B) for a number of reasons including urban density and income. This makes BEVs' penetration in Italy particularly difficult until small and relatively cheap BEVs make their appearance in the market. For the same reasons, in Italy the Renault Twizy

[7] There is no official data on the average distance travelled for the Italian passenger cars. Such estimate has been made by the website facile.it.

quadri-cycle and the carsharing Share&go electric car have been quite successful. The petrol\diesel FIAT 500 and the Daimler Smart are largely used in urban centers, but only the latter is so far available in the electric version.

Pairwise comparison between BEVs and equivalent ICEVs

Instead of using average values, we compare pairs of models of the same brand and of similar size and accessories. The selected pair and their technical characteristics are reported in Table 5. They belong to the segment A – Small cars and B - Medium cars.

Table 5 – Techno-economic characteristics of the selected pairs

Brand	Fuel	Model	Engine displ. (cc)	Car size	KW	Accele-ration	Battery (kWh)	Tank (liters)	Segment
Smart Forfour	P	1.0 61c	999	350/167/155	52	16	0	28	A
Smart Forfour ED	E	Youngster		350/167/155	41	12.7	17.6	0	A
Renault Clio	P	1.2 Intens	1.149	406/173/145	55	12	0	40	A
Renault Zoe	E	Zoe Life, R90		408/173/156	80	13.5	41	0	A
VW up	P	1.0 75 CV move up!	999	360/164/150	55	13.5	0	35	A
VW E-UP	E	e-up!		360/164/150	60	12.4	18.7	0	A
Nissan Pulsar	P	PULSAR VISIA	1197	4.387/1.768	85	10.7	0	48	B
Nissan Leaf	E	LEAF VISIA		445/177/155	80	11.5	24	0	B
WV Golf	P	1.0 –TSI Bluemotion	999	427/179/148	85	9.7	0	50	B
VW E-Golf	E	Volkswagen e-Golf		427/179/148	100	10.4	24.2	0	B

*Acceleration (0-100 km/h in sec.) P = Petrol, E = Diesel

A graphical comparison of their $_C$TCO varying the annual distance driven is presented in Figure 1.

