ICT-Emissions

Deliverable 6.3: Results of application of ICT measures in ICT-EMISSIONS partner cities

SEVENTH FRAMEWORK PROGRAMME

FP7-ICT-2011-7

COLLABORATIVE PROJECT – GRANT AGREEMENT N°: 288568

Deliverable Number D 6.3

Version number: 1.0

Delivery date: 26th May 2015

Author(s): Cristina Valdés Serrano

Author(s') affiliation (Partner short name): UPM

Document Control Page

Title	Results of application of ICT measures in ICT-EMISSIONS partner cities
Creator	Cristina Valdés Serrano
Editor	Cristina Valdés Serrano
Brief Description	This report describes the results of the ICT-measures applied in the partner cities.
Publisher	ICT-EMISSIONS Consortium
Contributors	Alvaro García Castro, Christian Vock, Werner Maier, Giorgio Magra, Marco Cianfano, Giacomo Tufanelli
Type (Deliverable/Milestone)	Deliverable
Format	
Creation date	03/02/2015
Version number	1.5
Version date	26/05/2105
Last modified by	
Rights	Copyright "ICT-EMISSIONS Consortium". During the drafting process, access is generally limited to the ICT-EMISSIONS Partners.
Audience	☐ internal ☒ public ☐ restricted, access granted to: EU Commission
Action requested	☐ to be revised by Partners involved in the preparation of the deliverable ☐ for approval of the WP Manager ☐ for approval of the Internal Reviewer (if required) ☒ for approval of the Project Co-ordinator
Deadline for approval	

Version	**Date**	**Modified by**	**Comments**
Structure	03/03/2015	Cristina Valdés Serrano	Structure and T.O.C.
Draft	13/05/2015	Alvaro García Castro, Christian Vock, Werner Maier, Giorgio Magra, Marco Cianfano, Giacomo Tufanelli, Cristina Valdes, Fiamma Pérez Prada	Contents
Second draft	26/05/2015	Christian Vock, Giorgio Magra, Cristina Valdes, Fiamma Pérez Prada	Contents

Contents

List of figures

List of tables

0 INTRODUCTION

This deliverable reports the results of all the different measures simulated at different scales and considering different fleet compositions.

The deliverable is structured as follows:

Chapter 0 summarizes all the scenarios included in this report as well as a description of the different fleet compositions considered for emissions calculations in each case study (for more detail in these case studies see D 5.1).

Chapter 1 describes the modelling process followed in each measure (for more detail in the Methodology see D2.1), and its particularity for each city, as well as the results for all the different scenarios considered.

Finally, Chapter 2 summarizes all these results and presents the Conclusions reached within this research.

0.1. MEASURES AND SCENARIOS

Distributed in the different case studies (Madrid, Turin and Rome), six different ICT measures have been analysed. These measures cover a wide range of all the ICT categories described in D2.1: Navigation and Travel Information, Traffic Management and Control, Driver Behaviour Change and ADAS.

Table 1 summarizes the measures, case studies and either traffic and emissions scenarios calculated.

Table 1: Difference between smoothed speeds value of VSL algorithm

Type of measure	Measure	Case study	Traffic scenarios	Emissions scenarios
Navigation and Travel Information	Green Navigation (GN)	Madrid	15	30
Traffic management and control	Variable Speed Limits (VSL)	Madrid	4	6
	Urban Traffic Control (UTC)	Turin	2	4
		Rome	3	6
Driver behaviour change	Eco driving	Madrid	27	36
		Turin	24	24
ADAS	Start and Stop	Madrid	Na	30
		Turin	Na	30
		Rome	Na	12
	Automated Cruise Control (ACC)	Munich	5	12
		Turin	5	5

0.2. FLEET COMPOSITIONS

Simulations were run for different fleet compositions. This means that the distribution of the vehicles into different classes, fuel types, or emission technologies changed between the different fleet compositions.

0.2.1. MADRID

For the Madrid test case 3 different fleet compositions are defined. Not all of them are used in all scenarios. The 3 compositions cover the following situations:

- **Fleet 2014:** the current situation (for Madrid based on registration numbers of the year 2014)
- **Fleet 2014 Hybrid:** A situation based on 2014 numbers if 10% of the vehicles are hybrid vehicles. The hybrid vehicles in the scenario are simulated with the advanced vehicles inside the micro emission simulation
- **Fleet 2030:** A future situation with expectations for a composition of vehicles in the year 2030. The hybrid vehicles in the fleet 2030 are modelled using COPERT emission factors.

The main difference between the fleets was done on the fuel types (for passenger cars) and on the emission technologies (for all macro vehicle types). Figure 1 to Figure 3 show the compositions for the 3 fleets. The top left chart shows the fleet composition according to the macro vehicle types (passenger cars, light duty vehicles (LDV), heavy duty vehicles (HDV), and busses) which was kept the same for all fleets.

The top right chart shows the distribution according to the fuel types. For the fleet 2014 Hybrid the share between gasoline, Diesel, and other vehicles is unchanged, but the absolute numbers are reduced to cover for the 10% share of Hybrid vehicles. The fleet of the year 2030 shows a nearly unchanged percentage of gasoline driven vehicles, while the share of the Diesel driven vehicles is reduced in favour of Hybrid cars.

The share of the emission technologies is shown in the bottom charts, separately for Diesel (left chart) and gasoline (right chart) driven vehicles. The general trend is that for the fleet 2014 a large amount of vehicles cover only Euro class 4 and older while for the fleet 2030 the share of these vehicles is reduced to about 30%. The largest number of vehicles in the year 2030 are covering Euro 6 and higher.

