D1: Data Collection Campaign

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Index

Illustrations

Tables

Executive Summary

This report documents the data collection campaign of eco-driving measure and eco-routing measure that were conducted in two cities of Spain. It is the first results under the national project Eco-Traffic which is one of the projects of the Spanish National Plan in the context of challenge number 4-Intelligent, sustainable and integrated transport.

The report aimed to reveal the potential of the two driving behaviour measures under different driving environment. The experiment was carried out in April and May 2017 in Madrid and Caceres respectively. Fourteen conductors have driven two different vehicles, along four itineraries, before and after having attended an efficient driving course.

By using an On-board diagnostic device (OBD-Key), the GPS position, the speed and others relevant variables have been obtained second by second. The fuel consumption is further calculated using the Vehicle Specific Power model (VSP). All data collected were elaborated through the software "R" and the database has been created.

In these terms the methodological approach follows four stages: data collection campaign, data base creation, database validation and data analysis.

Data have been analysed in respect to two different aspects. The first one is to compare the reduction of fuel consumption by adopting an Eco-driving behaviour, depending on the kind of itinerary (extra urban, urban or mixed), while the second one is to analyse the efficiency of eco-driving depending on the type of roads and on the traffic conditions.

Results underline that Eco-Driving in general performs its efficiency at different levels; moreover it also shows its limits on certain road sections and traffic conditions: in motorways and highways Eco-driving is more effective in congested situations than in free flow conditions. On contrary, the results show the opposite in local streets.

1. INTRODUCTION

1.1. Posing the problem

Cities are facing the most serious challenges on climate change and air pollution that never had. “By August 2, 2017, we have used more from nature than our planet can renew in the whole year” (Global Footprint Network, 2017). The same experts explain in their report that we use more ecological resources and services than nature can regenerate through overfishing and overharvesting forests and we are emitting more carbon dioxide into the atmosphere than forests can sequester: currently 60% of the ecological deficit is caused by the necessity to absorb carbon dioxide emissions (Hertwich and Peters, 2009).

It is noticed that carbon dioxide is not the only one noxious gas causing climate change, rather climate change is caused by a range of gases, known collectively “greenhouse gases” (GHG), which alter the energy balance of the climate system, and the more important ones, in decreasing order of concentration, are: water vapor, carbon dioxide, methane, nitrous oxide and ozone, (EPA, 2014).

GHG emissions come from different sources across the economy. The magnitude of emissions and diversity of sources means that no single technology, policy, or behavioral change will be able to “solve” climate change; rather a portfolio of solutions is needed. (“Climate techbook”, C2ES center for climate and energy solutions)

According to the International Energy Outlook 2013 Reference case, transport sector “accounted for 26% of global energy consumption in 2010 and transport energy use is expected to increase by 1.1% every year over the next few decades, above 2-3% in emerging economies” (Energy Information Administration, 2013).

More in details, passenger cars and heavy duty vehicles account for more than two-thirds of the transport-related greenhouse gas emissions and over one-fifth of the total emissions of carbon dioxide (CO2), the main greenhouse gas (Monzón, 2017). Road transport was responsible for almost 73% of all GHG transport emissions in 2013 (TERM, 2015).

During the past decades there has been an ongoing debate on how and to what extent different policies and strategies influencing the mitigation of climate change impacts of transportation.

Innovative transport technologies and mobility solutions are required to bring disruptive change to the transport sector that tackles the problems. In this context, two of the win-win solutions both for society and car users are application of Eco-driving measure which aiming to reduce fuel consumption by modifying drivers´ behaviour, and route choice (eco-routing) which is designed to provide route guidance to drivers based on real time information and following a minimum fuel consumption criterion.

Literature reflect both advantages and disadvantages of eco-driving measures, as well as big variability depending on individual heterogeneity and the implementation level of eco-drivers and eco-routers (Xia et al, 2013). Thus, it is proposed to analyse the impacts of these behaviours in the ECO-TRAFFIC project from three different perspectives:

1. First of all, carrying out real measurements of these behaviours through a campaign of data collection in which itineraries are followed or without following eco-driver and eco-route behaviour. This campaign have been done in two cities with very different characteristics – Madrid and Caceres - whose municipalities have expressed their support and interest in participating in ECO-Traffic project.

2. With these field measurements, individual variations are estimated. These variations in behaviour, and therefore in the impacts, will be parameterized in order to transfer the impacts to a modelling process – micro and macro scale – in order to analyse the effect of different penetration levels of eco-drivers and eco-routers as well as different traffic conditions. The expected results obtained in micro/macro simulation in consonance with scientific literature and results evidenced in the project ICT-Emissions, will highlight substantial variations according to the type of road, traffic conditions, penetration levels of eco-driving and eco-routing. This therefore implies the need of analysing practical feasibility of implementing these measures.

3. Finally, from the previous results, a campaign of surveys and a focus group will be carried out to analyse drivers' acceptability to the impacts that eco-driving and eco-routing may have in their itineraries, as well as the degree of awareness they have on these impacts and the Administrations' disposition to promote the implementation of these measures.

The hypothesis is then based on the potential of measures to improve driving patterns to reduce emissions of both GHGs and pollutants. Based on this hypothesis, as well as previous research in this area, the project includes the following three General Objectives (GO) that were mentioned in the proposal:

- GO1) Analyse the potential reduction of emissions (both GHGs and pollutants) from the driver's point of view: an efficient way of driving and a route choice that minimizes consumption.
- GO2) Know the degree of acceptability as well as awareness of the benefits and disadvantages that this variation in driver behaviour can produce.

- GO3) Propose recommendations that can serve planners and operators involved in traffic management.

Looking for objectives more specific (SO: specific objective), we have distinguished them depending on the general ones in order to focus more deeply our research on its.

GO1) Analyse the potential reduction of emissions (both GHGs and pollutants) from driver's point of view: an efficient way of driving and a route choice that minimizes consumption.

- SO1) To measure in practice the variation of speeds and emissions produced by eco-driving and eco-routing at the individual level by means of the on-board installation of in-vehicle devices that allow the collection of instantaneous information of multiple explanatory parameters that make up the driving profile followed.

- SO2) Study the effect that eco-driving and eco-routing can produce as a function of the penetration of the percentage of drivers that modify their behaviour:

    - SO2.1) Micro-simulation based on field data of driver behaviour with different percentages of conduction type eco-driving in a selection of routes.

    - SO2.2) Generalize the results of driving eco-driving at the city level (up-scaling).

    - SO2.3) Modelling with field data of eco-routing in urban areas (route selection, known as eco-routing).

    - SO2.4) Modelling the combined effects of eco-driving and eco-routing.

GO2) Know the degree of acceptability as well as awareness of the benefits and disadvantages that this variation in driver behaviour can produce.

- SO3) Analysis of the acceptability of eco-driving and eco-routing: perception of benefits and disadvantages by users.

- SO4) Analysis of the degree of awareness that drivers have about the effects that eco-driving and eco-routing can have on speed, travel time and emissions.

- SO5) Analysis of the potential and willingness of the authorities to implement measures to support efficient driving.

This report as the first result came from the project ECO-TRAFFIC targets to the GO1-SO1 and presents the results of variation of fuel saving and emissions produced by eco-driving and eco-routing at the individual level. Meanwhile, it introduces the detailed methodology of data collection, data process and analysis method.

1.2. Researche questions and the methodology

This chapter ¨**Introduction**¨ presents the necessity of implement effective strategies to control energy consumption and reduce air pollution by posing the problem of road transport and their effects on climate change. The general and specific objectives of the project were also presented. To achieve the goal of GO1-SO1, this reporst addressed in two main research questions, briefly reassumed in:

1. How eco-driving efficiency is affected under different external factors?
2. What are the effects of eco-driving and eco-driving on emissions and fuel consumption depending on driving environment (i.e., road type and traffic condition)?

In order to answer these two questions, a systematic method is developed for this work and presented in the following Figure 1.

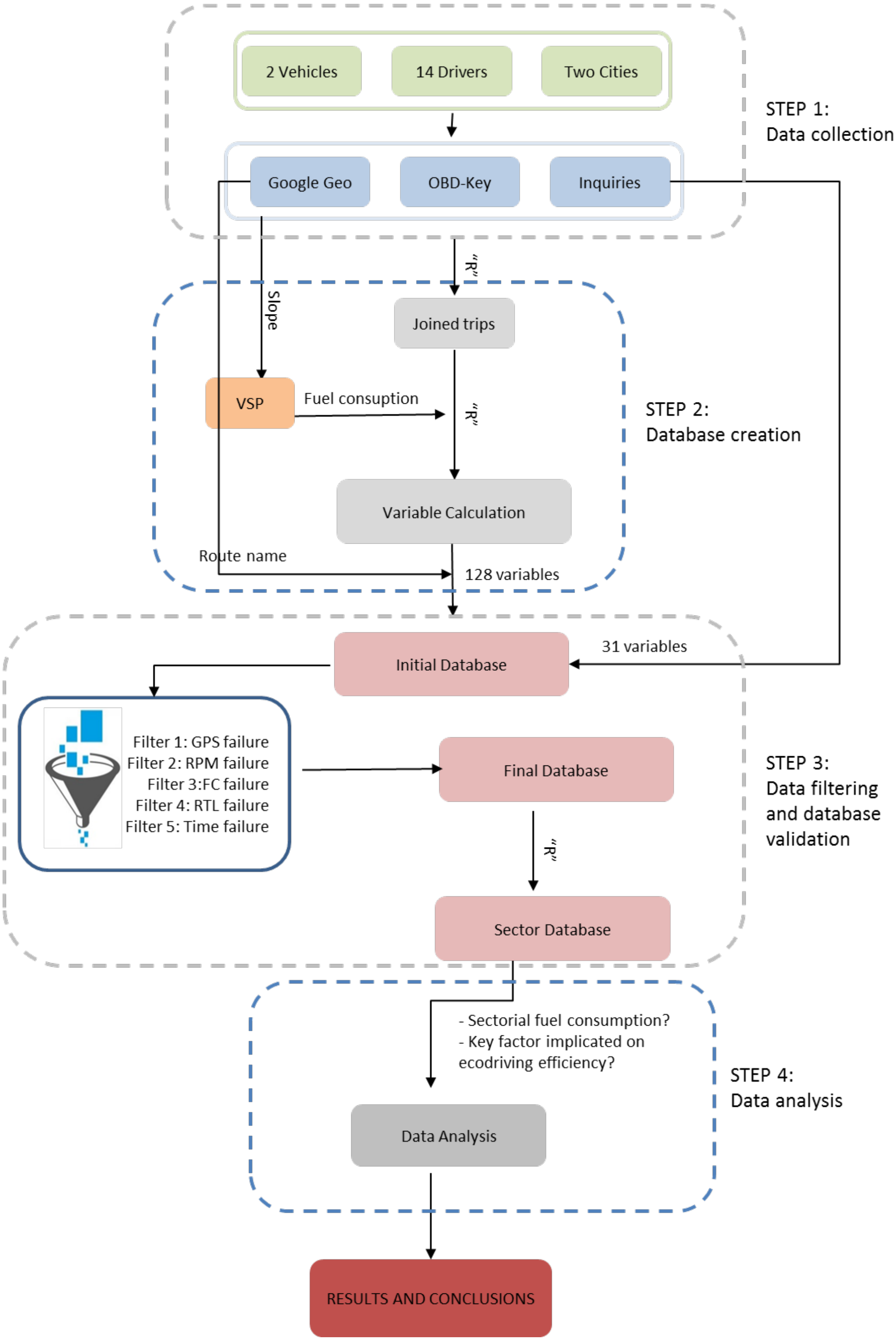


Figure 1 Flow chart of the methodological approach.

The next chapter ¨**Background**¨ will firstly present a general review of the framework focusing on the eco-driving and eco-routing concept and evolution. In that chapter, by revising the definitions and variability of results found out in different case studies (both simulations and field tests), we designed the current methodology for answering the two research questions.

The processing of data could be typically classified in five elementary tasks. In particular these tasks are the collection of raw data (Chapter of ¨Data collection campaign¨), the cleaning of erroneous data samples and the integration of data into a road network (Chapter of ¨Data creation and validation¨), the mining and evaluation of traffic information (Chapter of ¨Results of data analysis¨).

Data collection campaign which is the first step of the methodology is the third chapter which describes the details of the experiments conducted in Madrid and Caceres including vehicles, participants, routes and equipment, etc.

The following chapter of ¨**Database Creation**¨ explains the second and third steps of methodology of data process used on this work. It sums up the main steps of the database constrution: the main data integraion, the data cleaning (including the database creation and validation through a filtering process), and the data analysis.

In the chapter of **Results**, after a brief description of the general eco-driving as well as eco-routing performances obtained through the experiment both for Madrid and Caceres, the two remainder parts have been dedicated to analyse results obtained in order to answer to the two main research questions posed on the first chapter.

Finally, on the last chapter **Conclusions and Policy recommendations**, basing on the results obtained on each sub-analysis described in the chapter five, the main findings and conclusions concerning some policies recommendations are presented, in order to give my contribution on the definition of new and more appropriated sustainable transport policies.

2. BACKGROUND: ECO-DRIVING AND ECO-ROUTING

As individual change their behaviour result in trivial GHG emissions, it leads insignificant results when considering the aggregate impacts across the entire world. Individual energy consumption (and consequent CO2 emissions) consists of household energy use and personal (non-business) transport. The personal transport measures are various, like modal split (use non-motorized mode), purchasing less polluted vehicles (hybrid or electric vehicles), reduce vehicle-miles (carpooling, public transit, household relocation, etc) and alter driving style.

Eco-driving is one of the personal transport measure involving such things as accelerating moderately, anticipating traffic flow and signals, thereby avoiding sudden starts and stops; maintaining an even driving pace, driving at or safely below the speed limit; and eliminating excessive idling. The recent research by Sanguinetti et al (2017) unified the typologies from six mutually measures of eco-driving behaviors, i.e., driving, cabin comfort, trip planning, load management, fueling, and maintenance.

These measures include efficient driving, which has large individual fuel savings. Due to concern about emissions and climate change, eco-driving takes on importance from the 90s. Eco-driving can be defined as the change in driving mode with the aim of reducing fuel consumption, but it is different from the previously coined concept of "hypermiling" in which the safety was secondary with respect to the saving in fuel consumption

This simple definition includes several concepts, depending on the level of decision (Sivak and Schoettle, 2012):

- Strategic level: Vehicle selection and maintenance.
- Tactical level (also called **eco-routing** in the literature): Route selection and vehicle loading.
- Operational level: Driver behaviour. This level is best known as **eco-driving**.

This project is focused on the operational and tactical levels, which are those that directly affect current traffic: eco-driving and eco-routing. The strategic level of eco-driving in relation of vehicle selection is out of the scope of this deliverable.

2.1. Eco-driving: definition and evolution

At operational level, efficient behaviour is based on follow some easy eco-tips like accelerating and braking smoothly, shifting gears at low revs, maintaining a constant speed and anticipating traffic to avoid stopping as much as possible (Barkenbus, 2010). The advantages of eco-driving, of course, go beyond CO_2 reductions. They include reducing the cost of driving to the individual and producing tangible and well-known safety benefits (with fewer accidents and traffic fatalities).

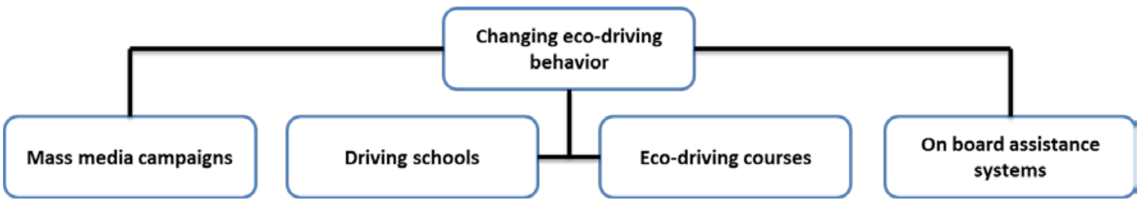


Figure 2 Changing to eco-driving behavior strategies (García, 2016)

Figure 1 performances four main ways to promote individual car user adopt eco-driving measure, including mass media campaigns (television, app, virtual games and so on), driving schools, eco-driving course and on-board assistance systems. To be efficient, the driver must adapt his / her driving style, which is achieved with awareness (ECOWILL, 2013) and specific training courses (IDAE, 2015):virtual games involving driving skills are increasingly common and can have a positive impact on driver behaviour. In some countries, such as the Netherlands, training in efficient driving techniques is widespread in driving schools (Wilbers and Wardenaar, 2007). The most common eco-driving course consists of a test drive prior to the theoretical or practice course. A serious eco-driving technology working with the driver and to deliver the most effective feedback to drivers on eco-driving by optimizing the driver-power train-environment feedback loop are provided by Automobile manufacturers (Hof et al., 2012).

Two approaches are widely used to assess the impact of eco-driving: field tests and traffic simulations.

