Modelling the adoption intention and installation choice of an automotive after-market mild-solar-hybridization kit

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ABSTRACT

Despite the recent commercial success of hybrid, plug-in hybrid and electric vehicles their market share is still insufficient to produce either a significant impact on energy consumption on a global basis or a profitable automotive segment. In this context, the possibility of upgrading conventional vehicles to hybrid electric vehicles is gaining increasing interest.

To this aim this paper investigated and modelled the intention to install an after-market hybridization solar-kit (HySolarKit) in order to ascertain the main behavioural determinants of the choice process and set up an operational model with which to estimate the market potential of such technology. In particular, two behavioural stages of the choice process were analysed and modelled: (i) the intention to adopt the HySolarKit; (ii) the choice to install the HySolarKit. Both issues were addressed through ad hoc stated preference surveys carried out in two different Italian cities, and through the specification and the calibration of discrete choice models based on the behavioural paradigm of random utility theory. Different modelling solutions (homoscedastic and heteroscedastic) were compared in terms of goodness-of-fit and sensitivity to level-of-service attributes. The results showed the technological potential of the HySolarKit, and that both behavioural stages may be effectively modelled through random utility theory. Estimation results allowed an interpretation of the main determinants of the investigated phenomena, making it possible to quantify the potential effects and the concerns towards such a green solution, and making it possible to draw up operative marketing strategies. In particular, the intention to adopt the kit mainly depends on socio-economic factors as well as activity-related and attitudinal attributes, whereas the probability of installing the kit is greatly affected, to the same extent, by installation cost, the charging cost and the weekly mileage driven.

Keywords:

Hybrid vehicles;

after-market hybridization kit;

intention to adopt;

choice to install;

discrete choice model;

random utility

1 Introduction

The transport sector plays a crucial and increasing role in the world's energy use and greenhouse gas emissions. Currently, transport accounts for around a quarter of EU[*] and US[†] greenhouse gas emissions, making it the second largest greenhouse gas emitting sector after the energy sector. In particular, about three quarters of transport-related greenhouse gas emissions in 2011 (IEA, 2013[‡]) were from road transport which alone constitutes about 70% of the entire transportation sector, 20% of total EU emissions of carbon dioxide and 27% of total US emissions. Furthermore, while emissions from other sectors are generally falling, those from transport have increased since 1990 (by 36% in the EU and by 18% in the US) and, as highlighted by the International Energy Agency, this rapid growth has been driven by emissions from the road sector, which has increased by 52% since (IEA, 2013). In such a context the transport sector needs to significantly improve its environmental performance, and the electrification of individual mobility may be a promising option for road transport to achieve such objectives.

Currently, electric, hybrid, plug-in hybrid and vehicles (EVs, HEVs and PHEVs) are emerging as automotive products that, unlike the past, have the capability of enhancing vehicle performance, reducing fuel consumption and limiting the environmental impact of personal transportation.

Although there are several issues and concerns surrounding the adoption of E/HE/PHEVs (Van Bree et al., 2010; Egbue and Long, 2012; Larson et al., 2014; Rezvani et al, 2015), there are many potential benefits: (i) greater energy security, as nations can reduce reliance on foreign sources of oil (Fontaine, 2008; Greene, 2010a), (ii) reduction of greenhouse gas emissions in most settings (Kintner-Meyer et al., 2007; Samaras and Meisterling, 2008; Sioshansi and Denholm, 2009; King et al., 2010); (iii) shifting other emissions away from polluted urban centres by reducing (or eliminating) tailpipe emissions (Thompson et al., 2009; Duvall and Knipping, 2007; Sharma et al, 2012); (iv) EVs can potentially offer lower CO_2 emissions (Ehsani et al., 2010), particularly in markets where carbon use is low (Karplus et al., 2010). As matter of fact, numerous encouraging signs can be observed: different automotive manufacturers are rolling out electric vehicles with a greater frequency than in the past (Sullivan et al., 2009; Cui et al., 2011) and it is expected that there will be a significant

[*] http://ec.europa.eu/clima/policies/transport/index_en.htm
[†] http://www.epa.gov/climatechange/ghgemissions/sources/transportation.html
[‡]IEA, 2013. Co2 emissions from fuel combustion: highlights international energy agency statistics

enhancement of the supply chain (i.e. battery, power electronic and electric motor producers) and of charging infrastructures (providers, network operators, energy utilities and service providers). In addition, the large-scale introduction of renewable energy sources for electric energy production should render the environmental impact of EVs more sustainable, and markets for electric vehicles are expected to grow as economic conditions improve (EPRI[§]; Sikes et al., 2010).

Nevertheless, though there has been recent commercial success, especially in terms of hybrid electric vehicles (HEV), the market share is still insufficient either to reach a mass market or to produce a significant impact on pollution abatement and energy consumption on a global basis (Ulrich, 2005; Tamor et al., 2013; Feng and Figliozzi, 2013). Moreover, the scenario is unlikely to change drastically in the next few years, since considerable investments in production plants would be needed and the market does not seem to provide for the expected growth of such technologies. Therefore, the possibility of upgrading conventional vehicles to hybrid electric vehicles is gaining interest.

Among diverse options for hybridization, researchers at the Energy and Propulsion Laboratory of the University of Salerno have patented a system based on electrification of rear wheels in front-wheel-drive vehicles by adopting in-wheel motors and adding a lithium-ion battery (HySolarKit). Thus, the vehicle is transformed into a through-the-road parallel hybrid electric vehicle. Such technology can be installed in any traditional vehicle and helps to make hybrids more feasible and affordable in current energy markets. Moreover, it allows a substantial reduction in fuel consumption and CO2 emissions (18-20%) that may be compared with the benefits of HEVs, while representing a lower investment cost.

Within this technological context, the aim of this paper is to investigate the impact of such an emerging technology in terms of consumer acceptance and adoption. In particular, the paper addresses two crucial issues: (i) the analysis of the determinants that would affect the users' potential behaviour, (ii) the estimate of the market potential of such a kit.

Up to now research on consumer acceptance or the adoption has focused on traditional E/HE/PHEVs and has usually been addressed through forecasting models, analyzing the barriers against consumer adoption (Al-Alawi and Bradley, 2013; Rezvani et al., 2015), investigating vehicle usage (Tamor et al., 2015b; Pearre et al., 2011), the range of convenience (Tamor et al., 2014), the available transportation alternatives (Tamor et Milačić., 2015a) or the users' driving behaviour (Liu et al., 2015). To the authors' knowledge, after-

[§] http://www.epri.com/Our-Work/Pages/Electric-Transportation.aspx market technologies have not been yet investigated nor in behavioral terms, neither in terms of potential market penetration.

Such issues seem worth of interest for different reasons.

First, the technology is relatively new and presents interesting environmental and technical potentialities. Indeed, an extensive reconversion of the actual vehicle fleet to hybrid or electric in a short/medium-term scenario is rather unrealistic, therefore, the kit may be an effective and affordable solution. Upgrading conventional vehicles to solar-hybrid could have a relevant and short-term impact on fuel consumption and carbon dioxide emissions due to transportation, since it may potentially be applied to most of the current fleet, and without requiring expensive reconversion of production lines for cars. Moreover, the kit makes it possible to upgrade the power and the performance of the car and reduce recharging time and cost from the grid thanks to the free solar recharge.

Secondly, those factors which affect existing E/HE/PHEVs market analysis do not affect our analysis. Indeed, the technology may be easily understood by potential users, it will be mounted on a vehicle which is already owned (and known) by the user, it will not require any significant change in driving behaviour, consumers are not required to shift their behaviour away from fuelling at a gasoline station towards plugging in their personal vehicle, finally, consumer evaluation of ownership and use costs is much simpler. By contrast the main features of the kit could significantly affect potential users' behaviour. As a matter of fact, the kit needs to be installed on an existing vehicle, photovoltaic panels must be installed on the car roof, the car design will be definitively modified, the car transmission system will be modified and the installation cost may not be negligible.

With respect to the previous considerations, two behavioural stages of the choice process were analysed and modelled:

(i) the intention to adopt the HySolarKit,

(ii) the choice to install the HySolarKit.

These two stages, interpreted within the Random Utility paradigm, are consistent with the widely adopted behavioural paradigms aiming to interpret behavioural change (e.g. the transtheoretical model, Prochaska and Di Clemente, 1983) which assume that users first build a belief towards a specific choice context or towards a specific solution (e.g. technological solution), and then make a decision. In the former stage (belief/intention), it can be assumed that the main technological features, and attitudinal and social attributes primarily affect user behaviour, whereas specific quantitative characteristics such as installation cost, environmental and consumption benefits play a secondary role. In the latter stage (choice), the previous characteristics obviously play a predominant role.

Modelling these two stages may be of interest for two reasons: to understand the determinants of both behavioural stages; to set up a system of models able to forecast the market penetration of such technology.

Modelling the intention makes it possible to estimate the potential market interested in the new technology. Modelling the choice, along with the previous model, allows more reliable estimation of the market share.

Both issues were addressed through a stated preference survey which was designed *ad hoc* and carried out in two different Italian cities (Salerno and Avellino), and by specifying and calibrating binomial choice models based on the behavioural paradigm of utility theory. In particular, two binomial logit models were specified and estimated, several specifications were tested and different modelling solutions (homoscedastic and heteroscedastic) were compared in terms of goodness-of-fit and in terms of sensitivity to the level of service attributes. Models were calibrated taking into account typical instrumental attributes and users' socioeconomic characteristics, but also the current vehicle usage, the available household number of cars, the users' concerns for environment, fuel consumption and car design.

Estimation results allowed interpretation of the relative weights, making it possible to quantify the potential effects and concerns towards such a green solution, and making it possible to draw up operative marketing strategies.

The paper is organised as follows. In section 2 the technological framework is described, section 3 presents the state of play regarding the models and the determinants investigating consumers' attitudes to electric vehicles, whereas in section 4 the methodology is introduced. Section 5 discusses the case study. Section 6 introduces and discusses the estimation results and the sensitivity analysis. Conclusions are drawn in section 7.

2 Technological framework

The desire to reduce carbon emissions due to transportation sources over the past decade has led to the development of new propulsion technologies. Among the options currently available for alternative propulsion, electricity seems the only potential energy source for transportation that addresses the simultaneous need for fuel diversity, energy security, reductions in greenhouse gas emissions, and improvements in air quality that is widely available and produced domestically. However, nowadays electricity has a share of transportation energy that is well below 1%, and their market penetration is not (and will not be, in the near future) enough to have a significant impact on energy and emissions savings. Indeed, the premium for electric and hybrid vehicles, the limited market readiness, and incomplete customer technology awareness, make such vehicles still inadequate to displace conventional fuel-powered automobiles.