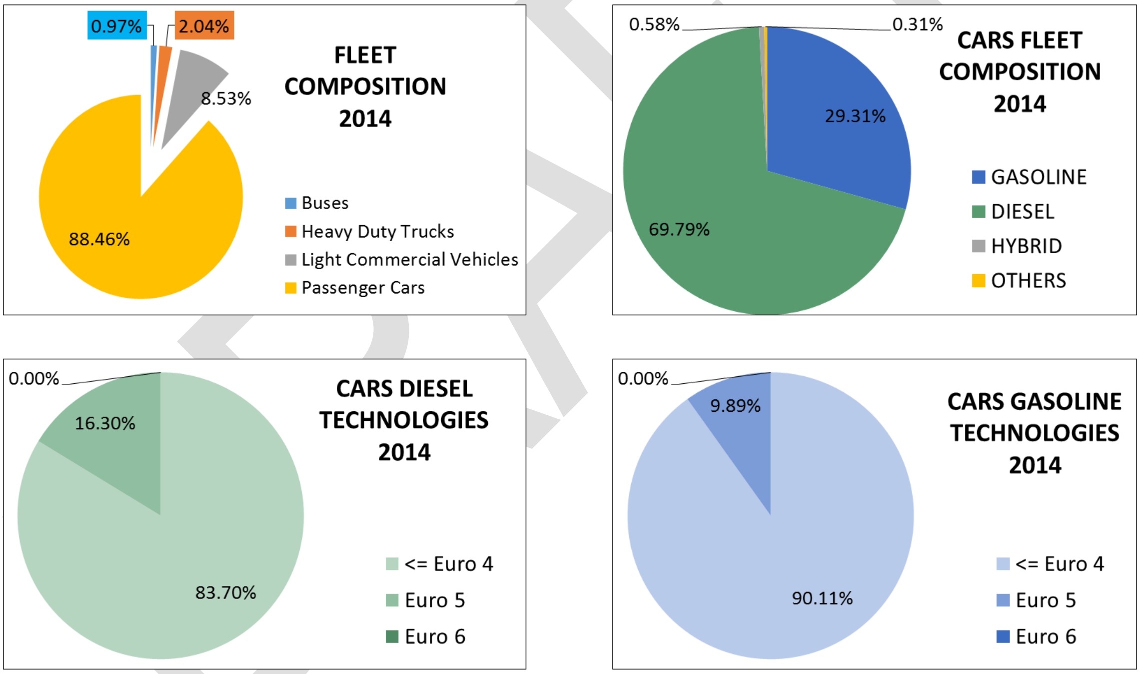


Figure 1: Madrid, Fleet 2014

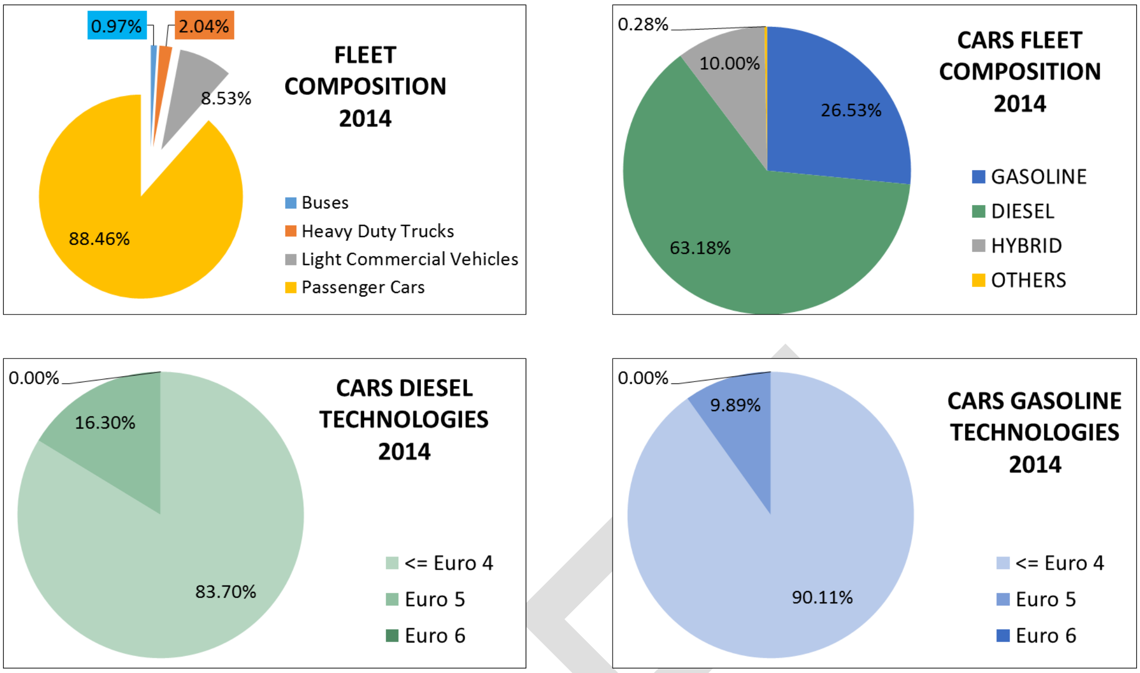


Figure 2: Madrid, Fleet 2014 Hybrid

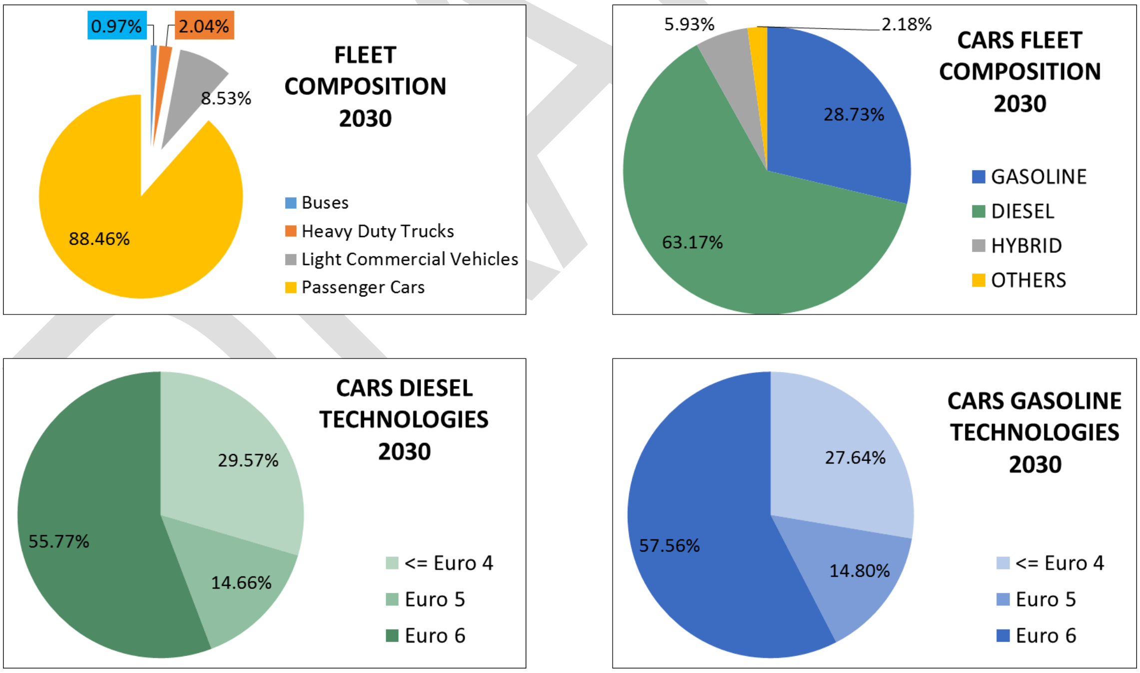


Figure 3: Madrid, Fleet 2030

0.2.2. Turin

For the Turin test case 3 different fleet compositions are defined. Not all of them are used in all scenarios. The 3 compositions cover the following situations:

- **Fleet 2013:** the current situation (for Turin based on registration numbers of the year 2013)
- **Fleet 2013 Hybrid:** A situation based on 2013 numbers if 10% of the vehicles are hybrid vehicles. The hybrid vehicles in the scenario are simulated with the advanced vehicles inside the micro emission simulation
- **Fleet 2030:** A future situation with expectations for a composition of vehicles in the year 2030. The hybrid vehicles in the fleet 2030 are modelled using COPERT emission factors.

The main difference between the fleets was done on the fuel types (for passenger cars) and on the emission technologies (for all macro vehicle types). Figure 1 to Figure 26 show the compositions for the 3 fleets. The top left chart shows the fleet composition according to the macro vehicle types (passenger cars, light duty vehicles (LDV), heavy duty vehicles (HDV), and busses) which was kept the same for all fleets.

The top right chart shows the distribution according to the fuel types. For the fleet 2013 Hybrid the share between gasoline, Diesel, and other vehicles is unchanged, but the absolute numbers are reduced to cover for the 10% share of Hybrid vehicles. The fleet of the year 2030 shows a significant decrease of gasoline driven vehicles, while the share of Hybrid, Diesel and other vehicles is increased.

The share of the emission technologies is shown in the bottom charts, separately for Diesel (left chart) and gasoline (right chart) driven vehicles. The general trend is that for the fleet 2013 a large amount of vehicles cover only Euro class 4 and older while for the fleet 2030 the share of these vehicles is reduced to about 30%. The largest number of vehicles in the year 2030 are covering Euro 6 and higher.

