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Simulating the uptake of electric motorized two-wheelers in Italy. An agent-based model parametrized with a discrete choice experiment

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ABSTRACT

Electric motorized two-wheelers (e-M2Ws) have the potential to reduce noise and air quality in urban environments. The paper develops an agent-based model, parametrized with a discrete choice experiment, to forecast e-M2Ws' uptake in Italy. The application considers two market segments: mopeds and (seated) scooters. A scenario analysis is performed assessing the e-M2Ws prospects in different technological and policy scenarios. We find that electric mopeds enjoy a higher consumers' acceptance than electric scooters. Our model predicts that they might play a relevant role in most scenarios, achieving in 2030 a market share ranging between 21.1 % and 44.2 %. On the contrary, electric scooters have much poorer prospects, achieving in 2030 a maximum of 5.5 % market share.

1. Introduction

Worldwide, motorized two-wheelers (M2Ws) exceeded 56-million-unit sales as for October 2024, projected to reach about 63 million in 2029. Such a number does not consider scooters or mopeds with an engine displacement of less than 50 cc. In the same period, the passenger cars sold worldwide were not much higher, equal to 78-million-units (Statista, 2024). Asia accounted for most of the M2Ws sold worldwide (47.5 million), with China and India reaching 15- and 16.3-million-unit sales, respectively. In Europe, 1.7 million M2Ws were sold, the two largest markets being Italy and France with 338 and 282 thousand units, respectively. The success of M2Ws depends on many factors, varying between countries, cities, and rural areas. They include their affordability (the average price in 2024 is estimated equal to US$2,600 (Statista, 2022)), low space requirements for circulation and parking, thus avoiding queue and parking difficulties, low operating costs, flexibility, and riding pleasure (Eccarius & Lu, 2019; Will et al., 2021). Empirical studies show that M2Ws are particularly useful for solo, short-distance, multi-stop trips.

M2Ws have, however, also negative features. Hula et al. (2021) underlined that motorcycle riders are much more vulnerable to suffer serious injuries from accidents than car drivers are. Hernandez et al. (2019) estimated that internal combustion engine (ICE) M2Ws generate more CO, CH4, NOx, HC and particulate matter per vehicle-mile travelled than passenger vehicles. Furthermore, the perceived noise level generated by an ICE M2W exceeds that of most other vehicles, being roughly twice that of automobiles at speeds of over 30 mph and surpassing even that of medium trucks and buses at speeds of over 50 mph.

The recent development of electric M2Ws (e-M2Ws), equipped with a lithium-ion battery, has the potential to improve the quality of the urban environment (Hernandez et al., 2019; Koossalapeerom et al., 2019; Essen et al., 2019). Since e-M2Ws produce no exhaust gases during operation, they contribute to improve air quality, especially in congested traffic conditions. In addition, and perhaps even more importantly, e-M2Ws contribute to reduce drastically noise pollution compared to ICE M2Ws. Recent studies, focusing on the life cycling assessment, confirm their positive environmental impact on global and local pollutants, while highlight the need for battery recycling (Schneider et al., 2023; La Fleur et al., 2024). Yet, their market share is still very limited. According to the Statista website (Statista, 2024), e-M2Ws had a 12 % market share worldwide in 2023, 13.7 % in Asia, 3.8 % in Africa, 3.8 % in Europe. The leading country for e-M2W penetration is China, where sales were equal to 32.9 %. Concerning some European countries, e-M2Ws' market share was 4.4 % in Germany and 2.9 % in Italy, respectively.

This paper develops an agent-based (AB) model parametrized with a discrete choice experiment. The model comprises three agents: the M2W buyers, the M2W producers and the policy makers. The decision-making process of the M2W buyers is modelled in detail and is parametrized via a discrete choice experiment performed in Trieste, Italy, in the years

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2020 and 2021. The model is implemented to forecast the uptake of e-M2Ws in Italy, up to the year 2030, for two market segments: electric mopeds (e-mopeds) and electric seated scooters (e-scooters). Five scenarios are considered: i) the technological trends concerning the riding range and the electric engine power; ii) the economic trends concerning the purchasing costs of buying e-mopeds/e-scooters; iii) the purchase subsidy; iv) a tax internalizing the external costs; and v) the application of a parking fee. The results of our study could be of interest to the mopeds and scooters manufacturers and policy makers, since understanding buyer's motives and market trends is crucial to successfully produce, promote and regulate them.

We believe that our study makes the following contributions to the literature. First, to the best of our knowledge, it represents the first attempt to apply an AB model to simulate e-M2Ws' uptake. We performed a similar attempt with reference to electric cars (Scorrano & Danielis, 2022). Second, in our model, the buyers' decision-making process is parametrized with preference data, a not very common feature among AB models which rely mostly on heuristics or cost parameters only. This allowed us to consider not only monetary variables but also the M2Ws' technical features such as engine power and riding range. Third, the estimated utility functions account for the agents' socio-demographic characteristics, their knowledge and experience with e-M2Ws, and attitudes towards the environment. Fourth, another uncommon feature is that the utility functions are estimated by combining both revealed and stated choice data, thus reducing the hypothetical bias inherent in parameters estimated with stated choice data only. Such a methodology should increase the reliability of decision criterion applied to model agents' choices. Fifth, the AB model is applied to simulate the e-M2W uptake in two specific market segments, mopeds and seated scooters, since they have quite distinct characteristics as discussed in Section 4.1. Therefore, we thought is worthwhile to perform two different estimations, in contrast with the studies we have reviewed that analyzed the e-M2W segment in general terms. Sixth, the model is applied to Italy, a European country with a high level of M2W use, whereas the existing estimates concerned Asian countries. Although our model is parametrized with choice data relative to Trieste, a medium-sized city located in the northeast of Italy, the methodology developed can be easily applied to other cities, regions or countries.

The structure of the paper is the following. Section 2 reviews the previous studies concerning M2W choice and forecasting the e-M2W uptake. Section 3 illustrates the design and working of the AB model, the discrete choice experiment and the econometric results obtained by estimating the collected stated and revealed preference data. Section 4 explains the implementation and validation of the model. Section 5 presents the performed scenario analysis, discussing the scenario assumptions and simulation results. Section 6 draws some policy implications and discusses the limitations of the study.

2. Related literature

To our knowledge, there exists very few studies forecasting e-M2W uptake. Sulistyono et al. (2021) applied system dynamics simulations to model the adoption-diffusion of electric motorcycles in Indonesia. The estimates are performed at macro level. The overall motorcycle market is driven by population and GDP trends. The representative consumer chooses by comparing the life cycle cost per kilometer between the ICE and electric motorcycle. They predicted a market share for electric motorcycles of around 41 % in 2030, depending on the subsidies and the electricity price. Using the same methodology, a more sophisticated model published by Yuniaristanto et al. (2024) reached a more conservative conclusion. They estimated that the electric motorcycle market share in Indonesia might reach 5.7 % in 2030 and advocated for more charging stations and vehicle tax abolition.

The International Council on Clean Transportation published a report, authored by Rokadiya et al. (2021), estimating the uptake of e-M2Ws in India on the basis of upfront costs and a total cost of ownership. In their study, they considered scooters and motorcycles, whereas mopeds were left out to the analysis. Their predictions were based on costs, i.e., upfront costs or total cost of ownership, although they acknowledged that consumers do not always value or calculate future savings, and numerous factors other than total ownership costs affect consumers' willingness to buy electric. They concluded that 100 % electric share of new sales by 2035 scenario is ambitious but achievable, given technology availability and the many policies levers the central government and state-level governments have at hand (such as the National Mission on Transformative Mobility and Battery Storage and the Faster Adoption and Manufacturing of Electric Vehicles scheme). An important conclusion from their study is that the larger the battery pack (i.e., the longer the range), the later parity is reached in all three metrics they consider (upfront cost, 5-year TCO, and 10-year TCO).