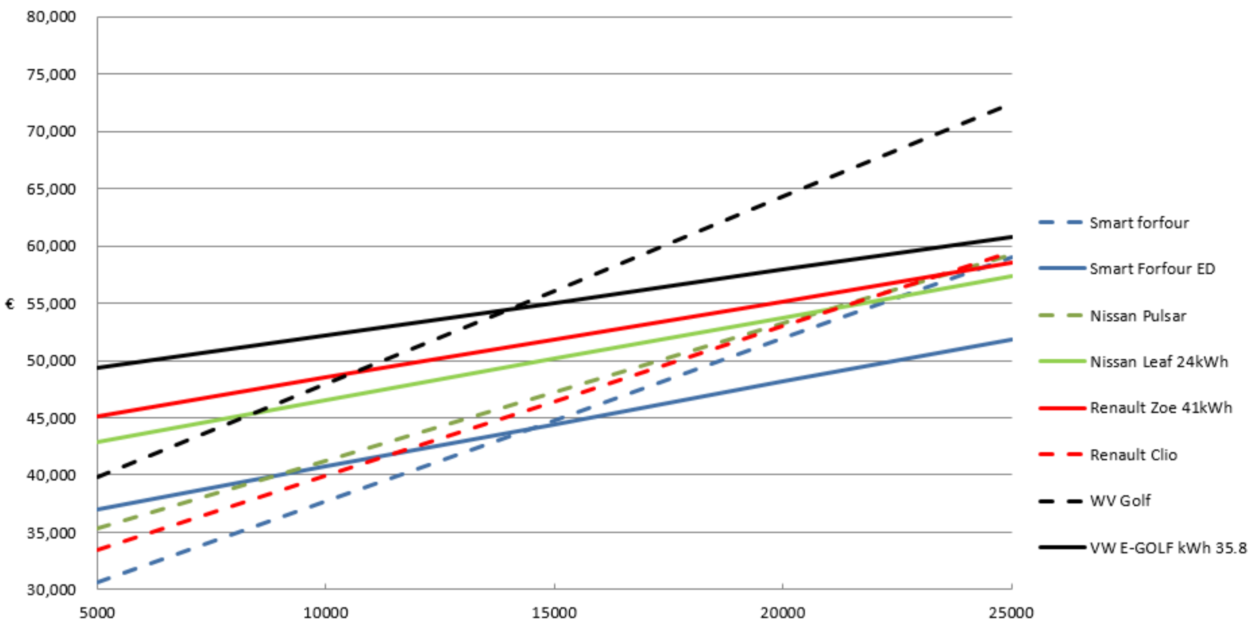

Figure 1 – $_C$TCO varying the annual distance driven

ICEVs are depicted with dashed lines, whereas BEVs with solid lines. The lines corresponding to ICEVs have lower intercepts than those of BEVs (lower fixed costs), but their slope is higher (higher variable costs). Lines with the same color and indicating comparable cars cross in one point, which identifies the break-even distance, i.e. the how many kilometers one has to travel annually to have equal $_C$TCO, under the hypothesis of 10 years of ownership/use of the car. Table 6 and Table 7 present the numerical values.

Table 6 - Detail of costs for 10,000 km per year and 10 years of ownership

	ICEV	EV	ICEV	EV	ICEV	EV	ICEV	EV	ICEV	EV
	Smart forfour	Smart Forfour ED	Nissan Pulsar	Nissan Leaf 24kWh	Renault Clio	Renault Zoe 41 kWh	WV Golf	VW E-GOLF kWh 35.8	VW up	VW E-UP
MSRP	12,960	24,559	18,090	30,690	16,350	33,250	20,400	37,600	12,600	27,150
Annual variable cost	3,049	1,991	2,859	1,950	2,908	1,879	3,396	1,796	2,797	1,617
$_C$TCO	37,687	40,711	41,280	46,503	39,936	48,488	47,944	52,170	35,290	40,268
$_S$TCO	888	405	881	405	890	405	889	405	868	405
$_T$CO	38,575	41,116	42,161	46,908	40,826	48,893	48,833	52,574	36,158	40,673
$_C$TCO difference		3,024		5,224		8,551		4,226		4,978

Table 7 – Km to be yearly driven to break-even the $_C$TCO

Smart forfour	Smart Forfour ED	Nissan Pulsar	Nissan Leaf 24kWh	Renault Clio	Renault Zoe 41kWh	WV Golf	VW E-GOLF kWh 35.8	VW up	VW E-UP
	14,455	-	21,066	-	23,510	-	13,981	-	17,611

The last row identifies the difference between $_C$TCO between a BEV and the corresponding ICEV. It can be noticed that such difference, with an annual distance driven equal to 10,000 km, lies between 3,000 and 8,000 euro. These values indicate the subsidy that would be needed to equalize the $_C$TCO. At the moment and contrary to other European countries, BEVs enjoy no subsidy in Italy. Although the $_C$TCO cannot by itself explain the purchasing behavior, buying a BEV in Italy is not justified on the basis of the $_C$TCO. At least a 4,000-6,000 euro subsidy would be needed to balance the BEVs' unfavorable $_C$TCO. Such a result is in line with Lévay et al. (2017)'s findings for the year 2014.

It is important to bear in mind that these estimates stem from specific assumptions on some key parameters of the model, such as:

- percentage of urban trips: 60%
- real discount rate: 4%
- gasoline price per liter: €1.579
- diesel price per liter: €1.427
- electricity price per kWh: €0.18
- social cost of a tons of CO_2: €17.5
- the annual savings in parking costs or access fees for BEVs: €0

A comparison between electric and equivalent conventional cars with an incentivizing urban policy

National and local policies could greatly impact BEVs' diffusion (Sierzchula et al., 2014; Lieven, 2015; Diao et al., 2015; Lévay et al., 2017). Some policies have a non-monetary nature (public charging infrastructure, use of bus lanes), others have direct monetary implications (tax exemptions, direct subsidies). In Italy, up to now, there has been an only weak and intermittent political support for BEVs at national level. On the contrary, at the urban level more and more cities (e.g., Rome, Milan, Turin, Florence) have promoted policies favoring alternative fuel vehicles. The monetary savings for the urban commuter are difficult to quantify (Diao et al., 2015, terms them "intangible costs"). Assuming an annual saving of 200 euro due to lower parking or access fees compared to an ICEV, our model produces the results reported in Table 8 and Table 9.