Therefore, the possibility of upgrading conventional vehicles to hybrid vehicles is gaining interest. Hybridization can be achieved in different ways. In this paper, the analysis focuses on hybridization by means of electrification of rear wheels in front-wheel-drive vehicles, often by adopting in-wheel motors. In such a way, the vehicle is transformed into a through-the-road (TTR) plug-in hybrid electric vehicle. Nonetheless, the benefits in terms of fuel savings are lower than on a native hybrid, due to the constraints posed by the TTR structure, and by the absence of downsizing. On the other hand, the addition of electric propulsion may offer further advantages: *a)* enhancement of vehicle power and performance, especially acceleration; *b)* increase in vehicle reliability, due to the presence of two propulsion devices; *c)* better driveability, due to the possibility of exploiting advanced vehicle control schemes. This paper deals with a specific solution, developed by the E-prob Lab of the University of Salerno (Italy) and currently being road-tested[**].

The interest and the potentiality of such a kind of after-market mild-solar-hybridization kit are manifold.

First of all, an extensive reconversion of the actual vehicle fleet to hybrid or electric in a short/medium-term scenario is rather unrealistic, due to the continuing effects of the economic crisis in many countries. Nevertheless, most people may intend or need to have a more sustainable/low impact vehicle for personal (e.g. pro-environmental attitudes or beliefs) and/or for practical motivations (e.g. to reduce travel costs, have access to restricted access zones, free circulation on preferential lanes). In this case, the kit may be an effective and affordable solution.

Secondly, upgrading conventional vehicles to solar-hybrid could have a relevant and short-term impact on fuel consumption and carbon dioxide emissions due to transportation, since it may potentially be applied to most of the current fleet, and without requiring expensive reconversion of production lines for cars. As a matter of fact, in most countries, such as

[**] Title: Kit for transforming a conventional motor vehicle into a solar hybrid vehicle, and relevant motorvehicle obtained by the kit
Inventors: Rizzo, G.; Pianese, C.; Arsie, I.; Sorrentino, M.; Pub. No.: WO/2011/125084 / Int. Application No.: PCT/IT2011/000102

Italy[††], the majority of the circulating vehicle fleets rely on obsolete technologies that do not comply with the most recent emissions standards (e.g. EURO 4 or EURO 5). In such a context, the kit may be a feasible solution for greening the existing fleet, anticipating the goals that are considered as a first Milestone in the European electrification road-map[‡‡].

Finally, the kit makes it possible to upgrade the power and the performance of the car, by converting it into a four-wheeled vehicle, and this reduces recharging time and cost from the grid in plug-in mode, thanks to the free solar recharge. Furthermore, the integration of renewable energy into the automotive sector could be an extra boost both for automotive electrification and clean energy sources market penetration into the future energy portfolio.

The hybridizing equipment (Figure 1) consists of: in-wheel motors; an auxiliary Lithium-ion battery pack; flexible photovoltaic panels installed on the vehicle's roof and hood; an additional control system that interacts with existing vehicle components and optimizes energy flows.

The vehicle is also equipped with an EOBD gate (On Board Diagnostics protocol), which allows access to data such as pedal position, vehicle speed, engine speed, manifold pressure and other variables. A mild parallel hybrid structure is obtained by substituting/integrating the rear wheels with in-wheel motors.

In this way, the vehicle can operate in pure electric mode (when ICE is switched off or disconnected by the front wheels) or in hybrid mode (when the ICE drives the front wheels and the rear in-wheel motors operate in traction mode or in generation mode, corresponding to a positive or negative torque).

The VMU implements control logics compatible with typical driving styles of conventional-car users, which receive the data from the OBD gate, from the battery (SOC estimation) and drives in-wheel motors by appropriately acting on the electric node. The battery can be recharged by: rear wheels, when operating in generation mode; photovoltaic panels; a regular electric power outlet, when the vehicle is connected to the grid power in plug-in mode. However, technical opportunities and challenges are presented by Rizzo et al. (2014), while Marano et al. (2013) performed a model-based analysis, through a modular approach, where different powertrain configurations are considered, specifically with different battery sizes, different in-wheel motor power, and different flexible PV panel efficiency.

place Figure 1 about here

[††] About 50% of the vehicles circulating in Italy do not comply with EURO4 standards
[‡‡] Multiannual Roadmap for the Contractual Public Private Partnership European Green Vehicles Initiative, October 2013, http://www.egvi.eu/uploads/Modules/Publications/ppp-egvi-roadmap-oct2013.pdf

From the technical viewpoint[§§], currently a 4kWh battery is mounted on the prototype and the PV panels have a power of 270W. Production of 1500 kWh can be assumed for each kW installed, hence an average daily production of about 1.1 kWh. In this case, about three days are required for a full solar charge of the battery. As regards charging times in plug-in mode, they obviously depend on the type of the charging system. In this case two types may be adopted. Level 1 refers to single-phase alternating current (AC) using grounded receptacles as used in domestic applications. In Europe it may be 13 or 16 amps at 240 volts delivering 3 kW of power. The EV may incorporate a standard domestic power cord to connect the vehicle to a domestic socket outlet or a level 1 charging station. Therefore, charging time for a 4kWh battery is less than two hours. Level 2 delivers up to 20 kW of power from either single- or three-phase alternating current (AC) sources of 208-240V at up to 80 amps. Individuals can install a level 2 charging station at home, In this case, charging may take about 15 minutes for 20 kW or 40 minutes for 6 kW. Moreover, since the batteries usually work in the range of 0.2-0.95, the previous estimates could be further reduced by a factor of about 0.75. In terms of battery duration, theoretical and experimental estimates indicate that the prototype, fully charged, is able to travel about 15 km in hybrid mode and in an urban context. However, increased autonomy can be easily achieved by using different batteries.

With proper knowledge and communication between the vehicle and the grid (V2G) or infrastructure (V2I), the proposed kit can achieve a reduction in fuel consumption and CO2 emissions of up to 18-20% (for selected configurations), comparable with HEV benefits, but at a lower investment cost and without invalidating performance or safety. Indeed, higher acceleration and better vehicle control are guaranteed by the presence of two additional electric wheels and higher engine efficiency conditions (i.e. high load) thanks to the combined operation with electric motors.

Compared to potential competing alternative fuel vehicles, the following advantages may be identified. With respect to Conventional Vehicles: (i) possibility to have a 4x4 hybridized car; (ii) possibility of a free solar recharge; (iii) up to 20% fuel and emission savings .With respect to Hybrid Electric Vehicles: (i) much lower cost (from 1/5 to 1/10); (ii) solar recharge (there are not such vehicles on the market at present); (iii) possibility to transfer the kit to another car; (iv) possibility to set up the kit on lpg or natural gas car in turn improving fuel saving; (v) better acceleration and vehicle control due to 4wd. With respect to Electric Vehicles: (i) much lower cost (considering cars with similar space and performance); (ii)

[§§] http://www.solaritaly.enea.it/Documentazione/L'energia%20fotovoltaica.pdf much higher range (that of the conventional car); (iii) solar recharge (there are not such vehicles in the market at present); (iv) possibility to transfer the kit onto another car; (v) better vehicle control due to 4 wheel drive, of which two of them are independently controllable.

3 Consumer attitudes to electric mobility: approaches, models and determinants

Although a study of EV demand was published thirty years ago (Beggs et al., 1981), most model-based academic studies on alternative fuel vehicles (AFVs) have been conducted in the last 10–20 years.

In general, the majority of literature has aimed to understand how consumers perceive E/PE/PHE vehicles and which factors influence consumer intentions to purchase them and/or which factors may be considered barriers against consumer adoption. To this aim, different interpretative and theoretical frameworks have been investigated and, within the previous theoretical frameworks, different modelling approaches have been proposed.

First of all, two main approaches may be identified: not behavioural and behavioural.

Not Behavioural approaches are predominantly based on system dynamics, diffusion and time series models (a recent and interesting review may be found in Al-Alawi and Bradley; 2013). Most notable contributions are mainly founded on the Bass diffusion model (1969, 2004) (McManus and Senter, 2009; Centrone et al., 2007; Cao, 2004; Jeon, 2010; Becker, 2009; Won et al., 2009; Higgins et al., 2012), the Gompertz growth model (Muraleedharakurup et al., 2010; Lamberson, 2008) or the logistic model (Trappey and Wu, 2008; Muraleedharakurup et al. 2010).

Behavioural approaches, are founded on an interpretative paradigm of the phenomenon and, where possible, propose a coherent theoretical framework, which is able to model, simulate and/or forecast users' adoption of E/PE/PHE vehicles. They rely on three mainstreams theories (for recent detailed reviews the reader may refer to Al-Alawi and Bradley, 2013; Rezvani et al., 2015): (i) Agent-Based models (ABM), (ii) Psychological and sociological theories (Theory of Planned Behaviour - TPB; Value-Belief-Norm theory - VBN; habits, diffusion of innovation diffusion theory), (iii) Consumer Choice Theory (CCT).

ABM is a computer based simulation method that creates a virtual environment to simulate the action and interaction of each agent. Recently, several researchers have applied the ABM to EV and PHEV market penetration analyses (e.g.Sullivan et al., 2009; Sikes et al., 2010, Eppstein, et al., 2011, Cui et al. 2011; Garcia, 2007; Zhang et al., 2011; Shafiei et al., 2012;

Brown, 2013). Results from these models indicate factors or barriers that might affect the introduction and acceptance of E/PE/PHEVs, however, they depict penetration rate scenarios which are very different from each other, sometimes even contrasting with each other, and thus, are not easily transferable to different case studies nor able to give generic operational insights. Moreover, the calibration and implementation of ABMs are quite complex due to the poor availability of data,

The TPB assumes that the potential consumers' decision making process is based on rational evaluations of stimuli and possible consequences of decisions (Ajzen, 1991). The behaviour is affected by consumer attitude, perceived feasibility of the decision and perceived expectations of certain reference groups or subjective social norms. Notable contributions in the EVs field have been made by Lane and Potter (2007), Moons and De Pelsmacker's (2012) and Egbue and Long (2012).

The VBN theory (Stern, 2000) views internal normative beliefs and values as motives for pro-environmental behaviour and, thus, it assumes that consumer EV adoption behaviour is predominately affected by consumer environmental values, beliefs, and norms. The most notable contribution to consumer EV adoption is the pioneering paper by Lane and Potter (2007). It shows results from two research projects aimed to investigate the links between consumer beliefs, knowledge, attitudes, intentions and vehicle purchase/use behaviours, as well as exploring the consumer attitude-action gap.