Our methodology differs from the previous literature for four reasons: i) the adoption of an AB model parametrized with a discrete choice experiment; ii) the reliance on both stated and revealed preference data; iii) a separate analysis for mopeds and scooters; iv) the application concerning a European country (Italy).

The main difference is the use of the AB model, instead of the system dynamics one. Both methodologies have pros and cons. System dynamics has a long tradition of building simulation models to predict nonlinear behavior of complex systems over time using stocks, flows, internal feedback loops, table functions and time delays (Forrester, 1987; 1994). The interaction among the model components takes place typically at an aggregate level. System dynamics allows the researcher to take into account variables and trends that play a role at macro level, such as population and GDP trends. AB models, also called individual-based models, have a long tradition as well (Von Neumann, 1951; Schelling, 1969; 1971). They are computational models that simulate actions and interactions of autonomous agents whose combined actions result in the behavior of a system and its outcomes. Agents have properties and behaviors, including the possibility to send/receive signals from other agents, thus interacting with one another. Based on the information and messages, they adapt and modify their choices. AB models are particularly useful when agents are numerous and heterogeneous, hence the representative agent assumption does not hold. Because of their properties, AB models have been used in many scientific domains including biology, ecology and social science. Scorrano & Danielis (2022) presented a survey of their application to forecasting the adoption of electric cars.

The second main difference is that AB models need to specify how agents make choices at individual level. The total cost of ownership rationale, used by Sulistyono et al. (2021), Rokadiya et al. (2021) and Yuniaristanto et al. (2024) is certainly relevant. However, the large literature on modelling the choice among M2Ws of different fuel types has demonstrated that, in addition to the monetary variables, non-monetary variables play a role (see Scorrano & Rotaris (2022) for a recent survey). The investigated attributes include financial attributes (purchase price, operating costs, lifecycle costs, and maintenance costs), technical attributes (maximum speed, emission levels, lifespan of the battery, engine power, acceleration, and removable battery) and other attributes (style, distance between refueling/recharging stations, manufacturing country). Such attributes are then complemented by the common users' characteristics (age, gender, education, motorcycle ownership, number of motorcycles per household, household size, daily journey time, trips per day).

Most of the studies apply the discrete choice methodology and estimate models with varying degrees of complexity (multinomial logit, random parameter logit, hybrid choice). These models allow researchers to investigate the role of vehicles' attributes in determining consumers' choice. More recently, some studies applied the theory of planned behavior and structural equation modelling to analyze the role played by (economic, financial, technical) perceptions, attitudes (environmental concern, risk aversion) and social influence (social norms and peer pressure). This study builds on this literature by incorporating in a discrete choice modelling framework several vehicles' attributes and consumers' socio-characteristics (including knowledge, experience, environmental concern) that proved relevant in explaining M2Ws' choice in our previous studies. Differently from previous literature, we incorporate both stated and revealed preference data to mitigate the hypothetical bias issue characterizing the stated choice methodology.

Many interesting conclusions can be drawn from the e-M2W literature. Many studies underlined that e-M2Ws suffer from technical drawbacks such as poor riding performances, low speed, insufficient riding range, long charging time, and high purchase costs. Fiscal incentives might of course help in spurring uptake; however, the literature also indicated the role played by environmental concern, especially regarding the local air quality, and social norms. These findings, together with the empirical evidence that we will provide in Section 4.1, motivated our decision to forecast the uptake of scooters and mopeds, separately, instead of grouping them in a single category as in the previous literature.

The large majority of previous studies investigated Asian cities and countries, ranging from Taiwan (Chiu & Tzeng, 1999), Laos (Sun & Zhang, 2013), Vietnam (Jones et al., 2013; Thuy & Hong, 2019; Nguyen-Phuoc et al., 2024; Truong et al., 2024), China (Zhu et al., 2019; Liu & Lai, 2020), Indonesia (Guerra, 2019; Murtiningrum et al., 2022; Awirya et al., 2023; Balijepalli et al., 2023) and India (Patil et al., 2021), for the obvious reason that they are widely used by the population and the air pollution levels are alarmingly high. One study (Wahab & Jiang, 2019) referred to Ghana (Africa) where the use of M2Ws is on the rise. This paper builds on the discrete choice model that we estimated in the past concerning Italy (Scorrano & Danielis, 2021; Scorrano & Rotaris, 2022), the only European country so far analyzed within this literature.

3. The agent-based model parametrized with a discrete choice experiment

3.1. Model description

We assumed that the e-M2W adoption rate is determined by the decisions made by three types of agents (Fig. 1). M2W buyers evaluate the relative utility of the e-M2W vs. the ICE M2W and decide which one to buy. Their decision is based on the technical and financial features of the M2Ws and on their socio-demographic characteristics. If they opt for an e-M2W, the adoption level increases thus influencing other buyers' decision via indirect experience and word of mouth. Thus, an interaction among individual buyers is incorporated in the model. M2W producers determine the M2W features based on technical development and competitive pressures. Policy makers define the financial incentives and disincentives for e-M2W adoption. A more detailed description of the agents' decision rules and behavior over time follows.

3.2. M2W buyers' purchasing decision

The AB model is centered on the M2W buyers' purchasing decision. We assume that the purchasing decision is based on the utility maximization paradigm, taking into consideration several monetary and non-monetary variables concerning the M2Ws and the buyers' socioeconomic characteristics (Fig. 2). The selection of which variables to include and how to parametrize the decision model is based on the statistical analysis of the experimental data illustrated below. Some of the variables are influenced by external factors (technical progress, adoption level) or other decision makers (M2W producers and policy makers).

Note that the decision of whether to buy a M2W or, alternatively, buy a bike, a car or walk is outside the scope of the model. Neither have we considered the possibility of renting/sharing a M2W or buying a used one. Our focus lies exclusively on simulating the market share of e-M2Ws relative to ICE M2Ws under alternative scenarios.

3.2.1. The discrete choice experiment

Taking stock of a discrete choice methodology, we analyzed buyers' preferences for M2W using a random parameter logit (RPL) model. An individual n is assumed to take into consideration J alternatives in each choice situation t and to choose the alternative with the highest utility. The utility U_{njt} is defined as:

$$U_{njt} = ASC_{nj} + \beta'_{nj}X_{njt} + \gamma'_j Z_n + \varepsilon_{njt} \quad (1)$$

where ASC is the alternative-specific constant, X is the vector of attributes, Z represents the socioeconomic characteristics, β and γ are unknown coefficients. The vector β_n differs across individuals since respondents' tastes are assumed to be heterogeneous. The random part of the utility ε_{nj} is assumed to be independent and identically distributed (IID) extreme value type 1. Defining V_{nj} the systematic part of the utility function and $f(\beta|\varphi)$ the density function of β with φ representing the parameters of the density function, the probability that an individual n chooses j can be calculated as:

$$P_{nj} = \int \frac{e^{V_{nj}(\beta)}}{\sum_j e^{V_{nj}(\beta)}} f(\beta|\varphi) d\beta$$

As this probability is not a closed form, it is simulated for any given value of φ.

