Using living labs to investigate the transition towards electric mobility: the e-mobiliTI experiment in Southern Switzerland

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Abstract

The diffusion of electric vehicles is one of the most promising opportunities to reduce dependency on fossil fuels and to pave the way for the transition to a more sustainable mobility. However, apart for the main barrier still represented by the purchase cost, the adoption of electric vehicles is still hindered by other barriers, such as autonomy, recharge time any general performance. Therefore, fostering a change in the present mobility patterns requires to go beyond the traditional technological approach and to explicitly address consumers perceptions and behaviour.

In 2012 we launched the e-mobiliTI project to get a deeper understanding of the factors favouring or opposing the transition to e-mobility. This project builds upon the living lab approach, focusing on a small sample of families located in Southern Switzerland. Family members accepted to be monitored in all their trips, in exchange for the availability, for a period of three months, of electric cars and bicycles, public transport seasonal tickets and car and bike-sharing subscriptions. In Spring 2013 a first three-months monitoring phase allowed us to identify their present mobility patterns and styles, while in Spring 2014, during a second three-months monitoring phase, the participants experienced the new mobility options in real-world settings. In order to monitor travel behaviour, we relied on both quantitative automatic data-gathering techniques and on qualitative focus groups and interviews. Automatic data-gathering was performed thanks to a specifically developed smartphone application that relied on GPS tracks. To identify the significant variations of mobility patterns between the two monitoring phases, we developed a data mining approach based on regression trees.

In this paper we present the results of the e-mobiliTI project and conclude with a critical analysis of our approach, especially regarding the problems in automatic data gathering and mobility profiling and the limited representativeness of our results, due to the small size of our sample and the short duration of the testing period.

Keywords

living lab, electric mobility, mobility transition, automatic tracking

1 Introduction

The diffusion of electric vehicles (EV) is one of the most promising opportunities to reduce dependency on fossil fuels and to pave the way for the transition to a more sustainable mobility also in Switzerland (De Haan and Zah (2012)). The cost of electric vehicles has worldwide sensibly decreased, up to the point that in a few years it is expected to become equivalent to conventional internal combustion engine (ICE) vehicles (see for example World Bank (PRTM Management Consultants) (2011)). Apart for the main barrier still represented by the purchase cost, the adoption of electric vehicles is however still hindered by barriers such as the autonomy range, the availability and diffusion of recharge points and the overall perceived performance (see for example Everett *et al.* (2011), Turrentine *et al.* (2011), Deloitte (2010), Cocron *et al.* (2011), Graham-Rowe *et al.* (2012), National Research Council [NRC] (2013)). Are these real barriers or are they just psychological, a priori barriers, that can be removed by means of direct experience?

In Switzerland, according to the 2010 Swiss Transport and mobility census OFS-ARE (2012), 84% of the trips are shorter than 10 kilometers and 73% of them are less than 5 kilometres long. According to these numbers, more than 80% of the demand for personal mobility could be covered by electric mobility. Moreover, a widespread network of public charging stations is nowadays available all over the urbanised areas. In Switzerland, thanks to the "EVite" initiative by the Swiss Association eMobility, up to 250 public fast-charge stations will be installed in the next years. Finally, the Tesla car-maker has just installed eight "super-chargers" stations all over Switzerland, as a special benefit for the owners of Tesla vehicles.

Despite these progresses, and even though the diffusion of electric vehicles is increasing from year to year, in Switzerand their number keeps in the order of 0.050% of the present car fleet (Swiss Federal Statistical Office (2013)). Therefore, understanding and, at a later stage, fostering the transition towards more sustainable mobility patterns, imposes to go beyond the traditional technological approach, to integrate psychology, sociology and cultural aspects and to explicitly address consumer perceptions and behaviours [Geels et al., 2011].

In this paper we present the outcomes of the e-mobiliTI living lab, a socio-technical field experiment (Schot (2001), Geels and Schot (2007)) we developed in Southern Switzerland between 2012 and 2015. Focusing on end-users experiences and adopting a bottom-up perspective, we investigated the potentials for the diffusion of electric vehicles and their effectiveness in promoting a wider transition in the current mobility patterns. Here we shortly describe the research framework of the e-mobiliTI living lab (Section 2), then we address the general design of the experiment (Section 3) and the methodologies and devices we used to track and profile the users' mobility patterns - both when they were using their current means of transport and when they were experiencing electric vehicles and new mobility options (Section 5). After, we illustrate the outcomes of our experiment: we describe the current mobility patterns of the users (Section 4) and discuss on their use of the electric vehicles and their implications on the users' mobility patterns (Sections 6 and 7). We conclude with a critical analysis of our approach, proposing suggestions for future research activities (Section 8).

2 The theoretical framework

The e-mobiliTI project is grounded in the theoretical framework of the Strategic Niche Management (SNM) approach, developed in the late Nineties at the European level and already successfully applied in the transportation sector (Kemp *et al.* (1998), Schot *et al.* (1999), Kemp *et al.* (2000)).

Acknowledging that technological and behavioural aspects are strictly interconnected, the SNM approach states that complex transitions can be obtained in terms of *regime shifts*, by artificially creating protected spaces for testing and developing new technologies. That is, new technologies are artificially made attractive and real life users are allowed to exploit them. Offering the technology a protected space, in which it is defended by the full force of normal selection processes, the analysis of the users' behaviour allows to assess the effects of the technology itself, both in terms of technical and economical viability and in terms of social desirability. Information gathered during SNM processes thus allows to identify the most effective policies capable of favouring the diffusion of the technology on the market and able to expand the niche size, with a gradual implementation of the transition. The niche is always composed of *a group* of persons: it allows to examine collective problems beyond a single-actor perspective, however giving each participant the same opportunities and importance. Provided that a significant number of participants is involved, the social dimension of the niche guarantees that diversity, openness and multidisciplinary aspects are considered (Pallot *et al.* (2010)), thus favouring a later wider spread and adoption of the innovative technology.

Following a more recent definition, we indicate such bottom-up and user-centred inter-disciplinary processes as "living lab" processes. This definition is effective in highlighting the involvement of *real-life users* for the exploration of new technologies in their own, *real-world* settings (Higgins and Klein (2011)). The term "living lab" was first introduced by W. Mitchell, K. Larson and A. Pentland in the MIT laboratories (Media Lab and School of Architecture and City Planning) (Eriksson *et al.* (2006)), when they gave real-life end users the possibility to test smart and energy-efficient building performances, by living in those buildings for a certain period of time. They were in fact convinced of the need for explicitly taking into account the social aspects of technological innovation, as the only way to facilitate a large-scale diffusion of the innovation itself, and, in general, to determine a real transition in the society. Living labs thus configure as test-beds for "*in vivo*" experimentation of new technologies or policies, as opposed to "*in vitro*" experimentation (Dutilleul *et al.* (2010)). The possibility of testing, validating and refining innovation by monitoring real-life users in their real-life context has in fact proven to be far more effective than testing and validating it in simply *realistic scenarios* (Almirall *et al.* (2012)) or than simulating users behaviour. Even though still lacking a formal supporting theory (Schuurman *et al.* (2012)), the concept of living labs gained momentum and started being used in a variety of processes (Dell'Era and Landoni (2014)), insomuch that it has become a mandatory activity in a variety of Horizon 2020 call for research projects within the European Union.

The SNM and Living lab methodologies are especially effective in systems offering environmental and social benefits which are undervalued on the market (Kemp *et al.* (2000)), in particular by single individuals, as in the transportation sector. Successful experiences in this sector were for example gathered in Denmark since 2009, with the TryAnEV/Insero E-mobility project (Agerskov and Høj (2013)). For less recent experiences, one can for example refer to Hoogma *et al.* (2002).