Research	Study type	Variables	Effects
Johansson et al. (1999)	After eco-driving instructions. On-road test	Fuel consumption and emissions	10.9% reduction in fuel consumption
Johansson et al. (2003)	After eco-driving instructions. On-road test	Fuel consumption, emissions, speed and acceleration indicators. Engine speed	8% fuel consumption reduction with fuel consumption monitoring. 1.2% without monitoring
Hornung (2004)	On-road test after eco-driving training course.	Fuel consumption	15% in short term and 12% reduction in long term
Vermeulen (2006)	After eco-driving instructions. On road test	Fuel consumption and emissions	7% reduction for gasoline cars and 8-10% for diesel
Taniguchi (2007)	After eco-driving training. On-road test.	Fuel consumption	20% fuel consumption reduction
Kobayashi et al.(2007)	Moderate and smooth acceleration. Network Simulation	Emissions and travel time	Network effects. 3% reduction in CO_2 for low ad medium traffic and 12% increment in congestion
Henning (2008)	After eco-driving instructions. On road test.	Fuel consumption	Average 25% reduction of fuel consumption in short term and 10% long term
Onoda (2009)	Summary of Eco Drive program in Europe. On-road test	Fuel consumption	5% after training and 10% with feedback
Symmons et al. (2009)	After eco-driving training course. On-road test	Fuel consumption, gear changes, brake applications, etc.	27% reduction in fuel consumption
Saboohi and Farzaneh (2009)	Gear change optimization. Simulation	Fuel consumption	Savings of 1.5 l/100km
Barth and Boriboonsomsin	On-road test. Dynamic eco-	Fuel consumption	Reduction of fuel consumption of 13%. CO_2

(2009)	driving system	and CO_2	reduced 12%
Larsson and Ericsson (2009)	With acceleration advisory tool. On-road test	Fuel consumption, 20 driving pattern parameters	No significate changes in fuel consumption
H. Lee et al. (2010)	With eco-driving assistance system. On-road test	Fuel consumption	No difference
FIAT (2010)	After eco-driving instructions. On road with feedback test.	Fuel consumption	6% average and 16% maximum
Smit et al. (2010)	After eco-driving instructions. On-road test	Fuel consumption and emissions	Vary from a reduction up to around 10% to a small increase around 0.5%, depending on the driver and road.
Qian and Chung (2011)	Moderate and smooth acceleration. Network Simulation	Fuel consumption, CO_2 emissions &travel time	Network effects. Fuel consumption reduced 4% for free flow and incremented 25% in congestion
Orfila (2011)	Change in car-following model. Network simulation	Fuel consumption	Increments for high eco-driving penetration rate and congested interurban. Savings up to 19.6% in urban congested
Azzi, Reymond, Mérienne and Kemeny (2011)	After eco-driving instructions. With and without feedback. On Lab	Polluting emissions	5% reduction with verbal instructions, 10% to 12% with feedback
Rakha and Kamalanathsharma (2011)	Dynamic V2I system. Modeling	Fuel consumption	Up to 23.8% fuel consumption reduction
Boriboonsomsin Barth and Vu (2011)	With eco-driving feedback device. On-road test	Vehicle fuel economy	An average of 6% reduction for city drive and an average 1% for highway drive
Andrieu and Saint Pierre (2012)	After eco-driving instructions and training course. On-road test	Fuel consumption, average speed, average acceleration, etc.	12.5% of fuel consumption reduction after instructions and 11.6% using an assistance system
Qian and Chung (2013)	Moderate acceleration. Network simulation	Fuel consumption and CO_2 emissions	Maximal savings of 10% in fuel consumption
Sun et al. (2013)	Dynamic eco-driving system. Modeling signalized	Fuel consumption and CO_2 emissions	25% reduction of fuel consumption and CO_2

	corridors		
Xia et al. (2013)	With dynamic eco-driving system. Network simulation	Fuel consumption and CO_2 emissions	10-15% savings for individual vehicles. 1%-4% for total fleet, depending on traffic situation
Ma et al (2015)	vehicle-engine combined model for bus drivers	Fuel consumption	10% and reaches a maximum of 20% under different road conditions
Díaz-Ramirez et al (2017)	National freight fleet	Fuel consumption	reductions of 6.8% and 5.5%

Table 1 Summary of eco-driving research studies

Results of several studies show a great variability, from 2% to 7% average fuel savings and up to 20% in individual savings . However, very few studies take into account different percentages of ECO penetration (García Castro, Monzón, 2014; Kobayashi, Tsubota, and Kawashima, 2007; Qian and Chung, 2011, Orfila,2011), and the first evidence suggests that a high percentage of efficient drivers is not positive in scenarios with high traffic volumes.

It's interesting to keep on mind that also driver feedback appears to be different depending on the duration of exposure (Stillwater, Kurani, Mokhtarian, 2017). Short term studies reported a higher mean change in fuel economy (up to 10%), than long term studies.

Despite the clarity of Eco driving efficiency in ideal conditions, in order to quantify real impacts of this technique in terms of saving in fuel consumption generally there have been two main approaches: field tests and traffic simulations.

A lot of researches regarding relations between simulation of eco-driving behavior and different topics have been developed in literature; from these studies it seems clear, therefore, that eco-driving can be a good measure for reducing emissions, however, very few of these investigations address how that efficient driving influences traffic flow and whether this influence varies with the level of congestion, and with the number of drivers doing eco-driving.

2.2. Eco-routing: definition and evolution

At operational level: eco-routing implies to follow a route recommendations based on the minimization of the environmental impact produced. Several authors have concluded in their studies that eco-route navigation is a tool with a lot of potential in the reduction of fuel consumption (Boroboonsomsin et al., 2012, 2014, Yao & Song, 2013, Guo et al, 2013).

The implementation of this concept is however more complicated, since the optimum speed profile to reduce fuel consumption, and therefore CO2, can produce an increase in emissions of some types of pollutants, such as CO and HC (Bandeira et al, 2013, Mensing et al, 2014).

A study conducted in Sweden (Ericsson et al, 2006) concludes that emissions could be reduced by around 8.2% if the eco-route route were followed. In line with this result, Kono et al. (2008) estimate that eco-route practice can reduce emissions production by around 9%, while increasing travel times by another 9%. The findings of Ahn and Rakha (2013) for the case of Cleveland and Colombia (Ohio) are also consistent with the above - between 3.3% and 9.3% in fuel economy, but not necessarily a time saver. However, Ahn and Rakha (2013) also conclude that the configuration of the road network is a significant factor in estimating the potential benefits of eco-routing.

Monzón, Perez and Valdés (2016) show on a conference paper how the impact of eco-routing varies substantially with the level of traffic. Furthermore on 2017 they affirm that by taking into account the results obtained on the ICT-emissions project (Castro, Monzón, Romana, 2016), that have analyse the impact of different green navigation penetration rates on CO_2 emissions, and by recognizing the different spatial impacts of GHG and air pollutant emissions, they argue that Eco-routing systems present clear benefits for combating climate change but they could be inefficient to reduce air pollution in urban environments.

Recent researches investigate the plug-in navigation system to aid comprehensive engery management (Fiori et al, 2017). Using real traffic information collected from smart-phone, GPS or other soucres (i.e., big data) is being studied and will provide better in trip plan for travellers in respect of engery saving.

3. DATA COLLECTION CAMPAIGN

The purpose of the Eco-Traffic project is to measure the effect that both eco-driving and eco-routing have on an individual vehicle under real traffic conditions. To this end, a campaign was carried out to collect data under different road environment considering various road types (i.e., urban roads, highway, urban arterial with roundabouts) and different traffic conditions (i.e., congestion, medium congestion and free flow). The campaign was conducted in two cities - Madrid and Cáceres- of Spain with very different characteristics.

The following contents starts presenting the details of pre-experiment design, the experiment itself including experimental cars, route, etc, and the post-trip survey.

3.1. Pre-experiment design

The experiment was designed to be carried out in two periods: with and without eco-driving behaviour. During the first period of the experiment, drivers following the established itineraries drove according to their usual driving pattern. After finishing the first period, the group of drivers were trained with professional teacher. Then drivers drove the same itineraries as the first preiod but adopting the eco-driving techniques in the second period.

The pre-experiment design aimed to answer the questions of when, where, how the experiment should be done, and what type of datas required. Regarding on this, there were several criteria considered in the design.

- Firstly, we studied the characteristics of the two cities in respect of area, mobility, geographical factors.

Regarding the city of Madrid, the metropolitan area of Madrid is the third largest metropolitan area in the European Union with a population of almost 6.0 million in 2,879 km^2. The highway network of Madrid comprises four orbital highways, eight free radial highways and four tolled radial highways. The car use trends lead to increased congestion on the road network, particularly in the area inside the outer ring. According to a report of the Madrid Local Government (Dirección General de Sostenibilidad y Planificación de la Movilidad, 2013), 68% of passenger cars are diesel and 31% gasoline. In this sense, the sample of the two different vehicles is representative of the Madrid fleet composition. Moreover, 60% of the population of the MMA reside within the outer ring. The average population density of Madrid is 805/km^2 while high densities inside of outer ring (4,157/km^2) and extremely low ones in the outer area (474/km^2).

The city of Cáceres is presented at the beginning of 2017 as a city that has managed to maintain a moderate and constant growth, despite the population contraction that has occurred in other similar cities and to a large extent caused by the current economic crisis. 55% of all the movements that take place in the city are done by the use of the private vehicle. Public transportation captures 10% of global mobility and pedestrians, despite the size of the city, only account for a third of all travel. The city of Caceres needs to implement measures that encourage the use of public transport and pedestrian mobility to make it a more sustainable city. In a complementary way it seems very convenient to know the savings of fuel and emissions produced by efficient driving in the city.

- Secondly, in order to collect driver behaviour data of eco-driving and eco-routing in interurban area under different road environment, the external factors like vehicle type, departure time, experiment participants and routes were involved and addressed.

These data colletion campaign was made with vehicles of different typology, in order to analyse the different impacts between different kind of fuel (gasoline and diesel) and to be able to apply them to the composition of the fleet of each city when transferring the impacts to city scale.

Drivers were engaged to cover different routs along different itineraries, during different driving shifts over a broad period of the day (12 hours) organized in such way to cover always the peak hoursto obtain a sufficient data sample for the different traffic situations (free circulation, moderate traffic and congestion), as well as to avoid alterations in the way of driving as consequence of the meteorology (rains, snow and mist, etc.).

Moreover in the selection of the drivers it is fundamental that they have different profiles in terms of sex, age and other significant variables according to the literature.

Regarding the data collection for eco-routing measure, we have determined a series of itineraries, and for each of them several alternative routes with the same origin and destination. One of the routes is in each case the least estimated time while the others are determined to minimize their fuel consumption.

Routes that are close to the minimum distance are followed. Once these itineraries and routes have been determined, the drivers have carried out these itineraries in an iterative way, following each week one of the routes previously established for each itinerary. The information collected will proceed the same as in the previous task.

Measurements of the parameters that configure the driving profile (instantaneous speeds, accelerations, RPM, etc) as well as the consumptions were obtained by the installation in vehicles of an on-board device – OBD (on board diagnostic)-Key (http: //www.obdkey .com) - which allows to obtain and store this information with instantaneous character, in addition to the geographic location of the vehicle at any time.

3.2. The experiment

The main data collection campaign took place in coordination with the Transport Research Centre of the Universidad Politécnica de Madrid (UPM) for the case of Madrid and the Universidad de Extremadura (UNEX) for the case of Caceres. The following sub-chapters give details of the experiment conducted both in April and May 2017.

3.2.1. Test vehicle

Regarding the vehicle segmentation, these vehicles can be classified in segments small (Fiat Punto) and medium (Opel Astra), which corresponds approximately to 75% of the fleet in Madrid. The cars were rented from a local car-sharing company Bluemove (https://bluemove.es/es). Two new cars were available on a weekly basis, so that the least number of kilometres would be made to each car, given the limitation imposed by the company. The two vehicles are registered under Euro 5 standards; the average fleet age in Madrid is 9.3 years (Dirección General de Sostenibilidad y Planificación de la Movilidad, 2013).

Features	**Astra**	**Fiat**
Commercial classification	Saloon	Mini
Gear shift type	Manual	Manual
Maximum authorized mass	1393	930
HP power	70	77
Dimensions (LxWxH) (mm)	4419 x 1814 x 1510	3546 x 1627 x 1488
Seats	5	4
EURO Standard	5	5
Emissions (gCO_2/km)	109	115
Emissions (gCO_2/l)	2,658	2,347
Classification by relative consumption	A	D

Table 2 Technical information on the vehicles used in this research

Figure 3 Fiat 500 while driving

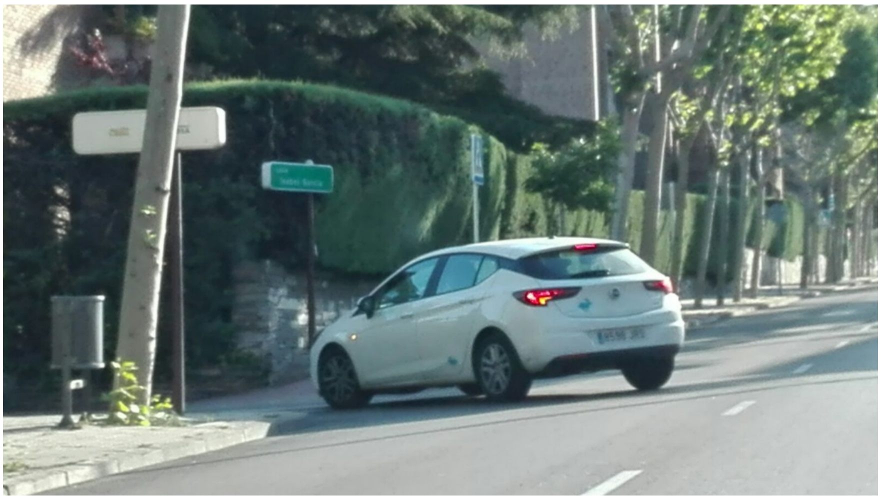


Figure 4 Opel Astra while driving

3.2.2. Experimental participants

For the various conductions required in the experiment, a number of drivers were involved for the experiment about one month.

In the case of Madrid, 12 drivers in total were engaged to conduct the vehicles during two driving periods of 9 days each. Due to contract limitations, drivers were students of Universidad Politécnica de Madrid (UPM) and academic staff, aged between 23 to 50 years old. The sample was almost gender balanced, being 8 males and 6 female.

In the case of Cáceres, also 12 drivers were engaged to conduct the vehicles during two driving periods of 4 days each. Due to contract limitations, drivers were students of Universidad de Extremadura (Escuela Politécnica de Caceres) and academic staff, aged between 21 to 44 years old, being 8 males and 4 females.

In both cases Madrid and Cáceres, drivers were hired to cover 12 hours / day of driving, always covering the peak hours of the day by shifting their drivings.

During the days of driving there were 6 people per vehicle, with 3 shifts of 4 hours each one with 2 people (driver and assistant take turns) that performed iteratively the routes along the series of itineraries that had been previously agreed by the research team.

Figure 5 Some drivers engaged in the experiment in Madrid and Caceres

3.2.3. Eco-driving training

24 drivers who took the program in two cities at different times. This training program was taught by instructors from two local driving schools (Course developed at Autoescuela Abril in Madrid (http://www.autoeabril.com/autoescuela-Madrid-cursos-conduccion-eficiente.aspx) and Autoescuela Las Arenas in Caceres (https://www.autoescuelalasarenas.com/#inicio).

The trainning includes an theoretical class and operational practice with the instructors. An analysis of key performance indicators (KPI) was used to assess drivers' performance, its relationships with fuel consumption and the means to incentivize better performance for top decision managers. The practical session on the road was conducted for the participant drivers.

The course of the driving school was structured as follows:

- First driving session: the participants drive the vehicles loaded by the established route and arerecorded in the cabin sheet the different parameters of their driving, average speed, gear changes made and consumption.
- Theoretical class: the delivery of the key concepts of efficient driving is carried out, explained by professionals of Autoescuela Abril, as well as the material to support their explanations for the dynamization of the class and try to reach the Recipient in a more effective way.
- Second driving session: The people attending this training repeat the driving of the vehicle on the same route as before, to check the effectiveness of the information that will be provided, again picking up the parameters to compare with the previous ones.
- Final pooling. Analysis of results: to see if they have assumed the knowledge and techniques that were intended analysing the data

At the time of signing up, conductors had to fill in a format indicating the number of years of driving experience and the typical driving behaviour, in order to give us the possibility to include these information in our database to get a wider range of possible analysis. The fact that people engaged had different driving experience permited us to do an analysis also regarding different level of eco-driving penetration after attending the efficient driving course, as function of the ability of the conductor, in other words, how different person perceive and change their behaviour receiving at the same time the same advices.

3.2.4. Routes and itineraries

Case of Madrid

The data collection campaign was focused on two inter-urban municipalities of Madrid, Pozuelo Nuevo and Majadahonda. They were selected due to the analysis based on the Synthetic Mobility Survey of Community of Madrid 2014, in which it was shown the amount of trips between both municipalities.

The campaign included four itineraries between these two municipalities and the civil engineering school (Escuela de Caminos) of Universidad Politécnica de Madrid (UPM), and for each itinerary, three routes were chosen. As seen in Figure 6, the first itinerary (named CP) links the University with Pozuelo Nuevo, the second one (named PC) Pozuelo Nuevo and Majadahonda, the third one (named MP) is between Majadahonda and Pozuelo Nuevo while the fourth one links Pozuelo Nuevo and the University in question (PC). All the itineraries contains three different possible routes, each one with different characteristics.

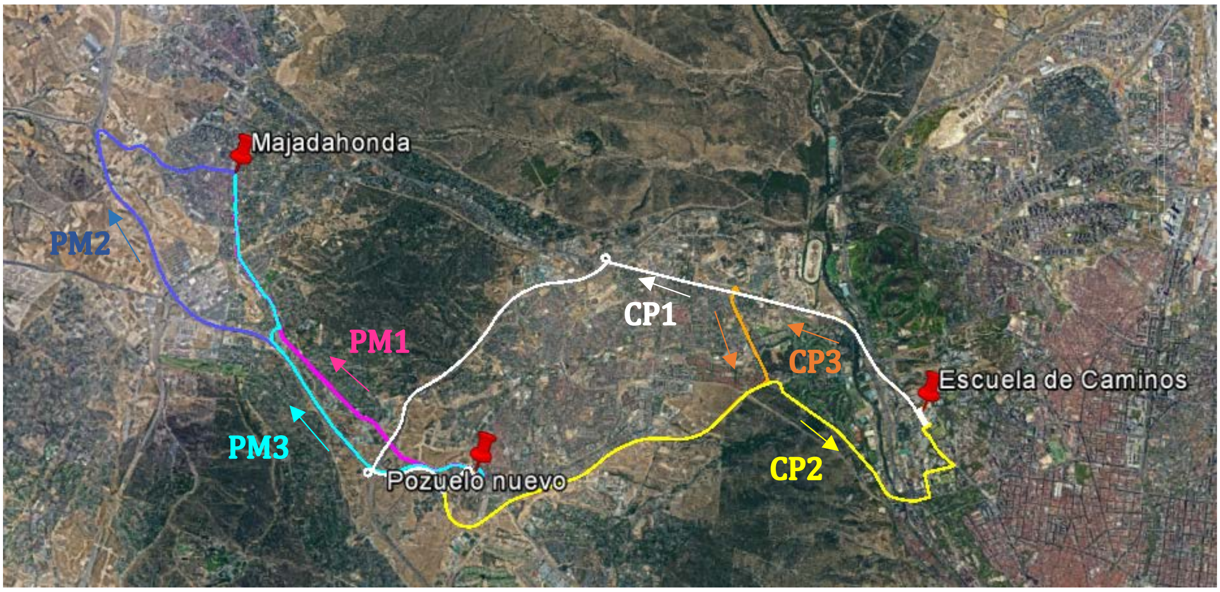
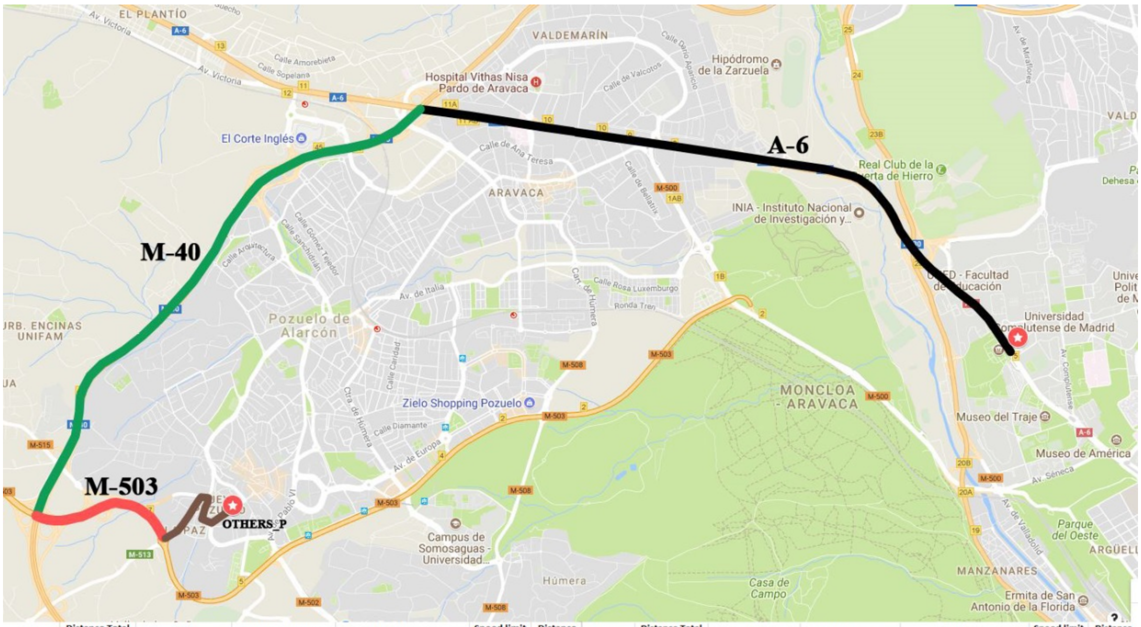


Figure 6 Monitored itineraries in the data collection campaign in Madrid

The following figures (7-12) provide a glance of each themonitored itineraries but with marked road section. Table 3 list the detailed description of each route by road sections. Meanwhile, the table below each map which provides the information of length, road types, as well as speed limits for each road section that were involved.