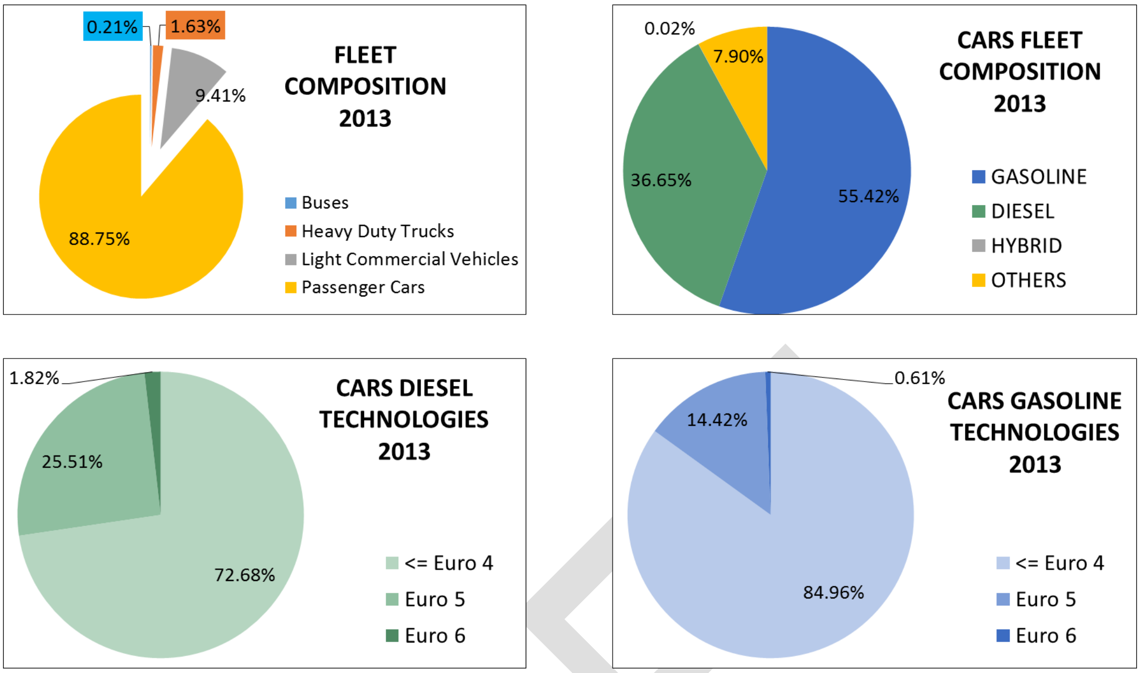


Figure 4: Turin, Fleet 2013

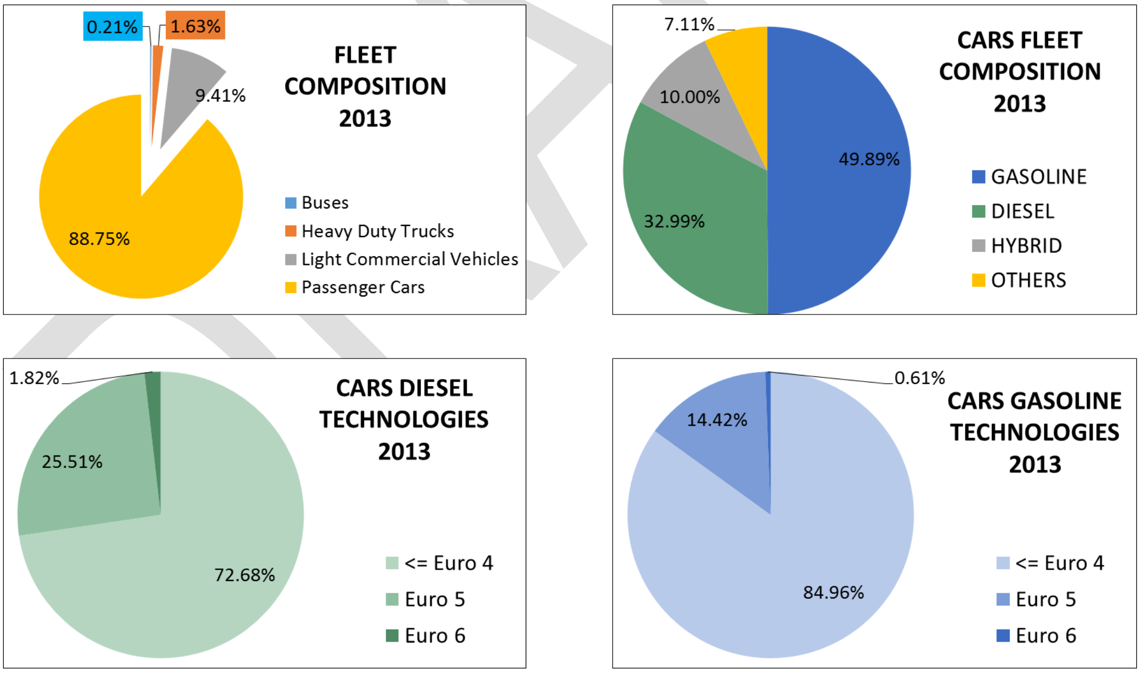


Figure 5: Turin, Fleet 2013 Hybrid

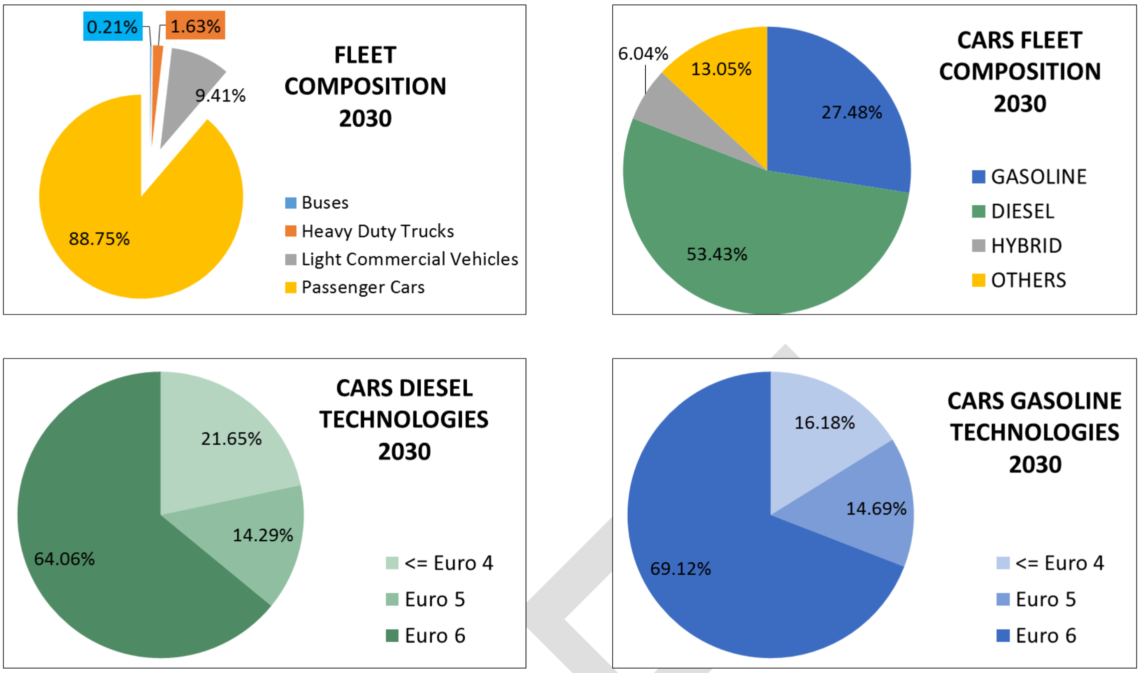


Figure 6: Turin, Fleet 2030

0.2.3. Rome

For the Rome test case 2 different fleet compositions are defined. Not all of them are used in all scenarios. The 2 compositions cover the following situations:

- **Fleet 2013:** the current situation (for Rome based on registration numbers of the year 2013)
- **Fleet 2030:** A future situation with expectations for a composition of vehicles in the year 2030. The hybrid vehicles in the fleet 2030 are modelled using COPERT emission factors.

The main difference between the fleets was done on the fuel types (for passenger cars) and on the emission technologies (for all macro vehicle types). Figure 7 to Figure 2show the compositions for the 2 fleets. The top left chart shows the fleet composition according to the macro vehicle types (passenger cars, light duty vehicles (LDV), heavy duty vehicles (HDV), and busses) which was kept the same for all fleets.

The top right chart shows the distribution according to the fuel types. The flee-t of the year 2030 shows a significant decrease of gasoline driven vehicles, while the share of Hybrid, Diesel and other vehicles is increased.

The share of the emission technologies is shown in the bottom charts, separately for Diesel (left chart) and gasoline (right chart) driven vehicles. The general trend is that for the fleet 2013 a large amount of vehicles cover only Euro class 4 and older while for the fleet 2030 the share of these vehicles is reduced to about 30%. The largest number of vehicles in the year 2030 are covering Euro 6 and higher.

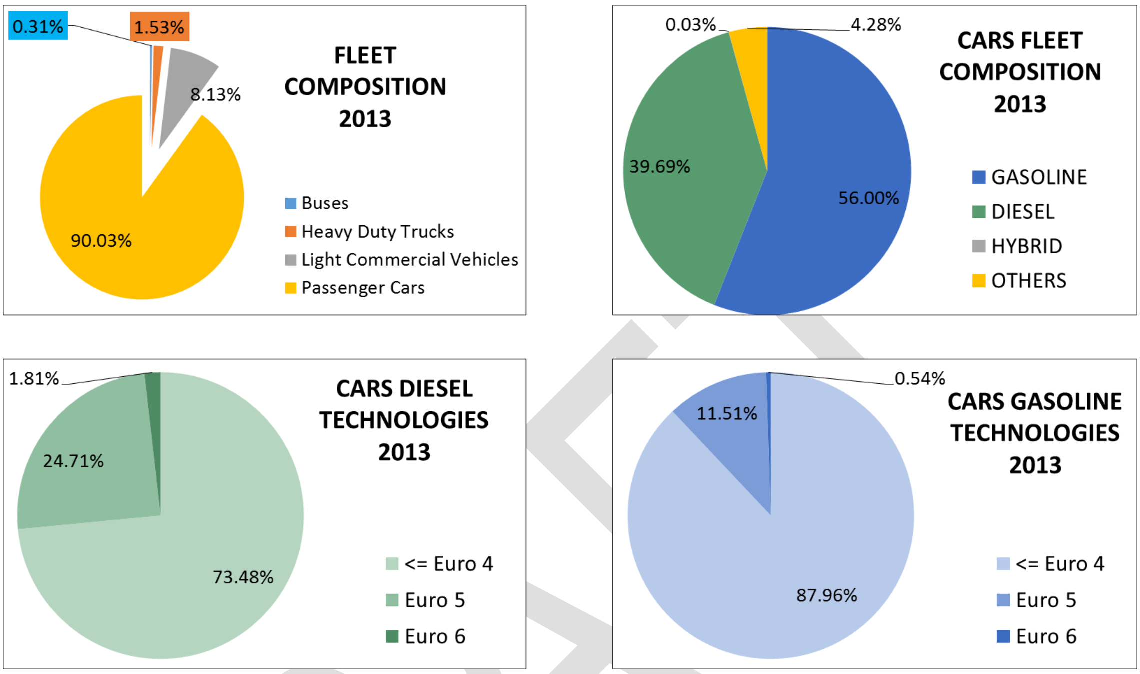


Figure 7: Rome, Fleet 2013

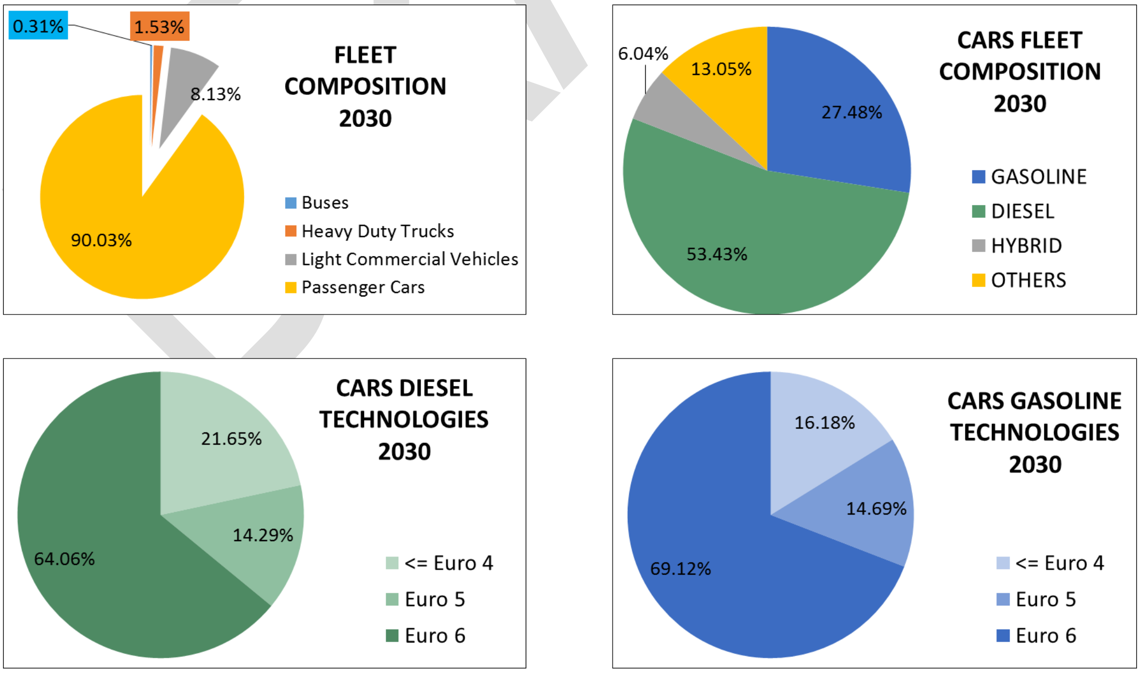


Figure 8: Rome, Fleet 2030

1 ICT MEASURES: SIMULATION RESULTS

As previously said, thie chapter describes how each of the measures has been simulated according to the ICT Emissions methodology (see D2.1 for more detail), the different scenarios considered and the results obtained, either in terms of traffic and CO2 emissions.

Each subchapter includes all the different case studies where each measure has been simulated.

1.1. VARIABLE SPEED LIMITS

1.1.1. MADRID

1.1.1.1. Modelling description

Measure description

Variable Speed Limits (VSL) can be defined simply as speed limit management systems which are time dependant and utilize traffic detectors to determine the appropriate speed.

The tested section is a 3 lanes motorway (southbound) with traffic intensity in the afternoon peak hours rounding 3,300 veh/h, (upstream) and with a length of 6.6 km. Most of the section is limited to 90 km/h, except the last 100 m., limited to 70 km/h. (tunnel entrance). The congestion is usually caused by the bottleneck situated in the M500 junction, as around 2,800 vehicles merge in the M30 in peak hour.

Figure 9 shows the tested section (marked in Figure 1 from A to B) with the Variable Message Signs (VMS) as well as the bottleneck junction where the congestion usually starts (M500).