3 The e-mobiliTI living lab

We launched the e-mobiliTI living lab in Southern Switzerland in 2012 with the aim of understanding the factors favouring or opposing the transition to electric mobility, along with their wider implications on mobility patters, learning from the direct experience of common citizens. In this section we provide a general description of the objectives and key aspects of the whole e-mobiliTI process, updating and showing in greater detail some of the elements we already presented in Cellina *et al.* (2013).

3.1 The research questions and the design of the field experiment

The e-mobiliTI living lab experiment was designed to answer the following research questions:

- can electric vehicles (EVs) effectively replace conventional internal combustion engine vehicles (ICEVs), without imposing limitations on their users or causing regrets in the overall satisfaction of their mobility needs?

- does the availability of EVs uniquely result in the replacement of ICEVs (”substitution effect”)? Or does it foster a wider change in mobility patterns, favouring slow mobility, public transport and shared mobility services (Geels *et al.* (2011) and Fujimoto and Poland (2013) (”transformation” effect)?

To answer these questions, we set up a field experiment involving a small number of families living in Southern Switzerland.We were interested in two categories of users:

- the ”Old users”, i.e. families who already used electric cars or bicycles, having made a choice in favour of electric mobility before the launch of the project. According to Rogers' categories for the diffusion of innovation Rogers (2010), they could be classified as EV ”early adopters”. They were "experts" and could provide hints and suggestions directly taken from their previous personal experience;
- the ”New users”, i.e. families interested in testing new mobility options, in particular electric cars and bicycles. According to Rogers' categories, they represented the ”early majority” consumers. That is, they were intrigued by EVs but, for a number of reasons, they did not make any explicit, personal choice towards them.

Involving users taken from these two categories allowed us to follow and analyse the whole process of adoption of EVs and to assess whether a substitution effect or a wider transformation of the present mobility patterns is more likely to occur.

As shown in (see Figure 1), the field experiment was divided in two Phases. During Phase 1, held in Spring 2013, we performed a three-months monitoring period, aimed at identifying the users' current mobility patterns and styles. That is: we simply followed them in order to understand how much they travelled and with which means of transport. During Phase 2, held in Spring 2014, we performed a further three-months monitoring period, aimed at identifying the users' mobility patterns and styles while they were experiencing new mobility options in their complex, real-world settings. The innovative mobility options they tested in Phase 2 were the following (see Figure 2): every ”New users” family got an electric car (*Nissan Leaf*), an electric bicycle (*Flyer T series*) and three months season tickets for each member of the family, allowing access to all the public means of transport in the whole Southern Switzerland (Canton Ticino, Arcobaleno season ticket) and to the *Mobility* and *Publibike* car and bike-sharing services. Every member of the ”Old users” family, instead, received the free season tickets for public transportation, car and bike-sharing. Due to budget limitations, we could not provide them with electric bicycles. Finally, they already had their own electric car.

Comparing the mobility patterns observed during the two monitoring phases allowed us to answer our research questions.

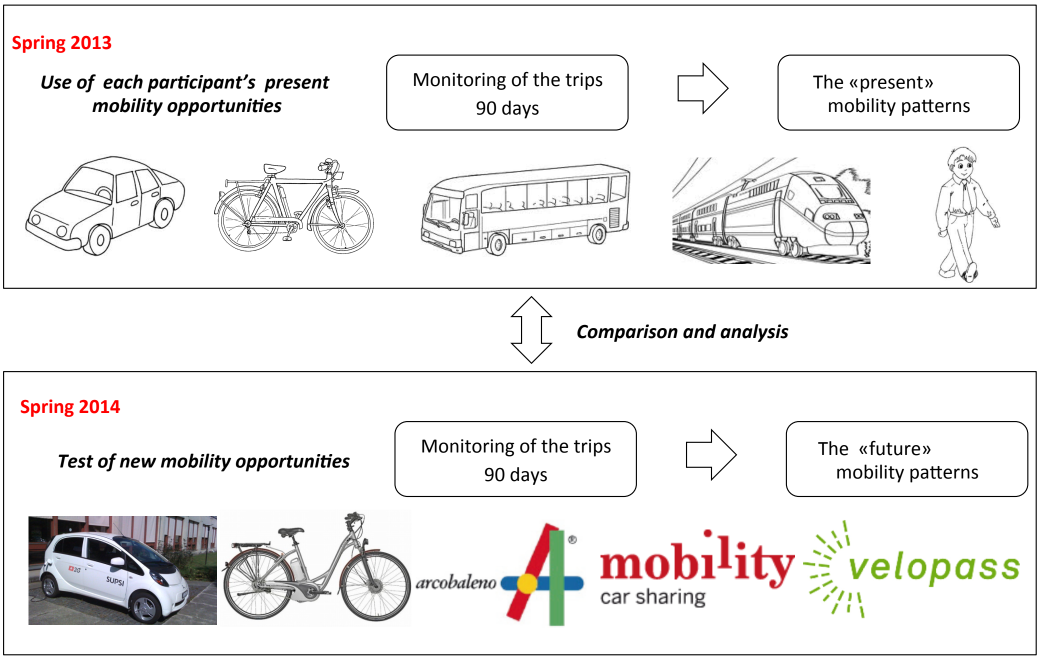


Figure 1: The two phases of the e-mobiliTI experiment.

Mobility options	Phase 1	Phase 2
'Old users" families	Their own electric car and other means of transport	Their own electric car and other means of transport; and, for every member of the family: - a public transport season ticket (Arcobaleno); - a car-sharing season ticket (Mobility); - a bike-sharing season ticket (Publibike Lugano).
'New users" families	Their own means of transport	Their own means of transport; an electric car (Nissan Leaf); an electric bicycle (Flyer T Series); and, for every member of the family: - a public transport season ticket (Arcobaleno); - a car-sharing season ticket (Mobility); - a bike-sharing season ticket (Publibike Lugano).

Figure 2: The mobility options available to the participants to the e-mobiliTI living lab.

Participants to the project accepted to be monitored in all their trips, in exchange for the opportunity of testing the new mobility options for the three-months in Phase 2. Providing them with the new mobility options, we removed the present main barrier to the diffusion of electric cars and bicycles, that is their price, and created a niche in which we can analyse the participants behaviour with respect to other barriers, such as: range, recharge and overall performance for the electric cars; physical effort and safety for the electric bicycles; status-symbol and limited flexibility for car and bicycle sharing; limited time flexibility, punctuality and comfort for public transport.

In order to monitor travel behaviour and to identify the mobility patterns of the participants, in both Phases we relied on both quantitative automatic data, gathered by means of smart mobile devices, and on qualitative insight on perceptions and motivations, gathered by focus groups and individual interviews. In our approach, therefore, qualitative data supported and integrated quantitative, automatic data.

3.2 The study area

The families involved in the e-mobiliTI living lab were from the City of Lugano and its surroundings (cf. Figure 3). Accounting for around 135'000 inhabitants, Lugano is the main city in Canton Ticino, the Italian-speaking part of Switzerland. The Lugano conurbation is characterised by heavy urban sprawl and its inhabitants have a strong tendency to use the private car for the majority of their trips. According to the 2010 Swiss Transport and mobility census (OFS-ARE (2012)), on average in the Lugano agglomeration people travel 27.7 kilometers per day, using private motorised means of transport (PMT) for 75% of the daily kilometers travelled. For a comparison with global Swiss data, consider that an average Swiss citizen travels 36.7 kilometers per day, with a PMT modal share of 66%, thus in Lugano people travel less, but are much more dependant on PMT than in the rest of Switzerland.