Together with the previous theories, several psychological and sociological theories have also been investigated. In particular, Schuitema et al. (2013) and Noppers et al. (2014) connect self-image with purchase intentions towards EVs by utilising the self-image congruency theory. (Sirgy, 1986). Axsen et al. (2012) apply lifestyle theory (Giddens, 1991) and hypothesise a relationship between a pro-environmental lifestyle and purchase intentions for EVs. Noppers et al. (2014) also examine the costly signalling theory (Miller, 2009). Peters and Dütschke (2014) apply the diffusion of innovation (DOI) theory (Rogers, 2003).

The cited psychological approaches have made it possible to comprehend the complexity of the phenomenon, allowing for an investigation into different perspectives in order to derive the main barriers and determinants that may affect E/PE/PHEVs' consumer adoption. All of these propose qualitative and quantitative results grounded on descriptive statistical analyses, yet no study has hitherto proposed any modelling framework which is able to forecast the potential market penetration.

CCT relies on a theoretical framework which assumes that benefits and utility maximization are the basis of potential consumer behaviour. The consumer choice theory, aside from having a robust psychological/behavioural background, is consolidated and widely adopted in transportation choice analysis, it is more tractable, allows for an easy and methodologically sound interpretation of the phenomenon and, above all, makes it possible to specify models which are able to forecast different scenarios.

The drawback of consumer choice modelling is twofold. Firstly, there are no historical data sets. Therefore, the decision to purchase and/or sensitivity to the attributes of the vehicle must be estimated or derived from a stated preference survey. Secondly, it is not easy to take attitudes, beliefs, social norms and qualitative attributes into account explicitly.

However, CCT can count on a wide range of models and applications investigating alternative fuel vehicle (AFV) market penetration and/or consumer behaviour determinants, especially since the 1990s. After earlier studies on AFVs by Beggs et al. (1981), Train (1980) and Hensher (1982), the first systematic contributions of note were those of Train (1986), Golob et al. (1996) and Brownstone et al. (1996, 2000) who investigated consumer behaviour within the random utility paradigm through the specification of structured models, multinomial logit (MNL) and/or mixed logit models (MMNL).

Starting from the year 2000, the potential demand for EVs has been investigated through: the Rank ordered model (Dagsvik et al., 2002); Mixed (Hybrid) Multinomial Logit models (Batley et al., 2005; Bolduc et al., 2008; Hackbarth and Madlener, 2013; Glerum et al., 2013); Multinomial Logit models or Nested Logit models (Santini and Vyas, 2005; Potoglou and Kanaroglou, 2007; Sikes et al., 2010; Struben and Sterman, 2008; Qian and Soopramanien, 2011; Lee et al. 2013); the multiple discrete-continuous model (Ahn et al., 2008); the utility-based and a regret-based model of consumer preferences (Chorus et al., 2013).

Within the previous modelling frameworks, and by focusing on the determinants which affect user behaviour, E/PE/PHEVs ownership (or adoption) may be interpreted in light of instrumental, hedonic and symbolic attributes (e.g. Heffner et al., 2006; Kurani et al., 2007; Skippon and Garwood, 2011; Schuitema et al., 2013).

Instrumental attributes refer to the features that can be derived from functions performed by the E/PE/PHEVs. Hedonic attributes refer to the emotional experience derived from using new technologies, such as joy or pleasure (Dittmar, 1992; Roehrich, 2004; Voss et al., 2003). Symbolic attributes are related to the sense of self or social identity that is reflected, or built from the possession of new technologies (Dittmar, 1992; Roehrich, 2004).

In this conceptual context, most of the previously cited contributions have mainly focused on the instrumental and functional attributes of E/PE/PHEVs, and in most of the analyses E/PE/PHEVs have usually been judged in relation to their current cost, performance, convenience, comfort and aesthetics. In particular, the determinants reported in Table 1 proved to be significant.

Together with the above attributes, several contributions have explored the relevance of non-instrumental attributes: environmental attitudes or beliefs, hedonic and symbolic attributes or emotions.

Most of the contributions on non-instrumental attributes directly investigated the role of the perception of environmental benefits (Graham-Rowe, 2012, Caperello and Kurani, 2011; Gardner and Abraham, 2007; Lieven et al., 2011; Musti and Kockelman, 2011), of environmental awareness (Hsu et al., 2013; Bolduc et al., 2008), of pro-environmental attitudes (Egbue and Long, 2012, Skippon and Garwood, 2011; Krupa et al., 2014; Carley et al., 2013; Graham-Rowe, 2012) and of knowledge and beliefs about the environment (Axsen et al., 2012, Egbue and Long, 2012, Carley et al., 2013, Krupa et al., 2014 and Lane and Potter, 2007). If on the one hand, most of the cited contributions have pointed out the positive effect of such attitudes, on the other hand, it has been also shown that the environmental benefits of EVs are not highly valued by most drivers. Indeed, the utility of EVs was primarily evaluated in light of whether they could meet personal mobility needs as well as internal combustion cars can. In particular, Graham-Rowe (2012) found that drivers were not convinced that plug-in EVs would allow them to meet these valued goals and some were sceptical about the net environmental benefits of EVs. Furthermore, Oliver and Rosen (2010), Kollmuss and Agyeman (2002) and Stern (2000) argue that consumer concern for the environment will not necessarily result in pro-environmental behaviour and there is a gap between the environmental attitude and behaviour.

Very interesting, are also those few studies that to date have investigated whether and to what extent the adoption of EVs is influenced by perceptions of hedonic and symbolic attributes, or by emotions and feelings (Schuitema et al., 2013). Indeed, as stated by Jensen (1999), Steg (2005) and Steg et al. (2001), car ownership serves to provide social status, self-esteem and autonomy, and such a symbolism is often based on the visual appeal of vehicles, hence, it is mainly based on hedonic attributes.

place Table 1 about here

In this conceptual framework, EVs may be perceived as symbols to construct and express self-identity and/or lifestyle (Skippon and Garwood, 2011, Graham-Rowe et al., 2012, Axsen et al., 2012, Schuitema et al., 2013 and Burgess et al., 2013). In particular, Gardner and Abraham (2007), Mann and Abraham (2006) and Steg (2005) indicated that driver motivations are also affected by the desire to gain pleasure or enjoyment, or minimise negative effects, when making journeys.

With regard to EVs, Skippon and Garwood (2011) found that, after an experience with battery EVs, people attributed clear symbolic meanings to them: agreeableness, conscientiousness and openness to experience. Graham-Rowe et al. (2012) carried out a study in the UK and reached two contrasting conclusions: one part of the participants felt good about driving such a vehicle or felt less guilty about driving because of the associated environmental benefits .whereas the remaining part stated that they were embarrassed to drive an EV. Moreover, they did not think the vehicles looked as nice as other cars, and felt ashamed that they could not drive as quickly or confidently as other car users. Different analyses were carried out by Schuitema et al. (2013) that investigated the role of instrumental, hedonic and symbolic attributes in the intention to adopt electric vehicles. They showed that HEV ownership was seen as symbolic of ‘‘making a difference’’, maturity, intelligence and awareness. Furthermore, they indicated that instrumental attributes are important largely because they are associated with other attributes derived from owning and using EVs, including the pleasure of driving (hedonic attributes) and identity derived from owning and using EVs (symbolic attributes). Finally, according to the same study, drivers felt that EV designers had undervalued vehicle aesthetics and visual identity, and the tested EVs were perceived as uninspiring or “soulless”.

Finally, single contributions have further highlighted the importance of pro-leasing and pro-convenience attitudes (Glerum, 2013), pro-technology attitudes (Bolduc et al., 2008; Struben and Sterman, 2008), driving habits (Bolduc et al., 2008) and social influence (Axsen and Kurani, 2010). Furthermore, it has been also shown that consumer emotions and feelings may affect (positively or negatively) attitudes and intentions to adopt EVs (Moons and De Pelsmacker, 2012 and Schuitema et al., 2013; Graham-Rowe et al., 2012). Consumer emotions are shown to be important in the domain of car purchase (Steg, 2005), pro-environmental behaviour (Bamberg and Möser, 2007, Onwezen et al., 2013 and Steg and Vlek, 2009), consumer adoption of innovations (Shih and Schau, 2011 and Watson and Spence, 2007) and consumer adoption of EVs (Graham-Rowe et al., 2012, Moons and De Pelsmacker, 2012 and Schuitema et al., 2013).

In conclusion, the E/PE/PHEVs consumer adoption problem has been widely investigated in the last ten years by pursuing numerous and different theoretical approaches. Qualitative and quantitative analyses have been carried out on revealed and/or stated preferences surveys, and various factors affecting adoption behaviour have shown significant results.

The adopted interpretative and theoretical paradigms have pointed out how the choice phenomenon is quite complex and might not be simply and solely interpreted within a unique theoretical framework. Indeed, if, on the one hand, Consumer Choice Theory has been shown to be an effective tool to model the intention and choice to adopt an alternative fuel vehicle, on the other hand, the contributions based on the Theory of Planned Behaviour or Value-Belief-Norm theory indicate that, together with typical instrumental and easily quantifiable attributes (e.g. costs, range, maintenance, cost of driving, cost of ownership), several other attributes may play a significant role. Moreover, existing contributions allow for a good interpretation of the specific investigated case studies but do not seem to be easily transferable to different case studies. This may depend on the theoretical frameworks themselves, but may also significantly depend on the immature perception of these new technologies. Indeed, almost all the contributions have highlighted that, despite the positive attitude to P/H/EVs, there may be considerable taste heterogeneity and uptake will depend on achieving comparable attributes to conventional vehicles, on symbolic attributes and/or on the existence of supportive technological, legislative and fiscal policies on both the supply and demand sides. Moreover, different studies also report contrasting results.

Such drawbacks, while on the one hand, open several stimulating research perspectives, on the other hand, they represent a significant limitation for EV manufacturers that cannot ground industrial and/or marketing policies on robust and transferable analyses. In other words, there are more uncertainties than certainties related to potential consumers' behaviour.

In conclusion, two significant issues are worth of interest: the modelling of the perception (the intention to adopt) of new technologies and the choice to adopt these technologies. In the current state, the utility maximisation framework seems an effective tool since it is able to interpret the phenomenon, it allows including instrumental and attitudinal attributes and supports market penetration analyses.