Route	Distance Total (km)	Road	Road Description	Nº of Lanes	Speed limit (km/h)	Distance (km)
CP1	15.1	OTHERS-Caminos	Local street		50	0.45-1.45
		A-6	Natinoal Highway. Dynamic message	3*3 and 4*4 (from M30) seperated by HOV lane	80	5.7
		ACCESS M-40	ACCESS	1 lane	40	0.6
		M-40	Urban Motorway	3*3, seperated by barrier	100	5
		ACCESS M-503	ACCESS	1 lane	40	0.6
		M-503	Urban Motorway	2*2,seperated by barrier	90	1.3-2.7
		OTHERS-Pozuelo	Urban arterial, collector and Local street	3*3, seperated by barrier	100	0.5-2

Route	Distance Total (km)	Road	Road Description	Nº of Lanes	Speed limit (km/h)	Distance (km)
PC1	13	OTHERS-Pozuelo	Urban arterial, collector and Local street	including M-515	50	0.5-2
		M-40	Urban Motorway	3*3, seperated by barrier	100	4.1
		ACCESS A-6	ACCESS	2 lanes to 1 lane	60	0.95
		A-6	Natinoal Highway. Dynamic message sign	3*3 and 4*4 (from M30) seperated by HOV lane	80	5.8
		Salida A-6	ACCESS	1 lane	30	0.13
		OTHERS-Caminos	Local street		50	0.45-1.45

Figure 7 Details of the routes CP1-PC1

Route	Distance Total (km)	Road	Road Description	Nº of Lanes	Speed limit (km/h)	Distance (km)
CP2	11	OTHERS-Caminos	Local street			0.45-1.45
		A-6	Natinoal Highway. Dynamic message sign	3*3 and 4*4 (from M30) seperated by HOV lane	80	0.65-1
		OTHERS-Moncloa	Urban collector	1*1	40	1.3
		Others-Seneca	Urban collector	1*1 with double continued line, on-street parking both side	40	1.1
		M-500	Urban Motorway	2*2, seperated by barrier	90	2.6
		ACCESS M-503	ACCESS	1 lane	40	0.6
		M-503	Urban Motorway	2*2,seperated by barrier	90	4.5
		OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2

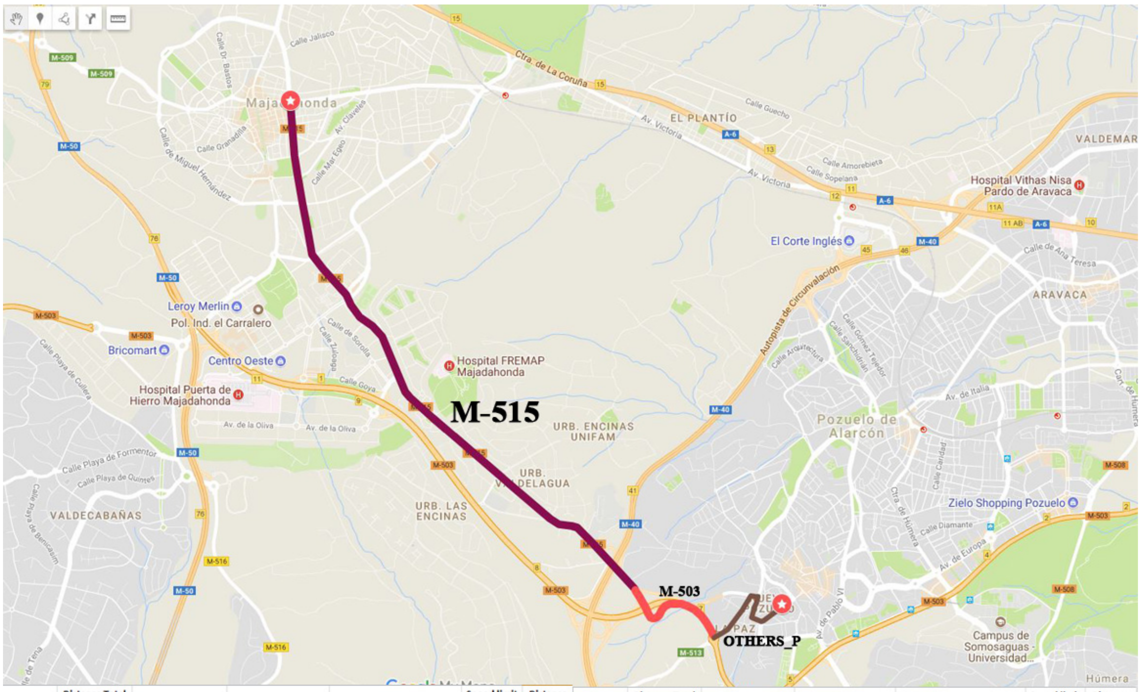
Route	Distance Total (km)	Road	Road Description	Nº of Lanes	Speed limit (km/h)	Distance (km)
PC2	11.6	OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2
		M-503	Urban Motorway	2*2,seperated by barrier	90	3.3
		ACCESS M-500	ACCESS	1 lane	40	0.4
		M-500	Urban Motorway	2*2, seperated by barrier	90	1.7
		OTHERS-Moncloa	Urban collector	1*1	40	1.4
		OTHERS-Seneca	Urban collector	1*1 with double continued line, on-street parking both side	40	2
		A-6	Natinoal Highway. Dynamic message sign	3*3 seperated by HOV lane	80	0.8
		OTHERS-Caminos	Local street		50	0.45-1.45

Figure 8 Details of the routes CP2-PC2

Route	Distance Total (km)	Road	Road Description	Nº of Lanes	Speed limit (km/h)	Distance (km)
CP3	12.5	OTHERS-Caminos	Local street		50	0.45-1.45
		A6	Natinoal Highway. Dynamic message	3*3 and 4*4 (from M30) seperated by HOV lane	80	3.8
		ACCESS M-500	ACCESS	1 lane	40	0.6
		M-500	Urban Motorway	2*2, seperated by barrier	90	1.5
		ACCESS M-503	ACCESS	1 lane	40	0.6
		M-503	Urban Motorway	2*2, seperated by barrier	90	4.5
		OTHERS-Pozuelo	Urban arterial, collector and Local street		90	0.5-2

Route	Distance Total (km)	Road	Road Description	Nº of Lanes	Speed limit (km/h)	Distance (km)
PC3	12	OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2
		M-503	Urban Motorway	2*2,seperated by barrier	90	3.6
		ACCESS M-500	ACCESS	1 lane	40	0.25
		M-500	Urban Motorway	2*2, seperated by barrier	90	1.7
		A-6	Natinoal Highway. Dynamic message sign	3*3 and 4*4 (from M30) seperated by HOV lane	80	3.5
		Salida A-6	ACCESS	1 lane	40	0.13
		OTHERS-Caminos	Local street		50	0.45-1.45

Figure 9 Details of the routes CP3-PC3



Route	Distance Total (km)	Road	Road Description	Nº of Lanes	Speed limit (km/h)	Distance (km)
PM1	8	OTHERS-Pozuelo	Urban roads		50	0.5-2
		M515	Urban arterial with many roundabouts, without traffic light, existing many crosss for pedestrain and traffic calm sign to 20km/h.	2 and 2, seperated by bicycle lane,Both sides haveon-road parking which influence traffic	50	6

Route	Distance Total (km)	Road	Road Description	Nº of Lanes	Speed limit (km/h)	Distance (km)
MP1	8.5	M-515	Urban arterial with many roundabouts, without traffic light, existing many crosss for pedestrain and traffic calm sign to	2 and 2, seperated by bicycle lane,Both sides haveon-road parking which influence traffic	50	6
		M-503	Urban Motorway	2*2, seperated by barrier	90	1.2
		OTHERS-Pozuelo	Local street		50	0.5-2

Figure 10 Details of the routes PM1-MP1

Route	Distance Total (km)	Road	Road Description	Nº of Lanes	Speed limit (km/h)	Distance (km)
MP2	13	OTHERS-Majadahonda	Urban arterial	Av. Dr.Marañón & Av. Dr.Caler	50	1.3
		M-509	Urban arterial with many roundabouts, without traffic light, existing many crosss for pedestrain and traffic calm sign to 30km/h.	2*2 seperated by barrier	50	1.6
		M-50	Urban Motorway	3*3, seperated by barrier	120/100	2.1
		ACCESS M-503	ACCESS	2 Lanes with tunel	100	1
		M-503	Urban Motorway	3*3 (outside of M-40), 2*2 seperated by barrier	90	5.6
		OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2

Route	Distance Total (km)	Road	Road Description	Nº of Lanes	Speed limit (km/h)	Distance (km)
PM2	12.5	OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2
		M-503	Urban Motorway	3*3 (outside of M-40), 2*2 seperated by barrier	90	6.2
		M-50	Urban Motorway	3*3, seperated by barrier	120/100	2.6
		M509	Urban arterial with many roundabouts, without traffic light, existing many crosss for pedestrain and traffic calm sign to 30km/h.	2*2 seperated by barrier	50	1.3
		OTHERS-Majadahonda	Urban arterial	Av. Dr.Marañón & Av. Dr.Caler	50	1.4

Figure 11 Details of the routes MP2-PM2

Route	Distance Total (km)	Road	Road Description	Nº of Lanes	Speed limit (km/h)	Distance (km)
MP3	8	M-515	Urban arterial with many roundabouts, without traffic light, existing many crosss for pedestrain and traffic calm sign to 20km/h.	2 and 2, seperated by bicycle lane,Both sides haveon-road parking which influence traffic	90	3.7
		M-503	Urban Motorway	3*3 (outside of M-40), 2*2 seperated by barrier	90	3.8

Route	Distance Total (km)	Road	Road Description	Nº of Lanes	Speed limit (km/h)	Distance (km)
PM3	8	OTHERS-Pozuelo	Local street		50	0.5-2
		M-503	Urban Motorway	3*3 (outside of M-40), 2*2 seperated by barrier	90	3.9
		M-515	Urban arterial with many roundabouts, without traffic light, existing many crosss for pedestrain and traffic calm sign to 20km/h	2 and 2, seperated by bicycle lane,Both sides haveon-road parking which influence traffic	50	3.1

Figure 12 Details of the routes MP3-PM3

Route	Distance Total	Road	Road Description	Nº of Lanes	Speed limit (km/h)	Distance (km)	IMD	IMD pesados	%pesados
CP1	15.1	OTHERS-Caminos	Local street		50	0.45-1.45			
		A-6	Natonal Highway. Dynamic message sign	3*3 and 4*4 (from M30) separated by HOV lane	80/120	5.7	130,364	6,500	4.99%
		ACCESS M-40	ACCESS	1 lane	40	0.6			
		M-40	Urban Motorway	3*3, separated by barrier	100	5	77,333	2,871	3.71%
		ACCESS M-503	ACCESS	1 lane	40	0.6			
		M-503	Urban Motorway	2*2,separated by barrier	90	1.3-2.7			
		OTHERS-Pozuelo	Urban arterial, collector and Local street	3*3, separated by barrier	100	0.5-2			
CP2	11	OTHERS-Caminos	Local street			0.45-1.45			
		A-6	Natonal Highway. Dynamic message sign	3*3 and 4*4 (from M30) separated by HOV lane	80/120	0.65-1			
		OTHERS-Moncloa	Urban collector	1*1	40	1.3			
		Others-Seneca	Urban collector	1*1 with double continued line, on-street parking both side	40	1.1			
		M-500	Urban Motorway	2*2, separated by barrier	90	2.6	54,695	991	1.81%
		ACCESS M-	ACCESS	1 lane	40	0.6			

		503							
		M-503	Urban Motorway	2*2,separated by barrier	90	4.5	48,724	1,323	2.72%
		OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2			
CP3	12.5	OTHERS-Caminos	Local street		50	0.45-1.45			
		A6	Natonal Highway. Dynamic message sign	3*3 and 4*4 (from M30) separated by HOV lane	80/120	3.8	130,364	6,500	4.99%
		ACCESS M-500	ACCESS	1 lane	40	0.6			
		M-500	Urban Motorway	2*2, separated by barrier	90	1.5	54,695	991	1.81%
		ACCESS M-503	ACCESS	1 lane	40	0.6			
		M-503	Urban Motorway	2*2, separated by barrier	90	4.5	48,724	1,323	2.72%
		OTHERS-Pozuelo	Urban arterial, collector and Local street		90	0.5-2			
MP1	8.5	M-515	Urban arterial with many roundabouts, without traffic light, existing many crosss for pedestrain and traffic calm sign to 20km/h.	2 and 2, separated by bicycle lane,Both sides haveon-road parking which influence traffic	50	6			

		M-503	Urban Motorway	2*2, separated by barrier	90	1.2	48,724	1,323	2.72%
		OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2			
MP2	13	OTHERS-Majadahonda	Urban arterial	Av. Dr.Marañón & Av. Dr.Calero	50	1.3			
		M-509	Urban arterial with many roundabouts, without traffic light, existing many crosss for pedestrain and traffic calm sign to 30km/h.	2*2 separated by barrier	50	1.6	17,663	590	3.34%
		M-50	Urban Motorway	3*3, separated by barrier	120/100	2.1	61,870	6,408	10.36%
		ACCESS M-503	ACCESS	2 Lanes with tunel	100	1			
		M-503	Urban Motorway	3*3 (outside of M-40), 2*2 separated by barrier	90	5.6	43,872	4,883	11.13%
		OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2			

MP3	8	M-515	Urban arterial with many roundabouts, without traffic light, existing many crosss for pedestrain and traffic calm sign to 20km/h.	2 and 2, separated by bicycle lane,Both sides haveon-road parking which influence traffic	50	3.7			
		M-503	Urban Motorway	3*3 (outside of M-40), 2*2 separated by barrier	90	3.8	43,872	4,883	11.13%
		OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2			
PC1	13	OTHERS-Pozuelo	Urban arterial, collector and Local street	including M-515	50	0.5-2			
		M-40	Urban Motorway	3*3, separated by barrier	100	4.1	77,333	2,871	3.71%
		ACCESS A-6	ACCESS	2 lanes to 1 lane	60	0.95			
		A-6	Natinoal Highway. Dynamic message sign	3*3 and 4*4 (from M30) separated by HOV lane	80	5.8	130,364	6,500	4.99%
		Salida A-6	ACCESS	1 lane	30	0.13			
		OTHERS-Caminos	Local street		50	0.45-1.45			
PC2	11.6	OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2			
		M-503	Urban Motorway	2*2,separated by barrier	90	3.3	48,724	1,323	2.72%
		ACCESS M-	ACCESS	1 lane	40	0.4			

		500							
		M-500	Urban Motorway	2*2, separated by barrier	90	1.7	54,695	991	1.81%
		OTHERS-Moncloa	Urban collector	1*1	40	1.4			
		OTHERS-Seneca	Urban collector	1*1 with double continued line, on-street parking both side	40	2			
		A-6	Natonal Highway. Dynamic message sign	3*3 separated by HOV lane	80	0.8			
		OTHERS-Caminos	Local street		50	0.45-1.45			
PC3	12	OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2			
		M-503	Urban Motorway	2*2,separated by barrier	90	3.6	48,724	1,323	2.72%
		ACCESS M-500	ACCESS	1 lane	40	0.25			
		M-500	Urban Motorway	2*2, separated by barrier	90	1.7	54,695	991	1.81%
		A-6	Natonal Highway. Dynamic message sign	3*3 and 4*4 (from M30) separated by HOV lane	80/120	3.5	130,364	6,500	4.99%
		Salida A-6	ACCESS	1 lane	40	0.13			
		OTHERS-Caminos	Local street		50	0.45-1.45			
PM1	8	OTHERS-Pozuelo	Urban roads		50	0.5-2			

		M515	Urban arterial with many roundabouts, without traffic light, existing many crosss for pedestrain and traffic calm sign to 20km/h.	2 and 2, separated by bicycle lane,Both sides haveon-road parking which influence traffic	50	6			
PM2	12.5	OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2			
		M-503	Urban Motorway	3*3 (outside of M-40), 2*2 searated by barrier	90	6.2	43,872	4,883	11.13%
		M-50	Urban Motorway	3*3, separated by barrier	120/100	2.6	61,870	6,408	10.36%
		M509	Urban arterial with many roundabouts, without traffic light, existing many crosss for pedestrain and traffic calm sign to 30km/h.	2*2 separated by barrier	50	1.3	17,663	590	3.34%
		OTHERS-Majadahonda	Urban arterial	Av. Dr.Marañón & Av. Dr.Calero	50	1.4			
PM3	8	OTHERS-Pozuelo	Urban arterial, collector and Local street		50	0.5-2			
		M-503	Urban Motorway	3*3 (outside of M-40), 2*2 separated by barrier	90	3.9	43,872	4,883	11.13%

		M-515	Urban arterial with many roundabouts, without traffic light, existing many crosss for pedestrain and traffic calm sign to 20km/h.	2 and 2, separated by bicycle lane,Both sides haveon-road parking which influence traffic	50	3.1			

Table 3 Road Sections and Description of Madrid

Case of Cáceres

Because the city of Caceres is small and can be traversed side by side in less than 15 minutes, a single itinerar has been selected. It starts from the train station located in the western part of the city and ends at the School of Technology (University of Extremadura) located in the eastern part of the city.