The model can be estimated using both revealed preference (RP) and stated preference (SP) data since they have complementary characteristics. RP data represent actual choices; hence, they are useful to estimate market shares and the main determinants of people's real choices but suffer from collinearity issues. Moreover, RP data do not allow to test new alternatives or attributes different from the existing ones. On the

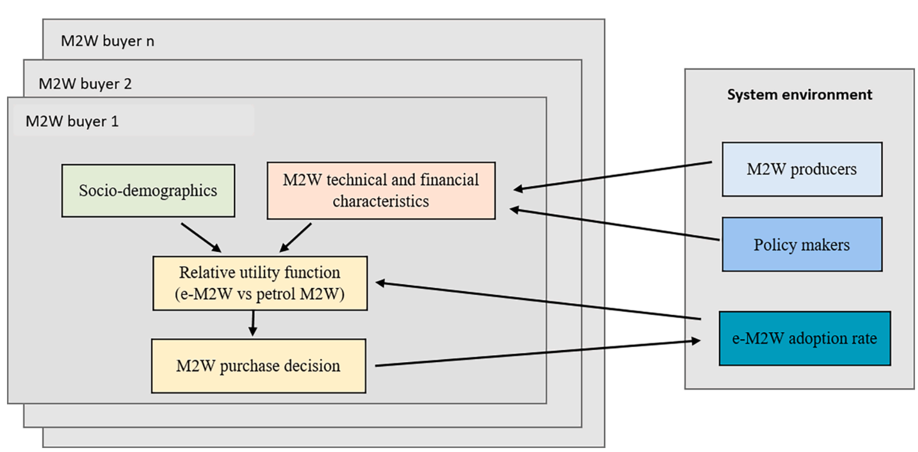

Fig. 1. General overview of the M2W purchase simulation model.

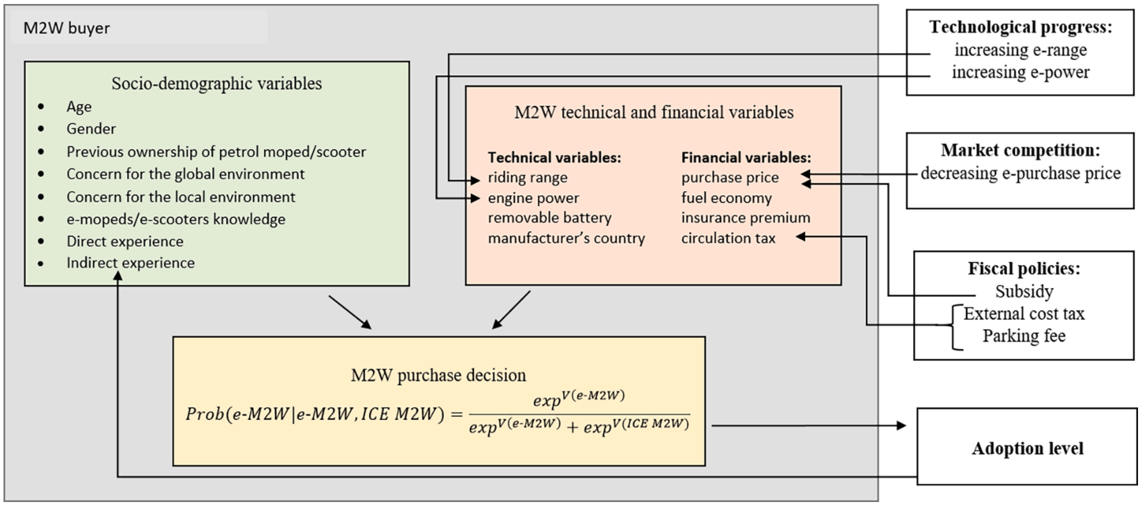

Fig. 2. Illustration of the determinants of M2W purchase decision.

contrary, SP data are collected in controlled experiments, thus allowing the researcher to define the attributes of the choice alternatives. SP data, however, suffer from the hypothetical bias. Combining both data types have been proposed in the literature to exploit their pros and minimize their cons (Bhat & Castelar, 2002). Technically, the joint estimation takes place by 'scaling' the utility function.

We performed a discrete choice experiment via a web-based questionnaire administered to a representative sample of Trieste (Italy) population in November 2020-February 2021. We collected 708 questionnaires. A detailed description of the questionnaire can be found in Scorrano & Rotaris (2022). In the first part, we asked respondents socio-demographic information, including gender, age, profession, educational level. The sample composition is illustrated in Table 1.

We asked information about respondents' actual M2W ownership and collected data about the main characteristics of the M2W owned (propulsion system, purchase year, price, range, power, etc.). The revealed preference data show that our sample bought mostly ICE M2Ws. Over 282 respondents with a M2W, 272 chose an ICE M2W and only 10 an electric one.

In the second part of the questionnaire, we asked respondents to state their choice between an e-M2W and an ICE M2W in 10 hypothetical scenarios. The alternatives consisted of the following attributes: manufacturer's country, purchase price, fuel cost, insurance premium and annual circulation tax, maximum riding range, engine power, and removable battery. An example of a choice scenario is depicted in Fig. 3. An efficient design was developed using the Ngene software (Bliemer & Rose, 2011).

In the third part, we asked respondents about their knowledge of e-M2Ws, their previous experience with them and their attitudes and beliefs about the environment. We measured respondents' knowledge with a composite indicator, by merging the scores of the questions examining subjective and objective level of knowledge and considering an equal weighting of the two components. We considered both respondents direct and indirect (via friends/acquaintances) experience with riding e-M2Ws. We then investigated respondents' concern for the environment by asking their level of dis/agreement with 11 statements. We were able to identify two indicators for environmental concern, at local and global level, based on the results of a factor analysis. Details can be found in Scorrano & Rotaris (2022).

Finally, we estimated the RPL model with the Apollo package in R (Hess & Palma, 2019). Table 2 reports the estimates obtained. The vehicle attributes' parameters are statistically significant and have the expected sign. The ASC electric signals that, *ceteris paribus*, respondents assign a negative utility to e-M2Ws. Increasing riding range and engine power increases utility. Note that the coefficient of e-M2Ws range is 6 times larger than that of the ICE one. An increase in purchase price, fuel economy, and insurance premium plus circulation tax negatively affects utility. The possibility of removing the battery is positively valued, in line with Huang (2015). In addition, respondents assign a larger utility to "made in Europe" M2Ws with respect to those "made in China".

Gender differences have no influence. This finding is in line with Eccarius & Lu (2019) who found gender conflicting evidence. With regards to age, 21–35 years old respondents assign a higher utility to e-M2Ws. ICE M2Ws' owners are less inclined to buy an e-M2W. These findings signal hysteresis and adversity to change.

Both indicators of environmental awareness have the expected sign, but only the parameter of the concern for the local environment was compatible with the data. E-M2W knowledge and previous direct experience with e-M2Ws do not seem to affect in a significant way the utility associated with e-M2Ws, while indirect experience plays a positive and statistically significant role.

As a results of the experiment, we parametrized the AB model

Table 1
Sample composition.

		Of which			M2W ownership		Gender	
Age Class	%	students	employed	pensioners or other	No	Yes	Female	Male
14–19	25.5 %	23.7 %	1.6 %	0.2 %	51.8 %	48.2 %	45.5 %	54.5 %
20–29	31.1 %	22.0 %	9.1 %	0.0 %	48.5 %	51.5 %	41.0 %	59.0 %
30–39	9.3 %	0.0 %	8.8 %	0.5 %	25.0 %	75.0 %	27.5 %	72.5 %
40–49	14.1 %	0.0 %	13.2 %	0.9 %	14.8 %	85.2 %	32.8 %	67.2 %
50–59	12.3 %	0.0 %	11.6 %	0.7 %	11.3 %	88.7 %	22.6 %	77.4 %
60–69	6.7 %	0.0 %	3.7 %	3.0 %	6.9 %	93.1 %	17.2 %	82.8 %
70–79	0.5 %	0.0 %	0.0 %	0.5 %	0.0 %	100.0 %	0.0 %	100.0 %
80–89	0.5 %	0.0 %	0.0 %	0.5 %	0.0 %	100.0 %	0.0 %	100.0 %
Total	100.0 %	45.7 %	48.0 %	6.3 %	34.6 %	65.4 %	35.5 %	64.5 %

Attributes	Seated e-M2W	Seated ICE M2W
Manufacturer's country	China	Europe
Purchase price	€4,000	€3,500
Fuel cost (€/100 km)	€0.6	€5.5
Insurance premium + circulation tax	€125	€300
Max riding range	100 km	300 km
Engine power	7 kW	3 kW
Removable battery	Yes	
YOUR CHOICE	□	□

Fig. 3. Example of a choice task.