Table 8 - Detail of costs for 10,000 km per year and 10 years of ownership

	ICEV	EV	ICEV	EV	ICEV	EV	ICEV	EV	ICEV	EV
	Smart forfour	Smart Forfour ED	Nissan Pulsar	Nissan Leaf 24kWh	Renault Clio	Renault Zoe 41 kWh	WV Golf	VW E-GOLF kWh 35.8	VW up	VW E-UP
MSRP	12,960	24,559	18,090	30,690	16,350	33,250	20,400	37,600	12,600	27,150
Annual variable cost	3,049	1,791	2,859	1,750	2,908	1,679	3,396	1,596	2,797	1,417
$_{C}$TCO	37,687	39,089	41,280	44,881	39,936	46,865	47,944	50,547	35,290	38,646
$_{S}$TCO	888	405	881	405	890	405	889	405	868	405
TCO	38,575	39,494	42,161	45,286	40,826	47,271	48,833	50,952	36,158	39,051
$_{C}$TCO difference		1,402		3,602		6,929		2,603		3,356

Table 9 – Break-even point for total private cost\year

Smart forfour	Smart Forfour ED	Nissan Pulsar	Nissan Leaf 24kWh	Renault Clio	Renault Zoe 41kWh	WV Golf	VW E-GOLF kWh 35.8	VW up	VW E-UP
	12,065	-	17,629	-	20,947	-	12,453	-	15,131

It can be observed, comparing Table 6 and Table 7 with Table 8 and Table 9, that the annual distance driven needed to reach the $_{C}$TCO break-even would be reduced by almost 2,000 Km and the needed subsidies drop to 1,500-7,000 euro. This underlines the importance of urban policies to support electric mobility. In a small town or in a village, such policies are not in place, hence, their impact might be nonexistent or reduced. A location-specific analysis is needed to take in account these aspects along the lines suggested by Windisch (2013) and Diao et al. (2015).

6. Conclusions

Buying a car implies making a complex choice based on monetary and non-monetary variables as well as on psychological, ideological or sociological motivations. Such a choice is not always rational or fully-informed. The TCO model could be useful since it allows: a) car drivers or fleet managers to take informed purchasing decisions, including not only the initial purchasing cost but the entire lifetime costs of the vehicle; b) OEMs to evaluate the market potential of the different types of vehicles and to define their price strategies; 3) transport policy decision makers to better calibrate their policies. We claim that a TCO model needs to be country-, time-, vehicle-time-, location-specific.

We have developed such a model for Italy, able to evaluate and simulate both the $_{C}$TCO and the $_{S}$TCO. In this paper three applications are presented:

a) a comparison between the 10 best-selling BEVs and ICEVs;
b) a pairwise comparison between BEVs and ICEVs with similar characteristics and brand;
c) and the above comparison b) with urban policies favoring BEVs.

We find that in Italy the MSRP of the BEVs is much higher than that of the best-selling ICEVs. Such a gap is compensated by the lower variable costs only in the case of a very high annual traveled distance (20,579 km per year per 10 years), which is much above the current Italian average one. Such a distance - equivalent to 57 km a day for 360 days - is, however, within the range of most BEVs. Considering that Italy is also lagging behind in terms of charging infrastructure, it is not surprising that the BEVs' share is almost insignificant.

The difference between the $_{C}$TCO and the $_{S}$TCO - which represents the amount of the subsidy economically justifiable on the basis of the social costs - varies between €315 and €581, considering the entire lifetime of the vehicle. Therefore, even if the social costs are internalized, the BEVs will not be cost-competitive. These results are in line with previous findings by Prud'homme and Koning (2012), Zhao et al. (2015) and Bickert et al. (2015). On the contrary, they contrast with those obtained by Mitropoulos et al. (2017) for the USA[8].