However, the Lugano region is the most interesting area in Southern Switzerland for the variety of alternatives to conventional fossil fuelled PMT mobility it offers: besides a good network of public charging stations for electric vehicles and an efficient public transportation system, it also offers the Mobility car-sharing and Publibike bike-sharing services. Therefore, this region was a very interesting case study, both in terms of the need for a significant change in the dominant mobility patterns and in terms of the already available opportunities for change.

Figure 3: The Lugano region is located in the Italian-speaking part of Switzerland (Canton Ticino).

3.3 The sample of participants

Selecting the participating families was a crucial activity. We issued a public open call, promoted via the local media (newspapers, television, radio) and via flyers distributed all over the City of Lugano: therefore, participants were selected from a group of self-nominated candidates. The public call was open to generic *families*, i.e. either *single individuals* or *couples* or *couples with (older) children*. More than 350 candidates answered the call: a much higher number than initially expected, reflecting a very high interest of the general public for innovative mobility options. To select among them we performed a ”twinning process” between ”Old users” and ”New users”: we identified ”twins” of families based on the place of living and on the demographic features mentioned above (single, couple, couple with (older) children). Since the number of ”Old users” families in the Lugano area was very limited, we took the ”Old users” candidate families as fixed and identified the ”New users” candidate families that lived in their surroundings and were characterised by similar demographic features. This process identified a set of sixteen families, for a total number of twenty-seven persons actively involved (see Table 1).

Table 1: Demographic features of the e-mobiliTI sample.

	Old Users		New Users		Total	
	Families	Users	Families	Users	Families	Users
Singles	2	2	2	2	4	4
Couples	1	2	3	5	4	7
Couples with (older) children	4	7	4	9	8	16
Total	7	11	9	16	16	27

All family members older than fourteen years old were asked to participate in the project activities. However, not everyone decided to take part and, therefore, in some families only one of the parents was actively involved in the project activities, while the other parent opted not to take part to the project.

The sample obtained by this selection process included participants from a variety of socio-economic backgrounds with different attitudes towards ecology and mobility issues. In the sample there were pro-environment individuals, used to a sustainable lifestyle, side by side with lovers of driving, speed and sports cars. Therefore, even though we could not claim our sample to be representative of the actual diversity of the whole Lugano population given its limited size, we were confident that its wide level of variety provided a sufficiently wide spectrum of insights on the opportunities and barriers for the diffusion of electric mobility.

All the trips of the members of the e-mobiliTI sample were fully tracked during Phase 1, using the e-mobiliTI smartphone application developed on purpose. Between Phase 1 and Phase 2, however, four of them faced important personal changes heavily affecting their mobility patterns, such as the change of their place of residence or their workplace. Therefore, even though we kept on tracking their mobility patterns for the whole Phase 2, we did not use their quantitative data in the general assessment of the level of change in the mobility patterns. They were however useful for the project activities, since they were able to provide us with qualitative insights during interviews and focus group meeting. Furthermore, in Phase 2, three participants used the e-mobiliTI application only occasionally and the data we collected were not enough to draw any conclusion. Two of them were teenagers, with probably a low interest in their own mobility behaviour and its impact on society and the environment. The other one instead interrupted the project activities due to family reasons.

In the end, the quantitative data we collected that allowed effective comparisons between Phase 2 and Phase 1 only refer to twenty persons. Their characteristics are shown in Table 2.

Table 2: The sample of the comparable participants between Phase 1 and Phase 2.

	Old Users		New Users		Total	
	Families	Users	Families	Users	Families	Users
Singles	2	2	2	2	4	4
Couples	1	1	2	3	3	4
Couples with (older) children	3	6	4	6	7	12
Total	6	9	8	11	14	20

4 Current mobility patterns and potentials for change

During both tracking Phases, automatic data-gathering was performed thanks to a specifically developed smartphone application tracking GPS signals.The application has been described in detail in Förster *et al.* (2013), Cellina *et al.* (2013) and Rizzoli *et al.* (2014). In this paper, we focus on the analyses we performed on the GPS data tracked by the application.

The first problem we faced related to the filters to be applied to the data collected. In principle we were in fact interested in the mobility of the users as a whole, that is in both systematic and non systematic trips. In particular, we did not want to limit to analyse the trips performed during work-days[1]. However, at the same time we did not want to include in the analyses some long

[1]According to the Swiss mobility census, in fact, leisure time trips account for a large percentage of the daily kilometres travelled, around 40%.

and occasional travels performed for holidays, such as travels by plane to the Canary Islands or by train to Berlin - which would significantly affect modal share percentages. Including those trips would in particular create problems in the comparison with the data collected in Phase 2, during which similar occasional journeys were absent. Moreover, the users where not fully coherent between Phase 1 and Phase 2: in some cases they used the application also during occasional holiday trips, in other cases they left the smartphone at home. To avoid biases in the results, we decided to consider only trips within the Canton Ticino boundaries. This choice also makes sense considering that the range of the alternative options the users tested in Phase 2 mainly covers only Canton Ticino. To identify the subset of trips to be considered in our analyses, we applied a geographical filter, removing all the trips directed outside the Canton Ticino boundaries. The analyses we discuss here are therefore based on the subset of data referring to the mobility patterns within the Canton Ticino region.

In order to produce a general overview of the current mobility patterns of all the e-mobiliTI users within Canton Ticino, we opted for a direct comparison with the 2010 Swiss Transport and mobility census data for the Lugano agglomeration. We summarised the mobility patterns of the users according to two main indicators:

- the average number of daily kilometres travelled - equal to 27.7 km/day for the Lugano agglomeration, according to the Lugano 2010 census;
- the daily percentage of kilometres travelled with private motorized means of transportation (PMT: conventional ICE car, electric car or motorbike) - equal to 75% of the daily kilometers, according to the Lugano 2010 census.

As shown in Figure 4, using the Lugano 2010 census as a reference point, we can classify the users in four categories:

- ”Soft eco” users: they use PMT means of transportation less than the average Lugano inhabitants, however they travel more kilometers per day than the average;
- ”Strong eco” users: they use PMT means of transportation less than the average and also travel less kilometers per day than the average;
- ”Soft private motorised” users: they use PMT means of transportation more than the average, however they travel less kilometers per day than the average;
- ”Strong private motorised” users: they use PMT means of transportation more than the average and also travel more kilometers per day than the average.

Adopting such categories, the mobility patterns of the e-mobiliTI users registered in Phase 1 are shown in Figure 4. As shown in Table 3, in total three users out of twenty are classified as ”Eco users”, while seventeen are classified as ”Private motorized” users. Interestingly, according