Table 2
RP/SP RPL estimates.

	Estimate (Std. Err)
ASC electric (relative to ICE)	−3.795*** (1.346)
SD of ASC electric	1.31*** (0.404)
Purchase price (€ 1000)	−0.859*** (0.267)
SD of Purchase price	0.499*** (0.158)
Riding range e-M2Ws	2.253*** (0.725)
SD of Riding range e-M2Ws	0.031 (0.278)
Riding range ICE M2Ws (100 km)	0.352*** (0.135)
Fuel economy (€/100 km)	−0.168** (0.07)
Engine power (kW)	0.192*** (0.062)
SD of Engine power	0.177*** (0.056)
Insurance premium + Circulation tax (€)	−0.322*** (0.111)
Removable battery (Yes = 1, No = 0)	0.482*** (0.183)
SD of Removable battery	0.505** (0.251)
Manufacturer's country (Europe = 1, China = 0)	0.463*** (0.151)
SD of Manufacturer's country	0.507*** (0.175)
SP-to-RP scale	1.021*** (0.322)
Socio-demographics	
Gender: Male (vs. Female)	0.008 (0.182)
Age: 21–35 years old (vs. under 21)	0.638** (0.29)
Age: 36–55 years old (vs. under 21)	0.132 (0.224)
Age: over 55 years old (vs. under 21)	0.131 (0.282)
ICE M2W owner	−0.817** (0.323)
Attitudes and perceptions	
Concern for the global environment	0.001 (0.169)
Concern for the local environment	0.627** (0.247)
e-M2W knowledge	0.011 (0.172)
Indirect experience	0.408* (0.255)
Direct experience	0.185 (0.288)
Model diagnostics	
N. of individuals	431
N. of observations	4383
LL (0)	−3038.06
LL (final, whole model)	−2305.87
LL (RP)	−30.04
LL (SP)	−2272.31
Adj. Rho-square (0)	0.2325
AIC	4663.73
BIC	4723.28
Estimated parameters	26

Note: Statistical significance at 1 % (***), 5 % (**), 10 % (*).

assuming that agents' utility function differs depending on their age, previous ownership of ICE M2W, concern for the local environment and indirect experience, that is, all variables that have proven significant in our econometric analysis (Table 2). We excluded from the AB model variables such as gender, concern for the global environment, e-M2W knowledge, and direct experience, for which we cannot exclude that a zero coefficient lies within the confidence interval. We made such a simplifying assumption although it might be regarded as problematic since having a p-value higher than 0.05 does not imply that the variable is not relevant (Amrhein et al., 2019).

3.3. The M2W producers

The M2W producers are key actors of the system environment. They define the producing strategies and incorporate technical innovations in their products. Importantly, they set the relative M2W prices and promote commercial policies responding to the competitive pressures. At this stage of our AB model, their decision-making process is not explicitly modelled. We assumed that they pass on to the consumers the technical progress concerning engine power, battery range and prices assumed in the simulation scenarios described below.

3.4. The policy makers

The policy makers are another key actor of the system environment. They define the incentives and disincentives which influence the buyers' decisions. Among these, subsidies, registration taxes incorporating the external costs and parking fees play a major role. Similarly to M2Ws producers, we opted not to explicitly model their decision-making process. However, in the scenarios analysis we tested the impact of the implementation of these policies on the e-M2W share.

3.5. Agents' interaction

Agents' decisions have an impact on the other agents. As just described, the decisions taken by policy makers and M2W producers influence buyers' purchase. Most likely, buyers' reaction will affect M2W producers. For instance, if they buy more e-M2Ws, producers will increase their investments. If they positively react to subsidies or to the relative tax changes, politicians will enjoy a higher political constituency. At this stage of our modeling, these interactions are not explicitly established. The main interaction that is taken into account in the model is that within the buyers. The experimental results provided us with evidence that the agents' utility function is positively correlated with the indirect experience: an increase in the number of e-M2Ws increases the probability that e-M2Ws would be chosen. Such a variable generates an interaction between the agents' choices and an inter-temporal link between different states of the model.

4. Model implementation

The model is implemented using the Anylogic software, a multi-method simulation modeling tool developed by The AnyLogic Company supporting agent-based, discrete event, and system dynamics simulation methodologies.

4.1. Market identification: Mopeds and scooters

The M2W market is not univocally identified. Across statistical sources and scientific papers, the same term might contain different types of vehicles. Since two-wheelers also include bikes, some authors consider electric bikes as a subgroup of M2Ws (e.g., Eccarius & Lu (2019)). On the contrary, the World Health Organization (WHO) in its annual publication of the "Global status report on road safety" does not include electric bikes in their M2W registration data because they lack public registration requirements. Similarly, China legally classifies electric bikes as non-motor vehicles (Eccarius & Lu, 2019).

Another distinction is between M2Ws with an engine capacity below 50 cc and speed limit up to 45 km/h (categorized as L1 by the United Nations Economic Commission for Europe) and M2Ws with an engine capacity of over 50 cc and no speed limit (categorized as L3). The former are called pedelecs or mopeds. Pedelecs, less common than mopeds, are motor-propelled and are equipped with pedals. Mopeds are subject in different countries to different use conditions. In some European countries (e.g., Greece), they are not subject to registration and insurance, hence, it is difficult to quantify their number. On the contrary, in Belgium the registration of mopeds is mandatory since 2014 (Dorocki & Wantuch-Matla, 2021). In Italy, since 2012 mopeds are required to have a permanent number plate, but they are not registered with the Public Car Register. M2Ws with an engine capacity of over 50 cc can be further classified by engine size. In Italy, the main statistical bodies (ACI) and professional associations (ANCMA and UNRAE) use the term scooter (scooter, also in Italian) when the engine displacement is between 50 cc and 125 cc; and the term motorcycle (moto, in Italian) when the engine displacement exceeds 125 cc.

Classifying M2Ws became even more complex with the advent of alternative powertrains, such as liquefied petroleum gas, compressed natural gas, hybrid electric, plug-in hybrid and especially electric ones (have no combustion engine). Nonetheless, it is common practice, at least in Italy, to define a M2W an e-moped if the electric motor has up to 4 kW of power, an e-scooter when the electric motor has between 4 and 10 kW of power, and an electric motorcycle when it exceeds 10 kW of power. Note that throughout the paper we will use the term e-scooter to refer to the seated e-scooter (see Fig. 5) and not the increasingly popular standing e-scooter.

In this paper, we take the view that for market analysis it is useful to distinguish between mopeds, scooters, and motorcycles. In fact, from the point of view of the user, they are different products with different characteristics (summarized in Table 3) and, consequently, only partially overlapping market segments. Mopeds tend to be used mainly for short, low speed urban trips. Scooters are used both for short urban trips, with one or two passengers, and for medium distance, extra-urban trips. In Italy, scooters are not allowed to enter the Italian toll highways. On the contrary, motorcycles suffer no limitations; they are used both for commuting and for leisure, representing a useful means of transport for riding in the countryside and in the mountains.

This paper focuses only on the first two market segments: mopeds and scooters, since several electric compelling versions of mopeds and scooters have been in the market for at least 4–5 years. Electric motorcycles, on the contrary, do exist but they are still in their early phase. Another reason is that mopeds and scooters represent the largest share of M2Ws in city traffic, thus contributing the most to urban quality issues. Fig. 4 and Fig. 5 present a picture of the best-selling mopeds/scooters for each powertrain in Italy.