If, instead of comparing average values, we compare pairs of cars of the same brand and with similar characteristics, we reach the same conclusion: buying a BEV in Italy is not justified on the basis of the $_{C}$TCO. At least a 4,000-6,000 euro subsidy would be required to balance the BEVs' unfavorable $_{C}$TCO. Such a subsidy is, in fact, in place in many European countries and in the USA, where the BEVs diffusion is much higher than in Italy. Only recently, an Italian region, the Trentino Alto Adige Region, has introduced a subsidy of such an amount. These findings support the common argument that subsidies are, for the time being, a pre-requisite for BEVs' penetration. However, we agree with Lèvay et al. (2017) that incentives play a crucial role for the BEVs' market breakthrough, but larger market penetration can only be achieved if they become more price competitive: the €14,789 average price gap needs to be reduced. Such a scenario is not unlikely as the economics of scale reduce battery costs and the competition among OEMs grows.

Finally, we find that parking and access fees favoring BEVs could have a significant impact in reducing the need for subsidies or the distance driven to reach the $_{C}$TCO break-even point. Such urban policies are currently in place in many Italian cities in an effort to curb air pollution.

The estimates presented above suffer from the common data uncertainties, both related to the private costs and, even more so, to the social costs. Our future research agenda includes taking into account such an uncertainty by developing a probabilistic TCO model (Element Energy, 2011; Wu et al., 2015). A useful extension would be to forecast the cost and price changes that might occur thanks to technological improvements and economies of scale. Furthermore, we plan to implement a finer territorial characterization of the model, taking into account specific regions or urban areas. Focusing on specific vehicle usage types (intercity commuting vs. urban trips) or professions (taxi drivers, or sale persons) might also shed light on the pros and cons of the BEVs. An even more challenging extension would be to merge a TCO mobility model with a renewable energy production model in a fleet or household environment.

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[8] Using the representative model approach, Mitropoulos et al. (2017) find that HEVs are the best choice both for the $_{C}$TCO and for the $_{S}$TCO. With regards to the comparison between the ICEV and the BEV, they find the BEVs have both lower $_{S}$TCO ($2,023) and $_{C}$TCO ($3,854).

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Appendix

Vehicle Excise Tax

In Italy, the vehicle excise tax is a local tax to be paid on vehicles and motorcycles registered in the Italy. The tax is differentiated by Region of residency and is computed taking into account the engine displacement and the EURO category. Some propulsion systems enjoy specific exemptions. Electric cars are exempted from the 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 euro for each exceeding kW).

Discount rate

The present value of an ordinary annuity (PVA) is calculated as: $PVA = R \times \left[\frac{1-\frac{1}{(1+i)^n}}{i}\right]$

Where R is the amount of recurring cost, n is time expressed as number of years (the lifetime for all vehicle types is assumed to be 10 years), i is the real discount rate. The real discount rate is derived as follows:

$$i = \frac{(1 + nominal\ interest\ rate)}{(1 + inflation\ rate)} - 1$$

The nominal interest rate is assumed to be 5.0% and the inflation rate is assumed to be 1%.

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) assumes a 30% reduction in maintenance costs. This reduction is attributable to the reduced number of car components and fluids.

The external cost of CO_2

Table 10, derived from Rusich and Danielis (2015) on the basis of Torchio and Santarelli (2010), indicates CO_2 emissions for different types of fuels on the basis on the Italian electricity mix.

Table 10 – CO_2 emissions for different types of fuel (gCO_2 eq./km)

	Well-To-Tank p*	Tank-To-Wheel p	Well-To-Wheel p
Gasoline	26.05	153.05	179.10
Diesel	24.98	120.2	145.18
Bi-fuel CNG	25.79	126.8	152.59
Diesel HEV	20.02	95.6	115.62
Gasoline HEV	21.90	100.6	122.50
BEV	63.59	0	63.59
Bi-Fuel LPG	14.06	139.9	153.96

Source: Rusich and Danielis (2015) on the basis of Torchio and Santarelli (2010)

Our data indicates that BEVs emit 36% and 44% of the amount generated by gasoline and diesel cars. A recent estimate by Falcão et al. (2017) indicates that BEVs' emissions are 4.6 lower than conventional vehicles. As stated above, the median value of 17.5 euro per ton of carbon derived from Nocera et al. (2015) is chosen to value CO_2 emissions. For a comparison, Mitropoulos et al. (2017) adopt the value of $27 per ton of CO_2 and other GHGs.