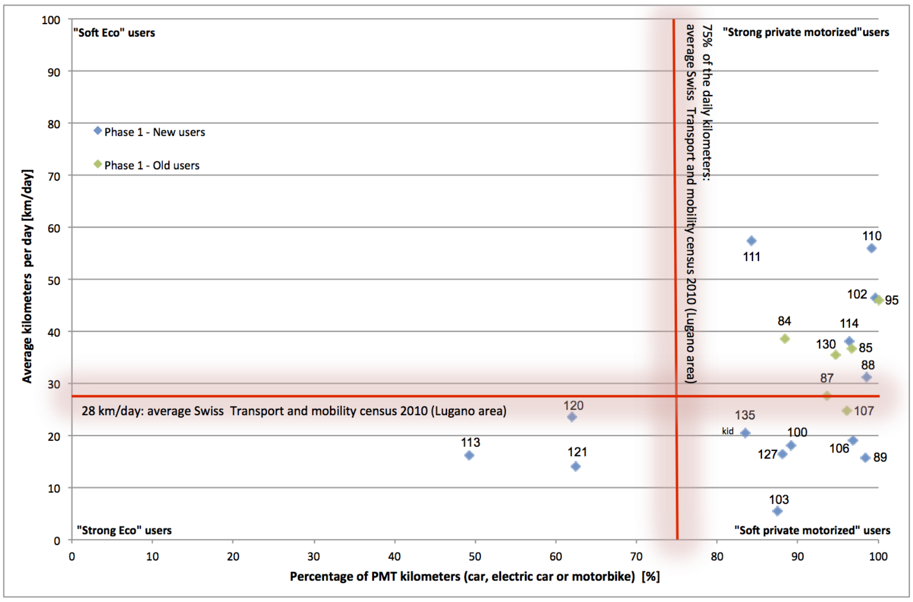


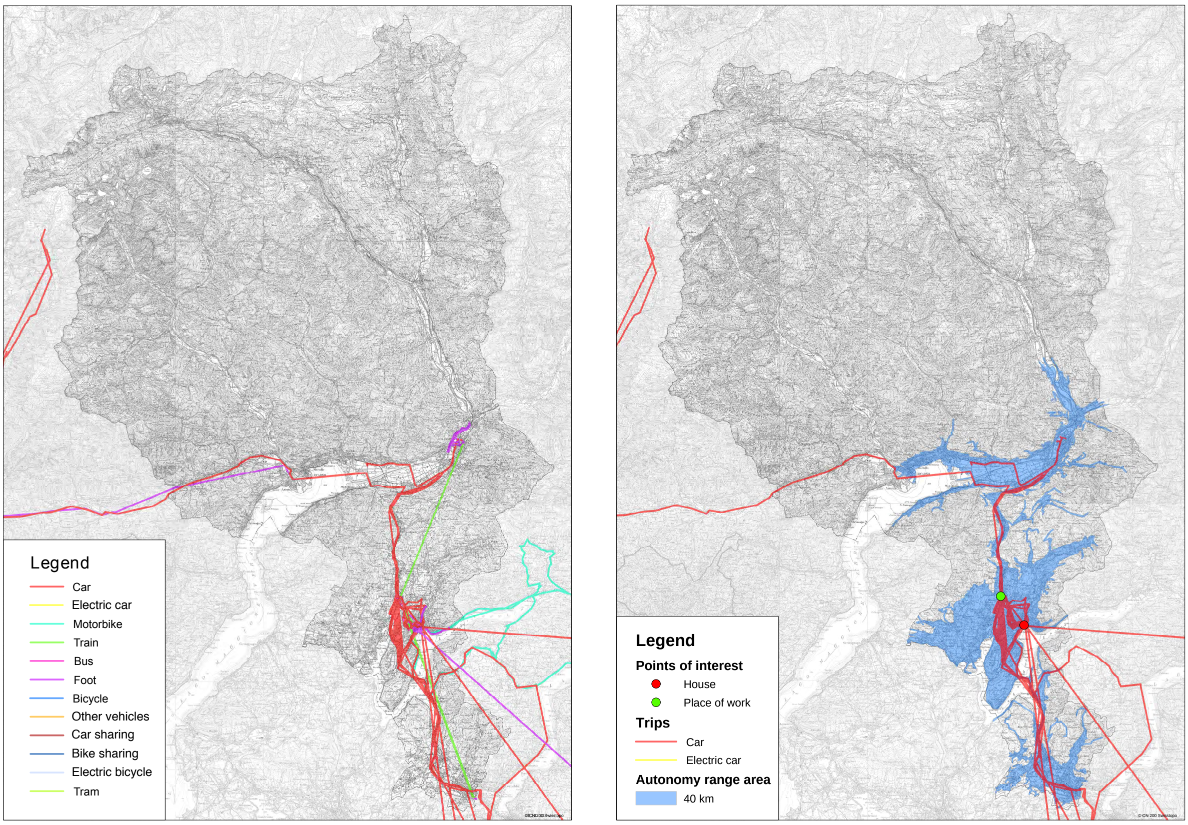
Figure 4: The mobility patterns of the e-mobiliTI users in Phase 1.

to such a classification, none of the ”Old users” falls into the ”Eco” category. Also, the whole sample shows a polarisation to higher percentages of use of PMT means of transport, respect to the average values registered by the 2010 Swiss Transport and mobility census for the Lugano area. The average daily kilometers travelled every day are, instead, much more heterogenous among the users and, on average, are very close to the 2010 census value for the Lugano area (29.4 km/day compared to 27.7 km/day).

Table 3: The classification of the e-mobiliTI users at the end of Phase 1.

Phase 1	”Eco” users	”Private motorized” users
New Users	3	11
Old users	0	6
Total	3	17

The GPS data were also analysed in order to produce maps of the users’ present mobility patterns and to identify their potential for change. Figure 5(a) shows for example the trips travelled in Phase 1 by one of the ”New users”, highlighting the different means of transport she used. Figure 5(b) shows instead an example of how we used the geographical data tracked in Phase 1 in order to assess the potentials for change. For each means of transportation the users would have experimented in Phase 2, we identified the main constraints which could prevent their use, thus identifying the correspondent potentials for change, on a qualitative basis. Between Phase 1 and Phase 2, however, we did not discuss with the users about such potentials, in order not to influence them. The conditions we considered were the following:



(a) (b)

Figure 5: The trips registered for an individual user in Phase 1: a) all the trips; b) the trips by car compared with the autonomy area of electric cars from her home (precautionary, considered as 50 km along the existing road network).

- for electric cars: all the return trips within a distance of 50 kilometers from home along the existing road network might have been effectively performed. We set the threshold to 50 kilometers on a precautionary basis, considering the worst case of lowered battery autonomy (100 km) during the coldest winter months; we also identified the longer than 100 kilometers trips travelled by car, in order to quantify the percentage of trips which would have been unfeasible using the electric car.
- for electric bicycles: all the return trips within a distance of 5 kilometers from home along the existing road network might have been effectively performed;
- for bicycles: all the return trips within a distance of 3 kilometers from home along the existing road network might have been effectively performed;
- for bike-sharing and car-sharing: all the sub-trips within a distance of respectively 3 and 30 kilometers from each station might have been effectively performed;
- for public transport: all the trips directed to places covered by the public transport network might have been performed. This was the weakest potential, since it did not take account of the restrictions on travel time and personal daily schedule a user might have had.

It is interesting to notice that, as shown in Table 4, on average in the ”New users” only 10% of the total trips registered in Phase 1 were longer than 100 kilometers. Considering only the ”Old users”, this percentage decreased to 4.1%. These percentages refer to the whole set of data tracked in Phase 1, before we applied the filter to the Canton Ticino region. In order to provide a realistic value for the potential for electric cars, we preferred in fact to consider the whole set of trips longer than 100 kilometers, no matter whether they were limited in the Canton Ticino region or not. Since these values also include the trips the users performed with other means of transport than the car, such as the train or the airplane, the global potential for electric cars appears to be very high. Finally, 21% and 13% of the users' trips are on average shorter than 5 and 3 kilometers, which means that also the potentials for the use of the electric and conventional bicycle are very interesting.

Those potentials are however purely dependant on one technical feature of the means of transport, that is the reasonable range of autonomy they can offer. In other words, they only depend on technology. The living lab helped us to understand if, and how, other infrastructural, socio-cultural and behavioural factors affected the practical implementation of those potentials.

Table 4: Lengths of the trips registered for all the users in Phase 1.