4 Methodological framework

Analysing car drivers' intention to switch to a different automotive technology is a complex task which involves a process of psychological and behavioural change, in which economic, psychological, attitudinal and social determinants concur in the final choice behaviour. The existing psychological theories converge on the fact that behavioural changes are mainly characterised by two prevailing behavioural stages.

In the first stage the behavioural intention is constructed. This stage is usually affected by several factors: behavioural beliefs, normative beliefs, social norms, past behaviour, motivations, control beliefs and preliminary evaluation of outcomes. In the second stage, users make the decision to change behaviour, experiment behaviour and, finally, to maintain such behaviour.

Within this conceptual framework, two main methodological approaches may be adopted: approaches based on psychological and social determinants and those based on economic assumptions (e.g. consumer choice theory). The former are mainly based on descriptive analyses of experimental surveys; they are able to analyse the two stages separately, which may allow an interpretation of the phenomenon but cannot rely on a formal mathematical formulation (e.g. the transtheoretical model, Prochaska and Di Clemente, 1984; precaution adoption process model, Weinstein, 1998; Tapestry Project, 2003[***]). This drawback is far from negligible if market penetration analysis or market forecasting needs to be carried out.

Approaches based on economic assumptions, as introduced in section 2, have been widely used. They are robust and consolidated, allow an interpretation of the phenomenon but, unlike the previous approach, allow estimates of potential travel demand, and allow to carry out sensitivity analyses.

In this paper the cited stages were separately investigated as a discrete choice problem (Figure 2), pursuing a consumer approach within the random utility theory framework.

place Figure 2- about here

In particular:

i) *the intention to adopt* can be interpreted as a measure of the rate of possible adoption of HySolarKit technology. The aim was to model and interpret the intention to adopt such technology, independent of its installation costs and detailed instrumental features of the technology (e.g. greenhouse gas emissions and fuel consumption). The alternatives were: "intention to adopt" or "no intention to adopt". Estimation results may permit behavioural interpretation of the phenomenon, make it possible to forecast the potential demand willing just to adopt the technology and, finally, may allow a more reliable estimate of the market potential if combined with a model able to estimate the installation choice.

ii) the choice to install estimates the probability of installing the HySolarKit conditionally upon being willing to adopt such technology. In this case, users are aware of the installation costs as well as the benefits in terms of greenhouse gas emissions and fuel consumption. As for the intention to adopt the technology, a binary choice context was investigated: "to install"

[***] http://www.transport-research.info/Upload/Documents/200810/20081002_161028_52677_TAPESTRY.pdf

or “not to install”.

As introduced above, the intention and choice to install the kit were modelled within the random utility paradigm. Homoscedastic (binomial logit model) and heteroscedastic (mixed binomial logit models) modelling solutions were investigated (Train, 2010; Cascetta, 2009).

5 Case studies

The analyses and model specifications were carried out on two different case studies: the municipalities of Salerno and Avellino.

Salerno is the capital city of Salerno province (region of Campania, southern Italy), situated 55 km southeast of Naples. It has a population of approximately 130,000, 54,500 households, an area of about 60 km^2, a residential density of 2,240 inhabitants per km^2 and an average of 1.50 cars per household. Four transport modes are usually available: car as a driver, walking, bus and motorbike.

Avellino is the capital city of the Avellino province (region of Campania, southern Italy), situated 58 km southwest of Naples. It has a population of approximately 55,000, 22,000 households, within an area of about 30 km^2, it has a residential density of 1,799 inhabitants per km^2 and an average of 1.60 cars per household. Three transport modes are usually available: car as a driver, walking and motorbike.

The Salerno case study consisted of 300 interviews and was investigated in the autumn of 2013, whereas the Avellino case study was investigated in the spring of 2014 and consisted in a greater number of interviews (600) since a greater number of information was collected in order to investigate psychological and attitudinal factors (addressed in a future paper). The sample size was preliminarily defined as being in accordance with the literature (e.g. Louviere et al., 2000). It is about 2% of the number of households with more than one car for Salerno (indeed, about 30% of the household own more than one car, and this was the target), and about 10% for the municipality of Avellino.

Respondents were randomly selected from different areas of each municipality (proportional to the number of households). Each respondent was assumed to be representative of his/her family, but was selected among residents who stated they owned at least one car and that they had the authority/power to make decisions regarding household car ownership (mainly householders). However, sample characteristics were consistent with census data regarding household type (single, married with no children, with one child, etc.) and matched the frequency distribution of the number of cars per household.

The survey was a face-to-face survey, a paper questionnaire was used and typical precautionary strategies were taken into account during the interviewing process: respondents carried out exactly the same survey; they were briefed about the decision context and were also introduced to the option features and to the possible benefits (with pictorial presentations). The response rate was 93% for Salerno municipality and 89% per Avellino (people that did not accept to respond were mainly people without any authority to make a decision), whole interview lasted approximately 10 minutes.

The questionnaires were identical and consisted in three parts. The first part aimed to gather information on family characteristics (geographical, travel characteristics, socio-economic, etc.) and on respondents' concerns towards the main features that usually affect the decision to buy a specific vehicle (e.g. fuel consumption, environmental impact, design). In the second part, respondents were introduced to the technology and its main characteristics: how it works, how it is installed, the different performances (e.g. acceleration, speed), and the environmental and fuel consumption benefits which can be achieved. An initial estimate of the benefits was given, then they were then asked about their intention to adopt the technology. It is important to point out that the intention was stated without the interviewees being aware of the installation cost and of accurate estimates of the benefits based on the real life cycle of the car owned by each respondent. In the third part the propensity to install the HySolarKit was investigated. To this aim, a more accurate estimate of the benefits obtainable in terms of fuel consumption was presented (based on the type of trip, on the number of kilometres travelled, on the type of vehicle owned). Different scenarios were then presented in which different installation costs were proposed (from 2,000 to 4,000 euros). The collected and investigated attributes are introduced in Table 2.

place Table 2 about here

6 Estimation results

6.1 Modelling the intention to adopt the HySolarKit

In this section the estimation results for the model aiming to interpret and simulate the intention to adopt the HySolar kit are presented. As introduced in section 4, homoscedastic and heteroscedastic formulations were investigated. In particular, the binomial logit model (BNL) and the mixed binomial logit with error components (MBNL-EC) were statistically significant.

Overall, the goodness-of-fit of both modelling formulations, and for both case studies, showed reliable results both for the likelihood ratio test and the adjusted rho-square tests.

It is worthy of note that similar attributes resulted to be statistically significant for both the cases studies. This result, obtained for two different cases studies and with different sample sizes, gives robustness to the proposed methodological framework and to the interpretation of the systematic utility coefficients.

In particular, estimation results indicated that three classes of attributes demonstrated statistically significant results: respondent-specific, activity-related and attitudinal attributes (see table 3). Furthermore, unlike existing experimental evidence in the EV market analysis, it is worth noting that some attributes – which were expected to affect users' behaviour - were not significant: the number of cars per household, the number of households, and the rate of car availability (the ratio of cars per household to households).

As regards the BNL, among the user specific attributes, only gender and age played a role in the users' propensity towards the HySolarkit. In particular, being male and younger increases the perceived utility of being interested in the kit. These results are reasonable since the male market segment is more interested in technological advances, and the same applies to younger respondents. Of further attention, the coefficients have values which are not negligible. The male coefficient is comparable to the alternative specific constant (ASC) for the Salerno case study and slightly smaller for Avellino. As regards the age, it has an effect similar for both case studies. In particular, the ratio with respect to the ASC varies from 0.38 (for 30 years old users) to 0.90 (for 70 years old).

Together with the above socio-economic attributes, the area in which users reside affects the probability of adopting the technology (ZoneRes). The binary attribute has a positive value for those users residing in the outskirts of the study area, thereby increasing interest in the kit. Indeed, such users represent a market segment particularly captive to the car transport mode (due to the absence of a transit system): they are usually characterised by a higher trip frequency and hence they are more interested in reducing fuel consumption. The role of the attribute is similar for both case studies, and it is almost a half of the ASC for the Salerno case study and a third for Avellino. This result can be interpreted in terms of the larger geographical extension of Salerno, in terms of the impossibility to use individual transport modes alternative to the car (e.g. walking, bicycle) and in terms of low frequency/reliability of the transit services.

The only attributes related to the household vehicle fleet that resulted statistically significant were the CarKm (for Salerno case study) and CarAge (for Avellino case study) of the vehicle on which the kit would be installed. As expected, as the CarKm (or CarAge) increases, the intention to install the kit increases (see Figure 3). For the Avellino case study, the ratio with respect to the ASC increases from 1.06 for one year old car, to 4.25 for four years old car; whereas, for the Salerno case study it increases from 0.61 for 5,000 kms, to 3.07 for 25,000 kms. In this case, assuming an average mileage of 7,000 kms (observed in the sample), the ratios are quite similar for both case studies.

place Figure 3- about here

As regards activity-related attributes, it is worth noting that the number of weekly trips by car may greatly affect users' intention. In particular, trip purpose seems to play a significant role and the same results may be observed for both case studies. Indeed, if the perceived utility of installing the kit decreases as the number of work trips increases. By contrast, the number of weekly trips for leisure purposes increases the intention to adopt the kit. These results indicate that the intention depends on the trip purpose for which the car is customarily used.

As shown in Figure 4, the effect of weekly trip is higher for work purpose and similar for both case studies. Indeed, for frequent and systematic trips (work purposes) the intention decreases. Indeed, the #weely_trip_work/ASC ratio decreases from -0.12 (-0.31 for Salerno) for 1 trip to -0.58 (-1.57 for Salerno) for 5 trips. This may be interpreted in several different ways: systematic car users might be unconvinced by (i) the reliability of the proposed technological system (in working activities a reliable system is fundamental); (ii) by the aesthetic impact of the kit (in working activities the car is often a status symbol); (iii) by the need to leave the car in the sun; (iv) by the need to recharge the battery (in the plug-in mode or in the solar mode) to gain benefits in terms of fuel consumption and/or greenhouse gas emissions.

It is interesting to note that the Salerno case study is more affected by the trip frequency. This result is coherent with that introduced for ZoneRes attribute. As matter of fact, Salerno is larger than Avellino and, consequently, the total weekly travelled distances increases (number of trips and the average trip length are greater than Avellino) , therefore reducing the intention to adopt.

place Figure 4- about here

For leisure trips, the #weely_trip_leisure/ASC ratio increases more slightly from 0.1 (for both case studies) to 0.45 (0.67 for Salerno). However, respondents travelling by car for leisure purposes are more willing to install the kit. Indeed, fewer such weekly trips are undertaken than for working purposes (see min/max values in table 2), the length of leisure trips is usually shorter (no need to recharge between two trips), and the activity duration (including parking time) is limited.