Table 3 illustrates some key characteristics of the two products. It can be observed that mopeds are lighter, have a smaller engine than scooters, but are characterized by lower range and lower top speed. Comparing across the two powertrains, on average e-mopeds still have higher acquisition costs than ICE mopeds (about one thousand euros more), although they have half the riding range, and less power. The maximum speed, however, is the same across powertrains since it is set by law.

The comparison is even less favorable for e-scooters relative to ICE scooters. In fact, they cost twice as much (about two thousand euros more), have similar or higher weight (because of the battery pack), have half of much riding range, and less power. In terms of acceleration, e-mopeds/e-scooters, having immediate torque, have an initial advantage: they accelerate faster at traffic lights but are overtaken by ICE mopeds/scooters after some meters. E-mopeds/e-scooters have usually three riding modes; in the sport mode their performance is comparable with ICE mopeds/scooters but at the cost of much lower riding range. Similar to electric cars, they enjoy regenerative breaking.

Overall, it seems fair to conclude that, for the time being (as of December 2024), neither e-mopeds nor e-scooters are technically or economically superior to their ICE counterparts. Consequently, it is not surprising that both still have a low market share in Italy (Fig. 6).

However, there is also a considerable difference in market share between the two types of e-M2Ws. Since they appeared in the market, e-mopeds enjoyed a growing interest reaching a market share of up to 25 % after the Covid pandemic. E-scooters are also gaining acceptance but at much lower market shares. Only in 2022, they peaked to about 15 %. The difference between the two market segments motivated us to examine their market prospects in a separate manner. Consequently, we opted for validating and implementing the AB model by treating the two products as separate. As a result of this choice, the implemented AB model comprises the coefficients of the utility functions deriving from the choice experiment referring to M2Ws in general, while the exogenous variables (price, engine powers, range, etc.) are market segment-specific, i.e. differentiated between mopeds and scooters. Admittedly, it is a second best solution: segment-specific coefficients would be the best choice. Such an improvement is left for future research.

4.2. Model validation

The validation of an AB model is a challenging task. Since our model is based on the random utility model, it should pass the test of conceptual validity (Knepell & Arangno, 1993) and macro-face validity (Rand & Rust, 2011). If dataset is representative of the population, it should also stand the test of empirical input validation (Rand & Rust, 2011) and data accuracy and adequacy (Knepell & Arangno, 1993).

As requested in the literature, the results of our model need to be history-friendly (Fagiolo et al., 2006). It can be seen in Fig. 7 that the model predictions reproduce accurately the observed data for both e-mopeds and e-scooters, thus results are in line with the empirical evidence.

Cross-model validation (Knepell & Arangno, 1993; Carley, 1996) is guaranteed since we compared the results of the AB model with those

Table 3
Definition based on technical characteristics in the Italian market.

	ICE moped	E-moped	ICE scooter	E-scooter
Fuel/energy	Petrol	Electricity	Petrol	Electricity
Price range (€)	990–2,499	1,990–3,190	2,340–4,899	4,490–7,450
Engine displacement	49–50 cc		51–125 cc	
Weight (kg)	84–104	72	106–134	115–197
Battery (kWh)		1–2.7		2.7–6.2
Certified Range (km)	194–300	40–100	240–320	110–150
Power (kW)	2.1–3.5	1.2–1.9	6.5–12.4	4–10
Maximum speed (km/h)	45	45	90–98.7	90–130
Emissions	Euro 2-Euro 5	–	Euro 2-Euro 5	–

Fig. 4. The 2023 best-selling ICE moped (Piaggio Liberty 50 cc) and ICE scooter (Honda Italia SH125) in Italy.

Fig. 5. The 2023 best-selling e-moped (Askoll, ES1) and e-scooter (Jonway MJS-e) in Italy.

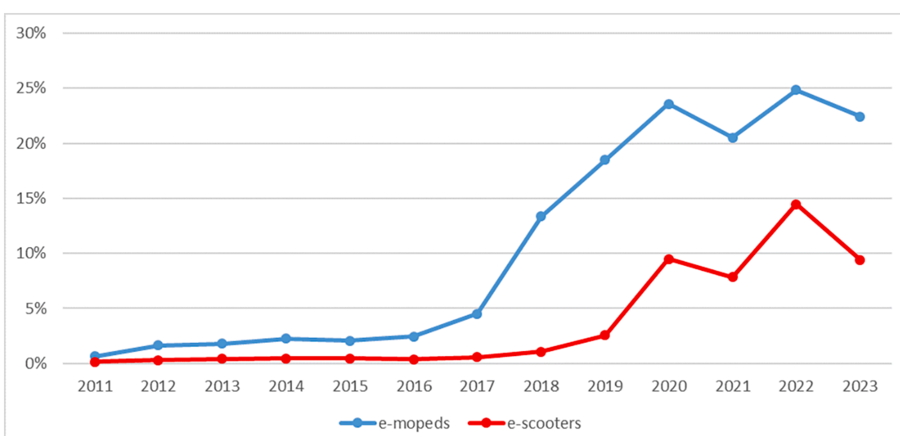

Fig. 6. Market trends for e-mopeds and e-scooters in Italy.

obtained using only the discrete choice modelling and found comparable results.

5. Scenario analysis

The validated model is used to simulate e-mopeds and e-scooters uptake in the scenarios described in Table 4.

5.1. Scenario assumptions

5.1.1. Technological progress

Battery costs have been rapidly declining in the last decade driven by improvements in cell chemistry, process technology and the increase of production scale. The question is whether they will continue to do so and by how much in the next decade. Since battery costs are considered the key enabler for the market breakthrough for many battery-powered products, various studies have been published attempting to predict future cost for lithium-ion, solid-state, lithium–sulfur and lithium–air batteries. Mauler et al. (2021) identified four main approaches: technological learning, literature-based projections, expert elicitations, and bottom-up modelling. They were able to extract 360 data points that predict a pack cost trajectory that reaches a level of about 70 $/kWh in 2050 and 12 technology-specific forecast ranges that indicate cost potentials below 90 $/kWh for advanced lithium-ion and 70 $/kWh for lithium-metal based batteries.

These estimates refer to battery cost in general, without reference to

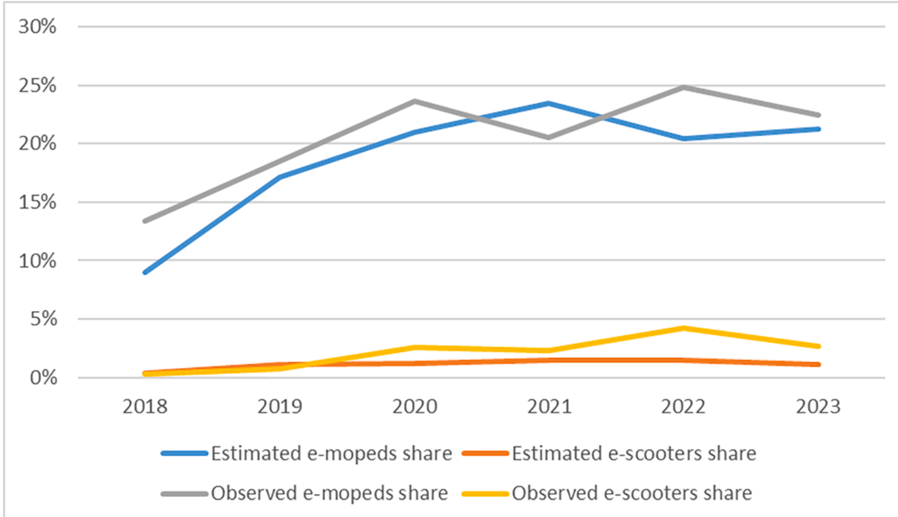

Fig. 7. Observed vs estimated e-mopeds and e-scooters market shares.

Table 4
Scenario description.