	% of trips > 100 km [%]	% of trips < 5 km [%]	% of trips < 3 km [%]
Old users	4.1	13.8	9.7
New users	9.9	24.7	14.9
All users	8.1	21.4	13.3

5 The methodology for the comparison of individual mobility patterns

To compare the individual mobility patterns between the two phases, we used a data mining approach. Let us introduce some terminology, following Cellina *et al.* (2013). A *trip* is a displacement of the user which starts and ends at the home of the users. A *segment* is part of a trip, associated with a single vehicle used (a bus, a car, on foot, etc.). Segments are separated by *stop* points. A stop is an interruption of the trip like for example refilling at the gas station. However there are also long stops, such as spending many hours at the office. A trip is thus a sequence of stops and segments, which starts and ends at the home of the user. The e-mobiliTI tracking system automatically decomposes the trips intro segments Cellina *et al.* (2013).

It is not obvious how to analyse the data referring to an entire trip, which involves multiple means of transportation. Moreover, the identification of the trips was not always reliable. The home of the user was defined as a small region of radius of 300 m around the home of the user. However sometimes communication problems prevented realizing that the user had returned home, causing different trips to get erroneously merged within a single one (for a detailed discussion, see Rizzoli *et al.* (2014)). To draw more reliable conclusions, for the specific comparison of individual mobility patterns between Phase 1 and Phase 2, we analysed instead the *sub-trips*. A sub-trip is a set of consecutive segments performed with the same vehicle and whose stops last less than 30 minutes. When a stop exceeds 30 minutes or the vehicle is changed, a new sub-trip is introduced. The sub-trips are immune from the identification problems of the trips.

Thanks to the information daily collected by the application, different features were available for each sub-trip, such as its length, its duration, its cause, the time and the day in which it has been performed, the number of persons in the vehicle. We aimed at estimating the probability of choosing a certain vehicle (ICE car, electric car, bike etc) given the features of the sub-trip. According to the data mining terminology, this was a problem of *classification*. Classification is the task of predicting the outcome of a categorical variable (in our case the vehicle chosen for the sub-trip) on the basis of a set of features. For our analysis, the classifier had to be both reliable and interpretable. Interpretability was important as it allowed us to easily discuss the results with the users. For this reasons we used decision trees as classifier. For a thorough discussion of decision trees see (Tan *et al.,* 2006, Chap.4) and (Witten and Frank, 2005, Chap.4).

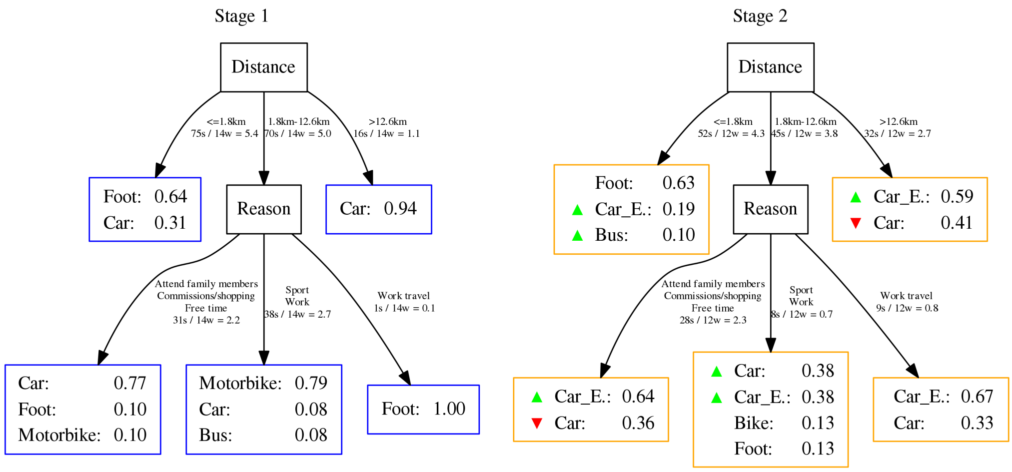
A decision tree starts from a root, where a condition is checked regarding a certain feature of the sub-trip, for instance its length. Depending on the sub-trip length, a different branch is followed down the tree. Further nodes are encountered where the value of other features is checked, and from which further branches depart. When a *leaf* is reached, the tree issues a probabilistic prediction: it returns the estimated probability of each vehicle for the given sub-trip.

An example of decision tree is shown in Fig. 6.

There is a wide literature on learning decision trees from data (Tan *et al.,* 2006, Chap.4). We relied on the WEKA implementation of the decision trees. WEKA[2] is an open-source software for data mining. Its decision tree algorithms are discussed in (Witten and Frank, 2005, Chap.4).

The goal of our analysis was to compare the mobility pattern of each user between Phase 1 and Phase 2. In Phase 1, we learned a tree for each user. In Phase 2, we updated the tree of each user. When updating the tree, we kept its structure fixed. We only updated the probability

[2] `http://www.cs.waikato.ac.nz/ml/weka/`



User 100

Marginal probability of vehicles   Accuracy 71%

Stage	Days	% valid	#Subtrip	Car	Car_E.	Motorbike	Bus	Bike	E_Bike	Foot
(1)	42	78%	161	40%	0%	22%	4%	0%	0%	34%
(2)	41	100%	133	▼23%	▲44%	▼0%	5%	1%	1%	26%

Figure 6: Example of a decision tree for an individual user. The tree of Phase 1 is shown on the left; the tree of Phase 2 is shown on the right. The up/down arrows in the right tree show the significant changes between Phases 1 and 2.

distribution on the leaves. The change in the mobility patterns of a certain user could be assessed by inspecting how the probability distribution changed on the leaves of its tree, as shown in Fig. 6.

Even if the user kept the same mobility habits between the two Phases, the probability distributions on the leaves were likely to be different between Phase 1 and Phase 2. This is because of the variability of a finite sample. We thus should have detected the changes which were *statistically significant*. To this end we used a statistical hypothesis test suitable to compare two independent proportions (Montgomery, 2007, Chap.4). The null hypothesis of the test was that the change of the proportion between Phase 1 and 2 was *not* significant. The alternative hypothesis was that instead the change was statistically significant. The test retained the null hypothesis until there was strong evidence that it was untrue. It accounted both for the difference between the proportions observed in Phase 1 and Phase 2 and for the number of subtrips performed in the two phases.

The significant changes between in Phase 1 and 2 were shown by red and green arrows on the leaves. The red arrows meant a statistically significant decrease of usage, and the viceversa for the green leaves.

Within the e-mobiliTI living lab we elaborated these trees in order to get a direct and immediate picture of the mobility patterns of every user and to identify the specific changes that took place between Phase 1 and Phase 2. They were discussed with each single user during individual interviews performed after the end of Phase 2. The discussion was aimed at getting a validation of the mobility patterns we had identified and especially at understanding the reasons why they did or did not change their patterns, with the final aim of identifying strengths and weaknesses of the means of transport they tested. In order to analyse the general mobility patterns at an aggregated level and to answer our research questions, however, we opted for a different approach. The following Sections show how we addressed our general research questions.