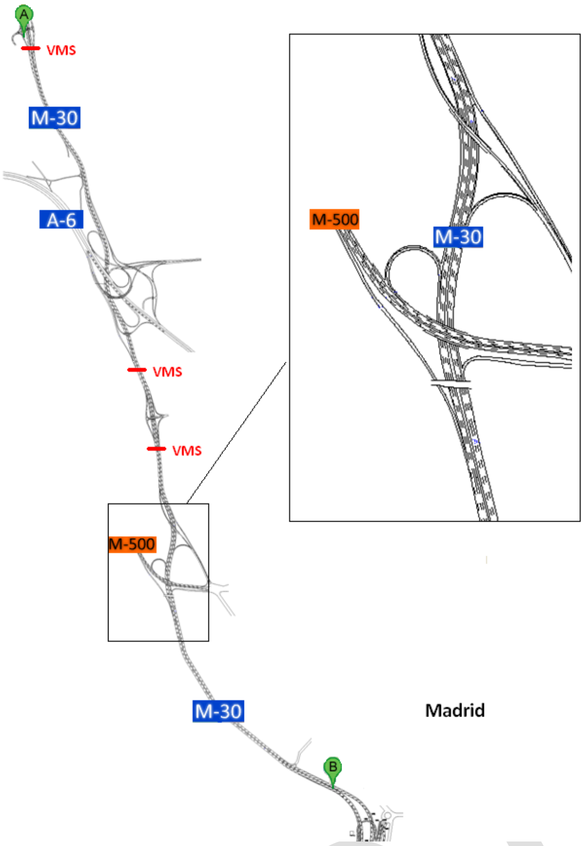


Figure 9: West section of the Madrid ring motorway

Modelling scale

Variable speed limits have been modelled at micro level with PTV VISSIM, while the emissions at this level have been calculated with AVL Cruise. Following the micro-to-macro interface procedure described in D6.2, PTV VISUM simulates the traffic at macro level and COPERT the emissions.

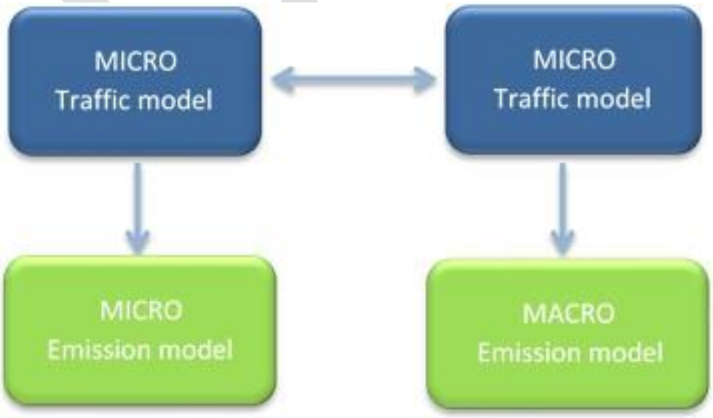


Figure 10: VSL: modelling scale

Modelling process description

VISSIM software includes the possibility of simulating VSL by adapting the Vehicle Actuating Programming or using the COM Interface. In this particular case the system has been implemented by means of programming the VSL algorithm in Visual Basic. Using this Interface, Visual Basic controls the parameters of VISSIM simulation.

In the case study of Madrid the VSL system consists of a Variable Message Sign situated between A6 and M500 junction, approximately situated half way of the section under study. This VMS (Panel 22241) display a recommended speed limit of 40, 50, 60, 70 or 80 km/h, depending on the control algorithm. The location of the panel in the M30 section modelled is shown in the Figure .

The real traffic speed is obtained from existing induction loops. The speed data is smoothed to avoid instantaneous speed fluctuations.

The algorithm is based on the smoothed speed on the measuring point PM22121, with the following conditions:

- Smoothed speed at or above 85 km/h.: recommended speed is not reported
- Smoothed speed between 84 and 50 km/h.: it is posted a recommended speed by subtracting 5 km/h. to the smoothed real speed and then rounding down to the nearest ten.

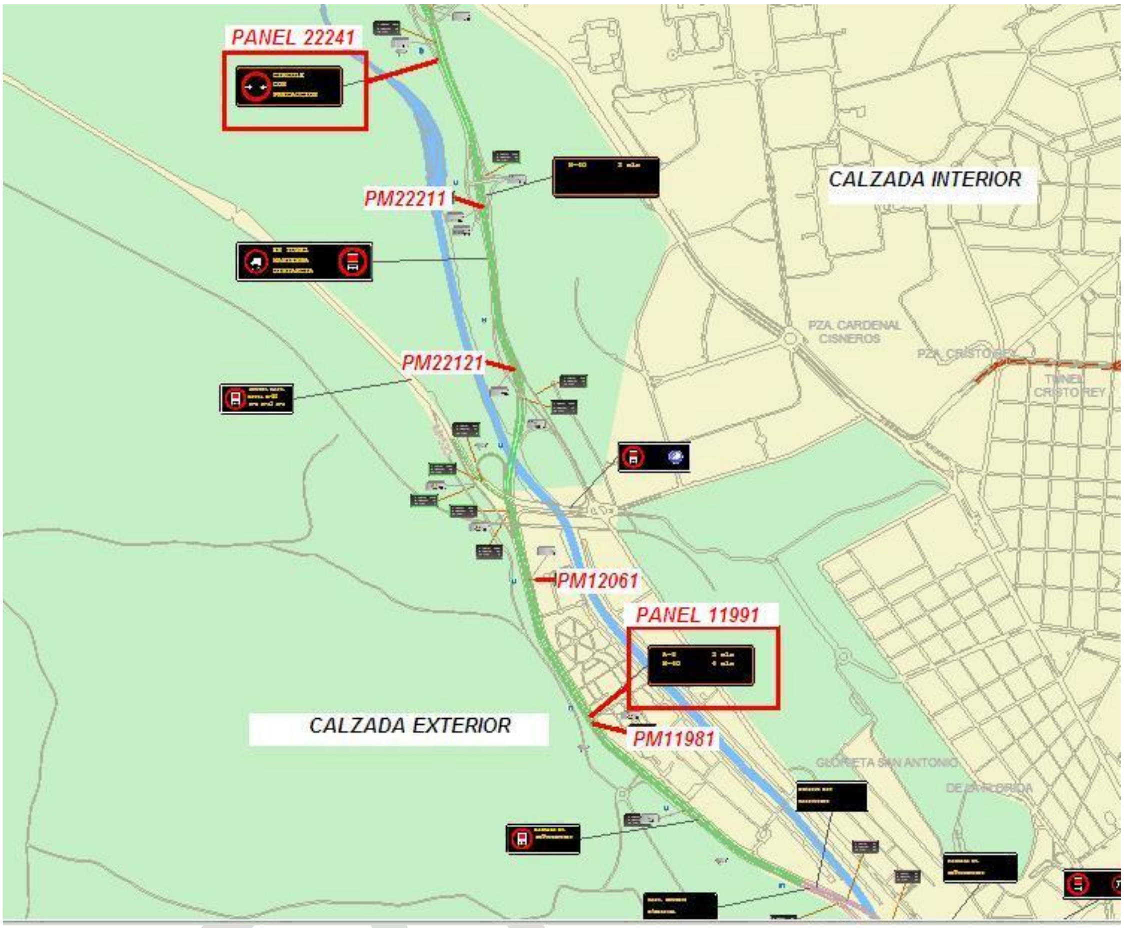


Figure 11: Location of Variable Message Sign and measuring points in the studied section of the M30 Urban Motorway

To extend the versatility of the system and its adaptation to complex situations, another condition must be fulfilled.

The difference between smoothed velocities in two measurement points is strictly higher than a given configurable value "DV". This value is shown in Table 2.

Table 2: Difference between smoothed speeds value of VSL algorithm

Panel	**Measurement points**		**Speed range**		**Difference between smoothed speeds**
			Vmax	Vmin	
22241	22121	22211	85	40	8

Implementation process and calibration of new desired speed decision

The base case model has been calibrated (see Deliverable 6.2) using traffic and floating car data from the evening of Wednesday March 13th 2013, while the VSL system was not activated. Therefore, it is necessary to calibrate the model for other day in which the system is activated. The day selected has been Wednesday 17th of April 2013.

It is important to remind that the posted speed is recommended and, consequently, the effects on the driver behaviour are not as much evident as they would be if the variable speed limits where mandatory.

The algorithm has been implemented in VISSIM using Visual Basic and the COM Interface, which allows to control externally some of the parameters of the model.

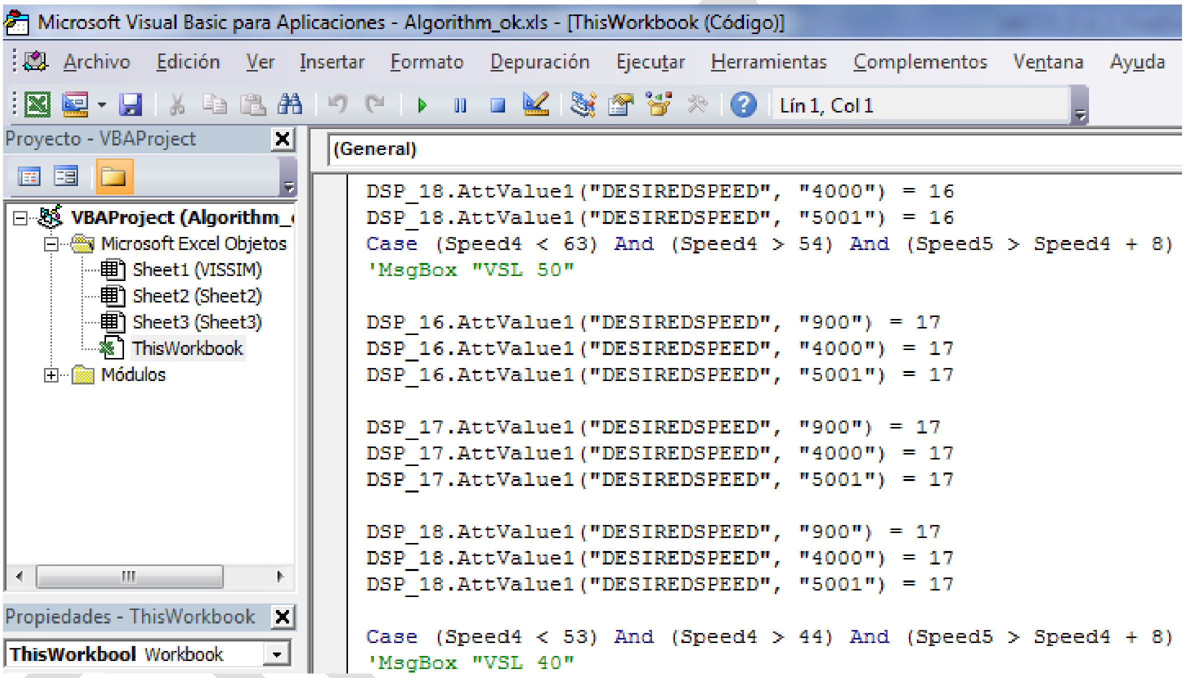


Figure 12. Algorithm implementation in Visual Basic through VISSIM COM Interface

The analysis of the speed profiles from floating cars does not show concluding results, so the procedure to obtain the new desired speed distributions is the following:

1. Using the calibrated basecase model, traffic inputs are changed according to the real data from 17th April. The other parameters are kept constant.
2. Routing decisions are adapted to fit traffic data collected from induction loops
3. Definition of new desired speed distribution affected by recommended speed limits.
4. Programming of Visual Basic code to control VISSIM and simulate the variable speed limits.