Four hierarchical street levels that define street function were considered: arterial streets (route AP/PA 1), minor arterial streets (route AP/PA 2), local streets (route AP/PA3) and distributor and collector streets (route AP/PA4). Local streets offer mainly land access service providing the lowest level of mobility. Distributor and collector streets channel traffic from local streets into the arterial system. Minor arterial streets serve trips of moderate length at a somewhat lower level of mobility than principal arterials. Finally, arterials have less variable circulation conditions than fully urban streets, being comparable to highways. Figure 13 and Table 4 shows the four different routes in map and their descriptions.

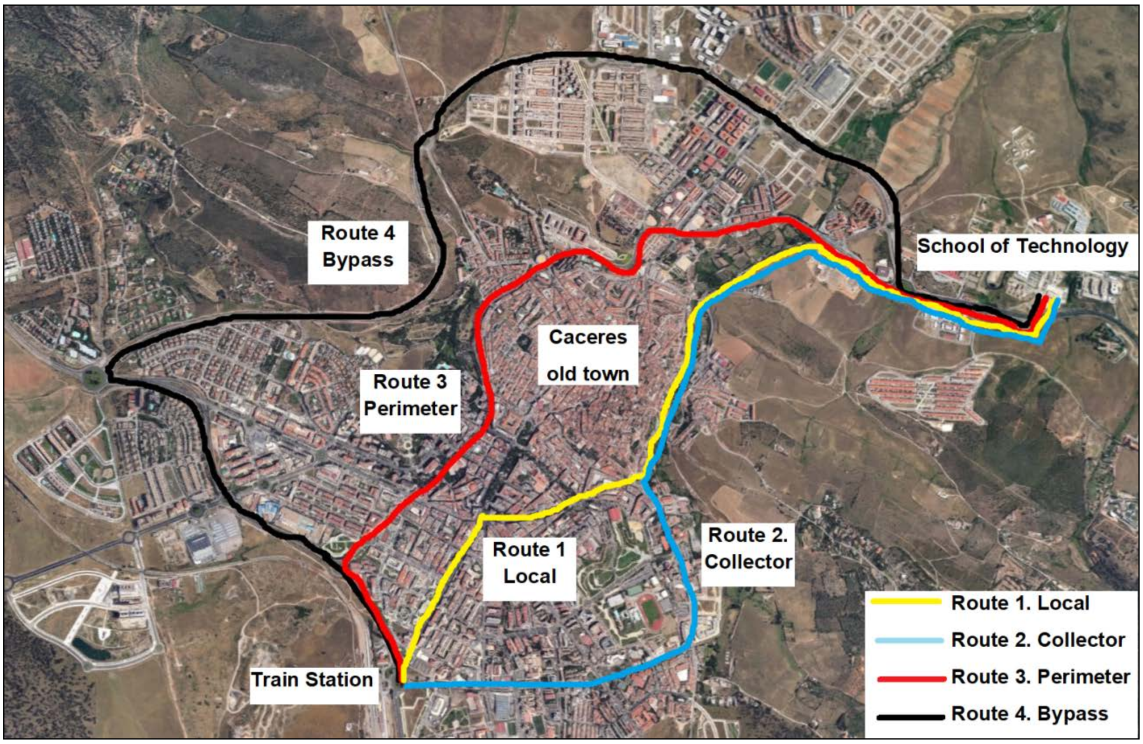


Figure 13. Monitored itineraries in the data collection campaign in Caceres

They can be ordered in terms of their increasing LOS, as follows:

Route 1 (local) runs along urban streets and passes right through the heart of Caceres city centre. It is 6.1 km long, and its travel time is around 15 minutes. This route has a dual carriageway with a median. Speed is limited to 50 km/h. It is regulated by traffic lights and suffers peak congestion problems.

Route 2 (collector) is 6.7 km long and its travel time is about 14 minutes. It is one of the most important avenues in Caceres as it provides access to the bus station, conference centre, sports arena, mortuary and hospital, leading to regular congestion problems. It also has a dual carriageway with a median, but due to its urban character the speed limit is 50 km/h, and 30 km/h in several sections.

Route 3 (perimeter) is the old bypass road, which is already integrated in the urban network. It also has a two-lane dual carriageway and a median, or is demarcated by a continuous double line. The speed limit is 50 km/h. It has a length of 6.7 km and a travel time of about 13 minutes. It has almost no congestion.

Route 4 (bypass) follows the outer city bypass known as "Ronda Norte". It has a length of 10.3 km and can be travelled in about 12 minutes. It is the longest and quickest route. It runs through the north of the city with a two-lane dual carriageway with a median. Intersections are in the form of roundabouts and pedestrian crossings regulated by traffic lights. Speed limits vary between 80 km/h and 40 km/h. Traffic is usually fluid all day.

Rout e	Distance Total	Road	Road Description	Nº of Lanes	Speed limit (km/h)	Distance (km)	IMD	IMD pesados	%pesad os
AP1	5.6	Av. de Alemania	Local street	2*2 separated by barrier. Parking both sides	50	1.1	10,56 2		
		Ronda del Carmen-Prof. Hernández Pacheco, Ronda puente de Vadillo	Local street	1 lane	50	2.8	6,858		
		Av. De la Universidad	Minor arterial	2*2 separated by barrier	50	1.1	5,111	189	3.70%
		Av. De las Ciencias y Av. De las Letras	Local street	1*1 with barrier	40	0.6			
AP2	6.1	Av. De la Hispanidad	Urban collector	2*2 separated by barrier. Parking both sides	30	1.7			
		Ronda San Francisco-Ronda Puente Vadillo	Local street	1 lane	50	2.7			
		Av. De la Universidad	Minor arterial	2*2 separated by barrier	50	1.1	5,111	189	3.70%
		Av. De las Ciencias y Av. De las Letras	Local street	1*1 with barrier	40	0.6			
AP3	6.3	N-630	Minor arterial	2*2 separated by barrier	50	0.9	10,81 0	303	2.80%
		Av. Virgen de Guadalupe	Urban collector	2*2 separated by barrier. Parking both sides	50	1.1	5,459		
		Av. Hernán Cortés-Av. De las Delicias	Minor arterial	2*2, separated by barrier	50	1.7	7,638		
		Av. UniversIdad	Minor arterial	2*2, separated by barrier	50	2.0	5,111	189	3.70%

		Av. De las Ciencias y Av. De las Letras	Local street	1*1 with barrier	40	0.6			
AP4	9.9	N-630	Minor arterial	2*2 separated by barrier	50	2.6	10,810	303	2.80%
		N-521. Ronda Norte	Major arterial	2*2 separated by barrier	40-80	6.0			
		Av. De la Universidad	Minor arterial	2*2 separated by barrier	50	0.7	5,111	189	3.70%
		Av. De las Ciencias y Av. De las Letras	Local street	1*1 with barrier	40	0.6			
PA1	6.2	Av. De las Ciencias y Av. De las Letras	Local street	1*1 with barrier	40	0.4			
		Av. Universidad	Minor arterial	2*2 separated by barrier	50	1.6	5,111	189	3.70%
		Ronda de Vadillo	Local street	1 lane	50	2.7			
		Virgen de la Montaña+Avda España+Gil Cordero	Local street	2*2 separated by barrier. Parking both sides	50	0.5			
		Av. Alemania	Local street	2*2 separated by barrier. Parking both sides	50	1	6,627		
PA2	6.4	Av. De las Ciencias y Av. De las Letras	Local street	1*1 with barrier	40	0.4			
		Av. Universidad	Minor arterial	2*2 separated by barrier	50	1.7	5,111	189	3.70%
		Ronda San Francisco	Local street	1 lane	50	2.7			
		Av. Hispanidad	Urban collector	2*2 separated by barrier. Parking both sides	30	1.6			
PA3	6.5	Av. De las Ciencias y Av. De las Letras	Local street	1*1 with barrier	40	0.4			
		Av. Universidad	Minor arterial	2*2 separated by barrier	50	2.5	5,111	189	3.70%

		Av. Hernán Cortés-Av. De las Delicias	Minor arterial	2*2, separated by barrier	50	1.8	9,048		
		Av. Virgen de Guadalupe	Urban collector	2*2 separated by barrier. Parking both sides	50	1.0	7,134		
		N-630	Minor arterial	2*2 separated by barrier	50	0.8	10,810	303	2.80%
PA4	10.2	Av. De las Ciencias y Av. De las Letras	Local street	1*1 with barrier	40	0.4			
		Av. Universidad	Minor arterial	2*2 separated by barrier	50	1.1	5,111	189	3.70%
		N-521. Ronda Norte	Major arterial	2*2 separated by barrier	40-80	6.1			
		N-630	Minor arterial	2*2 separated by barrier	50	2.6	10,810	303	2.80%

Table 4 Road Sections and Description of Cáceres

3.2.5. On-board equipment

For many applications, the speed and GPS information recorded by smartphones may be enough. However, the vehicles participating in this campaign also provided information extracted from the on-board diagnostics (OBD) system.

The methodology included the installation of an OBD key to extract data from each vehicle's OBD system. This was used to record instantaneous position, speed, acceleration, fuel consumption (l/h down to a precision level of five significant digits) and revolutions per minute (rpm). This device is easily installed by the user in the vehicle diagnostic port, and sends the data to a mobile phone via wifi with a frequency of 1 Hz (Figure 14).

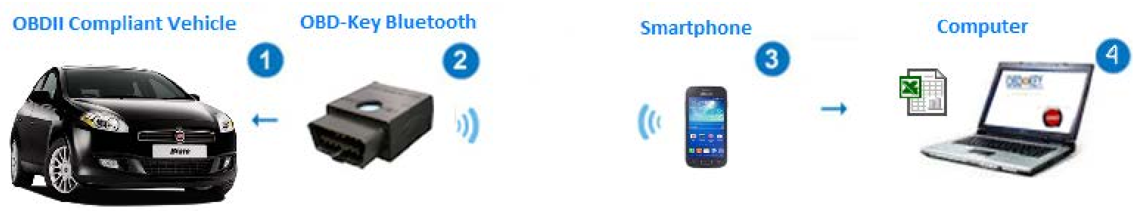


Figure 14. Data collection process

The following parameters were collected everyday before and after the drivers took the eco-driving training course:

- GPS position (longitude and latitude) and distance travelled (km)
- Travel time (h)
- Instantaneous speed (km/h)
- Fuel consumption (l)
- Number of stops, rpm, acceleration and deceleration (m/s2)

These data are necessary to measure the variation in speeds, accelerations and emissions produced by eco-driving and eco-routing at the individual level. They can be used in future research to build a micro and macro simulation.

3.2.6. Experiment time schedule

Figure 15 shows the time schedule of the data collection campaign in Madrid and Caceres respectively.

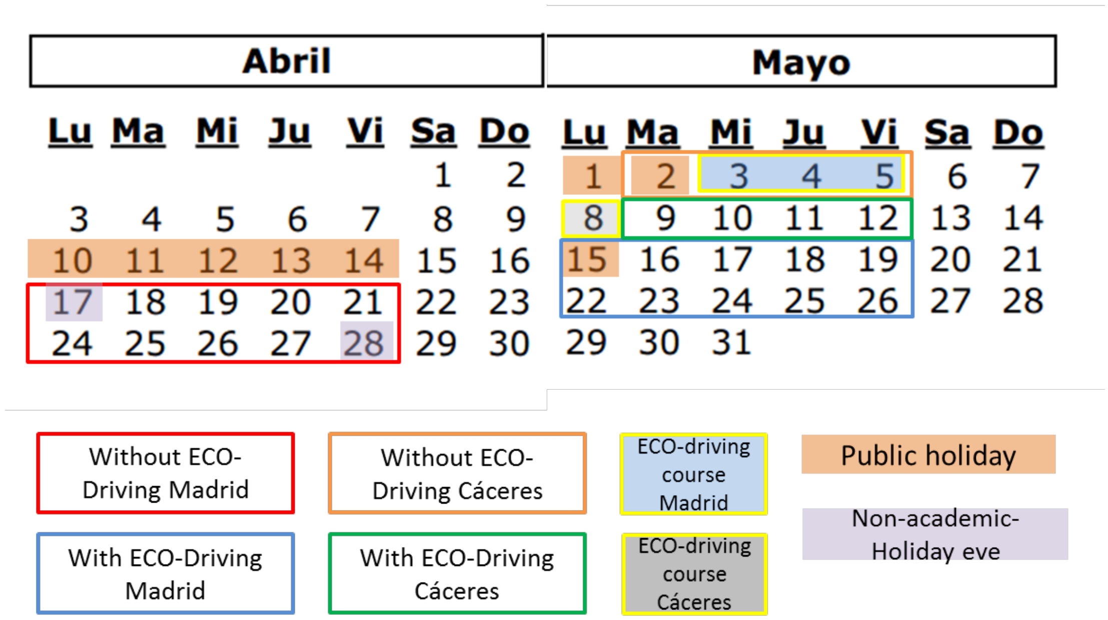


Figure 15. Data collection calendar and schedule

Case of Madrid

The first driving period begins on Monday, April 17. Because this day is considered non-academic in the city of Madrid, being able to alter the traffic significantly in relation to the rest of the week, it is used as a day to introduce drivers to the ECO-Traffic project. This day aims to raise awareness of drivers with the role they will play within the project, as well as explain in detail the operation of the OBD key II, the different itineraries that will perform, the convenient refuelling point, etc.

As mentioned in previous points, during two periods (18 to 28 of April and 16 to 26 of May) interspersed with an efficient driving course two vehicles were driven simultaneously (one with diesel fuel and another gasoline) along different itineraries.

Each day of driving consists of three shifts (for each of the used cars):

1st : 7:00-9:00
2nd: 14:00-17:00
3rd: 17:00-20:00
which cover the peak hours of the traffic in the marked itineraries. The shifts have a duration of 4 hours and are composed of 2 people, who will drive two hours respectively, being both driver and co-pilot during the same shift.

Driving shifts are adjusted so that all previous hours are covered for a better study, always starting 15 to 20 minutes before the rush hour starts, and ending the same, 15 or 20 minutes after finish the rush hour.

An examples of a driving day can be:

1º Shift	7:00-11:00
2º Shift	11:30-15:30
3º Shift	16:00-20:00

The rotating shifts of drivers is given in Annex I. The pair of drivers rotates between the two cars during the two weeks of driving before the course in the driving school, driving as they know how to (Table 4), and the two weeks after the course (Table 5), driving efficiently (ECO-driving), and assuming that the shift / schedule of the pair remains the same throughout the experiment, as it may be subject to the working hours of the drivers outside the scope of the project.

Caso de Cáceres:

Similar with the case of Madrid, the experiment started from the national holiday in May, first day as a beginning day, participants gathered and were taught to use the on-board equipment as well as get used the designed routes.

The first test was done from May 2 to May 5, 2017, and the second the following week, from May 9 to May 12, after taking the eco-driving training course. Each day of driving consists of three shifts (for each of the used cars) based on the local traffic conditions in order to cover all type of traffic states:

1st Turn 7:30 a.m.-11:30 a.m.
2nd Turn 12:00 a.m.-4:00 p.m.
3rd Turn 4:30 p.m.-8:30 p.m.

These turns were made during 4 days of a week without the drivers having received the eco-driving training and 4 days of the following week after receiving this training (see Annex I).

Following are the rotating shifts of drivers, in which the pair of drivers rotates between the two cars during the four days of driving before the course in the driving school, driving as they know how to, and the four days after the course, driving efficiently (ECO-driving), and assuming that the shift/schedule of the pair remains the same throughout the experiment.

3.3. Post-trip survey

At the end of each driving shift, the core driver had to fill out a designed survey with two parts, such as the one shown below in Annex II, consisting of three tables, A and B, and which both the driver and the co-driver had to sign.

Table A and B contains general information of the trip, like weather condition, the conducted routes, car environment, temperature and occurred accidents etc. The post-trip suvey is used to control execuation of the experiment as well as collect the real information of the road environment.

In addition to the Table C, drivers should also complete a driving satisfaction survey, which were analysed later by a team of UNED social psychologists, who collaborate in this experiment.

At the end of each route, the drivers filled out a brief questionnaire that included four attitudinal items. The items were designed based on the works of Betella and Verschure (2016) and Russel (1980), measuring main emotions experienced in the trip (bored-entertained, relaxed-stressed), perception of self-efficacy and the appraisal of circumstances associated with car driving. 1 to 7-point Likert-type scale was used as response scale (see Annex II Post-trip survey).

This short survey was carried out to analyse drivers' acceptability to the impacts that eco-driving and eco-routing may have in their itineraries, as well as on the overall assessment of the trip.

4. DATABASE CREATION AND VALIDATION

Last chapter described the details of how to clean erroneous data samples and integrate them into a road network. Thus this chapter focus on two steps that was presented in Figure 1: database creation and validation. In the process of database creation includes *data download*, *data integration* as well as *data cleaning*, etc. And then based on the certain certeria, several trips have been eliminated in the step of database validation, i.e., database validation.

4.1. Database creation

In the stage of Database Creation, all data collected on the previous stage have been joined and elaborated through the ¨R¨ programming lanague. The R language is widely used among statisticians and data miners for developing statistical software and data analysis. It permitted further calculating obtained data for each trip, as initial source data, second by second recordings.

Moreover, through Google Geo, knowing the instantaneous position recorded by the OBD preinstalled on the vehicles, we have obtained the slope of the route, and consequently we have been able to evaluate fuel consumption by using the VSP-Vehicle Specific Power model (more details in part 4.1.2).

By unifying all variables obtained and by using another time the software R, we have joined all data in a unique initial database composed by trips, each one characterized by 128 variables in part 4.1.3.

4.1.1. Data downloading

The raw data collected in the first stage were firstly downloaded to the local computers.There were 3 data sources contained different type of data, which are:

1. OBDKey devices connected to cars permited users immediately downloading information of all the trips through the TORQUE website,

where registered user and password can access the data list by personal computer.

In Figure 16 we can see the display of the website, with the list of all the trips recorded by the OBDII device that was installed in the experimental vehicle.