Scenario	Market competition	Technological progress	Subsidies	External cost tax	Parking fees
S1: Current scenario	Yes	Yes	Yes	No	No
S2: No subsidies	Yes	Yes	No	No	No
S3: External cost tax	Yes	Yes	No	Yes	No
S4: Parking fee	Yes	Yes	No	No	Yes
S5: Full cost internalization	Yes	Yes	No	Yes	Yes
S6: Maximum incentive	Yes	Yes	Yes	Yes	Yes

specific applications. However, Rokadiya et al. (2021) underlined that the smaller e-M2W pack poses fewer assembly challenges (fewer cells and simpler, lighter hardware). They projected a price reduction from 150 $/kWh in 2020 to 75 $/kWh in 2030.

The drop in battery cost should translate into larger batteries and longer riding range. Differently from electric cars, we are not aware of any paper or website that has tracked the variation of e-mopeds/e-scooters riding range over time. Hence, we collected data concerning two large companies: Niu Technologies and Askoll Italia. Niu Technologies is headquartered in Beijing, China, and was founded in 2014. It is one of the largest e-scooter producers in China, it had a total revenue of almost $500 million in 2022 and is listed on the NASDAQ stock exchange. Askoll EVA S.p.A. is the most successful Italian manufacturer of e-M2Ws for urban mobility so far, with a total revenue of €9 million in 2023. In Fig. 8 and Fig. 9, we present the evolution of range and engine power characteristics of their main models over time. A tendency can be observed to equip their models with more powerful electric engines and larger batteries allowing longer ranges. Also judging from their websites and video presentations, companies balance out the need for nippier and more powerful vehicles, able to ride longer ranges while at the same time keeping cost under control. In addition, manufacturers work on several other design and technical characteristics such as breaks, lighting, regenerative braking, electronics, connectivity, app control, trunk capacity, and the position of the battery in the scooter (under the seat or under the floor).

On the basis of the above observations, we assumed that e-mopeds/e-scooters will have in 2030 a riding range of 110/143 km from the 2021 average value of 70/100 km (Fig. 10). It is a large improvement that, however, will be still well below the current range of ICE mopeds/scooters (264/300 km). Concerning power, we assumed that e-mopeds/e-scooters will have in 2030 an engine power of 2.2/9 kW, up from the 2021 average values of 1.6/6.6 kW, reaching the levels of the alternative counterparts.

5.1.2. *Purchase price*

We assumed that the average MSRP of e-mopeds and e-scooters drops

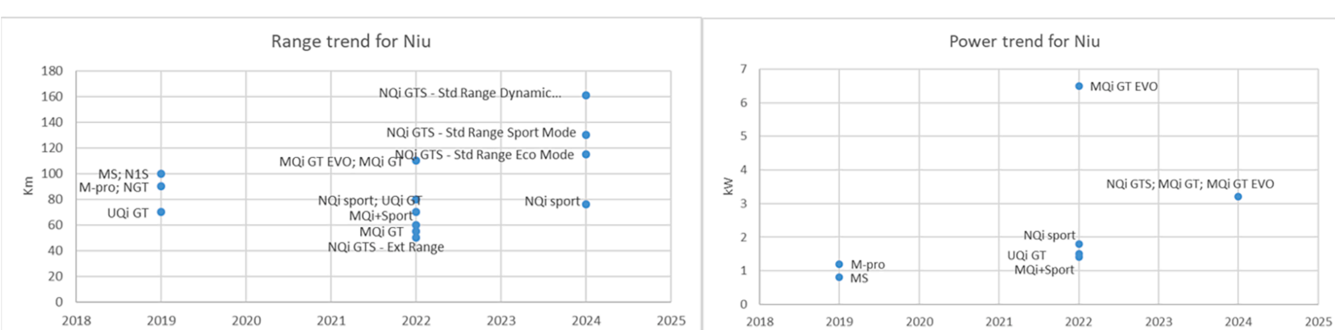

Fig. 8. Increasing range and power of NIU e-mopeds/e-scooters.

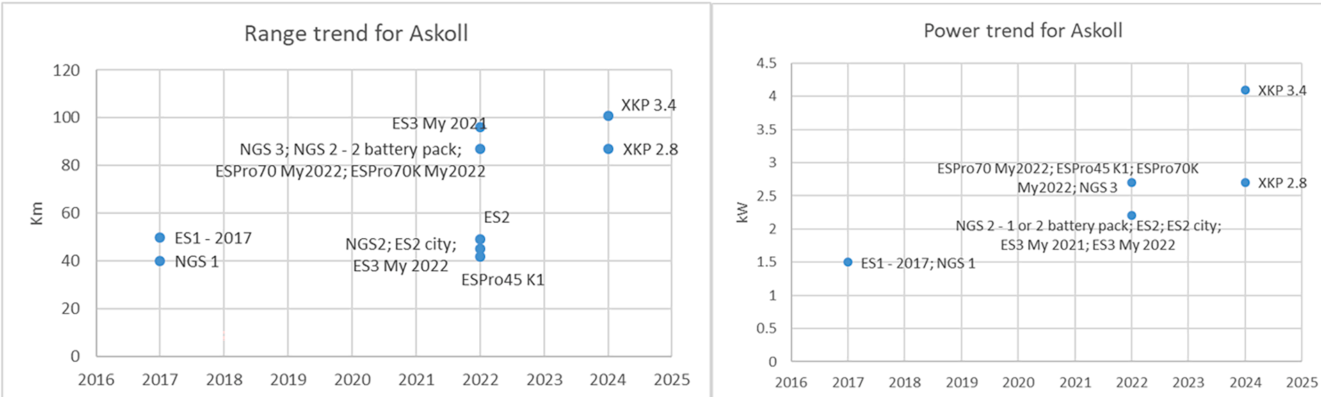

Fig. 9. Increasing range and power of ASKOLL e-mopeds/e-scooters.

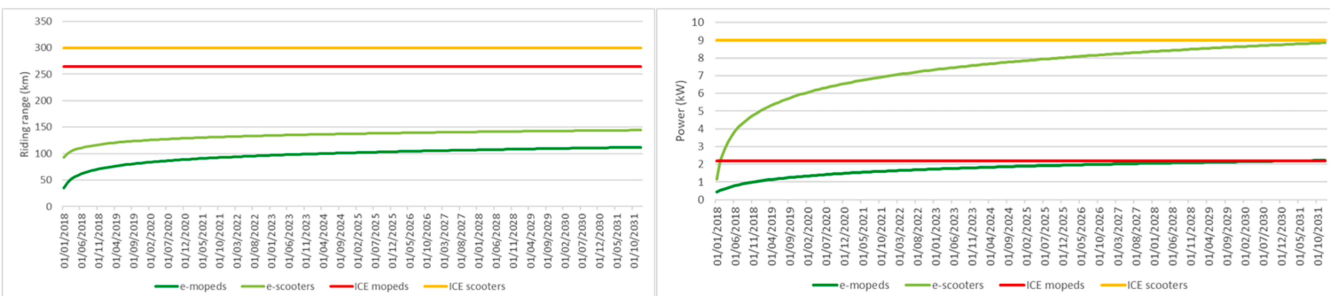

Fig. 10. Trend in the riding range and power for mopeds and scooters.

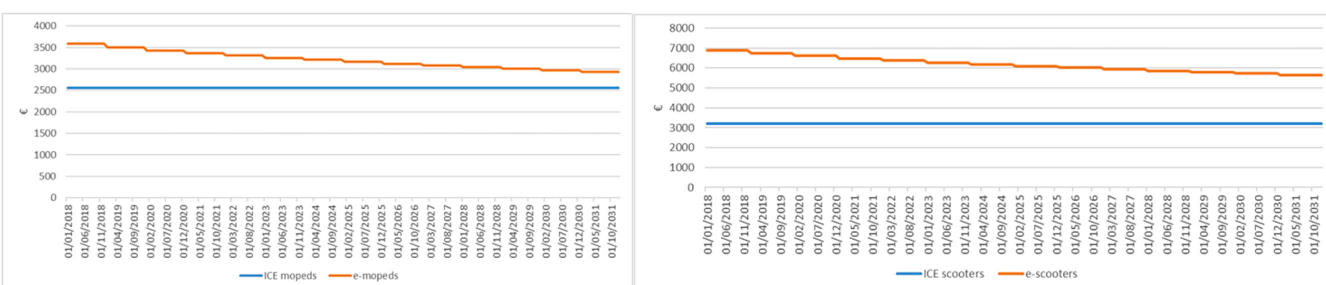

Fig. 11. Trend in the MSRP for mopeds and scooters.

from the 2021 values of €3,600 and €6,899 to €2,934 and €5,649 in 2030, respectively (Fig. 11).