6 The results: the ”substitution” effect

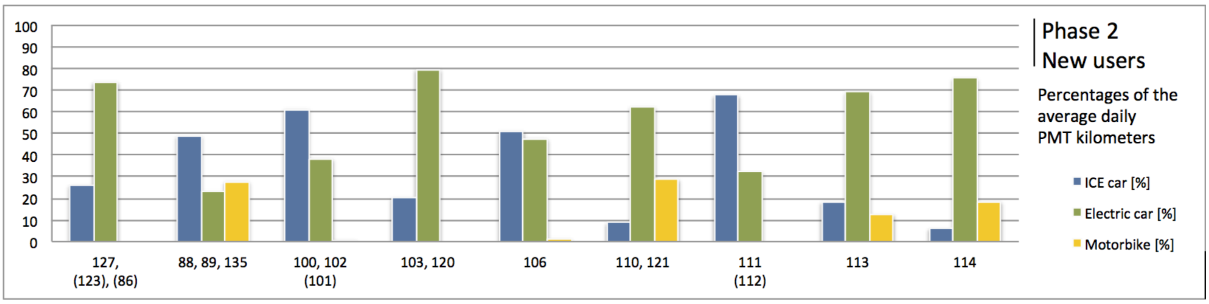
In this Section and in the next one we present the general results of the e-mobiliTI living lab, with reference to the research questions proposed in Section 3. We start with a discussion on how much the electric car was used, compared to the ICE car (”substitution” effect).

Figure 7 shows the percentage of the average daily kilometers each user travelled by each private motorized means of transport (PMT: car, electric car and motor-bike), over the total PMT kilometers travelled. Data are aggregated at the family level, since in each family only one electric car is available, even though there might be more than one person with a driving license. As shown in 7(a), if we consider Phase 2, in five ”New users” families out of nine (56% of them) the electric car is used more than double the amount of the ICE car. Also, in one family out of nine (11%), the electric car is used little less than the ICE car. On average, in Phase 2 the ”New users” families used the electric car for 63% of the average daily kilometers travelled by car (either ICE or electric).

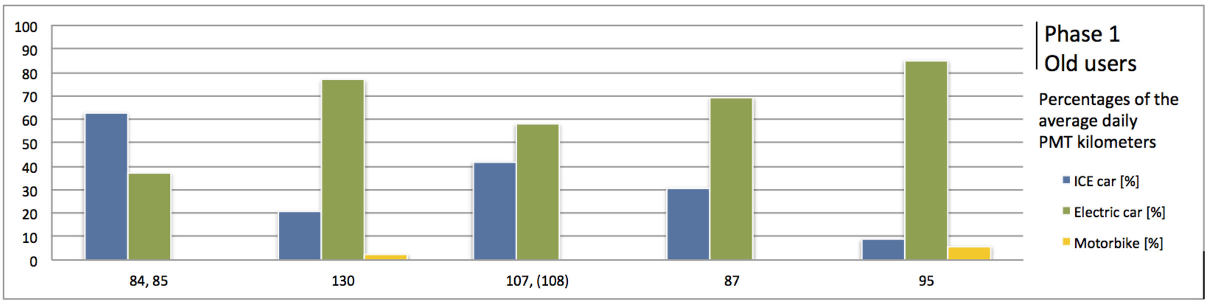
In particular, families of the users 113 and 114 display a very intense use of the electric car. In assessing these data, we must consider that they are "singles" (families composed of only one member), which is a bias factor. They can use the electric car whenever they like to, differently to other families where two users have to share the same electric car: when they need the car at the same time, one takes the electric car, while the other has to take the ICE car.

If we consider the number of trips travelled by ICE car and by electric car, we notice that in the ”New users” families the electric car is on average used for a number of trips double the one of the ICE car (Table 5). Further, the average length of each trip is very similar for both the electric and the ICE car, respectively being equal to 19.5 km and 23 km.

According to these data, we can affirm that the substitution between ICE and electric cars is actually taking place. To assess the intensity and effectiveness of such a substitution, we refer



(a) "New users" families in Phase 2.



(b) "Old users" families in Phase 1.

Figure 7: Percentages of the average daily kilometers travelled with each private motorized means of transport (PMT: ICE car, E car and motorbike), respect to the average daily PMT kilometres.

to the data we tracked for the "Old users" families. We consider data for Phase 1, that is when they used their own ICE and electric cars, without any external conditioning imposed by the presence of the public transport season tickets and car and bike sharing subscriptions offered by the e-mobiliTI project. In Phase 1 the "Old users" families used the electric car for 67% of the average daily kilometers travelled by car (either ICE or electric). Moreover, on average they used the electric car for a number of trips doubled with respect to the ICE car (see Table 5).

These data are totally coherent with those we registered for the "New users". This indicates that the "substitution" effect can be easily activated, requiring an adaptation period shorter than three months.

Differently from the "New users", however, data collected for the "Old users" in Phase 1 show that on average they travelled shorter trips by electric car (26 km/trip) than by ICE car (34 km/trip). This pattern is actually easier to be understood than the one we registered for the "New users": we expected in fact that, due to range limitations, users should opt for ICE cars especially for longer trips. We can explain this with a certain attitude we noticed in some of the "New users", who wished to test the electric car up to its limits. Longer monitoring periods and a larger sample would however be necessary to investigate this aspect into deeper detail.

In general, we notice that ICE cars are still conspicuously used both by the "Old" and by the

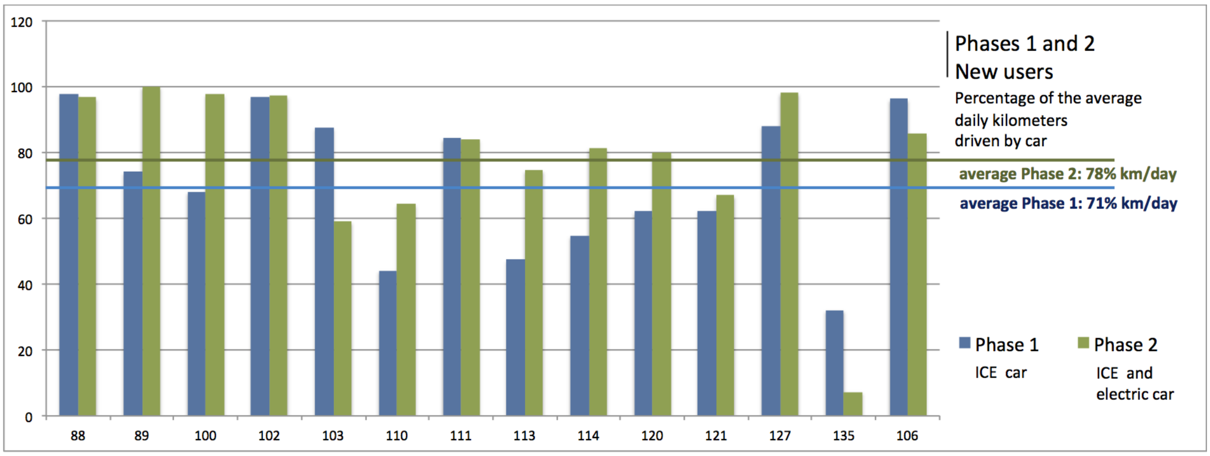
Table 5: Number and average length of the trips by electric and ICE car. The average length is obtained obtained by means of a weighted sum: for each family, we consider the average length of the trips of each user, multiplying it by the number of trips the user travelled.