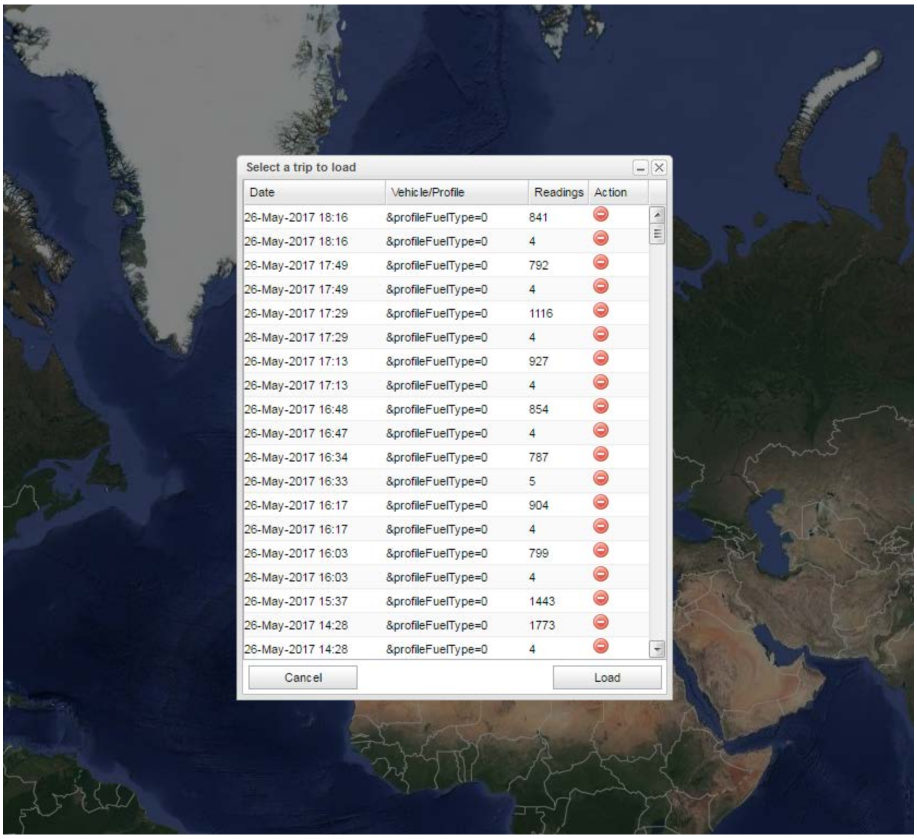


Figure 16. List of trips reordered by OBD on the website.

Selecting one of the files, we can have an overview of the trip including the route, the start and end point, as shown in Figure 17, and then we can easily download the file of the trip. The general view of trip serves to inical clean data with error which the trip was not completed.

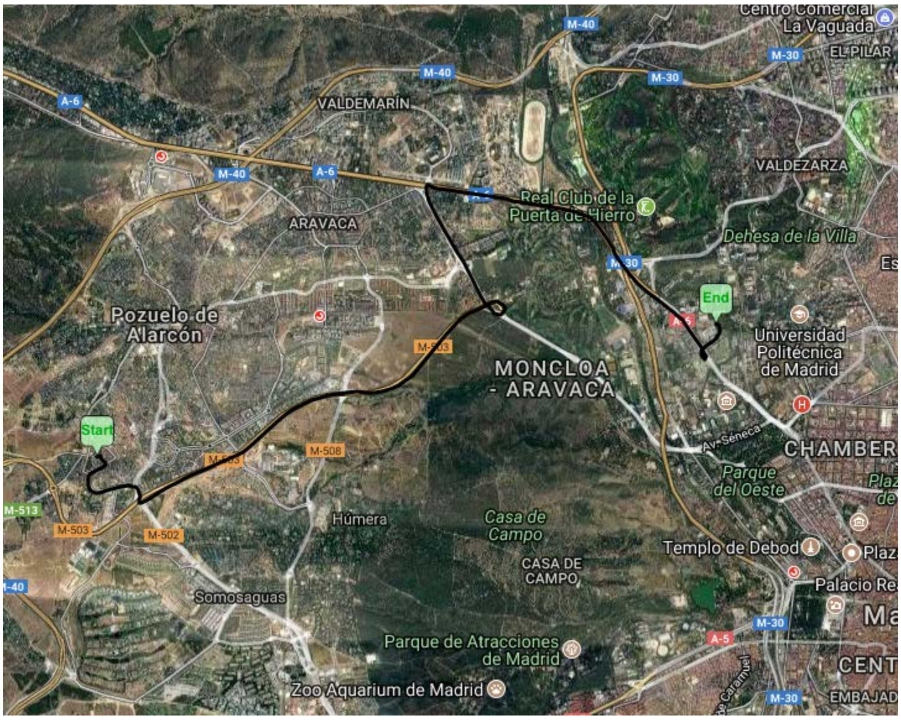


Figure 17. Example of route

2. Google Geo. This tool allows us to obtain data of the elevation and name of the road involved in each driving route, in order to evaluate the fuel consumptio using the VSP method. https://developers.google.com/maps/documentation/elevation/start
3. Traffic count data 2016. The traffic data like average daily intensity (ADI), velocity distribution, percentage of heavy vehicles in each road were obtained from the Community of Madrid and Ministerio de Fomento de España.

4.1.2. Data integration and cleaning

After download the data for each trip, it is necessary to integrate them into a single file in order to further prcess and clean them. To this content, we have adopted the software of ¨R studio¨ to integrate all downloaded data into a single file.

The data integration was conducted according to recorded time. Each trip contains the information of longitude, latitude, GSP speed, RPM, trip time, KPL, MPG, Trip distance by second. A single file was created to researve all mentioned data and ordered its departure time.

Regarding data cleaning, firstly we set up 3 basic rules to clean the error in the raw data. The data which not meet the conditions were deleted. The three rules are

i) The range of recorded trip time should be not more than 3 seconds, $t_{i+1} - t_i \leq 3$
ii) the range of acceleration should be between -3 and 3, (in this case, the error of acceleration was excluded), $-3 \leq a_{i+1} - a_i \leq 3$

iii) if the trip distance difference equals to 0, then delete it or, the distance not equals to 0 but the difference of GPS speed is 0, then delete the data as well. $d_{i+1} - d_i \neq 0 \; or \; d_{i+1} - d_i = 0 \; and \; v_{i+1} - v_i \neq 0$

More data cleaning is given in part 4.1.3 which is based on the integrated database.

4.1.3. Variables calculation

The integrated file records instantaneous position, speed, acceleration, fuel consumption (l/h down to a precision level of five significant digits) and revolutions per minute (rpm) by second of each trip.

Once the trips with error were filtered, the remaining records were processed in order to obtain the values for 128 variables for each trip, calculated according to traffic and emissions literature (Ericsson, 2001; Smit et al., 2007; Greenwood, Dunn and Raine, 2007; Beusen et al., 2009).

Based on the instant speed values recorded, variables can be calculated for each trip, including maximum speed, mean speed, maximum acceleration, maximum deceleration, number of stops and so on, and other statistically derived values such as standard deviation, 95th percentile, among others. Idling time, average rpm, coasting time and other engine variables were also calculated as they are useful for further research into fuel consumption and emissions.

The variables finally calculated and introduced into the databases can be found in the following Table 5:

Variables in Database	Description	Format	Range value	Unit
No	Number	NUM		
File ID	File ID	NUM		
Vehicle	vehicle ID	NUM	Astra=1; FIAT=2	
Route	Routes ID	NUM		
Itinerary	Itinerary ID	NUM		
Roads	Roads name	TXT		
Duration	trip duration in HH:MM:SS	TIME		second
Error	failed trips	NUM	1:GPS failed 2:OBD failed 3:Detour	
Eco-driving	It is ecodriving/not	NUM	1: eco-driving 0: no eco-driving	
driver ID	name of the driver	NUM	1 to 12	

Copiloto ID	name of the co-driver	NUM	1to 12	
Question 1	El manejo del vehículo le ha resultado facíl - difícil	NUM	1 to 7	
Question 2	Las circunstancias de la conduccion han side facíl - difícil	NUM	1 to 7	
Question 3	Durante el trayecto se ha sentido aburrido-entretenido	NUM	1 to 7	
Question 4	Durante el trayecto se ha sentido relajado-estresado	NUM	1 to 7	
Incident		TXT		
Weather	Weather of the recording day	NUM	Sunny=1; Raining=2 ; Windy=3; Others=4	
Window	Window	NUM	1: closed; 0: Open	
Aire condition	Air condition is on	NUM	0: off; 1: ON	
Temperature outside	Temperature outside of the car	NUM		℃
Temperature inside	Temperature inside of the car	NUM		℃
date	Recording Date	Date		
weekday	Day of the week	NUM		
start_time	trip start time_filtered data	NUM		
end_time	trip end time_filtered data	NUM		
duration_recorded	trip duration recorded by OBD_filtered data	NUM		second
lpk_sum	Total litro per kilometer_OBD	NUM		litro
lpk_ave	average total litro per kilometer_OBD	NUM		litro
trip_length	trip length_filtered data	NUM		kilomete r
max_speed	maximum speed	NUM		km/h
avg_speed	average speed	NUM		km/h
lpk_ave_mp_trip_length	average total litro per kilometer_OBD*trip length_Filtered data	NUM		litro
avg_rpm	average rpm	NUM		rev/min

max_rpm	maximum rpm	NUM		rev/min
min_rpm	minimum rpm	NUM		rev/min
min_acc_pos	minimum positive acceleration	NUM		m/s^2
max_acc_pos	maximum positive acceleration	NUM		m/s^2
min_acc_neg	minimum negative acceleration	NUM		m/s^2
max_acc_neg	maxmum negative acceleration	NUM		m/s^2
ave_acc_pos	average positive acceleration	NUM		m/s^2
ave_acc_neg	average negative acceleration	NUM		m/s^2
p95_acc_pos	95 percentile of positive accelerations	NUM		m/s2
p95_acc_neg	95 percentile of negative accelerations	NUM		m/s2
sd_acc_pos	standard deviation of positive accelaration	NUM		m/s^2
sd_acc_neg	standard deviation of negative accelaration	NUM		m/s^2
Pacc_0.1	time with more than 0.1 m/s^2 accelaration	NUM		second
Pacc_3	time with more than 0.83m/s^2 accelaration	NUM		second
Pacc_5	time with more than 1.389m/s^2 accelaration	NUM		second
Pdec_0.1	time wit less than -0.1m/s^2 accelaration	NUM		second
Pdec_3	time wit less than -0.83m/s^2 accelaration	NUM		second
Pdec_5	time wit less than -1.389m/s^2 accelaration	NUM		second
Pcru_0.1	time with accelaration rate between -0.1 and 0.1 m/s^2	NUM		second
Pcru_3	time with accelaration rate between -0.83 and 0.83 m/s^2	NUM		second
Pcru_5	time with accelaration rate between -1.389 and 1.389 m/s^2	NUM		second
perc_spd_0	percentage of 0 velocity	NUM		%
perc_spd_0_50	percentage of velocity between 0 to 50 km/h	NUM		%

perc_spd_50_70	percentage of velocity between 50 to 70 km/h	NUM		%
perc_spd_70	percentage of velocity more than 70%	NUM		%
PAA	Positive accumulated acceleration: Summation of V(i+1)-v(i) if V(i+1)>V(i)	NUM		
PAA_km	Positive accumulated acceleration per km: Summation of V(i+1)-v(i) if V(i+1)>V(i)	NUM		
PKE	Positive kinetic energy: Summation of V^2(i+1)-v^2(i) if V(i+1)>V(i)	NUM		
Nstop_aux_3	Number of stops being stop speed under 3km/h	NUM		
st_t_aux_3	Stop time being stop speed under 3km/h	NUM		s
Nstop_aux_3_per_km	Number of stops per km being stop speed under 3km/h	NUM		
st_t_aux_3_per_km	Stop time per km being stop speed under 3km/h	NUM		s/km
st_t_aux_3_percent	%Stop time being stop speed under 3km/h	NUM		%
Nstop_aux_5	Number of stops being stop speed under 5km/h	NUM		
st_t_aux_5	Stop time being stop speed under 5km/h	NUM		
Nstop_aux_5_per_km	Number of stops per km being stop speed under 5km/h	NUM		
st_t_aux_5_per_km	Stop time per km being stop speed under 5km/h	NUM		
st_t_aux_5_percent	%Stop time being stop speed under 5km/h	NUM		
Nstop_aux_3_144	Number of stops being stop speed under 3km/h and starting to count when speed >14.4	NUM		
st_t_aux_3_144	Stop time being stop speed under 3km/h and starting to count when speed >14.4	NUM		
Nstop_aux_3_144_per_k	Number of stops per km	NUM		

m	being stop speed under 3km/h and starting to count when speed >14.5			
st_t_aux_3_144_per_km	Stop time per km being stop speed under 3km/h and starting to count when speed >14.5	NUM		
st_t_aux_3_144_percent	%Stop time being stop speed under 3km/h and starting to count when speed >14.4	NUM		
Nstop_aux_5_144	Number of stops being stop speed under 5km/h and starting to count when speed >14.4	NUM		
st_t_aux_5_144	Stop time being stop speed under 5km/h and starting to count when speed >14.4	NUM		
Nstop_aux_5_144_per_km	Number of stops per km being stop speed under 5km/h and starting to count when speed >14.5	NUM		
st_t_aux_5_144_per_km	Stop time per km being stop speed under 5km/h and starting to count when speed >14.5	NUM		
st_t_aux_5_144_percent	%Stop time being stop speed under 5km/h and starting to count when speed >14.4	NUM		
Vmax	Maximum recorded speed	NUM		Km/h
Vave_t	Average speed as lenght/time	NUM		Km/h
Vave_vi	Average speed as average of recorded speeds	NUM		Km/h
Vave_wo_3	Average speed without considering speeds under 3 km/h	NUM		Km/h
Vave_wo_5	Average speed without considering speeds under 5 km/h	NUM		Km/h
V95	95 Percentile of instantaneus recorded	NUM		Km/h

	speed			
Vmedian	Speed median	NUM		Km/h
cov	Speed variation coeficient (Ratio of standard deviation to the mean %)	NUM		
sum_fc	sum of fuel consumption using VSP model	NUM		litro/s
avg_fc	average fuel consumption using VSP model	NUM		litro/s
max_fc	maximum fuel consumption using VSP model	NUM		litro/s
min_fc	minimum fuel consumption using VSP model	NUM		litro/s
sum_co2	sum of CO2 using VSP model	NUM		g/s
avg_co2	average CO2 using VSP model	NUM		g/s
max_co2	maximum CO2 using VSP model	NUM		g/s
min_co2	minimum CO2 using VSP model	NUM		g/s
sum_co	sum of CO using VSP model	NUM		mg/s
avg_co	average CO using VSP model	NUM		mg/s
max_co	maximum CO using VSP model	NUM		mg/s
min_co	minimum CO using VSP model	NUM		mg/s
sum_hc	sum of HC using VSP model	NUM		mg/s
avg_hc	average HC using VSP model	NUM		mg/s
max_hc	maximum HC using VSP model	NUM		mg/s
min_hc	minimum HC using VSP model	NUM		mg/s
sum_nox	sum of NOx using VSP model	NUM		mg/s
avg_nox	average NOx using VSP model	NUM		mg/s
max_nox	maximum NOx using VSP	NUM		mg/s

	model			
min_nox	minimum NOx using VSP model	NUM		mg/s
max_slp_pos	Maximum positive slope	NUM		
min_slp_pos	Minimum positive slope	NUM		
max_slp_neg	Maximum negative slope	NUM		
min_slp_neg	Minimum negative slope	NUM		
avg_slp	Average slope	NUM		
avg_slp_pos	Average positive slope	NUM		
avg_slp_neg	Average negative slope	NUM		
%vsp1	Percentage of time spent in VSP mode 1 (%)	NUM		%
%vsp2	Percentage of time spent in VSP mode 2 (%)	NUM		%
%vsp3	Percentage of time spent in VSP mode 3 (%)	NUM		%
%vsp4	Percentage of time spent in VSP mode 4 (%)	NUM		%
%vsp5	Percentage of time spent in VSP mode 5 (%)	NUM		%
%vsp6	Percentage of time spent in VSP mode 6 (%)	NUM		%
%vsp7	Percentage of time spent in VSP mode 7 (%)	NUM		%
%vsp8	Percentage of time spent in VSP mode 8 (%)	NUM		%
%vsp9	Percentage of time spent in VSP mode 9 (%)	NUM		%
%vsp10	Percentage of time spent in VSP mode 10 (%)	NUM		%
%vsp11	Percentage of time spent in VSP mode 11 (%)	NUM		%

Table 5. Variables calculated in the data collection campaign

Moreover, we have further calculated the fuel consumption based on the VSP model. The (VSP) method is a convenient single measure that can be used directly to predict emissions. VSP approach to emissions characterization was developed by several researchers (Jimenez-Palacios, 1999) and further developed as part of the MOVES (motor vehicle emissions simulator) model.

VSP model

VSP is a direct measure of the road load on a vehicle: it is an accredited methodology demonstrated to characterize vehicles and driving profiles using real-world on-road measured data (Rolim et al, 2014).

Informally it represents the ratio between the instantaneous energy requested by the vehicle and its mass. To estimate the power demand by the vehicle, the VSP methodology combines speed, acceleration and road grade, according to the following equation, which is applicable to light-duty vehicles (Jimenez-Palacio, 1999).

$$VSP\left[\frac{W}{kg}\right] = \frac{Power}{Mass} = \frac{\frac{d}{dt}\left(E_{kinetic} + E_{potential}\right) + F_{rolling} * v - F_{aerodynamic} * v}{m}$$
$$= v(1.1 * a + 9.81 * grade + 0.132) + 3.02 * 10^{-4} * v$$

in which:

$E_{kinetic}$ is the kinetic energy

$E_{potential}$ is the potential energy

$F_{rolling}$ is the rolling resistance force

$F_{aerodynamic}$ is the aerodynamic resistance force

v is the instantaneous speed (m/s)

m is the mass (kg)

a is the acceleration (m/s^2)

$grade$ is the road grade (m/m)

Each second of driving was associated to a VSP bin, as presented in the next table, in which are shown the 14 VSP modes and the corresponding power requirements interval for each modes. (Faria et al., 2017)

VSP mode	W/kg
1	VSP < -2
2	-2 ≤ VSP < 0
3	0 ≤ VSP < 1
4	1 ≤ VSP < 4
5	4 ≤ VSP < 7
6	7 ≤ VSP < 10
7	10 ≤ VSP < 13

VSP mode	W/kg
8	13 ≤ VSP < 16
9	16 ≤ VSP < 19
10	19 ≤ VSP < 23
11	23 ≤ VSP < 28
12	28 ≤ VSP < 33
13	33 ≤ VSP < 39
14	VSP ≥ 39

Table 6 Correlation between VSP mode and W/Kg

Once we have obtained second by second the corresponding VSP mode, it's possible to correlate every mode with emissions by using the following table (Faria et al., 2017).