5. Adjustment of desired speed distribution to fit travel times data recorded by floating vehicles.

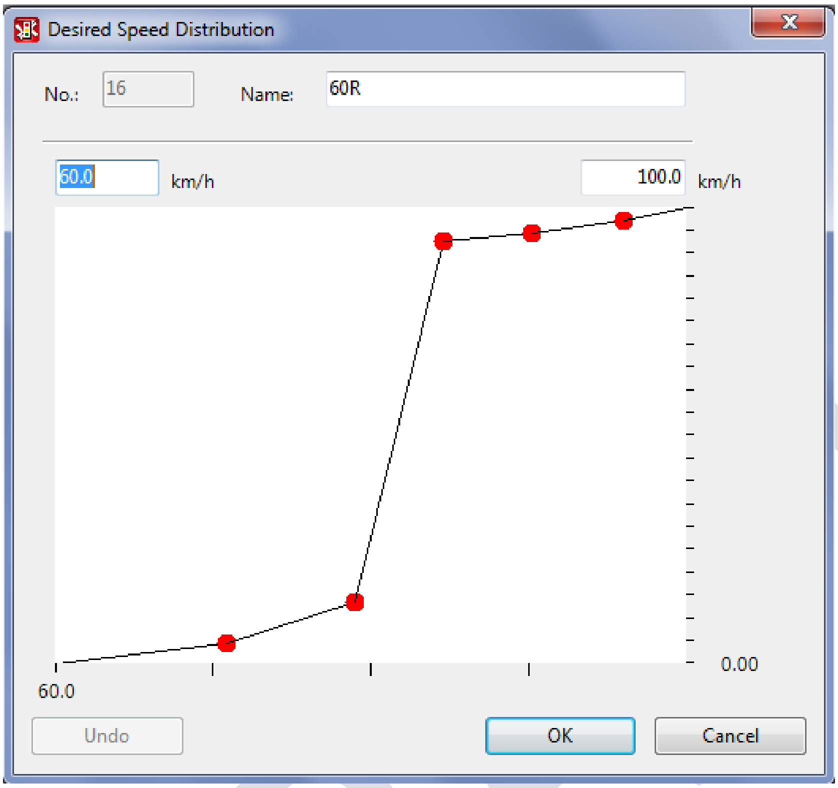


Figure 13: Example of desired speed distribution corresponding to a posted recommended speed of 60 km/h (Horizontal axis correspond to desired speed and vertical axis corresponds to cumulative percentage of drivers)

With this procedure, it has been possible to obtain a new desired speed distribution for each possible posted recommended speed limit (see an example on Figure 13) while achieving good results with regard to travel times (Figure 14).

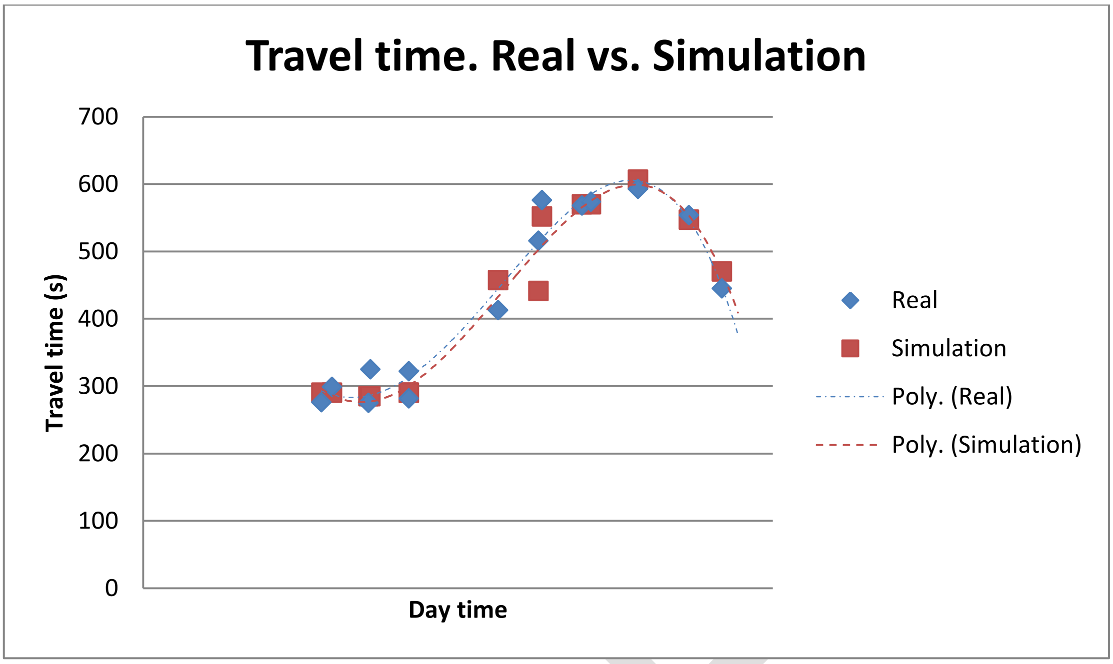


Figure 14. Results of calibration of desired speed distributions for recommended speed regarding travel times

<u>Upscaling to macro modelling</u>

Once the micro scenarios have been developed and simulated, the results here obtained are used to calculate the new fundamental diagram or speed intensity function to be used in the macro traffic models. In the case of VSL, the new function produces a capacity increase of 16% in the affected road, as shown in Figure 15.

In the new calibrated function, parameter c varies from 0.85 to 0.99:

$$t_{cur} = t_0 \times (1 + a \times \frac{q}{q_{max} \times \boldsymbol{c}}^{b})$$

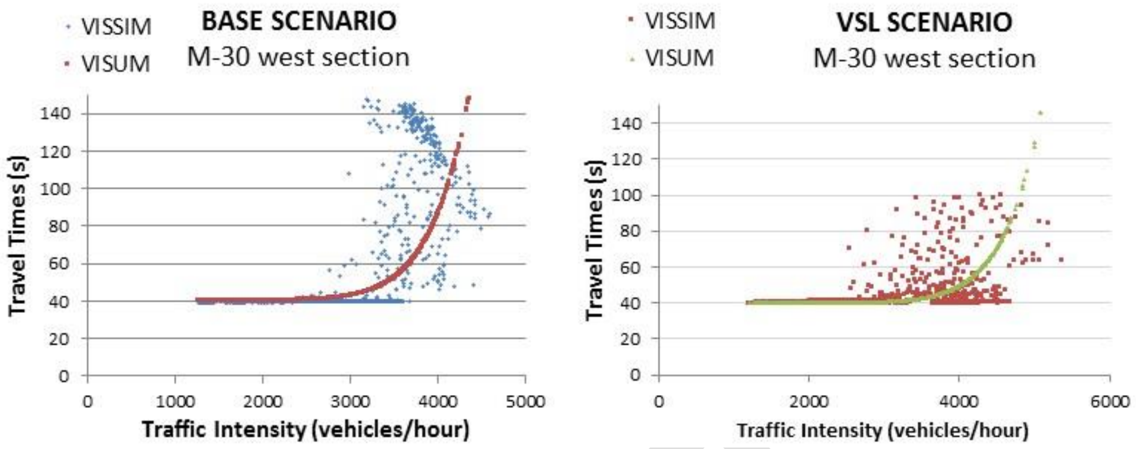


Figure 14. VSL: upscaling process. Speed intensity curves

Scenarios

At traffic level, four scenarios are considered: two at micro level – medium traffic and congested situation - and their corresponding two at macro level. As the system is activated only when there is a certain reduction in the speed recorded at certain points. Therefore, free flow conditions are not considered.