The external cost of local environmental pollution

The source of data for the estimation of the local urban and suburban pollution is Table 17, published in DG MOVE (2014), an "Update of the Handbook on External Costs of Transport (2014)".

Table 11 – The external cost of local environmental pollution (€/vkm) for Euro 6 cars

	Gasoline	Diesel	Electric	Plug-in hybrid
Urban local pollution(€/vkm)	0.0040	0.0070	-	0.0020
Suburban local pollution (€/vkm)	0.0010	0.0030	-	0.0005
Urban\highway local pollution (€/vkm)	0.0010	0.0030	-	0.0005
Local pollution for energy production (€/vkm)	-	-	0.0010	0.0005

The estimated external cost of diesel cars is almost twice as much as that of gasoline cars. For PHEVs we applied a value half than that of gasoline cars, on the basis of the empirical evidence showing that at least 50% of urban journeys are on electric mode.

BEVs produce zero emissions when in use, but they are still a cause of emission of local pollutants during the phase of energy production. As clearly shown by the Chinese case, if electricity is produced through coal plants close to urban areas, then the emissions of local pollutants affecting city inhabitants can be very large.

The Italian situation is well described by ISPRA (2016, p. 58). It is argued that the introduction of new regulatory tools, the replacement of oil with natural gas, the limited presence of coal plants and the increasing use of renewable sources, limited the emissions of local pollutants, and their value is also decreasing. Given the absence of official estimates for Italy (or Europe) on the external costs of local pollution to be associated with a vkm mileage employing a BEV, we opted for the following choice: attribute an external cost per km equal to the emissions released by ICEVs in suburban areas, given the fact that polluting emissions of energy plants are usually not located in urban areas. Donateo et al. (2015), using experimental values on charging habits in Rome, estimate local pollution from the BEVs to be lower than the ICEVs limits.

The external cost of noise

DG MOVE (2014) published an estimate differentiated for type of vehicle, day and night, traffic type (intense, not intense) and for areas (rural, suburban, and rural). These values are very heterogeneous: the value night\intense\urban is 15 times than the suburban one. As our values are only differentiated between urban and suburban journeys, we compute averages (between day and night, and between urban and suburban), reaching the following outcomes:

- cost of urban noise(€/km): 0.0113
- cost of suburban noise (€/km): 0.0002

Table 12 – Related TCO literature

Authors	Propulsion systems	Vehicle classes	Vehicle type	$_S$TCO	Reference country	Main findings
Kromer and Heywood (2007)	ICEV-SI, ICEV-CI, HEV, PHEV, BEV	One reference model per technology	Representative model (1)	GHG, energy	USA	No clear winner
Thiel et al. (2010)	ICEV-SI, ICEV-CI, HEV, PHEV, BEV	Midsize	Representative model (1)	CO_2	EU-27	electrification can reduce CO_2 significantly
Contestabile et al. (2011)	ICEV-CI, 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)	ICEV-SI, 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 & Company (2011)	ICEV-SI, ICEV-CI, 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)	ICEV-CI, BEV	A/B	Representative model (1)	CO_2, Local pollutants, noise	FR	BEVs have excess costs much above 10,000 euro for very small CO_2 gains
Propfe et al. (2012)	ICEV-SI, HEV, PHEV, REEV, BEV, FCEV	Midsize	Conceptual vehicle	no	DE	TCO gaps for alternative drivetrains will decrease significantly by 2020
Plötz et al. (2013)	ICEV-SI, ICEV-CI, 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)	ICEV-SI, 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)	ICEV-SI, ICEV-CI, 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. (2015)	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
Bickert 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)	ICEV-SI, ICEV-CI, HEV, PHEV	Small, Compact, Medium, Executive	Conceptual vehicle	CO_2, energy	D	BEVs needed premium range from 8,600 to 32,400 euro. BEVs will be economically viable in 2030.
Falcão et al. (2017)	ICEV-CI, 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 et al. (2018)	ICEV, HEV, BEV	Midsize		no	Italy	With incentivizing policies BEVs are cost competitive with respect to HEVs and are expected to gain market share in 2025 without subsidies.
Palmer et al. (2018)	ICEV, HEV, PHEV, BEV				UK, USA, J	