VSP mode	Pollutant							
	CO_2 (g/s)		CO (mg/s)		NO_x (mg/s)		HC (mg/s)	
	G	D	G	D	G	D	G	D
1	0.63	0.21	0.50	0.03	0.23	1.29	0.03	0.14
2	1.05	0.61	0.27	0.07	0.68	2.62	0.03	0.11
3	1.02	0.73	0.15	0.14	0.60	3.38	0.03	0.11
4	2.07	1.50	0.58	0.25	1.75	6.05	0.07	0.17
5	2.79	2.34	1.14	0.29	2.52	9.36	0.10	0.20
6	3.47	3.29	1.76	0.69	3.34	12.53	0.15	0.23
7	4.31	4.20	4.05	0.58	4.04	15.48	0.22	0.24
8	5.19	4.94	6.13	0.64	2.63	17.82	0.35	0.23
9	5.81	5.57	9.06	0.61	3.51	21.32	0.42	0.24
10	6.43	6.26	18.97	1.01	2.89	32.53	0.52	0.28
11	7.37	7.40	44.98	1.15	1.27	55.75	0.62	0.37

Table 7 Correlation between VSP mode and emissions

By using the methodology described above, each second of driving has been correlated to a specific VSP mode; finally, through the conversion model drawn from the same article (Fara et al., 2017) it has been obtained the instantaneous fuel consumption related to each VSP mode depending on the tipology of vehicle.

	Instantaneous fuel consumption (l)	
VSP mode	GASOLINE	DIESEL
1	0.01244	0.01116
2	0.01866	0.01674
3	0.020526	0.018414
4	0.0622	0.0558
5	0.08397	0.07533
6	0.11507	0.10323
7	0.14306	0.12834
8	0.16794	0.15066
9	0.19904	0.17856
10	0.22703	0.20367
11	0.27368	0.24552

Table 8 Relation between VSP mode and fuel consumption

In this way, we could compare the energy power requested by a vehicle in each itinerary and the relationed emissions. It permits us to do a comparison regarding emissions produced along different itineraries implicated on our study.

Moreover by using this methodology and taking advantage by the high resolution of real driving data (second by second analysis), it's possible to evaluate with a certain accurancy driving behavior patterns on emissions.

Consequently, by using this method, we can do a comparison not only with regards to the association between emissions and different routes implicated on our study, but also regarding the association between emissions and different driving behavior patterns or different type of vehicles (gasoline and diesel). From here the utility to use this methodology in this thesis: as VSP model leaves out the problem of kind of vehicle, we have no problem due to the weekly change of them, neither regarding different kind of fuel (gasoline or diesel).

4.2. Database validation

The intregrated database was validated according to the following 4 criteria. Those trips that did not satisfy one of the criteria were eliminated.

i. Trips with GPS positon partially or completely missing;
ii. Trips with missing revolution per minute recordings (partially or completely);
iii. Real trip length was not fully recorded;
iv. Timing failure

•Case of Madrid

After filtering all the 1001 trips recorded due to several errors discovered, there are finally 797 trips available for study.

From the initial database, a total of 204 trips (21%) were deleted:

- 39 trips have been dropped due to GPS-Failure
- 69 trips have been deleted since the data of RPM is missing.
- 57 trips have been deleted since the length of the trips is significantly bigger or smaller than the real trip length.
- 39 trips have been dropped due to data loss.

•Case of Caceres

After filtering all the 580 trips recorded due to several errors discovered, there are finally 476 trips available for study.

From the initial database, a total of 104 trips (19%) were deleted:

- 30 trips have been dropped due to GPS-Failure
- 16 trips have been deleted since the data of RPM is missing.
- 24trips have been deleted since the length of the trips is significantly bigger or smaller than the real trip length.
- 34 trips have been dropped due to data loss.

The trips with missing fuel consumption were remained since these value was replaced by the value calcaulted thourgh VSP model. By applying these four different filtering rules for each trip, the database was updated.

Moreover, in order to evaluate the eco-driving in different type of roads, we also created a more detailed database (as we called Database_Section) with variables of road name, road type, level of service.

This database was divided by route sector depending on defined road category. In these terms we were able to answer to the second research question: how is affected the eco-driving efficiency depending on the road section and traffic states?

It is notice that the road name of each trip was obtained from GoogleGeo using R programm based it is recorded GPS (Global Positioning System) position. However, through the empirical GPS tests have shown that the average accuracy of standard GPS receivers reaches approx. 15 m in urban areas (Modsching et al., 2006). It is necessary to correct the obtained road name manually that was also the most time-consuming task during the process of database validation.

5. RESULTS OF DATA ANALYSIS

To understand the efficiency of eco-driving, we made the comparison on average fuel consumption before and after the experiment for the two cities. Moreover, this chapter also gives the difference of fuel consumption among different routes is presented in order to understand the eco-routing patterns. All the results were obtained through the statistic software ¨SPSS¨.

5.1. Analysis of eco-driving

We conducted two different analysis, one with regards to the database_all which is introduced in part 5.1.1 and 5.1.2, and another one for results obtained from the database_section that focuses on the different road sections and is given in 5.1.3.

The results concerns the variation of fuel consumption between the first and the second period of the experiment.

5.1.1. General figures

The general figures of database_all are given for the case of Madrid and Caceres repectively. Table 9 and 10 present the number of trips conducted in Madrid and Caceres according to selected routes, types of vehicle and period of the experiment.

Period	Vehicle	CP1	CP2	CP3	MP1	MP2	MP3	PC1	PC2	PC3	PM1	PM2	PM3	Total
Without eco	Diesel	14	16	21	11	14	18	19	15	16	18	13	17	192
	Gasoline	22	25	19	17	16	14	24	22	16	15	19	16	191
With Eco	Diesel	20	14	16	16	17	16	13	16	16	13	20	14	225
	Gasoline	18	18	16	14	14	12	18	19	13	15	20	12	189
Total		74	73	72	58	61	60	74	72	61	61	72	59	797

Table 9 Number of trips by route, vehicle and period in Madrid

Period	Vehicle	AP1	AP2	AP3	AP4	PA1	PA2	PA3	PA4	Total
Without eco	Diesel	16	18	13	18	17	14	15	17	128
	Gasoline	16	13	14	17	14	13	16	15	118
With Eco	Diesel	17	12	10	14	15	16	14	16	114
	Gasoline	12	16	10	21	17	13	20	7	116
Total		61	59	47	70	63	56	65	55	476

Table 10 Number of trips by route, vehicle and period in Cáceres

Through table 10 and 11, we can see that the number of trips made by the two vehicles are very similar. However, there were 33 more trips conducted by diesel car in the period with eco-driving in Madrid. Considering this fact, the average fuel consumption variation may be different among vehicle type due to the different weight that each journey has depending on the first or second driving period.

Plus, the number of trips made for each route is relatively equal for both Madrid and Caceres. The great number of trips conducted in each route makes the evalution of fuel saving meaningful.

Considering different drivers, in Madrid drivers made an average 66 trips each one (32 without eco-driving and 34 with eco-driving) while in Cáceres drivers did average 40 trips (20 before and 20 after). Among them, 9 women comparing with 15 men conducted 58% of the trips (471 trips) during the whole experiment period. It needs to take account not every driver drove equally during the two period of the experiment. The one who did not drive sufficient trips were exclude in the analysis.

5.1.2. Analysis by external factors

This part shows the results of fuel savings as well as CO_2 emissions variation by external factors, like vehicle type, drivers and route for both Madrid and Cáceres.

To better develop the analysis, all results are given as changes in percentage in respect to the following three types of variables:

1) Variables related to fuel consumption: average fuel consumption (avg_fc), this variable directly represent fuel savings by driving pattern changing, and average fuel consumtion considering traffic states (avg_fc_km), this variable reflect the effects of eco-driving and road traffic;
2) Variables related to driving behaviour: average RPM (avg_rpm), average speed (avg_speed), average speed variation coeficient (Ratio of standard deviation to the mean %) (avg_cov), average of harsh acceleration (avg_acc).
3) Variables related to emissions: Average CO2 emission (avg_co2)

Case of Madrid							
Vehicle	avg_fc	avg_fc_km	avg_rpm	avg_speed	avg_cov	avg_acc	avg_co2
Diesel	-3.5%	3.2%	-12.5%	-0.2%	-6.6%	-36%	-3.5%
Gasoline	-6.1%	-4.1%	-11.5%	-3.3%	-8.0%	-50%	-4.8%
Case of Caceres							
Vehicle	avg_fc	avg_fc_km	avg_rpm	avg_speed	avg_cov	avg_acc	avg_co2
Diesel	-4.1%	3.2%	-19.3%	-6.1%	-11.0%	-52%	-3.9%
Gasoline	-12.4%	-1.1%	-20.6%	-10.1%	-11.0%	-63%	-9.4%

Average	-6.5%	0.3%	-16.0%	-4.9%	-9.2%	-50%	-5.4%

Table 11 Variation of the selected variables for Madrid and Cáceres

Through this first analysis, by considering the only case of diesel power, a reduction round 4% in fuel consumption in both cases Madrid and Cáceres has been obtained by using an eco-driving approach; on the other hand, in the case of the Gasoline power results are better and different: through the Gasoline vehicle in Madrid it has been reached a greater reduction of 6% which increase up to 12.4% in the case of Cáceres (Table 11).

By considering all results obtained, an average reduction of 6.5% in fuel consumption has been obtained by adopting an eco-driving behavior; in this sense the results are perfectly compatible with the ones achieved by other researchers. However, by considering the effect of different traffic conditions, fuel consumption can be strongly affected: more congestion were met in the second driving period, as consequence, a bit more (3%) fuel was used by diesel vehicle (which for example in Madrid covered more trips), and slight less for gasoline, obtaining global a mean value of fuel consumption almost equal comparing the first and the second driving period (0.3% vs 6% reduction respectively considering or not traffic condition). This consideration find a confirm and an explication through the analysis of results obtained from variables related to driving patterns: as it is seen, drivers have reduced their speed and the RPM, considerably made less harsh acceleration, and maintained same speed for longer time, but the corresponding reduction on fuel consumption has not at the same magnitude of reduction.

In these terms the efficient driving course seems to be usefull in terms of changing the behaviour approach during a driving sessions, but the consequent reduction in fuel consumption results to be really affected by unfavourable traffic conditions.

Finally, by adopting an efficient driving behaviour, emissions of CO_2 result to be reduced due to their direct relation with the fuel consumption (it would not be the same if we were speaking about NOx or PM).

- *Analysis per drivers*

Table 12 and 13 present the variation of the variables depending on the 24 drivers for the diesel and gasoline car respectively. The driver with ID of 11 and 14 did not complete the experiment, thus their trips were excluded in the analysis. Data obtained by drivers ID 12, 13 and 16 were eliminated from the database, due to the big difference between the number of trips covered during the first or the second driving periods; as previous mentioned, being a short term experiment, traffic conditions could strongly affect fuel consumption and results obtained by these drivers could strongly affect our analysis.

Driver	avg_fc	avg_fc_km	avg_rpm	avg_speed	avg_cov	avg_acc	avg_co2

ID							
1	-4%	0%	-16%	2%	5%	-64%	-3%
2	-3%	1%	-13%	1%	-6%	-51%	-3%
3	-7%	-1%	-12%	-3%	-12%	-42%	-8%
4	-4%	-5%	-20%	2%	-13%	-64%	-4%
5	-3%	5%	-14%	0%	-14%	-49%	-3%
6	0%	8%	-10%	2%	-7%	34%	0%
7	-2%	1%	-16%	2%	-15%	-24%	-2%
8	-2%	9%	-12%	-5%	5%	-32%	-3%
9	-1%	4%	-10%	6%	-9%	-27%	-2%
10	-2%	-6%	-8%	6%	-8%	16%	-2%
12	-5%	17%	-11%	-7%	12%	13%	-5%
13	-9%	5%	-4%	-6%	-18%	-42%	-10%
15	10%	3%	-12%	5%	-16%	-74%	10%
~~16~~	~~4%~~	~~32%~~	~~-14%~~	~~-4%~~	~~10%~~	~~99%~~	~~5%~~
17	-8%	13%	-13%	-10%	-3%	-7%	-8%
18	-11%	-5%	-20%	-9%	-9%	-61%	-11%
19	-18%	0%	-22%	-20%	-14%	-70%	-18%
20	-5%	9%	-35%	-11%	-17%	-36%	-5%
21	1%	-1%	-27%	-1%	-11%	-35%	2%
22	-6%	4%	-19%	-8%	-12%	-60%	-6%
23	-1%	12%	-26%	-9%	-11%	-58%	-1%
24	-1%	-2%	-4%	5%	-8%	16%	-1%
25	-2%	-3%	-19%	-3%	-13%	-58%	-2%
26	0%	3%	-23%	-9%	0%	-60%	0%
Avg	**-3%**	**4%**	**-16%**	**-3%**	**-8%**	**-31%**	**-3%**

Table 12 Variation of the selected variables by drivers (Diesel Car)

Driver ID	avg_fc	avg_fc_km	avg_rpm	avg_speed	avg_cov	avg_acc	avg_co2
1	-8%	-9%	-12%	-3%	0%	-66%	-6%
2	-6%	-7%	-9%	1%	-13%	-67%	-5%
3	-11%	-2%	-17%	-9%	-2%	-70%	-8%
4	-12%	-19%	-19%	-10%	-8%	-70%	-9%
5	-6%	2%	-10%	-2%	-12%	-51%	-5%
6	1%	-1%	-3%	2%	0%	-27%	1%
7	0%	-2%	-12%	3%	-17%	-33%	0%
8	-7%	2%	-20%	-5%	-12%	-63%	-5%
9	-8%	-9%	-9%	-2%	-4%	-64%	-6%
10	-7%	-1%	-11%	-6%	-10%	-24%	-5%
~~12~~	~~-10%~~	~~8%~~	~~-16%~~	~~-13%~~	~~16%~~	~~-29%~~	~~-8%~~
~~13~~	~~21%~~	~~-21%~~	~~17%~~	~~37%~~	~~-37%~~	~~30%~~	~~15%~~

15	-11%	4%	-17%	-15%	-2%	-59%	-9%
16	-8%	-1%	-12%	-7%	-11%	-59%	-6%
17	-13%	-4%	-12%	-8%	-7%	-53%	-10%
18	-15%	-4%	-21%	-17%	5%	-71%	-12%
19	-29%	-5%	-40%	-24%	-21%	-93%	-24%
20	-19%	-6%	-32%	-16%	-16%	-80%	-15%
21	-25%	-2%	-32%	-18%	-8%	-74%	-20%
22	-17%	-17%	-19%	-6%	-21%	-74%	-14%
23	5%	8%	-19%	3%	-23%	-23%	5%
24	-4%	7%	-11%	-9%	-8%	-43%	-2%
25	-8%	-4%	-18%	-2%	-17%	-26%	-6%
26	-12%	4%	-20%	-11%	-9%	-59%	-9%
Avg	**-9%**	**-3%**	**-16%**	**-6%**	**-10%**	**-52%**	**-7%**

Table 13 Variation of the selected variables by drivers (Gasoline Car)

The analysis of diesel car shows that 2 drivers increased fuel consumption, and 2 of them did not change; the results obtained through gasoline show that one driver increased fuel consumption, and 2 of them didn´t receive significant changes.

Globally the results show a clear heterogeneity among drivers. The eco-driving impact varies from +10% more fuel consumption up to almost -30% less consumption (Driver ID 19). These results confirm among other that the behavioral aspect really influences the eco driving efficiency, overall in terms of reduction in fuel consumption.

As found on the previous analysis, despite the variability of results on fuel consumption, almost all drivers change their driving patterns, as can be seen the value of RPM has been reduced, average 16% less, for both diesel and gasoline vehicles.

The value of the average speed has not been strongly affected by the adoption of an eco-driving behaviour, on contrary a strong reduction on harsh acceleration has been observed.

Furthermore, another time better results have been obtained from the analysis of the Gasoline vehicle than the ones from the analysis of the diesel one by comparing the reductions of speed covariance and average acceleration; this is reflected into an higher fuel savings by gasoline than diesel car.

It has not been conducted a deeper analysis on the effect that the driver himself can have on the reduction in fuel consumption adopting an eco-driving approach, but with this first simple analysis results seem clear: eco-driving is a driving approach strongly affected by the driver, that in some circumstancies could achieve amazing results of 30% less fuel consumption.

- *Analysis per route*

As difined in part 3.2.4, the data collection campaign was conducted along different routes in each city. The following contents firstly present two figures to give the overview of fuel variation by route and by vehicle (Figure 18 and 19); then two tables present the variation of the selected 7 variables by route firstly for the diesel car and then for the gasoline one (Table 14 and 15).