The scenarios considered for variable speed limits are shown in the following tables:

Table 3: VSL: Madrid case study. Scenarios considered at micro level

Scenario ID	Variables varying for each scenario		
	Traffic conditions	Number of replications	Fleet composition
112_01	Normal	10	Madrid 2014
113_01	Congested	10	Madrid 2014

Table 4: VSL: Madrid case study. Scenarios considered at macro level

Scenario ID	Variables varying for each scenario		
	Traffic conditions	Number of replications	Fleet composition
1020000	Congested	n/a	Madrid 2014
2020000	Medium	n/a	Madrid 2014
1020001	Congested	n/a	Madrid 2030
2020001	Medium	n/a	Madrid 2030

1.1.1.2. Results

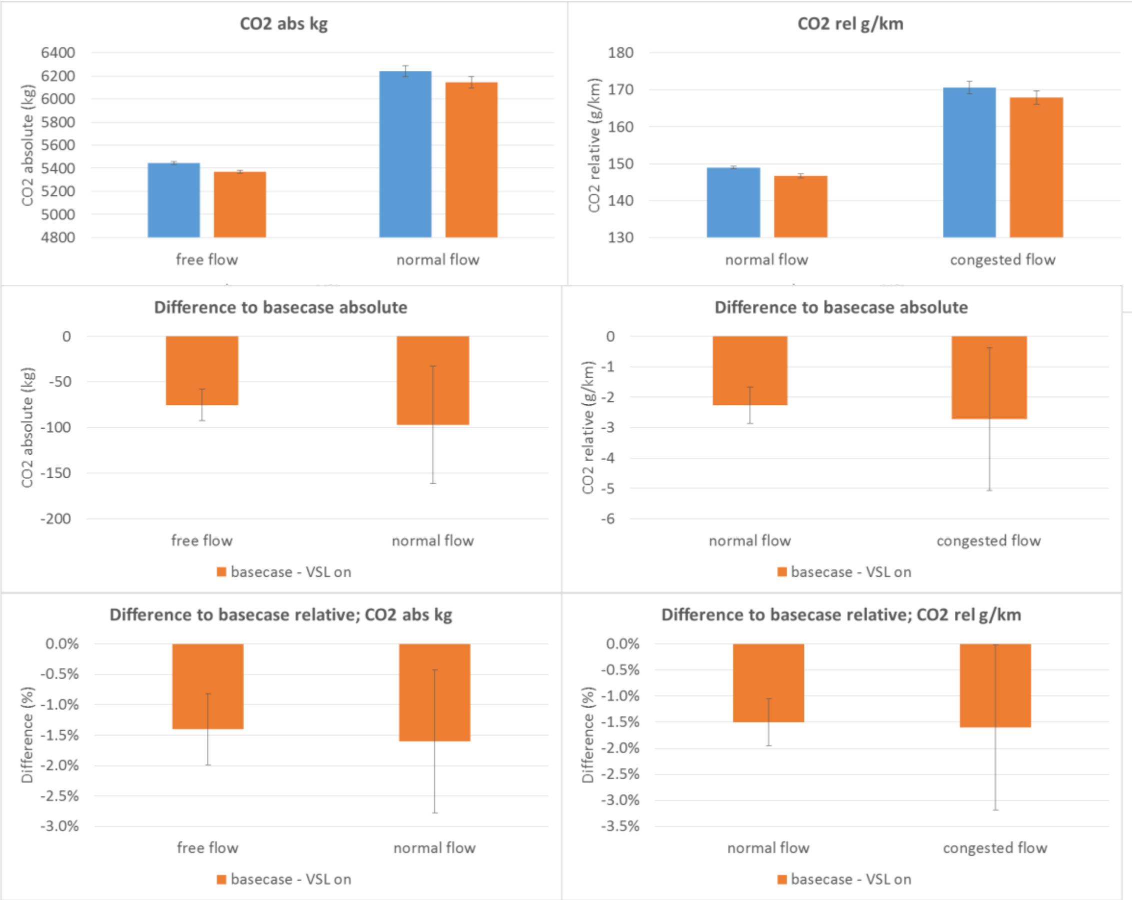
Micro level

At micro level, variables related to emissions, traffic and vehicle dynamics have been analysed. Table 5 shows the percentage of variation of each variable from the corresponding base case scenarios:

Table 5: VSL: Madrid case study. Results at micro level

Scenario ID	Absolute results			Variation with respect to the base case		
	CO2 abs kg	CO2 rel g/km	percent stop time (%)	CO2 abs kg	CO2 rel g/km	Percent stop time (%)
112_01	5369.4	146.70	0.85	-1.4%	-1.5%	-19.6%
113_01	6143.6	167.88	3.56	-1.6%	-1.6%	-6.4%

The results show both absolute and relative CO_2 emissions savings around 1.5%, which are in line with the floating cars measurements. We can observe a significant drop in the stop time percentage, which give us an idea of more homogeneous traffic flow due to the impact of variable speed limits.



o

Figure 105: Variable Speed Limits: Madrid case study, Absolute values and Difference basecase

Macro level

At a macro level, results in global terms are almost insignificant, as expected due to the little area where the measure was implemented compared to the whole region.

But when disaggregating these results into road types, we can observe that this capacity increase produced in the road with VSL ON does not benefit directly this road but allows traffic using other routes to re-route through this road and therefore produce a benefit in both veh-km and CO_2.

These results highlight the need of using a double scale approach to comprehend as much as possible the impacts a measure can produce.

Table 6: VSL: Madrid case study. Results at macro level

Scenario ID	Fleet	Absolute values				
		CO2 abs kg	CO2 rel g/km	veh·km	veh·h	average speed km/h
1020000	Madrid 2014	1,080,066	183	5,886,741	98,019	60
2020000	Madrid 2014	793,898	180	4,402,504	60,652	73
1020001	Madrid 2030	1,066,818	181	5,886,741	98,019	60
2020001	Madrid 2030	784,834	178	4,402,504	60,652	73
Scenario ID	**Fleet**	**Variation respect to the base case**				
		CO2 abs kg	**CO2 rel g/km**	**veh·km**	**veh·h**	**average speed km/h**
1020000	Madrid 2014	-0.06%	-0.09%	0.03%	-0.31%	0.34%
2020000	Madrid 2014	-0.10%	-0.04%	-0.06%	-0.07%	0.02%
1020001	Madrid 2030	-0.05%	-0.09%	0.03%	-0.31%	0.34%
2020001	Madrid 2030	-0.10%	-0.04%	-0.06%	-0.07%	0.02%

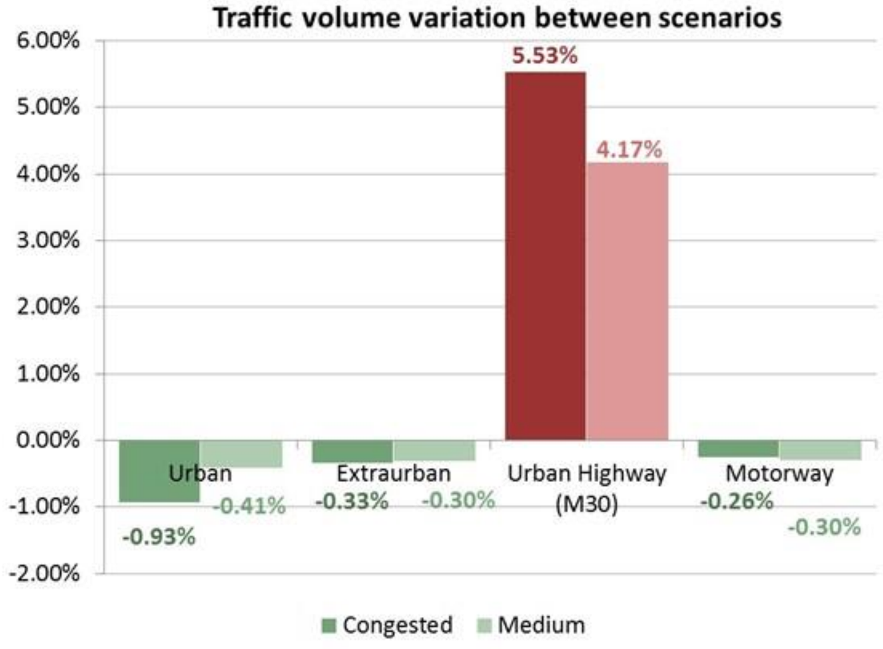


Figure 16: VSL: Madrid case study. Traffic volume variation by road type

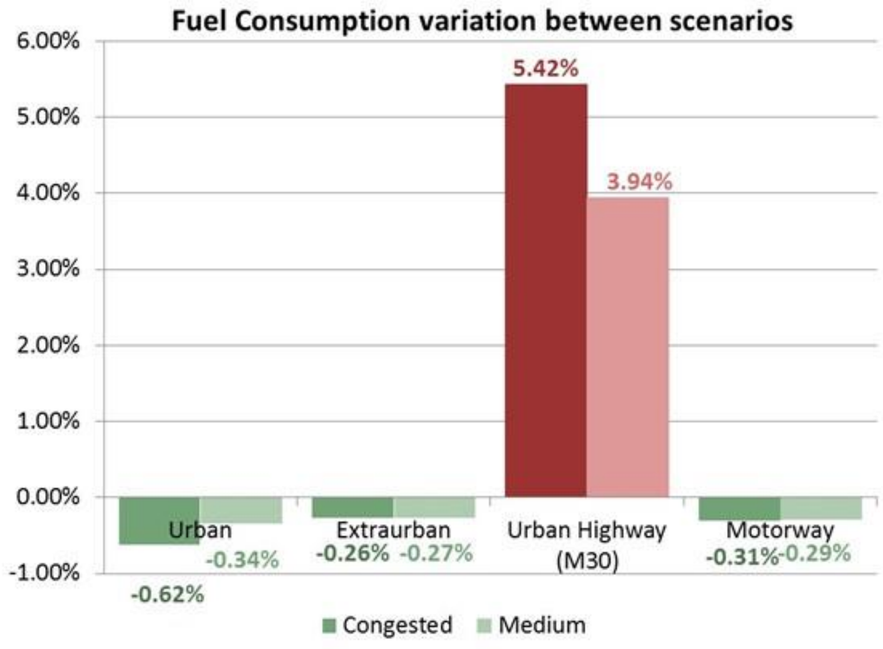


Figure 17: VSL: Madrid case study. Fuel consumption volume variation by road type

1.2. GREEN NAVIGATION

1.2.1. MADRID

1.2.1.1. Modelling description

Measure description

Green navigation implies routing recommendations based on calculation of environmental impact and real-time traffic situation. This means, in practice, people following the route which minimises their emissions.

This measure, as affects routes, has to be simulated at a macro level, as shown in the figure below:

Modelling scale

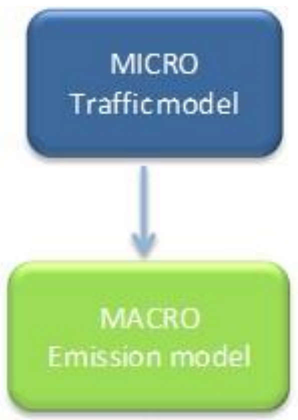


Figure 18: Green navigation: modelling scale

Modelling process description

For modelling green-navigation a new transport mode had to be defined in VISUM. This new transport mode, green-navigation drivers, has assigned a new impedance function defined in terms of fuel consumption (directly related to CO2 emissions) instead of the typical impedance function for conventional drivers which is based on time and monetary costs.