	Number of trips [num]		Average length of trips [km]	
	Electric car	ICE car	Electric car	ICE car
Old users - Phase 1	245	112	26	34
New users - Phase 2	441	224	19.5	23

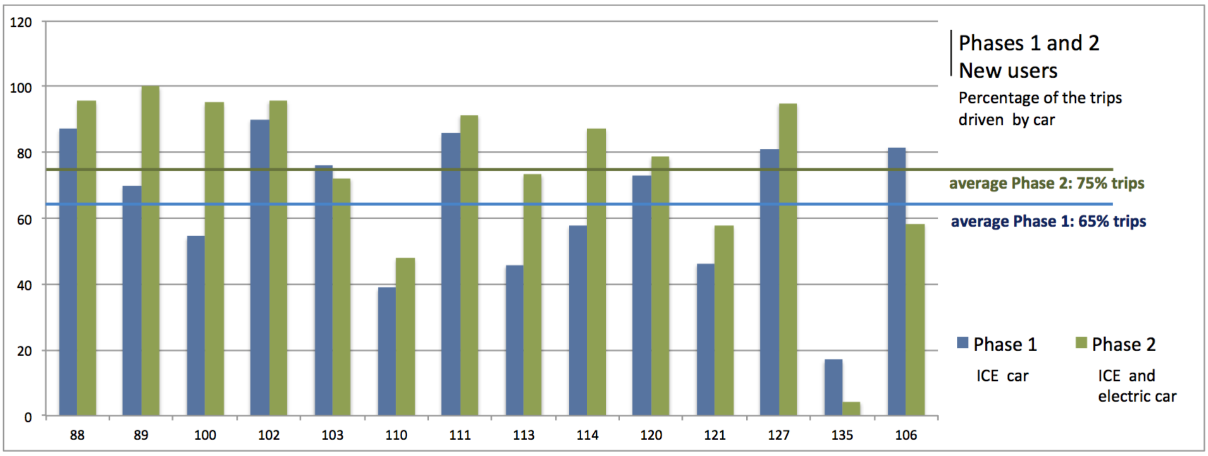
”New” users, on average accounting for 35% of the daily kilometers driven by car. This is partly due to the electric car limitations on the range autonomy; however, other factors come into play as well. Some of the trips travelled by ICE car, in fact, would have been perfectly compatible with the range autonomy of the electric car. To explain this phenomenon, one must recall that in each family there is only one electric car. Therefore, as already noticed, when two members of the family need to move by car, one of them will be compelled to drive the ICE car. From this point of view, in order to assess the pure ”substitution” potential, we should have only considered a sample of single users. Moreover, one must consider that we put a further constraint on the ”New users” regarding their use of the electric car: due to insurance problems, they were not allowed to go abroad with the electric car. Since Italy is very close to the Lugano area and it is a common visiting place both for leisure time and for shopping activities, one can imagine that we artificially prevented the use of the electric car for many week-end trips.

All in all, the data we gathered data show a remarkable potential for the diffusion of electric cars and indicate that an effective ”substitution” can occur. The last analysis we performed aimed at correlating the availability of an electric car with the intensity in the use of the car, either ICE or electric. We wanted in fact to verify whether a ”rebound effect” took place. To this purpose, we considered the data collected for the ’New users” and made a comparison between Phase 1 and Phase 2. As shown in Figure 8(a), the average percentage of the daily kilometers driven by car shows an increase between Phase 1 and Phase 2, moving from 71% to 78% of the average daily kilometers. In particular, eight ”New users” out of fourteen (57%) show a marked increase in the percentage of use of the car, attributable to the availability of the electric car. The same phenomenon is also registered for the number of trips performed by car, either ICE or electric. The average percentage of trips travelled by car moves in fact from 65% in Phase 1 to 75% in Phase 2.

We investigated the rebound phenomenon by means of individual interviews with the participants. The insight we gained shows that this is mainly due to a ”novelty effect”, combined with the awareness that the electric car would remain available for a limited period of time. During that



(a) Percentage of the average daily kilometers.



(b) Percentage of the number of trips.

Figure 8: A comparison between the use of the car, either ICE or electric, by the ”New users” in Phase 1 and in Phase 2.

period the users were led to use it as much as possible, in order to get acquainted with all its functionalities. We believe that a longer period of testing would have definitely reduced such a rebound effect. However, again going back to the ”Old users” data, we observe a consolidated tendency for a modal share strongly favouring the (electric) car. For the ”Old users”, in fact, the average percentage of the daily kilometers driven by car (both electric and ICE) reaches 95%, a much higher value than the average one provided by the Swiss Census of mobility and transport (75%).

7 The results: the ”transformation” effect

In this Section we comment on the wider implications an EV may produce on the mobility patterns of its users (”transformation effect”). Before entering the question whether a transformation happened or not, we must define what we mean by "transformation".

We decided to focus only on modal transformation (see Figure 9), since a transformation in the kilometers travelled on a daily basis is too strongly dependant on exogenous factors, such as the place of living and working, the activities performed during leisure time, the family needs and so on - all aspects which we did not directly influence during the e-mobiliTI field test.

Therefore, here we answer the question whether the availability of EVs encourages a wider transformation in the dominant patterns based on private motorised means of transport (PMT), increasing the use of slow mobility, public transportation and shared mobility services (car and bike-sharing).

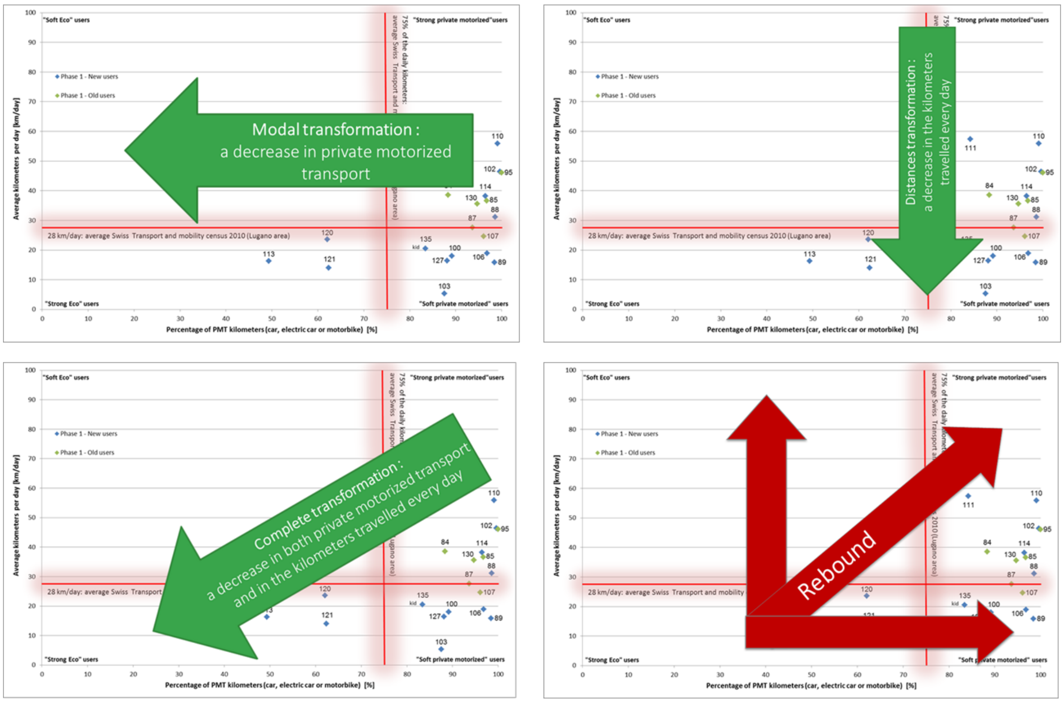
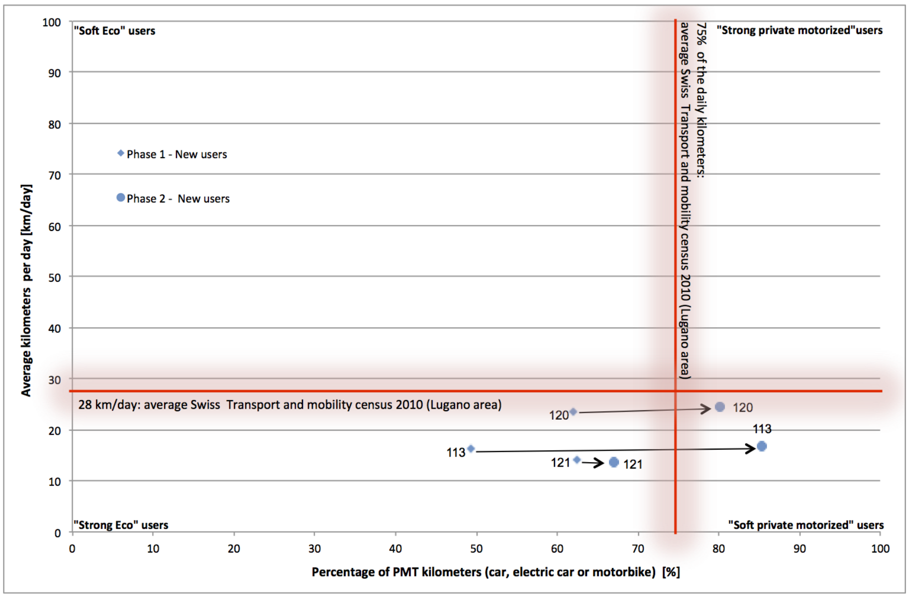