As regards the attributes representing the concerns declared by the respondents, different dummy variables were introduced for each of the investigated concerns and for each of the adopted rating scales (see Table 3).

Overall, all the attributes proved statistically significant.

Estimation results pointed out that two rating scales (moderate and severe) turned out statistically significant. The rating scale “no importance” was not significant since a negligible number of respondents declared it (about 5%), whereas the rating scale “mild” was not tested to avoid identification problems.

Environment is the most important (positive) aspect, followed by design and fuel consumption. In particular, user concerns towards/for environmental and energy consumption issues increases the utility of adopting the kit, whereas, as expected, users who are interested in the design of the vehicle are those who are less inclined to install the kit. Moreover, the rank of magnitude of the coefficients is the same for both case studies.

Although the results are consistent with expectations, since the kit makes it possible to reduce the environmental impact related to car use and has a not negligible impact on car aesthetics, some useful considerations can be made. However, it is interesting to note that the concern for fuel consumption does not seem to affect the intention to adopt much. Such a result on the one hand might seem strange, whereas on the other hand it can be interpreted in light of the urban travel patterns and of the statistical significance of the #weely_trip_work attribute. As a matter of fact, if the number of kilometres travelled (as usually happens in an urban context) or the number of systematic trips are small, it is reasonable that the concern for fuel consumption may marginally affect the intention to adopt the kit. By contrast, if the number of systematic trips increases (#weely_trip_work attribute) the intention to adopt is justified by the need to reduce the weekly travelling costs and marginally by the concern for fuel consumption. Indeed, as it is shown in the following section, when travelling costs are introduced the concern for fuel consumption proves to be non significant.

Analysing the numerical results the environment is 1.3 times greater than design and 9 times greater than fuel consumption for the Salerno case study. For Avellino, the environment is almost 1 times greater than design and 3.5 times greater than the declared concern towards fuel consumption.

Analysing the ratios with respect to the ASC, it should be noted that the dummy "severe" shows ratios varying from **0.8** for environment, to **0.6** for design and to **0.1** for fuel consumption. Almost the same happens for Avellino with the only difference being the slightly greater ratio observed for design (0.74).

Different considerations may be made for the dummy "moderate". If on the one hand the rank between the concerns continues to be the same, by contrast the corresponding values are 40-50% smaller than those observed for the dummy "severe". The ratios with respect to ASC decreases as expected and, particularly for fuel consumption, become negligible.

In conclusion, the intention is mainly driven by users' environmental and design concerns. Nevertheless, only the more "concerned" users are more motivated/interested to adopt the kit

Finally, estimation results for MBNL showed that only the error components formulation was statistically significant. Indeed, random taste variation across respondents was not appreciable in the attributes, but only as a random coefficient introduced in the "intention to adopt" alternative. However, the MBNL model did not allow a significant gain in terms of goodness-of-fit.

place Table 3 about here

6.2 Modelling the choice to install the HySolaKit

In this section the estimation results for the models aiming to interpret and simulate the choice to install the HySolar kit are presented. The models were calibrated only on the respondents who stated that they were potentially inclined to install the kit. In particular, since each respondent faced more than one scenario, a Binomial Logit model taking serial correlations among multiple responses into account was calibrated following the approach proposed in Ben-Akiva and Morikawa (1994) and Cantillo *et al.* (2007). For the Salerno case study 540 responses (180 individuals) were used, whereas 960 responses (320 individuals) were available for the Avellino case study

As for the "intention to adopt" model, homoscedastic and heteroscedastic formulations were tested and different systematic utility specifications were investigated starting from the attributes introduced in section 4. The most significant and accurate specifications are reported in Table 4.

First of all, for both case studies similar attributes were statistically significant and similar ratios with respect to the alternative specific constant were obtained. The only difference was in just one attributes, CarCatB, which increases the probability of not installing the kit if the user own a vehicle belonging to the segment of large, executive or luxury cars.

Compared to the "intention to adopt" model, the same socio-economic characteristics (regarding the householder) were statistically significant: Gender and Age. While such a result is understandable, since the respondents are the same and the choice to install the kit is obviously affected by the intention to adopt it, on the other hand it should be noted that the same does not apply to all the attributes estimated in the "intention to adopt" model. It can be concluded that the role of gender and age hold when potential users are called to decide to buy and install the kit. Furthermore, it is interesting to note that the relative importance of gender with respect to the age is smaller in the "choice to install" model, and this happens for both case studies. Therefore, it is possible to point out that when the installation cost is introduced, no difference can be appreciated between male and female potential users, whereas the age continues to be a sort of barrier to the installation of the kit.

Differently from the previous considerations, it is worth noting to highlight the fact that all the attitudinal attributes which were statistically significant in the "intention to adopt model" were not significant in the choice of installing the kit. This result is, however, interesting since it indicates that when installation costs are introduced, attitudinal preferences are set aside. In this case, users are more captive to the obtainable financial gain than to the possible hedonic and symbolic gains (or losses in the case of the design).

place Table 4 about here

With regard to the ZoneRes attribute, it continues to be statistically significant and increases the probability of installing the kit. As a matter of fact, users residing in the outskirts have to use the car more frequently, moreover, their trip length is greater than the trip length of those users residing in the urban centre. In this context, the kit may be an interesting solution to reduce the travel costs. Finally, ZoneRes shows the same relative weights with respect to the ASC (0.35 for Salerno and 0.39 for Avellino) that were estimated in the "intention to adopt" model.

As expected, the mileage of the car on which the kit will be installed plays a role in the systematic utility of installing the kit. Unlike the "intention to adopt" model, the mileage is no longer a continuous attribute, but it becomes a dummy attribute. For the Salerno case study, the threshold which is statistically significant was 25,000 km, showing that the propensity increased as the mileage increased. However, the probability of installing the kit increases only for mileage exceeding 25,000 km. As expected, respondents are more willing to modify the car after a certain time interval. In our case study, since the yearly average mileage in Italy is about 9,500 km and in the sample it was about 7,000 km (more urban trips), the number of years needed to reach 25,000 km may vary from three to four years. This time interval is a reasonable period after which users might decide to change the design and the technology of their owned car. Moreover, since it is reasonable to assume that in the same time interval the technology of the owned car, in terms of energy consumption and greenhouse gas emissions, would be outdated, users might be more motivated to update it without buying a new car. For the Avellino case study, since the age of the car was collected instead of the total mileage, the threshold was on the car age. In particular, and interestingly, the threshold which was statistically significant was four years that almost corresponds to 28,000 km, thus leading to a result (and comments) similar to that observed in the Salerno case study. Furthermore, the ratio with respect to the ASC is similar for both case studies, respectively, 1.06 for Salerno and 0.57 for Avellino.

As regards the effect of the installation cost, the differences between installing and not installing the kit were investigated and produced statistically significant results. In particular, Δcost relative weight indicates that installing behaviour is greatly affected by the financial gain obtainable, and the probability of installing the kit increases as the Δcost increases. This happens for high installation costs and/or when the weekly mileage is low, and thus the investment cost - spread over four years - does not allow any financial gain. Comparing the two case studies, it can be observed that Δcost relative weight is the same for both case studies.

To better understand the role (the incidence) of the Δcost, a sensitivity analysis was carried out on the sample used to calibrate the models. In particular, the probability of installing the kit was computed fixing the installation cost and increasing the weekly mileage. Three installation costs were investigated (2,000; 3,000; 4,000 euros), whereas the weekly mileage was increased (with respect to the stated mileage travelled) by 10% up to an increase of 50%.

Our results, as reported in Figure 5 allow two kinds of analyses: longitudinal (increasing the weekly mileage travelled and fixing installation cost); cross-sectional (fixing weekly mileage travelled and increasing the installation cost).

In the graphs on the right of figure 4, the probability of installing the kit is plotted against the percentage increase of the weekly mileage driven. In the graphs on the left, the marginal increase in the probability of installing the kit is plotted against a 10% increase in weekly mileage.

First of all, it is confirmed that the probability of installing the kit significantly depends on the installation cost. Moreover, the weekly mileage driven significantly affects the probability, independently of the installation cost. Without increasing the weekly mileage driven (weekly mileage = 0%), as the installation cost increases from 2,000 euros to 4,000 euros, the probability of installing the kit decreases from 17% to 2% for the Salerno case study, and from 13% to 1% for Avellino. The same phenomenon also occurs for different weekly mileages. In particular, differences between the probabilities of installing the kit are much greater.

As expected, as the weekly mileage rises, so does the probability of kit installation, with different marginal increases. This is much more significant for 2,000 euros, but not negligible for 3,000 and 4,000-euro installation costs.

Analysing the figures on the right, it may be observed that the marginal increase in probability is quite constant for a 2,000-euro installation cost for Salerno and slightly linear for Avellino. Whereas it increases almost linearly in the 3,000- and 4,000-euro scenarios. Indeed, for installation costs of 2,000 euros, the probability increases by about 10% for a 10% increase in weekly mileage in the Salerno case study, and from 6% to 9% in the Avellino case study. If installation costs increases up to 3,000 euros and weekly mileage increases up to 50%, the marginal variation varies from 4% to 10% for Salerno and from 4% to 10% for Avellino. If installation cost increase up to 4,000 euros, similar shapes can be observed but with much smaller values; however, a 50% increase in weekly mileage leads to a kit installation probability of 17% for Salerno and 9% for Avellino. Such a values are almost the same probabilities obtainable with a 2,000-euro installation cost, but with the current weekly mileage driven (weekly mileage = 0%).

Comparing the two case studies. It is possible to note that Avellino case study resent a smaller sensitivity to Δcost. Choice probabilities are smaller and increase with a rate which is less than linear.

This result may be interpreted in light of the different travel patterns that characterise the two case studies. Indeed, Avellino is smaller than Salerno, thus, the average trip length is about half of the average trip length which can be observed in Salerno, therefore, Avellino's residents are slightly less sensitive to the financial gain obtainable by the installation of the kit. It is confirmed that the travel patterns, significantly affect user's behavior and, thus, should be carefully taken into account.