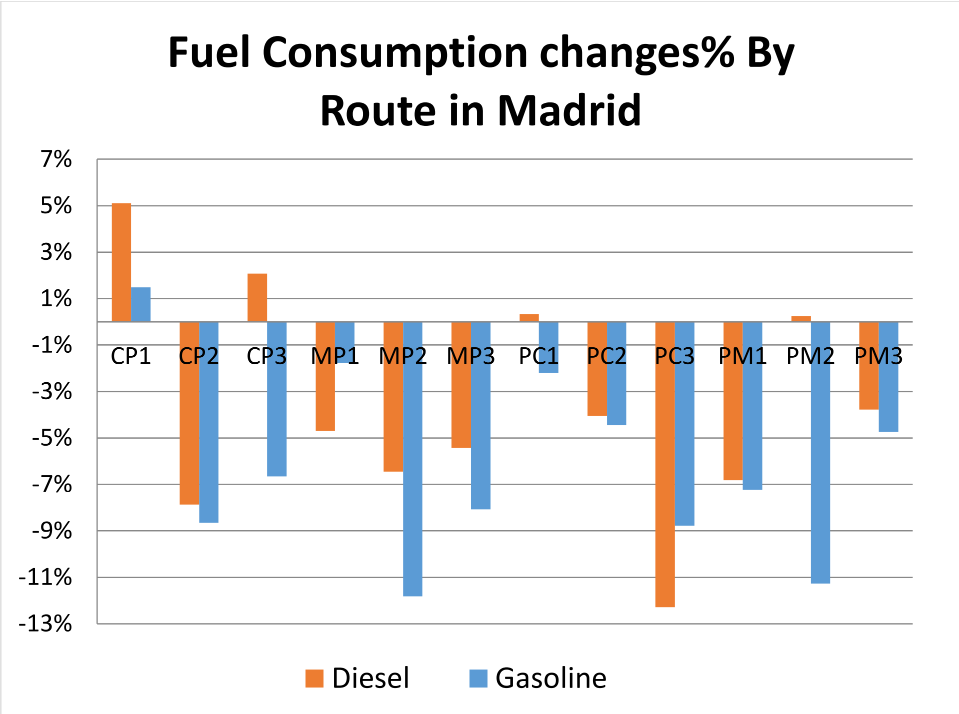


Figure 18 Fuel consumption chagnes by route by car for Madrid

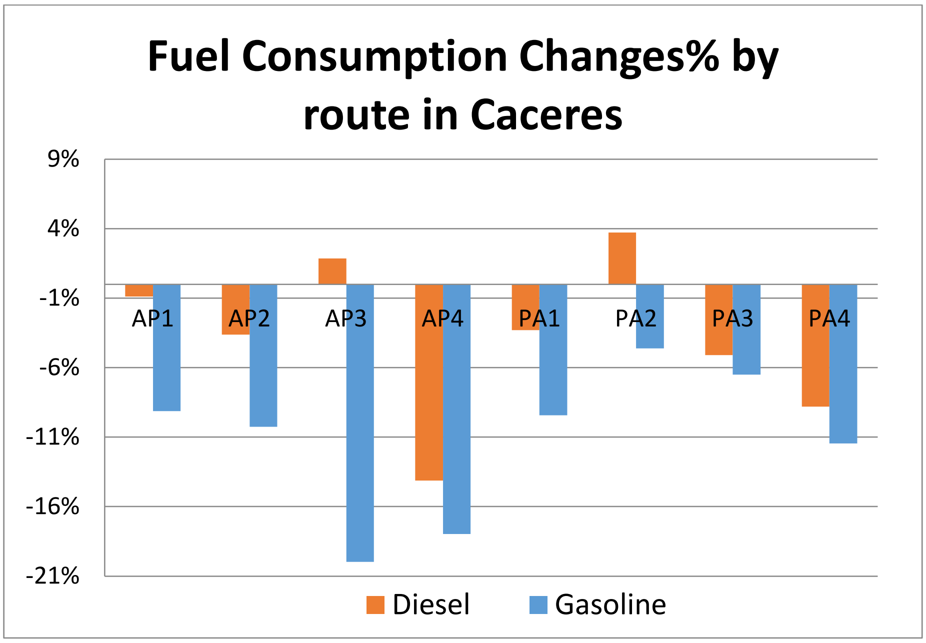


Figure 19 Fuel consumption changes by route by car for Cáceres

We see clearly fuel savings for most of the designed routes. By a first overview we can observe that diesel car in general have achieved worse resuts than the gasoline one: certainly, there is slightly increasing of fuel consumption in route CP3, AP3 and PA2 by the diesel car.

The specific reason of that may due to the unefficient drivers drove more in those routes. Another exception is the route CP1 (Caminos to Pozuelo through A6 and M40) in Madrid: for both vehicles, it received up to 5% fuel increasing. In part 5.13 we will present the characterisitics of each road to explain the reasons why CP1 does not suit for eco-driving drivers.

Route ID	avg_fc	avg_fc_km	avg_rpm	avg_speed	avg_cov	avg_acc	avg_co2
Case of Madrid							
CP1	5%	1%	-13%	10%	-17%	-5%	5%
CP2	-8%	2%	-14%	-6%	4%	-31%	-8%
CP3	2%	0%	-5%	6%	-14%	-33%	2%
MP1	-5%	-5%	-15%	5%	-19%	-30%	-5%
MP2	-6%	2%	-12%	-1%	0%	-45%	-6%
MP3	-5%	9%	-13%	-4%	-7%	-49%	-6%
PC1	0%	2%	-14%	3%	-8%	-21%	0%
PC2	-4%	9%	-8%	0%	-8%	-26%	-4%
PC3	-12%	11%	-19%	-13%	1%	-49%	-12%
PM1	-7%	-3%	-13%	-1%	-13%	-58%	-7%

PM2	0%	5%	-9%	3%	-10%	-55%	0%
PM3	-4%	6%	-17%	-2%	-4%	-25%	-4%
Case of Caceres							
AP1	-1%	0%	-17%	0%	-6%	-54%	-1%
AP2	-4%	-7%	-15%	3%	-13%	-9%	-4%
AP3	2%	14%	-18%	-8%	2%	-9%	2%
AP4	-14%	-4%	-22%	-10%	-22%	-68%	-14%
PA1	-3%	1%	-15%	-2%	-9%	-26%	-3%
PA2	4%	3%	-20%	2%	-20%	-47%	4%
PA3	-5%	2%	-17%	-7%	-3%	-48%	-5%
PA4	-9%	3%	-24%	-9%	-24%	-67%	-8%

Table 14 Variation of the selected variables by routes (Diesel Car)

Route ID	avg_fc	avg_fc_km	avg_rpm	avg_speed	avg_cov	avg_acc	avg_co2
Case of Madrid							
CP1	1%	-19%	-3%	6%	-20%	-23%	1%
CP2	-9%	-4%	-13%	-6%	-6%	-36%	-7%
CP3	-7%	-3%	-11%	-4%	-5%	-53%	-5%
MP1	-2%	-11%	-14%	11%	-28%	-44%	-2%
MP2	-12%	0%	-15%	-13%	4%	-54%	-9%
MP3	-8%	2%	-12%	-9%	2%	-61%	-6%
PC1	-2%	-6%	-7%	4%	-14%	-32%	-2%
PC2	-4%	-3%	-10%	-1%	-7%	-50%	-3%
PC3	-9%	9%	-13%	-8%	0%	-58%	-7%
PM1	-7%	-9%	-16%	-1%	-17%	-64%	-6%

PM2	-11%	8%	-15%	-11%	2%	-70%	-9%
PM3	-5%	-6%	-9%	-1%	-9%	-56%	-4%
Case of Caceres							
AP1	1%	-19%	-3%	6%	-20%	-23%	1%
AP2	-9%	-4%	-13%	-6%	-6%	-36%	-7%
AP3	-7%	-3%	-11%	-4%	-5%	-53%	-5%
AP4	-2%	-11%	-14%	11%	-28%	-44%	-2%
PA1	-12%	0%	-15%	-13%	4%	-54%	-9%
PA2	-8%	2%	-12%	-9%	2%	-61%	-6%
PA3	-2%	-6%	-7%	4%	-14%	-32%	-2%
PA4	-4%	-3%	-10%	-1%	-7%	-50%	-3%

Table 15 Variation of the selected variables by routes (Gasoline Car)

From Table 14 and 15, we could distinguish the particular changes on driving pattern along each route. Comparing the value of avg_fc and avg_fc_km, we find very distinct changes of fuel consumption due to the influence of traffic conditions. The experiment was conducted in a short term period, 9 days before and 9 days after attending the efficient driving course, so the current traffic varied a lot depending on the day, the departure hour, the incident as well as the weather; it is not the case in which due to long term analysis, the effect of the traffic state can be skiped. It has been demonstred that car consumes more fuel in congested roads, on the contray it uses less fuel in free flow condition. That is why in certain route for example CP1, PM1 and MP1, we see more fuel savings by gasoline car: along these routs this vehicle have covered more trips in free flow conditions than the diesel one.

With respect to driving patterns, most of experimental participants reduced greatly their speed and RPM, made less harsh acceleration, as well as maintained for longer time same speed, in another word, more eco-driving.

There are still several exceptions, for example in CP1 the average speed increased by both two vehicles and reasons can be found in drivers attitude or in different traffic conditions; moreover the reduction in fuel consumption along the itinerary CP1 in the case of the gasoline car changed from +1% to -19% respectively without and considering the different traffic conditions.

This and other cases find an explication as follow: looking at the increment on the average speed, we can absume that in the second driving period, traffic conditions were more frequently similar to free flow than to congested, in these terms we can explicate the different values of fuel saving without and with consider the traffic state. Along the itinerary CP1, composed mainly by highspeed roads, during free flow conditions the average speed increase and the fuel consumption can decrease.

5.1.3. Analysis by road types and Level of service

To answer to the second research question, the specific analysis is based on the database_section in which the trip is divided by road sections (see Table 3 and 4). The result is only available for Madrid case.

As mentioned, in the next tables different road types covered during the experiment have been crossed: National Highway, Urban Motorway, Urban arterial and local street. By dividing the itineraries into different road sectors is possible to analyse the different effect that the eco-driving technic can have on different kind of routs. Moreover to identify the current traffic state, the LOS of each road section has been defined (Table 16).

LOS	Speed ratio
A	≥0.8
B	≥0.6
C	≥0.5
D	≥0.4
E	≥0.3
F	>0.3

Table 16 LOS evaluation (Axer, Friederich 2014)

In this analisis we have taken into account the only "Speed ratio" between the average speed along the sector and its free flow speed (evalued es 95º percentile of the speeds along the sector) to define the LOS offered by each sector: six level of service have been defined (Axer and Friedrich, 2014).

The results on the selected variables as well as the LOS in two periods are given in the Table 17.

Row Labels	avg_speed	avg_fc	avg_co2	AVG_FC_KM	st_t_aux_5_percent	LOS_before	LOS After
ASTRA	-2.3%	-3.2%	-3.2%	7.9%	-0.9%	B	B
CP1	10.3%	-0.2%	-0.1%	3.6%	-2.1%	B	B
A-6	1.5%	1.3%	1.6%	4.0%	-0.5%	B	A
ACCESS A-6	-14.0%	-18.4%	-18.9%	39.7%	0.5%	B	A
ACCESS M-40	9.7%	11.7%	11.6%	8.5%	-0.8%		B

ACCESS M-503	6.8%	-21.7%	-22.2%	-8.3%	0.0%	A	B
M-40	4.6%	5.0%	5.6%	5.6%	-0.3%	B	A
M-503	33.5%	10.7%	10.2%	-29.9%	-8.3%	E	C
OTHERS-Caminos	4.6%	-5.7%	-6.4%	14.7%	-5.2%	D	C
OTHERS-Pozuelo	0.4%	-6.1%	-6.0%	-3.2%	-0.5%	B	B
CP2	-8.8%	-9.5%	-9.9%	9.4%	1.3%	B	B
A-6	13.0%	-0.6%	-2.2%	-14.4%	-18.4%	C	B
ACCESS A-6	-14.0%	-25.8%	-28.2%	11.2%	7.2%	B	B
ACCESS M-500	-6.2%	-22.2%	-22.5%	-5.5%	1.4%	A	A
ACCESS M-503	-4.6%	-1.6%	-1.6%	12.6%	0.0%	A	A
M-500	-0.3%	-1.5%	-1.3%	1.3%	-1.6%	B	A
M-503	-15.3%	-10.0%	-9.6%	11.7%	8.3%	A	B
OTHERS-Caminos	-13.5%	-7.9%	-7.8%	9.9%	-3.0%	C	C
OTHERS-Moncloa	-33.0%	-22.0%	-22.6%	49.4%	22.7%	B	C
OTHERS-Pozuelo	-3.4%	-3.1%	-3.9%	5.6%	-0.2%	C	C
OTHERS-Seneca	7.4%	2.2%	1.0%	-3.0%	-5.5%	C	C
CP3	-5.6%	-1.5%	-0.9%	13.7%	-0.6%	B	B
A-6	8.2%	6.9%	7.3%	19.7%	-2.5%	B	B
ACCESS A-6	12.8%	15.4%	18.3%	24.8%	-3.0%	B	A
ACCESS M-500	-0.4%	-15.6%	-15.0%	-4.6%	-0.9%	B	B
ACCESS M-503	-0.6%	7.0%	7.5%	-3.1%	0.0%	A	A
M-500	-4.7%	-6.9%	-6.4%	-1.6%	0.0%	B	A
M-503	-2.8%	-6.3%	-5.7%	3.0%	-1.6%	B	B
OTHERS-Caminos	-8.4%	-2.7%	-2.8%	18.2%	2.9%	C	C
OTHERS-Pozuelo	-0.2%	-3.5%	-4.0%	-10.3%	-1.3%	C	C
MP1	9.4%	-0.3%	-1.0%	-7.4%	-3.5%	C	B
M-503	21.5%	5.2%	5.4%	-13.2%	-3.2%	D	C
M-515	-0.9%	-8.1%	-9.0%	-0.2%	-0.9%	C	B
OTHERS-Pozuelo	6.7%	-0.8%	-1.7%	-4.3%	-2.1%	B	B
MP2	0.4%	-3.9%	-4.2%	4.3%	0.0%	B	B
M-50	5.0%	-0.1%	-0.1%	2.9%	-1.4%	B	A

M-503	4.7%	1.7%	1.9%	5.5%	-0.9%	C	C
M-509	-3.1%	-11.5%	-12.3%	-0.7%	0.5%	B	B
OTHERS-Majadahonda	-1.5%	-5.1%	-5.4%	7.8%	1.4%	C	D
OTHERS-Pozuelo	-7.2%	-9.2%	-10.3%	3.1%	-1.7%	B	B
MP3	-5.7%	-5.6%	-6.2%	11.8%	-1.0%	C	C
M-503	-12.5%	-6.9%	-7.0%	22.0%	-3.8%	D	D
M-515	3.9%	-2.0%	-2.8%	8.5%	0.6%	C	B
OTHERS-Pozuelo	-5.8%	-10.4%	-11.5%	8.5%	-2.5%	B	B
PC1	0.6%	1.3%	1.1%	4.5%	-0.3%	B	B
A-6	3.1%	-0.5%	-0.4%	3.2%	0.0%	B	A
ACCESS A-6	3.2%	14.2%	15.3%	9.1%	0.8%	A	A
M-40	-3.7%	-3.4%	-3.3%	6.6%	-5.4%	A	A
M-503	-3.4%	-12.7%	-13.7%	-1.9%	-9.6%	B	A
M-515	6.0%	4.9%	4.0%	-1.1%	-2.9%	D	C
OTHERS-Caminos	10.6%	6.4%	4.8%	6.9%	-1.2%	C	B
OTHERS-Pozuelo	-2.0%	-3.6%	-3.2%	5.4%	-0.3%	D	D
Salida A-6	-6.7%	24.7%	27.2%	15.1%	-0.7%	B	B
PC2	-4.6%	0.2%	0.1%	8.6%	0.2%	B	B
A-6	-2.1%	-9.8%	-10.7%	12.3%	-15.2%	B	B
ACCESS M-500	179.2%	5.9%	-1.3%	-58.2%	-0.6%	C	A
M-500	-3.6%	-7.5%	-7.5%	8.9%	-2.5%	B	B
M-503	-6.9%	-8.7%	-8.7%	17.4%	-0.2%	B	B
OTHERS-Caminos	-4.7%	2.1%	2.3%	8.3%	-2.3%	C	B
OTHERS-Moncloa	9.3%	8.6%	7.4%	10.9%	-3.8%	D	D
OTHERS-Pozuelo	0.5%	-2.7%	-2.7%	11.4%	0.0%	C	C
Salida A-6	-19.6%	7.7%	10.9%	3.4%	1.2%	A	A
SALIDA M-500	0.0%	0.9%	0.8%	4.5%	-0.1%	A	A
PC3	-9.4%	-3.7%	-3.4%	18.2%	2.0%	B	B
A-6	-19.6%	-18.6%	-18.7%	18.2%	0.0%	B	B
ACCESS M-500	-7.1%	26.8%	32.9%	52.8%	-0.5%	A	A
M-500	-9.0%	-10.7%	-10.0%	8.7%	-0.5%	B	B
M-503	-8.4%	-	-12.7%	6.3%	-2.7%	B	B

		12.8%					
OTHERS-Caminos	0.6%	5.6%	5.8%	22.8%	2.2%	C	B
OTHERS-Pozuelo	-12.1%	-9.6%	-10.4%	17.0%	-1.8%	C	C
Salida A-6	-10.9%	30.2%	33.0%	26.3%	-1.3%	B	B
PM1	-1.5%	-6.3%	-6.1%	0.1%	-2.7%	B	B
M-503	2.0%	-4.1%	-3.1%	-4.5%	-2.3%	B	A
M-515	0.0%	-5.8%	-6.3%	-3.5%	1.2%	C	B
OTHERS-Pozuelo	-9.2%	-10.6%	-10.7%	8.2%	1.2%	D	D
PM2	1.8%	-0.9%	-0.8%	12.0%	-2.2%	B	B
M-50	2.8%	1.8%	2.0%	23.3%	0.7%	B	B
M-503	1.7%	0.3%	0.8%	8.1%	-1.9%	A	A
M-509	1.6%	-4.5%	-4.8%	24.4%	-0.4%	B	B
OTHERS-Majadahonda	2.8%	-2.9%	-3.0%	4.6%	-4.6%	D	C
OTHERS-Pozuelo	0.3%	-0.5%	-0.7%	4.5%	-3.2%	D	D
PM3	-0.3%	-1.5%	-1.2%	6.1%	-0.7%	B	B
M-503	-0.1%	2.6%	3.3%	9.5%	0.3%	B	A
M-515	0.8%	-5.5%	-6.0%	1.1%	-0.1%	B	B
OTHERS-Pozuelo	-2.2%	-6.6%	-6.9%	8.2%	-2.2%	D	D

Table 17 Eco-driving efficinecy depending on the road sector and the LOS

From our analysis it results that congested roads in general consume more fuel then medium congested situation, and much more than free flow roads. However, there is clear higher fuel consumption in congested road than medium congested road if the road type is highway or urban roads, but the situation changes if the road is mixted, i.e, half highway and half urban roads.

Due to this short term experiment, we can not skip the strong influence of the traffic state: in general, less congestion corresponds to less fuel using meanwhile more free flow conditions correspond to less fuel using.

Globally, by adopting an eco-driving behavior it results that the average fuel saving reduces more in congested road situation, but it results less effective in free flow or medium situation.

In these terms, due to the high fuel consumption generated by congestion, road sectors that had worse traffic situations in the first driving period and better conditions in the second one reduce more fuel using and vice versa.

5.2. Analysis of eco-routing

As defined in part 2.2, eco-routing implies to follow a route recommendations based on the minimization of the environmental impact produced. In this part, we analyse the travel time, travel distance and average fuel consumption among different route which have the same origin and destination. This analysis aims to figure out under what kind of conditions, the eco route is also the least time consuming route and vice verse?

Results are presented in the following Table 18.