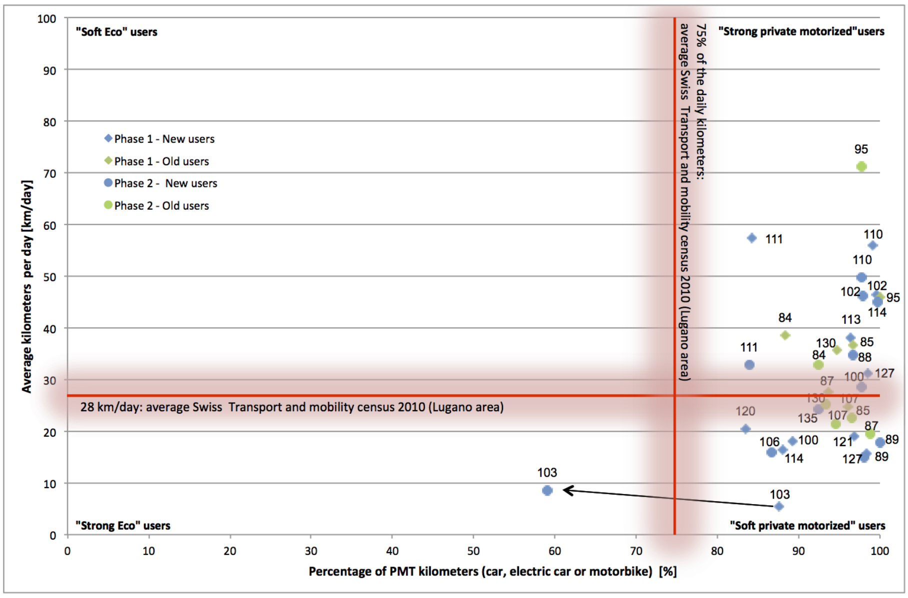
Figure 9: Possibilities of transformation of the mobility patterns.

To assess whether a modal change happened, we consider the percentage of kilometers travelled by private motorized means of transport in Phase 1 and compare it with the same indicator registered in Phase 2.

We first consider what happened to the "Eco users" identified in Phase 1. According to Figure 10, two of them moved to the "Private motorized users" category. Only one remained in the "Eco" category. Conversely, all the Phase 1 "Private motorized users", apart from one, remained in the "Private motorized category" also in Phase 2. That is, in total only three users out of twenty (15% of our sample) showed a significant change. However, only one went in the hoped for direction, that is towards a decrease in the use of private motorized means of transport.



(a) ”Eco” users in Phase 1.



(b) ”Private motorized users ” in Phase 1.

Figure 10: The transformation of the mobility patterns between Phase 1 and Phase 2.

Going beyond the classification and directly analysing the differences in the use of private motorized transport PMT, we observe that (see Table 6):

- the ”New users” show a tendency to the increase (six users) or the stabilisation (six users) of the percentage of the daily kilometers travelled by PMT;
- the ”Old users” show a tendency to the stabilisation (five users) of the percentage of the daily kilometers travelled by PMT - however, as noted in Section 4, starting from higher PMT percentages than the ”New users”.

In the ”New users”, when the PMT percentage increases, it is due to the use of the electric car. Also, considering both ”New” and ”Old” users, these data show that the availability of free season tickets for public transport, car and bike sharing (and, for the "New users”, of electric bicycles), had no meaningful influence in reducing the use of the car.

Finally, we highlight that, contrary to the expectations provided by the analysis of the potential for change (Section 4), the use of the electric bicycles was negligible. In more than half of the nine ”New users” families, in fact, they were only used on the first and last day of Phase 2, in order to bring them home and to hand them back at the end of the testing. In the remaining families, they were used for a few, very limited occasions, and mainly only in the first days of Phase 2.

Table 6: Average differences between Phase 1 and Phase 2 in the percentage of the daily PMT (private motorized transport) kilometers travelled.

Number of users [num]	New users	Old users	All users
PMT % increases	6	1	7
PMT % remains constant (difference <= 5%)	6	5	11
PMT % decreases	2	0	2

8 Conclusion and suggestions for future research

Based on the analyses proposed in the Sections above, the general conclusions we draw from the e-mobiliTI living lab are the following:

- performances of EVs (cars) are highly appreciated and are regarded as nearly comparable with those of ICEVs (cars);
- the availability of an EV might produce an increase in the use of private motorized transport (PMT), both in terms of kilometers travelled and number of trips performed (rebound effect);
- when the use of electric cars is precluded due to autonomy reasons, public transportation in combination with electric bicycles and innovative mobility options such as car and bike-sharing are not regarded as valuable alternatives to ICE cars;
- when a PMT means of transport is available, either ICE or electric, it markedly prevails over other mobility options. In such a case, even providing free access to alternative mobility options is not effective in producing a decrease in the use of private motorized means of transport.

Regarding the research questions proposed in Section 3, based on the e-mobiliTI sample we can answer that electric cars can effectively replace ICE cars, with the general satisfaction of the users. However, the availability of an electric car does not induce an automatic transformation towards overall more sustainable mobility patterns.

We discussed in detail this last issue during focus groups and semi-structured interviews with the e-mobiliTI users. The result is that in the Lugano area such a transformation did not happen because it would require further improvements in the quality of the offer of the mobility options other than the car. The users in fact ask for a significant increase in their attractiveness especially in terms of flexibility, capillarity, comfort and safety.

In conclusion of this paper we perform a critical analysis of our living lab experiment. From our perspective, main critical points are related to the size of the sample, the duration of the testing period and our capability to actively involve the users for a long period of time.

Our results in fact have limited representativeness, since the sample is very small. Specific mobility needs of the users in our sample might in fact have tangibly influenced the global results. In particular, a larger sample should have been essential in order to get further insights on the ”rebound” tendencies we identified both in the ”New users” and in the ”Old users”.

Moreover, the results we gathered are also influenced by the duration of the testing period. A three months testing period is not long enough to overcome the initial ”novelty effect”, which causes a strong interest in the new mobility option (the electric car), consequently leading to use it as much as possible. Based on the experience we collected during the e-mobiliTI living lab, a testing period of at least one year should have been definitely preferable, in order to detect effective changes in mobility patterns and to verify whether new, consolidated habits are created. Finally, we deem the difficulty of involving users for long monitoring periods as the the most challenging aspect. In order to guarantee their active participation in long-term living labs, in fact, one should strive to simplify and limit as much as possible the need for direct interaction with them. In our specific case, planning for future activities within our e-mobiliTI living lab strongly calls for the elaboration of more intuitive and more effective in the recognition of trips versions of the application for automatic mobility tracking.

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