Finally, it was found that the number of daily kilometers driven increases the probability of not installing the kit. This result is quite interesting since it points out that, if on the one hand users aim to reduce the weekly travelling cost, on the other hand users behavior may be negatively affected by the number of kilometers travelled each day. As a matter of fact, due to the operating autonomy of the battery pack (currently 15 km), the contribution given by the electric traction is null after a number of kilometers, therefore, if the car is not recharged in plug-in mode, users do not perceive any benefit. In our specific case, the DailyKm attribute shows a value comparable to the ASC after 13-20 kilometers.

place Figure 5- about here

Along with the binomial logit model, heteroscedastic models were also investigated. In particular, a mixed binomial logit model (MBNL) was specified by implementing the random coefficients formulation. Different distribution functions were tested and different combinations of attributes were investigated. Estimation results, reported in table 4, indicate that the MBNL formulation was statistically significant and showed a slightly better goodness-of-fit than the BNL model. As regards the systematic utility functions, no new attribute was statistically significant, ASC decreased its value and its significance, and only two attributes turned out to be normally distributed (Δ_{cost} and $Km_{(25000)}$ or $CarAge_{4years}$). Both attributes are those expected to be randomly distributed, and estimation results confirmed our expectations. Furthermore, the standard deviations had a non-negligible value.

Finally, it is interesting to point out that only for the Avellino case study can be observed a significant decrease in the ASC values. Such a results makes the MBNL a preferable solution due to its greater sensitivity to level of service attributes (Δ_{cost}).

7 Conclusions

The electrification and Hybridization of the actual vehicle fleet is considered as a first Milestone in the European electrification road-map. In this context, upgrading conventional vehicles to solar-hybrid could have a relevant and short-term impact on fuel consumption and carbon dioxide emissions due to transportation, since it may potentially be applied to most of the current fleet, and without requiring expensive reconversion of the production lines for cars.

The kit is an innovative, reliable and cost-effective way to upgrade conventional cars to green hybrid vehicles. In particular, the kit aims to convert conventional cars into hybrid-solar vehicles, reducing fuel consumption and emissions with limited investment costs and without invalidating performance and safety.

The economic benefits for the users would be significant, especially considering the economic scenario and the automotive market trends. According to modelling and simulations studies (Marano et al., 2013) and preliminary road tests, a vehicle equipped with the HySolarKit could achieve most of the benefits of a native hybrid vehicle, such as regenerative braking, optimal use of the two propulsion systems (thermal and electric), by limiting the (conventional) engine operations in low-efficiency conditions. Furthermore, the HySolarKit would benefit from free photovoltaic energy (stored during driving and parking mode), thus enhancing the benefits achievable through the kit. In terms of economic benefits for the users, a payback of 3-5 years is expected (without incentives), depending on the specific kit configuration (plug-in option, battery size, etc.), resulting from a net fuel saving of up to 20% in hybrid-solar mode (assuming up to one hour driving per day, mostly in urban settings). Of course, use of a plug-in would result in further fuel saving, while the adoption of incentives would reduce the payback period. Furthermore, the emissions reduction of up to 20% which is achievable through the HySolarKit could result in an upgrade in "European Emission Standards", e.g. upgrading a EURO3 vehicle to EURO4 (and so on), thus giving a longer life to older vehicles.

Within the proposed technological framework, the aim of the paper was twofold: (i) to investigate the main behavioural determinants of the choice process; (ii) to set up an operational model to be applied to real scenarios. In particular, the behavioural process was subdivided into two stages: the intention to adopt the technology and the choice to install it. Both stages were separately modelled through random utility theory models, assuming two binomial choice contexts: "intention to adopt or not to adopt"; "install or not to install".

Our results allow both operational and methodological conclusions to be drawn. First, the HySolarKit may be a promising technology since potential users showed both the intention to adopt the kit and the choice to install it. Secondly, for both behavioural stages it was possible to estimate statistically significant models, showing that the behavioural assumptions made were reasonable and, furthermore, that both stages can be fruitfully interpreted and modelled within the random utility paradigm. Modelling the two choice stages may be of interest for decision-makers or manufacturers, since it offers insights both into how to attract interest towards the technology in question and how to condition the choice to buy and install the kit. From the methodological viewpoint, heteroscedastic formulations were statistically significant only for the choice to install the model. Explicit simulation of taste variation allowed a better goodness-of-fit and a non-negligible decrease in the alternative specific constant. Thirdly, the estimation results made it possible to ascertain the main determinants of each behavioural stage, but also the differences between the two stages.

With regard to the intention to adopt, three classes of attributes were statistically significant: user-specific, activity-related and attitudinal attributes. Among the user-specific attributes, only gender and age played a role, whereas the only attribute related to the cars owned by the household was the number of kilometres travelled by the car on which the HySolarKit was to be installed. Together with the above socio-economic attributes, the area in which users reside affected the probability of being interested: residents in the outskirts of the study area were more intent on adopting the kit. As regards activity-related attributes, the perceived utility of installing the kit decreased as the number of work trips increased. By contrast, the number of weekly trips for leisure purposes increased the intention to adopt the kit. These results indicate that the degree of intention depends on the trip purpose for which the car is usually used. Finally, intention was significantly affected by users' concerns. The users' concerns towards environmental and energy consumption issues positively affected their intention, whereas users more influenced by vehicle design of the are less interested in the kit. Furthermore, the concern for fuel consumption seems to marginally affect the intention.

Interestingly, as regards the choice to install the kit, the same socio-economic characteristics were statistically significant. They continued to carry a similar weight in the systematic utility functions.

Unlike the intention behavioural stage, the mileage of the car on which the kit was to be installed was no longer a continuous attribute, but became a dummy attribute. The statistically significant threshold was 25,000 km or 4 years. As expected, users were more willing to modify their cars after a certain time interval.

With regard to the effect of the installation cost, the probability of installing the kit increased as the Δ_{cost} rose. This occurs when the weekly mileage is low and hence the investment cost - spread over four years - does not allow any financial gain. Finally, attitudinal attributes were not significant in the choice of installing the kit, indicating that when installation costs were introduced, attitudinal preferences did not play a significant role. Sensitivity analysis showed that the probability of installing the kit was greatly affected by the installation costs, but also by the weekly mileage driven. For instance, assuming 2,000 euros was the minimum acceptable installation cost, the probability of installing the kit decreased by about 70% with a 1,000-euro increase in the installation cost. The same probability may increase by more than 50% for a 10% increase in weekly mileage.

Finally, the following operational considerations can be made:

1) market segments captive to such a type of technology mainly consist in male and younger users. Thus investors should work on specific marketing policies if they wish to extend the potential market;
2) concerns affect intention but do not affect installation intention.
3) market penetration mainly depends on the installation cost and on the number of kilometres travelled. Therefore the installation costs should be carefully determined and/or specific subsidies should be contemplated; secondly any marketing or selling strategies should be carefully based on the real spatial travel patterns of potential users.
4) There is a car “age” for which the kit is perceived as a possible solution. This threshold, which in our case study was 25,000 km (4 years), should be investigated or calibrated.

From the previous analyses and considerations, different kinds of potential customers can be identified: car owners but also private/public companies. In particular, car owners tended to keep the car (on which to install the kit) for about 4/5 years, driving mostly in an urban environment and for a limited time per day, and that are oriented towards advanced mobility solutions (electric/hybrid) and interested in upgrading their conventional car to more sustainable emission standards (i.e from Euro 4 to Euro 5). Another important category may be represented by companies, municipalities and organisations owning fleets of cars. For most of them, the HySolarKit may be an affordable way to upgrade their fleet in order to reduce fuel cost and emissions..

In conclusion, several research perspectives seem worthy of interest. These include, first of all, the investigation of attitudes and preferences within a latent class model framework or through the estimation of hybrid choice models; secondly, the evaluation of the environmental effects that may be induced by different adoption rates of the HySorlaKit; finally, implementation of cost-benefit analysis to evaluate the financial and social feasibility of subsidy policies.

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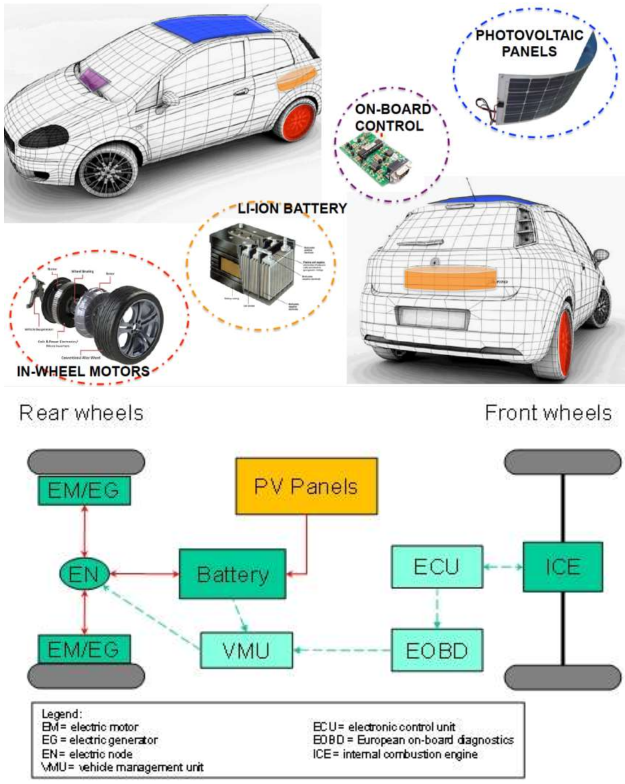