Route	LOS	Avg_Time (min)	Distance (km)	Avg_FC (10^{-4} litro/s)	Avg_CO2 (g/s)
Case of Madrid					
CP1	C	18.31	14.7	7.55	1,099
CP2	D	17.96	11.7	6.49	1,078
CP3	C	15.13	12.0	7.46	908
MP1	C	17.05	7.8	4.74	1,023
MP2	D	20.67	12.7	5.84	1,240
MP3	E	17.06	8.1	5.01	1,023
PC1	C	16.50	13.3	6.89	990
PC2	D	17.75	11.4	5.86	1,065
PC3	C	16.44	12.6	6.79	987
PM1	C	14.51	7.5	5.63	871
PM2	D	17.61	12.2	6.86	1,057
PM3	D	12.25	8.0	6.54	735
Case of Caceres					
AP1	D	14.71	5.9	3.99	883
AP2	D	13.74	6.3	4.12	824
AP3	D	13.64	6.5	4.45	819
AP4	C	13.36	10.1	6.38	801
PA1	E	16.55	6.0	6.00	993
PA2	D	15.24	6.4	6.29	915
PA3	D	13.71	6.4	7.10	822
PA4	B	12.95	10.0	9.26	777

Table 18 Results of eco-driving by route

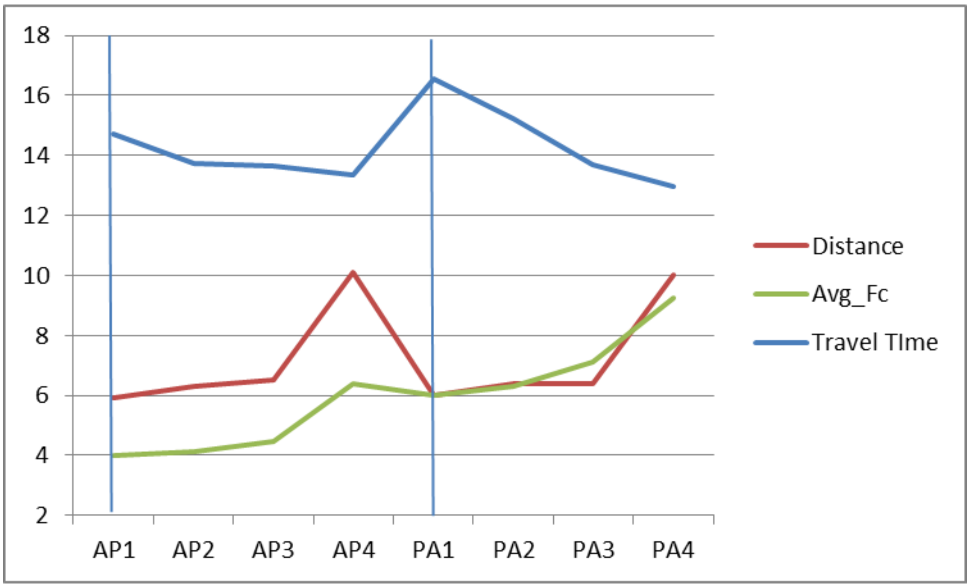


Figure 20 Average travel distance, trip time and fuel consumption by route (Cáceres)

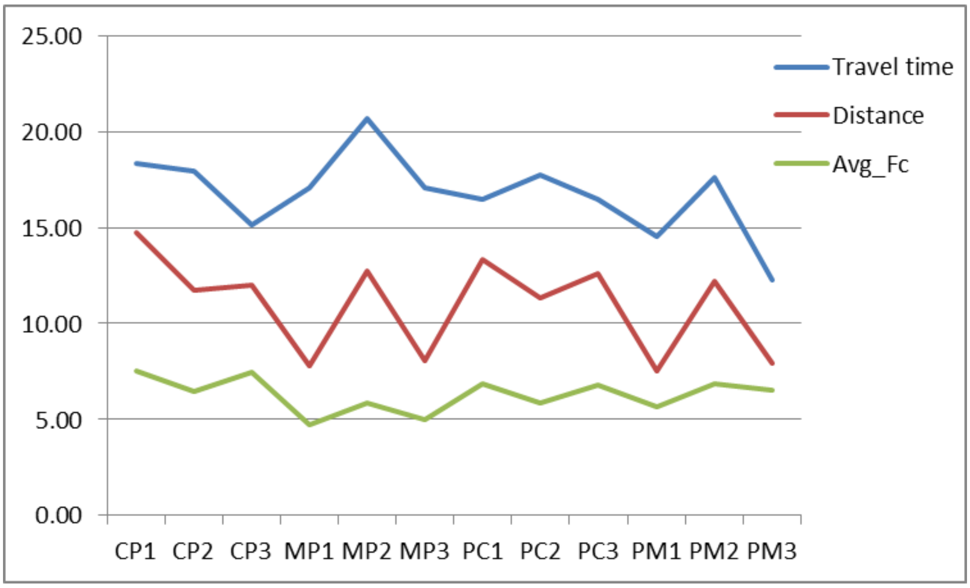


Figure 21 Average travel distance, trip time and fuel consumption by route (Madrid)

The findings of eco-driving are different by cities. In Madrid, the route with shortest distance, even though is not always least time consuming route, does result in the least fuel consumption. The CO_2 emissions are proportional relate to travel distance.

However, things are a bit different in Caceres. The CO2 emissions is not completely correlate to trip distance, but is relevant with the level of service of the route.

It can be explicated through the different topography and kind of itinerary of the cities on which the experiment has been developed. In the case of Madrid, the average slope is lower than Cáceres and the average speed is greather, covering more time rout sectors characterized by highspeed limits; due to the topography conformation of the city of Cáceres along which the itineraries have been covered, the fuel consumption results to be less affected by the length of the itinerary than in the case of Madrid.

6. CONCLUSIONS AND POLICY RECOMMENDATIONS

6.1. MAIN FINDINGS

The aim of the report is to analyse the potential reduction of emissions (both GHGs and pollutants) from driver's point of view: an efficient way of driving and a route choice that minimizes consumption. The main objective has been achieved through user designed data collection campaign and data analysis. It consists of four stages to achieve the final objective: (i) data collection, (ii) database creation, (iii) database validation, and (iv) results analysis with regards to fuel consumption and emissions.

With respect to the results analysis, we would like to underline that:

- By considering all data collected, it results that the general saving in fuel consumption due to the application of an eco driving behavior reach to average 6.5% without considering vehicle types or intineraries. This result is coincident with the most of the previous researches in this field (FIAT, 2010; Boriboonsomsin Barth and Vu, 2011; Díaz-Ramirez et al, 2017).
- Meanwhile, the eco-driving patterns considered in the study (average RPM, average speed, average COV, average positive acceleration) have strongly decreased, for example, the average positive acceleration reaching reduction up to 63% under certain circumstances. It was seen that drivers indeed modified their driving behaviour with more smooth speed, less aggressive acceleration/deceleration, and avoiding stops during the trip.
- From these data we can draw the first important conclusion of the study: fuel consumption can be really influenced by external circumstances, but the attendance on the efficient driving course results positive impacts to drivers.
- In comparison with the diesel car (OPEL ASTRA), the gasoline car (FIAT 500) results more efficient not only in saving of fuel consumption but also on emissions in both cities, where it results that with gasoline power eco driving has been more efficient than on the diesel one, producting a greater reduction in CO_2, CO, and HC.
- Results of this analysis open up horizons about the study of the driver's influence on the fuel consumption: eco-driving is a driving approach strongly affected by the drivers, whom depending on his attitude, his driving experience, his age and others factors in some circumstancies could achieve amazing results up to 30% less fuel consumption.
- Through the analysis of eco driving efficiency in respect of different routes, really interesting results have been obtained. Fuel consumption varies by different routes, as signal of the importance of the geometrical and functional aspects on the construction of roads.
- Not only the fuel consumption but also the reduction in fuel consumtion are strongly affected by the traffic states at different levels of magnitudes depending on the section road.

- Between the two cities, the main difference regard the eco-ruting concept. Actually while in the case of Madrid the fuel concumption seem to be strongly dependent on the length or the route, it is not the case of Cáceres, in which the strongest dependency of fuel concumption result to be on the traffic conditions. In Cáceres, the more LOS, the more fuel saving; in Madrid roads characterized by LOS D reduces fuel consumption better than the ones characterized by LOS C.

6.2. Policy Recommedations

Regards the contribution on transport planning, the project Eco-Traffic as one of the extension work to understand eco-driving efficiency, it opens a wider view to policy makers as well as drivers to applying eco-driving technique.

As the biggest reduction on fuel consumptions are relatively related to the reduction in the number of stops per km and the percentage of time spent with speed lower than 5 km/h, it results immediate to consider that by stopping and starting the car too many times, it can produce an increment on the average fuel consumption.

This study confirms that along roundabouts drivers should apply eco-driving techinique in order to save fuel: one of the ECO-tips learned was for example to avoid the stop of the vehicle in the access of a roundaboutand and to leave it going slowly leaving the pedal accelerator and without braking, but if there are big traffic flows it can produce safety problems.

In this terms my conclusion is to implement "**green wave**" of traffic lights on those roads in which there are heavy traffic flow, trying to produce a constant speed (and reduce strong accelerations/decelerations) in order to set the roundabouts free from big flows and permit the implementations of eco driving.

We have obtained data indicating the big dependency of eco driving efficiency on external causes, often not controllable. Due to its almost null cost to implement the technique it results really favorevle in any case, but due to the big dependency on external forces we have to improve and act on the road transport planifications.

The big strength of this study regards the amount of data analysed; indeed there have been investigated data regarding the effect of an efficient driving course, by monitoring data before and after the attending of the course, along different itineraries, through the conduction of different vehicles by different drivers at different day hours and it has been analysed an urban and extraurban context.

We need to create greater awareness of the role the driver has in limiting the emissive impact of his vehicle, in line with the boundary conditions.

In some circumstancies, eco-driving can significantly reduce fuel consumption: its social and financial value could be promoted and included in driving lessons, and to encourage the consciousness of its value could be useful to promote in-car equipment to measure fuel consumption.

Further analysis can focus on influences of drivers´attitude on eco-driving efficiency, and develop factorial analysis to investigate the key enternal factors of affecting eco-driving applications.

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- EEA, European environment agency, https://www.eea.europa.eu/
- Global Footprint Network, https://www.footprintnetwork.org/

Annex I Driving shift by drivers´ name

CAR RESERVATION		Tuesday 18		Wednesday 19		Thursday 20		Friday 21	
		ASTRA	FIAT	ASTRA	FIAT	ASTRA	FIAT	ASTRA	FIAT
6:45	8:00	Nuria	Martin	Oscar	Gonzalo	Gonzalo	Oscar	MB	Nuria
8:15	9:15	Gonzalo	Angela	Joseba	Nuria	Nuria	María	Joseba	Gonzalo
9:30	11:00	Nuria	Martin	Oscar	Gonzalo	Gonzalo	Oscar	MB	Nuria
11:15	12:30	MB	Joseba	Maria	Alvaro	Martin	Joseba	Oscar	Angela
12:45	13:45	Alvaro	Maria	Martin	MB	Alvaro	MB	María	Martin
14:00	15:30	MB	Joseba	Maria	Alvaro	Martin	Joseba	Oscar	Angela
15:45	17:00	Fran	Gloria	Rosalia	Jesus	Jesus	Rosalia	Fran	Gloria
17:15	18:15	Jesus	Rosalía	Gloria	Fran	Gloria	Fran	Rosalía	Jesus
18:30	20:00	Fran	Gloria	Rosalia	Jesus	Jesus	Rosalia	Fran	Gloria

CAR RESERVATION		Monday 24		Tuesday 25		Wednesday 26		Thursday 27		Friday 28	
		ASTRA	FIAT	ASTRA	FIAT	ASTRA	FIAT	ASTRA	FIAT	ASTRA	FIAT
6:45	8:00	Nuria	Oscar	Alessandra	Martin	Gonzalo	Joseba	Alvaro	Nuria	Nuria	Alvaro
8:15	9:15	Martin	Alessandra	Oscar	Nuria	Alvaro	Oscar	Joseba	Alessandra	Martin	Joseba
9:30	11:00	Nuria	Oscar	Alessandra	Martin	Gonzalo	Joseba	Alvaro	Nuria	Nuria	Alvaro
11:15	12:30	Alvaro	MB	Joseba	Gonzalo	Martin	Maria	Gonzalo	Oscar	Alessandra	MB
12:45	13:45	Gonzalo	Joseba	MB	Alvaro	Nuria	MB	MB	Martin	Oscar	Maria
14:00	15:30	Alvaro	MB	Joseba	Gonzalo	Martin	Maria	Gonzalo	Oscar	Alessandra	MB
15:45	17:00	Gloria	Fran	Rosalia	Jesus	Jesus	Rosalia	Gloria	Fran	Jesus	Rosalia
17:15	18:15	Jesus	Rosalía	Fran	Gloria	Fran	Gloria	Rosalía	Jesus	Fran	Gloria
18:30	20:00	Gloria	Fran	Rosalia	Jesus	Jesus	Rosalia	Gloria	Fran	Jesus	Rosalia

Table 19 Shifts during the first two weeks (without eco-driving)

CAR RESERVATION		Tuesday 16		Wednesday 17		Thursday 18		Friday 19	
		ASTRA	FIAT	ASTRA	FIAT	ASTRA	FIAT	ASTRA	FIAT
6:45	8:00	Alessandra	Martin	Oscar	Joseba	Nuria	Alvaro	Martin	Nuria
8:15	9:15	Joseba	Nuria	Martin	MB	Nuria	MB	Joseba	Alvaro
9:30	11:00	Alessandra	Martin	Oscar	Joseba		Alvaro	Martin	Nuria
11:15	12:30	MB				Alessandra			Alessandra
12:45	13:45	Alvaro				Oscar			Oscar
14:00	15:30	MB				Alessandra			Alessandra
15:45	17:00	Fran	Rosalia	Jesus	Gloria	Rosalia	Fran	Gloria	Jesus
17:15	18:15	Jesus	Gloria	Fran	Rosalia	Gloria	Jesus	Rosalia	Fran
18:30	20:00	Fran	Rosalia	Jesus	Gloria	Rosalia	Fran	Gloria	Jesus

CAR RESERVATION		Monday 22		Tuesday 23		Wednesday 24		Thursday 25		Friday 26	
		ASTRA	FIAT	ASTRA	FIAT	ASTRA	FIAT	ASTRA	FIAT	ASTRA	FIAT
6:45	8:00	Joseba	Alessandra	Alessandra	Martin	Oscar	Martín	Nuria	Oscar	Martin	
8:15	9:15	Martin	Oscar	Joseba	Nuria	Maria	Joseba	Alvaro	María	Joseba	
9:30	11:00	Joseba	Alessandra	Alessandra	Martin	Oscar	Martin	Nuria	Oscar	Martin	
11:15	12:30	Alvaro		Maria	MB	MB	Nuria	MB	Joseba	Maria	Alvaro
12:45	13:45	Nuria		Oscar	Alvaro	MB	Alvaro	Martín	Joseba	Oscar	MB
14:00	15:30	Alvaro		Maria	MB		Nuria	MB		Maria	Alvaro
15:45	17:00	Gloria	Jesus	Fran	Rosalia	Jesus	Gloria	Rosalia	Fran	Gloria	Jesus
17:15	18:15	Rosalia	Fran	Jesus	Gloria	Fran	Rosalia	Gloria	Jesus	Rosalia	Fran
18:30	20:00	Gloria	Jesus	Fran	Rosalia	Jesus	Gloria	Rosalia	Fran	Gloria	Jesus

Table 20 Shifts during the second two weeks (with eco-driving)

		Tuesday 2-May		Wednesday 3-May		Thursday 4-May		Friday 5-May	
RESERVATION		ASTRA	FIAT	ASTRA	FIAT	ASTRA	FIAT	ASTRA	FIAT
7:15	8:30	Yolanda	Eduardo	Ignacio	Pablo	Pablo	Ignacio	Eduardo	Yolanda
8:45	9:45	Pablo	Ignacio	Eduardo	Yolanda	Yolanda	Eduardo	Ignacio	Pablo
10:00	11:30	Yolanda	Eduardo	Ignacio	Pablo	Pablo	Ignacio	Eduardo	Yolanda
11:45	13:00	David	Isabel	Cristina	Juan	Juan	Cristina	Isabel	David
13:15	14:15	Juan	Cristina	Isabel	David	David	Isabel	Cristina	Juan
14:30	16:00	David	Isabel	Cristina	Juan	Juan	Cristina	Isabel	David
16:15	17:30	Jairo	Jesus	Marta	Jose Mª	Jose Mª	Marta	Jesus	Jairo
17:45	18:45	Jose Mª	Marta	Jesus	Jairo	Jairo	Jesus	Marta	Jose Mª
19:00	20:30	Jairo	Jesus	Marta	Jose Mª	Jose Mª	Marta	Jesus	Jairo

Table 21 Shifts without ECO-Driving

		Tuesday 9-May		Wednesday 10-May		Thursday 11-May		Friday 12-May	
RESERVATION		ASTRA	FIAT	ASTRA	FIAT	ASTRA	FIAT	ASTRA	FIAT
7:15	8:30	Yolanda	Eduardo	Ignacio	Pablo	Pablo	Ignacio	Eduardo	Yolanda
8:45	9:45	Pablo	Ignacio	Eduardo	Yolanda	Yolanda	Eduardo	Ignacio	Pablo
10:00	11:30	Yolanda	Eduardo	Ignacio	Pablo	Pablo	Ignacio	Eduardo	Yolanda
11:45	13:00	David	Isabel	Cristina	Juan	Juan	Cristina	Isabel	David
13:15	14:15	Juan	Cristina	Isabel	David	David	Isabel	Cristina	Juan
14:30	16:00	David	Isabel	Cristina	Juan	Juan	Cristina	Isabel	David
16:15	17:30	Jairo	Jesus	Marta	Jose Mª	Jose Mª	Marta	Jesus	Jairo
17:45	18:45	Jose Mª	Marta	Jesus	Jairo	Jairo	Jesus	Marta	Jose Mª
19:00	20:30	Jairo	Jesus	Marta	Jose Mª	Jose Mª	Marta	Jesus	Jairo

Table 22 Shifts with Eco-Driving

Annex II Post-trip survey

TABLE A. General Data

Date	__/__/2017
Driver	
Co-pilot	
Car	ASTRA (diesel) ◯ FIAT(gasoline) ◯
Mileage	______ (According to the car)
Initial time	__:__
End time	__:__
Weather	Clear ◯ Rainy ◯ Windy ◯ Fog ◯ Other◯ __
Routes	
Car environment	Window open ◯ Air conditioning ON◯ Window closed ◯ Air conditioning OFF ◯
Temperature	□ Outside (___) □Inside (___)

TABLE B. Significant incidents (accident, prolonged retention, device failure))

Time	Road	Kilometre	Incidence	Comments

Driver's signature: Co-pilot signature:

TABLE C. Perception of the trip (complete **individually**)

The handling of the vehicle has resulted	Easy						Difficult
	①	②	③	④	⑤	⑥	⑦
The circumstances of driving have been	Easy						Difficult
	①	②	③	④	⑤	⑥	⑦
During the journey you have felt	Boring						Entertaining
	①	②	③	④	⑤	⑥	⑦
	Relaxed						Stressed
	①	②	③	④	⑤	⑥	⑦