A percentage of the light vehicles OD matrices will be assigned depending on the green navigation penetration rate i.e. if a penetration rate 25% of green drivers is considered, the 75% of the OD matrix will be assigned for conventional drivers under the typical impedance function and the rest 25% to green drivers under a impedance function based on fuel consumption.

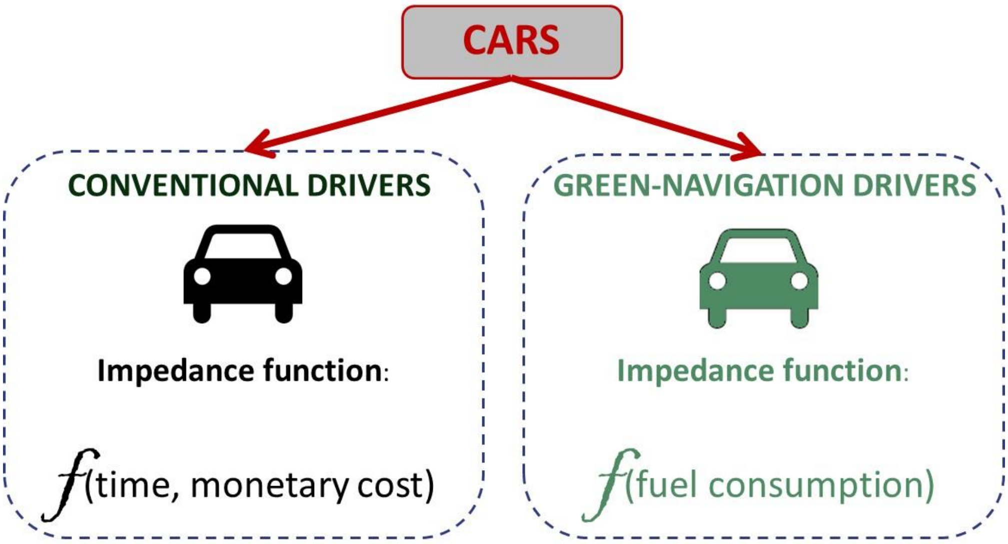


Figure 19: GN: Madrid case study. Modelling process

From different studies, five different fuel consumption functions were tested. Figure 20 shows the fuel consumption function selected, the one which better performs at congested traffic conditions.

$$FC = -0.000000000329612 * VCur^5 + 0.00000010979 * VCur^4 - 0.0000118935 * VCur^3 + 0.000530345 * VCur^2 - 0.00156253 * Vcur + 0.256344$$

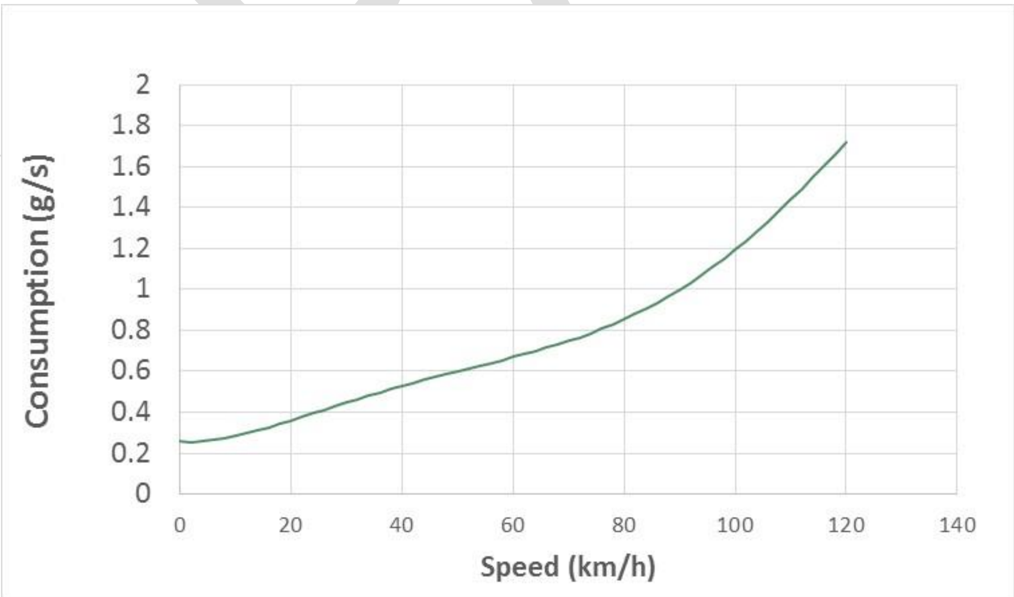


Figure 20: GN: Madrid case study. Fuel consumption function

The impedance function for green drivers will be:

$$I_{green} = FC(V_{Cur}) \cdot t_{Cur}$$

Green drivers will select their preferable route depending on the actual traffic conditions, therefore and to capture this effect accurately, the assignment process is divided in two steps or assignment groups. First heavy vehicles and conventional car drivers are assigned to the network and subsequently the impedance function of green drivers is calculated for the new traffic levels and average speeds. By the second assignment group, green drivers are assigned to the network but instead of doing it in a single step, the process is divided in ten stages in order to continuously capture the new traffic conditions. Therefore, a 10% of the OD matrix corresponding to green drivers is assigned in each sub-step and the impedance function is recalculated after every assignment.

Scenarios

A total of 30 scenarios have been considered for emissions calculations, while 15 for traffic results. Variables producing this wide range of scenarios are:

- Traffic level: free flow, medium flow or congested flow
- Penetration levels of green drivers: 10 - 25 – 50 - 75 and 90%
- Fleet composition: current fleet (2014) and an estimated future fleet for 2030

Table 7: GN: Madrid case study. Scenarios considered

Scenario ID	Variables varying for each scenario		
	Traffic conditions	Penetration level	Fleet composition
1010100	Congested	10%	Madrid 2014
1010200		25%	
1010300		50%	
1010400		75%	
1010500		90%	
2010100	Medium	10%	
2010200		25%	
2010300		50%	
2010400		75%	
2010500		90%	
3010100	Free	10%	
3010200		25%	
3010300		50%	
3010400		75%	
3010500		90%	
1010101	Congested	10%	Madrid 2030
1010201		25%	
1010301		50%	
1010401		75%	
1010501		90%	
2010101	Medium	10%	
2010201		25%	
2010301		50%	
2010401		75%	
2010501		90%	
3010101	Free	10%	
3010201		25%	
3010301		50%	
3010401		75%	
3010501		90%	

1.2.1.2. Results

In global terms we can see that results either in terms of traffic and CO2 emissions vary substantially according to the traffic level (Table 8), having a positive impact for low and high traffic situations but not for medium flow. These benefits increase more with lower penetration levels, while with penetration levels over 75% it seems to reach an asymptote.

When disaggregating these results into road types (see Figures 21 and 22), we can observe that the benefit concentrates in motorways and highways while urban streets and extraurban roads. This means drivers following “the greener route” are selecting shorter routes, though this may imply crossing the city centre or selecting a road with lower speed than a highway.

But this has a negative aspect, which is the time increase. As length has an important effect in CO2 emissions, green drivers choose routes similar to the minimum length, even having higher travel times.

Table 8: GN: Madrid case study. Results

Scenario ID	Fleet	Variation respect to the base case				
		CO2 abs kg	CO2 rel g/km	veh·km	veh·h	average speed km/h
1010100	Madrid 2014	1,056,702	186	5,670,037	104,863	54
1010200		1,027,891	189	5,429,470	112,046	48
1010300		1,004,249	192	5,219,216	119,181	44
1010400		995,127	194	5,122,863	123,496	41
1010500		992,567	195	5,089,764	126,563	40
2010100		785,752	181	4,334,405	64,127	68
2010200		776,873	183	4,239,302	68,014	62
2010300		769,455	186	4,143,273	73,160	57
2010400		762,274	187	4,071,007	77,280	53
2010500		757,649	188	4,029,276	79,920	50
3010100		368,772	180	2,043,922	25,151	81
3010200		365,169	180	2,024,069	26,146	77
3010300		361,186	181	2,000,422	27,952	72
3010400		356,937	181	1,976,709	29,516	67
3010500		354,845	181	1,964,965	30,461	65
1010101	Madrid 2030	1,042,711	184	5,670,037	104,863	54
1010201		1,013,204	187	5,429,470	112,046	48
1010301		988,728	189	5,219,216	119,181	44
1010401		979,013	191	5,122,863	123,496	41
1010501		976,213	192	5,089,764	126,563	40
2010101		776,658	179	4,334,405	64,127	68
2010201		767,388	181	4,239,302	68,014	62
2010301		759,401	183	4,143,273	73,160	57
2010401		751,916	185	4,071,007	77,280	53
2010501		747,167	185	4,029,276	79,920	50
3010101		364,536	178	2,043,922	25,151	81
3010201		361,024	178	2,024,069	26,146	77
3010301		357,135	179	2,000,422	27,952	72
3010401		352,977	179	1,976,709	29,516	67
3010501		350,929	179	1,964,965	30,461	65