Figure 6- Hybridization Kit - vehicle integration and system schematics

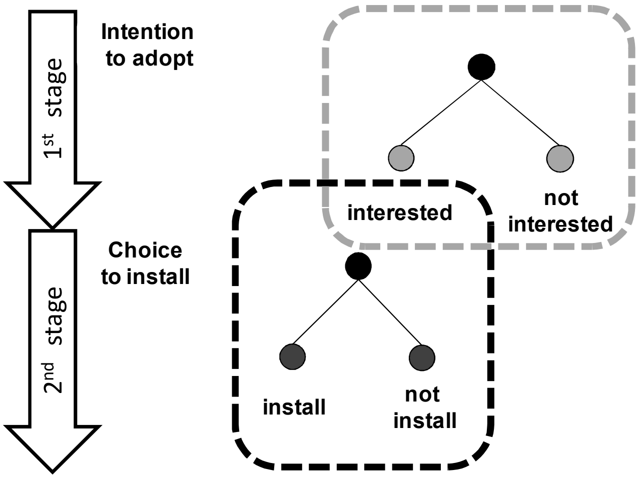

Figure 7-Behavioral stages

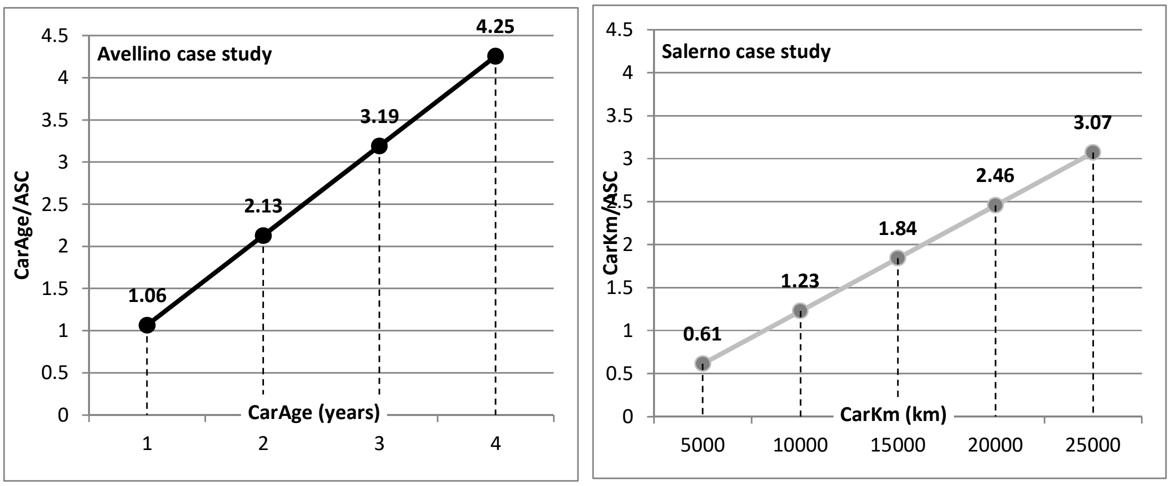

Figure 8- CarAge/ASC and CarKm/ASC ratios as CarAge and CarKm change

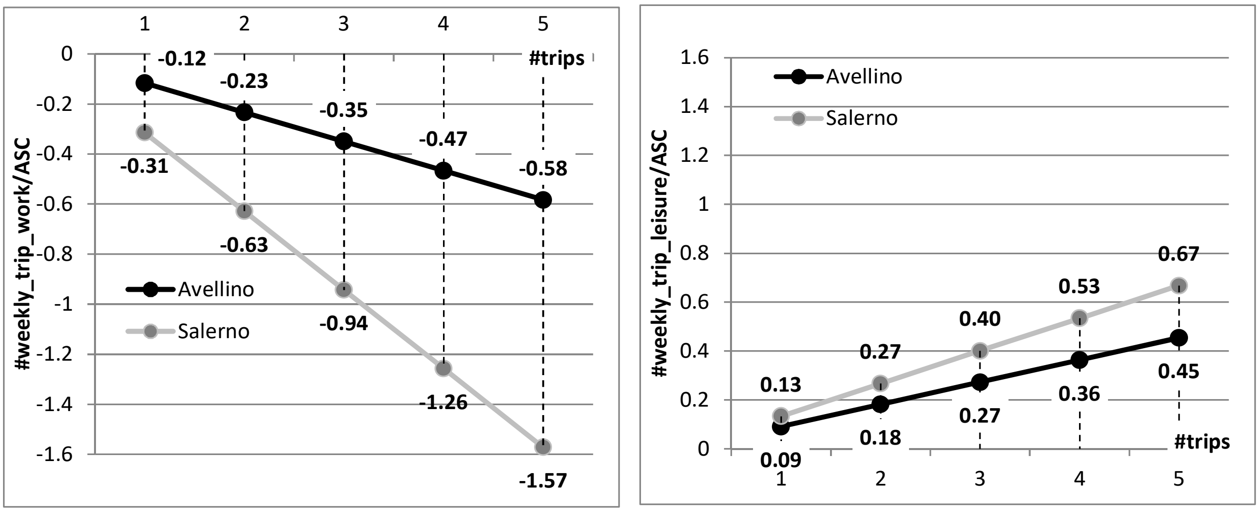

Figure 9- #weely_trip_work/ASC and #weekly_trip_leisure/ASC ratios as the number of weekly trips change

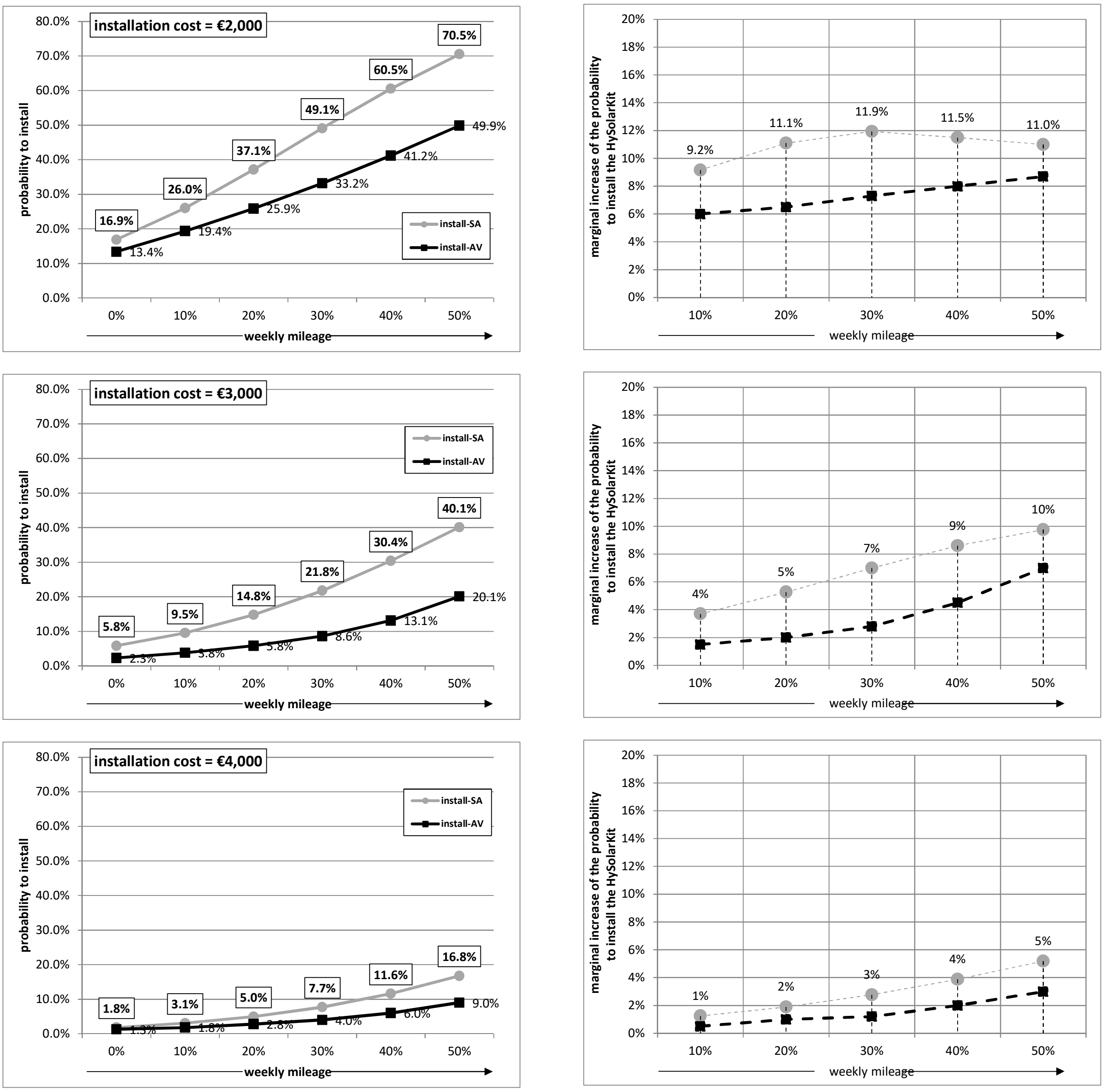

Figure 10- sensitivity analyses to installation costs and weekly mileage

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Table 5– Instrumental and functional attributes

attributes	contributions
purchase price running costs reliability performance driving rang recharging time	Beggs et al., 1981; Bunch et al., 1993; Chéron and Zins, 1997; Dagsvik et al, 2002; Santini e Vyas, 2005; Land and Potter, 2007; Kurani et al., 2008; Bolduc et al., 2008; Struben and Sterman, 2008; Diamond, 2009; Sovacool and Hirsh, 2009; Caperello and Kurani, 2011; Qian and Soopramanien, 2011; Skippon and Garwood, 2011, Lieven et al., 2011; Musti and Kockelman, 2011; Zhang et al., 2011; Egbue and Long, 2012; Lebaut et al., 2012; Graham-Rowe et al., 2012; Jensen et al., 2013; Hackbart et al., 2013; Lee, 2013; Tamor et al., 2013; Chorus et al. 2013; Van Rijnsoever et al., 2013; Krupa et al., 2014; Hoen and Koetse, 2014; Glerum, 2014
environmental performances	Potoglou and Kanaroglou, 2007; Struben and Sterman, 2008; Bolduc et al., 2008; Lebaut et al., 2012; Van Rijnsoever et al., 2013
technical/instrumental/functional, battery replacement, charging infrastruc. availability, acceleration, top speed luggage space	Dagsvik et al., 2002; Santini and Vyas, 2005; Bolduc et al., 2008; Struben and Sterman, 2008; Ozaki and Sevastyanova, 2011; Qian and Soopramanien, 2011; Zhang et al., 2011; Skippon and Garwood, 2011; Lebaut et al., 2012; Egbue and Long, 2012; Jensen et al., 2013; Lee et al., 2013; Van Rijnsoever et al., 2013; Carley et al., 2013; Krupa et al., 2014
driver/user types, technology attitudes and vehicle technologies	Sikes et al., 2010; Hackbarth and Madlener, 2013
government subsidies tax policies	Santini e Vyas, 2005; Lane and Potter, 2007; Potoglou and Kanaroglou, 2007; Diamond, 2009; Ozaki and Sevastyanova, 2011; Qian and Soopramanien, 2011; Zhang et al., 2011; Hsu et al., 2013, Lee et al, 2013; Glerum, 2013; Chorus, 2013; Hackbart et al., 2013; Hoen and Koetse, 2014; Krupa et al., 2014
brand, design number of vehicle types	Santini e Vyas, 2005; Potoglou and Kanaroglou, 2007; Lebaut et al., 2012; Egbue and Long, 2012; Chorus, 2013; Axsen and Kurani, 2013; Glerum, 2013; Hoen and Koetse, 2014
free parking, free access to restricted traffic zones, preferential lanes	Bolduc et al., 2008; ; Diamond, 2009; Chorus, 2013
age, income, monthly income, environ. awareness, residence, age of the owned vehicle	Dagsvik et al., 2002; Potoglou and Kanaroglou, 2007; Bolduc et al., 2008; Diamond, 2009; Axsen and Kurani, 2010; Qian and Soopramanien, 2011Hsu et al., 2013, Lee et al, 2013; Glerum, 2013; Hoen and Koetse, 2014