Such an assumption is based on the recent literature. More specifically, Rokadiya et al. (2021) estimated for the electric motorcycles and scooters manufactured in India a potential price decrease of 50–60 % in the decade 2020–2030 thanks to the increase in manufacturing volumes. However, since in India they are currently 3 to 5 times higher than the conventional ones, in 2030 they will still be higher depending on the battery size. E-scooters with a 75 km driving range will cost 39 % more, those with 250 km of range will be 96 % more expensive.

In Italy, we observed that the current price gap is lower. In 2021, e-mopeds were about €1,000 more expensive to buy (disregarding subsidies) than ICE mopeds (€2,560 vs €3,600). We assume that the price gap will slowly decrease to €400 in 2030, without reaching price parity. Regarding e-scooters, in 2021 they were twice as expensive (€6,899 vs €3,200). We assume that in 2030 e-scooters will still be 78 % more expensive than ICE scooters.

Table 5
Subsidies for e-M2Ws.

	e-M2W with scrapping	e-M2W without scrapping	ICE M2W with scrapping
2019–2021	40 % of MSRP (up to €4,000)	30 % of MSRP (up to €3,000)	–
2022onwards	40 % of MSRP (up to €4,000)	30 % of MSRP (up to €3,000)	40 % of MSRP (up to €2,500) + 5 % retailer discount

5.1.3. *Subsidies*

The Italian government provided financial incentives for buying a motorcycle since 2019. As illustrated in Table 5, in the years 2019–2021, subsidies were granted only to e-mopeds/e-scooters, at an increasing amount in case of scrapping of the old ones. In 2022, the new government decided to subsidize also the ICE ones, provided that the old mopeds and scooters were scrapped. The change in the policies was motivated by the principle of technological neutrality and the need to scrap the old and highly polluting mopeds and scooters.

In our scenario analysis, we assumed that 2022 subsidies are maintained up to the year 2030.

5.1.4. External costs

External costs of transport refer to the difference between social costs and private costs of using a motorcycle. Internalizing these costs, they become part of decision-making process of transport users. This can be done via fiscal instruments.

We derived the estimates of external costs of the motorcycles for Italy from the "Handbook on the external costs of transport", prepared for the European Commission and containing estimates at country level. Such estimates are based on a variety of methodologies including the damage cost approach, the avoidance cost approach, the replacement cost approach, the willingness to pay of individuals to (partly) avoid the damage or the willingness to accept the damage. They considered various types of externalities associated with air pollutants and gases, noise, accidents, congestion, and habitat damage. Table 6 reports their estimates for the average costs associated to each externality.

It can be seen that the highest costs, by far, are those associated with noise and safety. A motorcycle travelling an average daily distance of 5 km for 360 days a year causes a total annual external cost equal to €412.2 if ICE and €239.04 if electric. We assumed that the regulator imposes such a cost as an external cost tax, to be paid annually as the circulation tax.

5.1.5. Parking fee

Currently, in Italy as in many other countries, M2Ws' users do not pay for parking along the curbsides. We assume that, following the recent introduction of a M2W parking fee in Paris, Italy could adopt a similar policy. In fact, starting from September 1st, 2022 Paris introduced a fee to park in the 42,000 spaces dedicated for two-wheeled vehicles, with another 4,000 to be created as part of the scheme. M2W users need to subscribe to a residential package, adjusted rates or get free parking for electric vehicles. The rates change depending on the district. Residents can subscribe a subscription scheme at a cost of €22.50 a year. Membership of this scheme entitles users to park their M2W on the street at a cost of €0.75 per day or €4.50 per week. Different rates apply to nonresidents or visitors. Rates vary by arrondissement. In our scenario analysis, we operationalized the parking fee as annual fixed cost, similarly to the circulation tax. The maximum annual parking cost for a resident is set equal to €256.5 per year (€22.50 registration fee plus €0.75 per day, six days a week). To account for the variety of individual cases, we assumed a triangular distribution ranging from 0 to €256.5, with a mode equal to half of the maximum annual parking cost.

Another city that imposed a parking fee on motorcycles is Stockholm City. The city introduced a parking fee in April-May 2018 with a cost of €0.50 – €1 per hour in the different zones, imposing a cost up to €2,000 per year for each vehicle owner who chooses to commute with a powered two-wheeler to make the everyday journey to work. With the onset of the pandemic, however, the decision was made to allow M2W designated parking spaces to be used without charge.

Table 6
External costs – Average costs (€-cent per vkm) in Italy.

Type of externalities	ICE motorcycles	Electric motorcycles
Air pollution cost (tank-to-wheel)	1.42	0.02
Air pollution cost (well-to-tank)	0.57	0.16
Climate change	0.87	0.00
Noise cost	13.64	6.81*
Accident cost	6.16	6.16**
Congestion	0.00	0.00
Habitat damage	0.25	0.12*
Total	22.90	13.28

Source: EU (2019) – Handbook on the external costs of transport.
*Authors' assumption: electric motorcycles cause a noise equal to 50 % of the ICE ones.
*Authors' assumption: accident costs for electric motorcycles are equal to those of ICE ones.

5.2. Simulation results

As illustrated in Table 4 all scenarios are estimated assuming technological progress and purchase price reductions for e-mopeds/e-scooters only, whereas the technical and economic characteristics of ICE mopeds/scooters are kept constant. The impact of the envisage scenarios on the e-mopeds/e-scooters is illustrated in Fig. 12 and Fig. 13.

In the current scenario (S1), our model predicts that e-mopeds reach a 27.9 % market share in 2030, while e-scooters only 2.6 % market share. The drop of the market share between 2021 and 2022 is due to change in the subsidy regulations described in Section 5.1.3. Hence, there is an increase from the 2021 values of 20.5 % and 2.3 % but very limited. Concerning e-mopeds, the main reason for the limited uptake is the limited range (half as much as ICE mopeds), notwithstanding the upfront cost and power parity and the advantage in terms of operating costs. With regards to e-scooters, the very poor uptake is associated both with the differences in riding range and purchase price, that is not offset by the current subsidies.

Without subsidies (S2), our model predicts that in 2030 e-mopeds would reach a 21.1 % market share, while e-scooters 1.4 % market share, implying that the impact of the current Italian subsidies is positive but rather limited: 6.8 % for e-mopeds and 1.2 % for e-scooters. We believe that this result is in line with the empirical evidence about the Taiwanese experience reported by Eccarius & Lu (2019). They wrote that the Taiwan authorities introduced subsidies as early as 1998, reducing the e-M2W price at levels comparable to ICE M2Ws. However, "the uptake was slow for many years due to riders regarding e-M2W performance as inferior to M2Ws, lack of convenience and other complaints."

A tax equal to the external costs, as a policy approach alternative to subsidies, captured by S3, would generate a 28.7 % market share for e-mopeds and 2 % for e-scooters. The application of a parking fee on ICE mopeds and scooters (S4) without subsidies would generate a market share for e-mopeds and for e-scooters of 26.2 % and 1.9 %, respectively. The indication is that these various policy instruments generate similar market shares.