Table 6– Collected and investigated attributes

Attribute	meaning	type	SI	min	max
Gender	equal to 1 for male users	binary		0	1
Age	age of the respondent	continuous	years	24	70
Number of households	-	discrete	-	1	5
Car Availability	no. of household vehicles / no. of household members It can be interpreted as a measure of car availability, but also as a proxy measure of household income	continuous	-	0.25	1
CarCatB	If the car on which to install the kit belongs to one of the following segments: large, executive or luxury cars.	binary	-	0	1
ZonRes	Equal to 0 for users living to the historical centre, 1 if in the outskirts	binary		0	1
#weekly_trip_work	Number of household weekly trips by car for work purposes	discrete	-	3	6
#weekly_trip_leisure	Number of household weekly trips by car for leisure purposes	discrete	-	0	3
Att_Consump	Attitude/Concern towards/for fuel consumption. Each respondent was asked to rate his/her attitude/concern towards/for fuel consumption savings related to the use of internal combustion vehicle. The rating scale and the value associated to each rate was: no importance (0), mild (3), moderate (5) , severe (7).	dummy attribute for each scale	-	0	1
Att_Design	Attitude/Concern towards/for design issues. Each respondent was asked to rate how the design is important in the decision of which car to purchase. The rating scale and the value associated to each rate was: no importance (0), mild (3), moderate (5) , severe (7).	dummy attribute for each scale	-	0	1
Att_Environment	Attitude/Concern towards/for greenhouse gas emissions. Each respondent was asked to rate his/her attitude/concern towards/for environmental issues related to the use of internal combustion vehicles. The rating scale and the value associated to each rate was: no importance (0), mild (3), moderate (5) , severe (7).	dummy attribute for each scale	-	0	1
CarAge	Age of the owned car on which the respondent would install the kit.	continuous	years	1	10
CarKm	Mileage of the owned car on which the respondent would install the kit	continuous	km/10000	0.5	23
Km_x	equal to 1 if the mileage of the owned car is less than x km	binary	-	0	1
CarConsumption	Average fuel consumption per km of the car on which the respondent would install the kit	continuous	km/litre	10	25
DailyKm	Daily travelled kilometres	continuous	km	3	80
WeeklyFuelCost	Monetary cost of actual weekly fuel consumption	continuous	€	10	70
Δ_{cost}	Δ_{cost} = WCoutK – WcwithK	continuous	€	-4.4	17.2

In order to compare the scenarios with and without the kit, the financial gain was expressed in terms of weekly costs, rather than yearly costs or life costs based on the year of the vehicle owned by the respondent. Therefore, each respondent was preliminarily informed on the upfront cost, and successively he/she was also informed on the weekly cost which was expressly estimated with respect to the fuel consumption, the charging cost and the installation cost. To this aim, each cost was estimated taking into account the weekly kilometres effectively travelled by each respondent.

In particular, it was estimated the difference between the weekly fuel cost without the kit (WCoutK) and the weekly fuel cost with installing the kit (WCwithK).

WCoutK = *litre/km* × *€/litre* × *weekly km*

where:

- litre/km is the fuel consumption per kilometre of the car on which the kit will be installed. It depends on the type of car stated by the respondent and was estimated starting from manufacturers' data-sets.
- *€/litre* is the average fuel cost per litre.
- weekly-km is the number of the kilometres travelled as stated by the respondent

WCwithK = €/km × weekly km + Weekly_inst_cost + Charging_cost

where:

- litre/km is the fuel consumption per kilometre after installing the kit. This value depends on the type

	of car, on the type of trip (urban, sub-urban, inter-urban) and on the driving style. In our case study, the type of car was stated by the respondent and the considered trips were urban. As regards the driving style, average values were assumed. - Weekly_inst_cost. This is the weekly installation cost. It was obtained by distributing the total installation cost over 208 weeks (four years). This hypothesis was made on the assumption that four years is a reasonable economic life of the kit and of the car in which it will be installed. After four years it is reasonable to assume that the owner, due to the age and mileage of the car (the kit is not usually installed on a new car), will be interested in buying a new car. - Charging_cost. This is the monetary cost required to charge the battery fully. The charging cost was estimated by assuming that each user has to charge the battery every day (12 km is the duration of the battery and the average trip length is about 10 km). When in the solar mode, three days are sufficient to charge the battery; it can be assumed that solar charging corresponds to about 30% of the daily energy necessary to charge the battery fully. Starting from the energy cost (about €0.20 /kWh), and combining the charging time in the solar and plug-in mode, a daily charging cost of about €0.40 was estimated, corresponding to about 2 euros/week.

Table 7– Model of the intention to adopt: estimation results

Attribute		SALERNO CASE STUDY				AVELLINO CASE STUDY			
		Intention to adopt	No intention	Intention to adopt	No intention	Intention to adopt	No intention	Intention to adopt	No intention
		BNL		MBNL		BNL		MBNL	
Gender		+2.77 *(+1.93)*	-	+2.81 *(+2.84)*	-	+1.93 (+2.04)	-	+2.02 (+2.23)	-
Age		-	+1.28 *(+1.98)*	-	+1.25 *(+2.02)*	-	+1.10 *(+3.75)*	-	+1. 79 *(+3.84)*
ZoneRes		+0.730 *(+2.66)*	-	+0.867 *(+2.63)*		+0.340 *(+3.02)*	-	+0.560 *(+3.91)*	
#weekly_trip_work		-	+0.447 *(+2.83)*	-	+0.682 *(+2.84)*	-	+0.154 *(+2.09)*	-	+0.250 *(+2.70)*
#weekly_trip_leisure		+0.187 *(+2.48)*	-	+0.296 *(+2.53)*	-	+0.124 *(+3.02)*	-	+0.199 *(+3.23)*	-
CarKm		+1.72 *(+1.90)*	-	+1.68 *(+1.85)*	-				
CarAge						+1.404 *(+2.54)*	-	+1.200 *(+2.50)*	-
Att_Consump	"Severe"	+0.133 *(+2.12)*	-	+0.189 *(+2.16)*	-	+0.188 *(+2.38)*	-	+0.317 *(+3.49)*	-
	"Moderate"	+0.056 (+2.03)	-	+0.073 (+2.32)	-	+0.113 (+2.38)	-	+0.181 (+2.56)	-
Att_Design	"Severe"	-	+0.903 *(+2.77)*	-	+0.927 *(+2.96)*	-	+0.983 *(+3.08)*	-	+1.66 *(+2.69)*
	"Moderate"	-	+0.424 (+1.98)	-	+0.478 (+1.94)	-	+0.482 (+2.02)	-	+0.747 (+2.14)
Att_ Env	"Severe"	+1.22 *(+2.04)*	-	+1.42 *(+2.13)*	-	+1.00 *(+2.44)*	-	+1.57 *(+2.59)*	-
	"Moderate"	+0.708 (+1.93)	-	+0.801 (+2.03)	-	+0.520 (+2.380)	-	+0.895 (+2.380)	-
ASC		-	+1.48 *(+3.10)*	-	+1.28 *(+3.11)*	+1.32 *(+3.37)*	-	+2.31 *(+3.28)*	-
ASC (standard deviation)				-	+0.271 *(+2.25)*			+0.70 *(+2.56)*	-
#respondents		300		300		600		600	
#number of draws		-		2000		-		2000	
Init log-likelihood		-207.9		-207.9		-415.8		-415.8	
Final log-likelihood		-89.80		-90.87		-227.9		-224.2	
Pseudo rho-square		0.562		0.563		0.452		0.461	

* in parenthesis the t-test values

Table 8– Choice to install the kit model: estimation results

	SALERNO CASE STUDY				AVELLINO CASE STUDY			
	install	**not-install**	**install**	**not-install**	**install**	**not-install**	**install**	**not-install**
Attribute	**BNL**		**MBNL**		**BNL**		**MBNL**	
Gender	+1.64 (*+1.68*)	-	+1.94 *(+1.97)*	-	+2.08 *(+1.97)*	-	+2.01 *(+2.64)*	-
Age	-	+0.04 (*+1.84*)	-	+0.05 *(+1.80)*	-	+0.05 *(+2.37)*		+0.08 *(+2.37)*
ZonRes	+1.22 (*+1.12*)	-	+2.02 *(+1.66)*	-	+1.99 *(+1.68)*	-	+0.450 *(+2.16)*	-
Δcost	+0.314 (*+2.19*)	-	+0.39 *(+1.76)*	-	+0.29 *(+9.63)*	-	-	+0.344 *(+8.60)*
Δcost (standard dev.)			+0.16 *(+2.72)*	-			-	+0.04 *(+2.06)*
$Km_{(25000)}$	+3.81 (*+2.20*)	-	+4.63 *(+1.83)*	-				
$Km_{(25000)}$ (standard dev.)	-	-	+0.79 *(+1.84)*	-				
$CarAge_{(4y)}$					+2.95 *(+2.62)*	-	-	+0.188 *(+2.43)*
$CarAge_{(4y)}$ (standard dev.)					-	-	-	+0.012 *(+2.56)*
CarCatB					-	+1.26 *(+2.65)*	-	+2.16 *(+2.95)*
DailyKm	-	+0.520 *(+3.22)*	-	+0.584 *(+2.26)*	-	+0.420 *(+5.76)*	-	+0.264 *(+3.46)*
ASC	-	+3.59 (*+2.06*)		+4.24 *(+1.86)*	-	+5.16 *(+4.05)*	-	+1.61 *(+1.86)*
Correlation parameter		+1.25 *(+2.92)*		+1.78 *(+2.47)*	-	+3.82 *(+8.41)*	-	+4.84 *(+6.61)*
#respondents	180		180		320		320	
#observations	540		540		960		960	
number of draws	-		2000		-		2000	
Init log-likelihood:	-374.3		-374.3		-665.4		-665.4	
Final log-likelihood:	*-162.4*		158.3		-397.2		-380.6	
rho-square	0.566		0.577		0.403		0.428	
adjusted rho-square:	0.491		0.481		0.395		0.419	

* in parenthesis the t-test values