The combination of these instruments would increase e-M2Ws' market share. Scenario 5 "Full cost internalization" envisages the adoption of a parking fee on ICE mopeds and scooters and the introduction of a tax equal to the external costs. Their combined effect would increase the market share for e-mopeds to 35.4 % and that of e-scooters to 2.8 %. Adding the current subsidies to the policies into a "Maximum incentive" scenario (S6) would further push their market share to 44.2 % and 5.5 %.

6. Conclusions, policy implications and study limitations

E-M2Ws could improve air quality and reduce noise in densely populated areas. However, presently, in most countries, including Italy, they enjoy a quite limited market share. The AB model parametrized with a discrete choice experiment presented in this paper simulates the e-M2Ws' uptake under alternative scenarios. Although the choice experiment was performed in 2020–21 with reference to e-M2Ws in general, we thought worthwhile to distinguish between two markets segments, e-mopeds and e-scooters, since they exhibit in Italy quite different market penetration levels.

The scenario analysis indicated that, under the most likely technological and price trends, the current subsidy structure (S1) alone is not able to generate a significant market uptake for e-mopeds and e-scooters. Subsidies had a positive impact in helping e-mopeds to gain a reasonable market share (also thanks to M2W sharing (Scorrano & Danielis, 2021)) and e-scooters to enter the market. However, they need to be coupled with other policy instruments to generate a higher impact on the M2W market. The Italian specificity is that subsidies are granted to both e-M2Ws and ICE M2Ws. Such an approach should be revised if the aim is to capitalize the noise and environmental benefits that e-

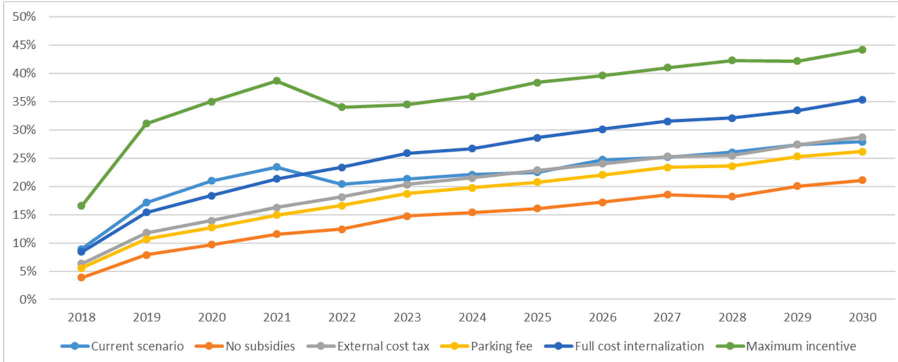

Fig. 12. E-mopeds uptake under alternative scenarios.

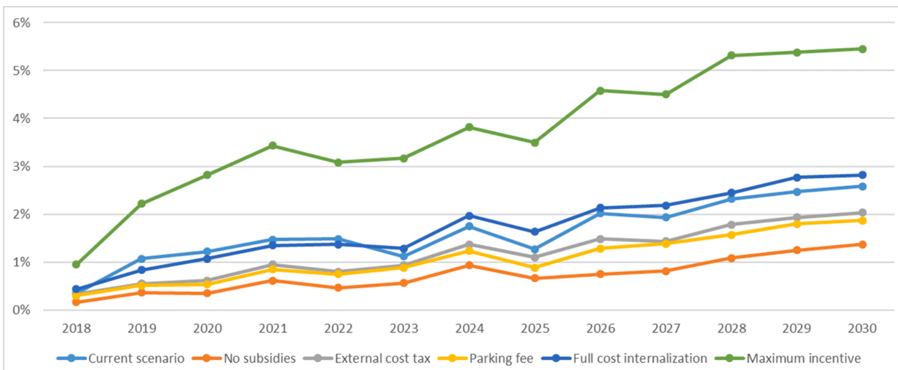

Fig. 13. E-scooters uptake under alternative scenarios.

mopeds/e-scooters could produce.

However, since subsidies are costly for the public budget and might not be sustainable over time, a tax internalizing the external costs caused by the mopeds/scooters might be considered and proved effective in our simulation (S3). Taxes can be levied as a purchase tax, thus altering the relative upfront costs, or during the use phase of the vehicles either as circulation tax or a fuel tax. The pros and cons of these instruments are well understood from the economic point of view (Parry & Small, 2005), while their political acceptability remains a considerable obstacle.

The simulations have also demonstrated the effectiveness of differentiated parking fees (S4) that could be considered and gradually introduced in many cities and localities, following the experiences of Stockholm and Paris. Again, the issue is not so much the effectiveness and implementation, but the political acceptability. An alternative tool to the fiscal one, probably less controversial in terms of acceptance, is the use of regulatory policies to promote e-M2Ws. An example is the use of preferential access to limited traffic zones, zero emission areas or reversed bus lanes, as implemented in London and in Vienna (Dorocki & Wantuch-Matla, 2021), and similarly to the approach used to promote electric cars. In Milan, when pollution levels exceed the European standards, ICE M2Ws are prohibited from circulation, while electric ones are allowed. These regulations would send a signal to both manufacturers and consumers spurring the adoption of e-M2Ws. Another potentially powerful regulatory tool would be to allow e-mopeds access to the cycling lanes, similarly to electric bikes, but carefully regulating the permissible speed. Dorocki & Wantuch-Matla (2021) quoted experiences in Iceland, Denmark, and in the Netherlands.

When combining these tools (S5 and S6), we found that e-mopeds could achieve in 2030 a market share of up to 45 %. On the contrary, in the scooter segment, that in Italy is 10 times larger than the moped one, e-scooters have grim prospects under most of the simulated scenarios, achieving in 2030 a maximum of 5 % of the market share. We believe that only dramatic improvements in battery technology, enhancing the mass and volume energy density, at constant or declining costs could lead e-scooters to exit their status of a niche market, unless draconian policy mandates are possible.

As all empirical studies, our simulations do not consider all relevant aspects and suffer limitations.

A first group of disregarded variables concerns the discrete choice model and the application of the choice criterion in the AB model. The advantage of the discrete choice approach is the possibility to consider both monetary and non-monetary variables and their relationship with the socio-economic determinants of the potential buyers. We have been able to specify some of them (purchase price, engine power, riding range, removable battery, and location of the manufacturers). However, other variables do probably play a role in determining the buyer's choice. They include maximum speed, weight, maintenance, refueling time, noise, trunk capacity after accommodating the battery pack, digital control display, and remote control via GPS. These unspecified variables are captured in our model in the alternative specific constant, which proved to be statistically negative. It means that, overall, they negatively influence users' acceptance of e-mopeds/e-scooters. However, new surveys might consider their relevance in more detail.

A simplifying assumption of the AB model is that the agents' estimated preference structure does not change until 2030, resulting in a potential underestimation of the e-M2Ws' uptake.

A second set of disregarded variables concerns the exogenous variables. In addition to those already included in the model (age, previous ownership of ICE moped/scooter, concern for the local environment and indirect experience), other variables might play a role. These might comprise the distance of the trip, weather conditions, hilly streets, and the parking availability.

We plan to tackle some of these issues in a future research project. In addition, since e-mopeds and e-scooters have different characteristics and market prospects, the use of separate questionnaires might be needed. Next, it would be useful, although quite challenging, to model the demand–supply interaction and the competition among manufacturers. It entails extending our AB model by explicitly modelling and parametrizing the interaction among M2W buyers, producers and policy makers, disregarded in our current model as described in section 3.6. A further aspect worth investigation is the impact of a swappable battery network, like the one already introduced by Gogoro in several Taiwanese cities.

CRediT authorship contribution statement

Mariangela Scorrano: Writing – review & editing, Writing – original draft, Software, Methodology, Formal analysis, Data curation. **Romeo Danielis:** Writing – review & editing, Writing – original draft, Validation, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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