Scenario ID	Fleet	Variation respect to the base case				
		CO2 abs kg	CO2 rel g/km	veh·km	veh·h	average speed km/h
1010100	Madrid 2014	-2.22%	1.48%	-3.65%	6.65%	-9.66%
1010200		-4.89%	3.09%	-7.74%	13.96%	-19.04%
1010300		-7.07%	4.78%	-11.31%	21.21%	-26.83%
1010400		-7.92%	5.78%	-12.95%	25.60%	-30.69%
1010500		-8.16%	6.19%	-13.51%	28.72%	-32.81%
2010100		-1.13%	0.49%	-1.61%	5.65%	-6.87%
2010200		-2.24%	1.58%	-3.76%	12.05%	-14.12%
2010300		-3.18%	2.94%	-5.94%	20.53%	-21.97%
2010400		-4.08%	3.79%	-7.58%	27.32%	-27.41%
2010500		-4.66%	4.23%	-8.53%	31.67%	-30.53%
3010100		-5.91%	-0.07%	-5.85%	-3.62%	-2.31%
3010200		-6.83%	-0.08%	-6.76%	0.20%	-6.94%
3010300		-7.85%	0.00%	-7.85%	7.11%	-13.97%
3010400		-8.93%	0.01%	-8.94%	13.11%	-19.50%
3010500		-9.47%	0.02%	-9.48%	16.73%	-22.46%
1010101	Madrid 2030	-2.31%	1.39%	-3.65%	6.65%	-9.66%
1010201		-5.08%	2.88%	-7.74%	13.96%	-19.04%
1010301		-7.37%	4.44%	-11.31%	21.21%	-26.83%
1010401		-8.28%	5.36%	-12.95%	25.60%	-30.69%
1010501		-8.54%	5.74%	-13.51%	28.72%	-32.81%
2010101		-1.14%	0.47%	-1.61%	5.65%	-6.87%
2010201		-2.32%	1.50%	-3.76%	12.05%	-14.12%
2010301		-3.34%	2.77%	-5.94%	20.53%	-21.97%
2010401		-4.29%	3.57%	-7.58%	27.32%	-27.41%
2010501		-4.89%	3.98%	-8.53%	31.67%	-30.53%
3010101		-5.90%	-0.05%	-5.85%	-3.62%	-2.31%
3010201		-6.80%	-0.05%	-6.76%	0.20%	-6.94%
3010301		-7.81%	0.05%	-7.85%	7.11%	-13.97%
3010401		-8.88%	0.07%	-8.94%	13.11%	-19.50%
3010501		-9.41%	0.08%	-9.48%	16.73%	-22.46%

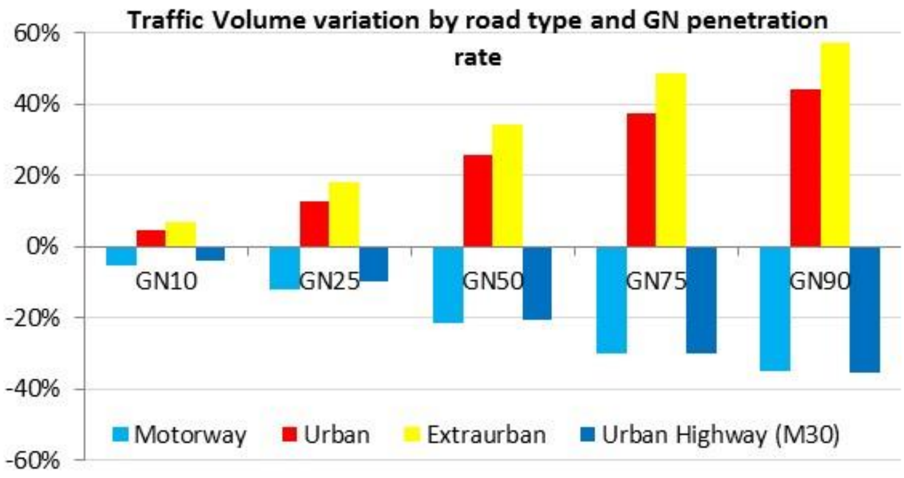


Figure 21: GN results: traffic volume variation by road type

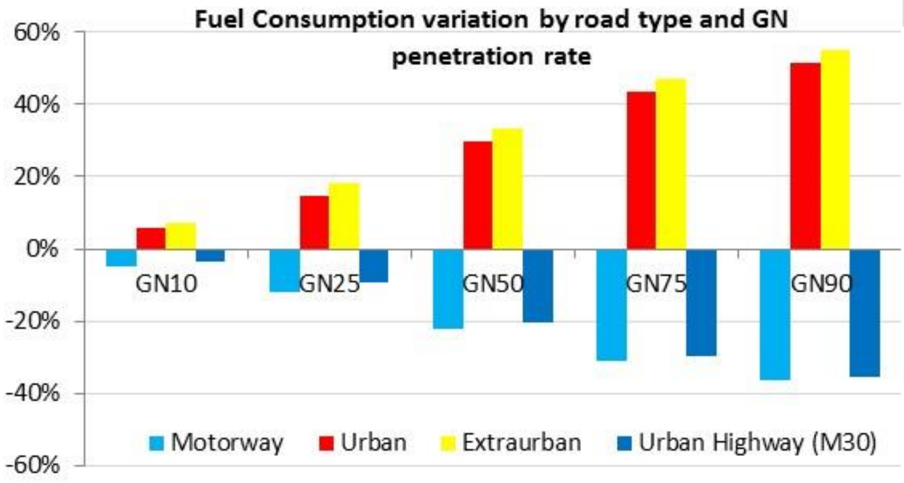


Figure 22: GN results: fuel consumption variation by road type

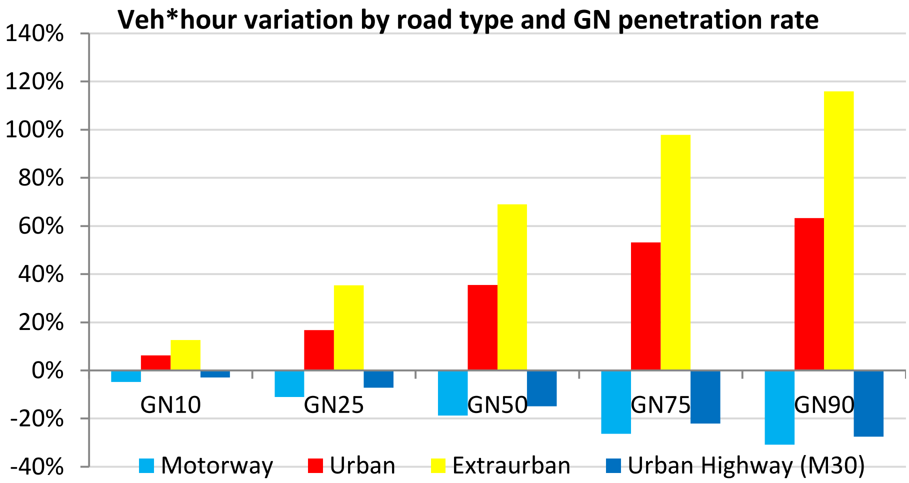


Figure 23: GN results: veh*hour variation by road type

1.3. URBAN TRAFFIC CONTROL

Measure description

Urban Traffic Control is an ICT measure that influences traffic flows allowing to reduce fuel consumptions and CO2 emissions by synchronizing and optimizing traffic lights along urban axes. Otherwise switching off the system involves an increase of congestion and travel times with resultant increase of pollutant emissions.

Modelling scale

Urban Traffic Control was simulated at both macro and micro level for the case of Rome, and only at micro level for the case of Turin.

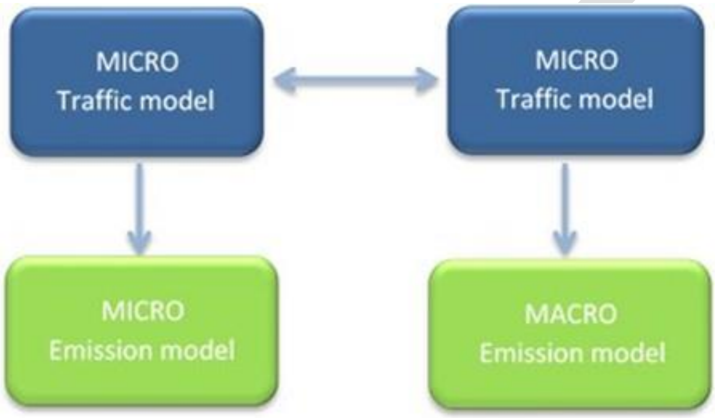


Figure 24: UTC: modelling scale

In Turin, the software used was AIMSUN, which includes the possibility of simulating UTC measure with adaptive control interface UTOPIA. In Rome, micro model assignment was carried out by using PTV-VISSIM, while macro traffic model is developed in Transcad.

1.3.1. TURIN

1.3.1.1. Modelling description

The tested section is a corridor of 1.6 km in Turin. The model will run for two traffic intensities: congested (in the morning from 8 to 9) and normal traffic condition (at lunch from 12 to 13).

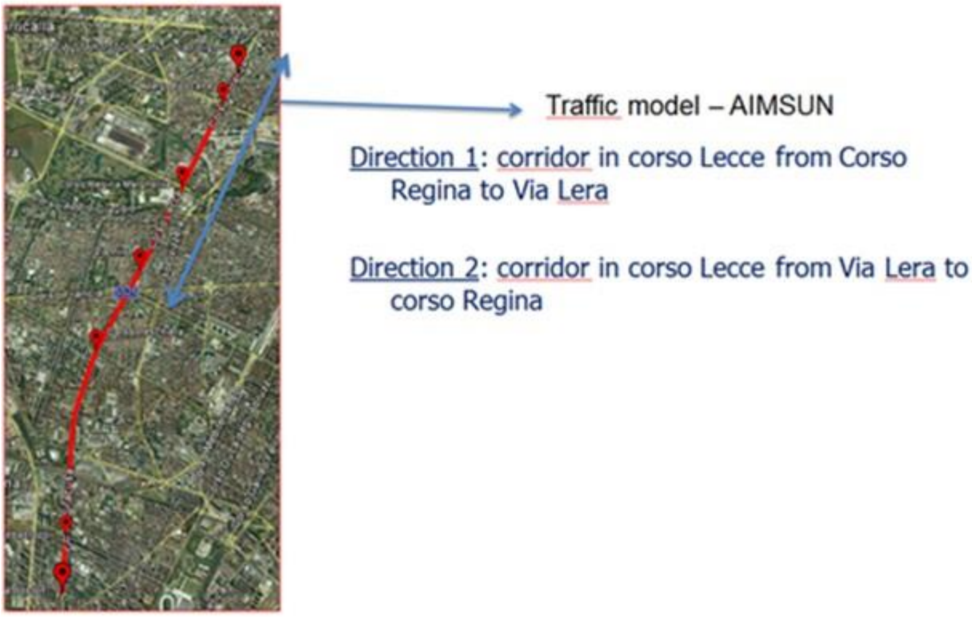


Figure 25: Turin's UTC test site

Modelling process description

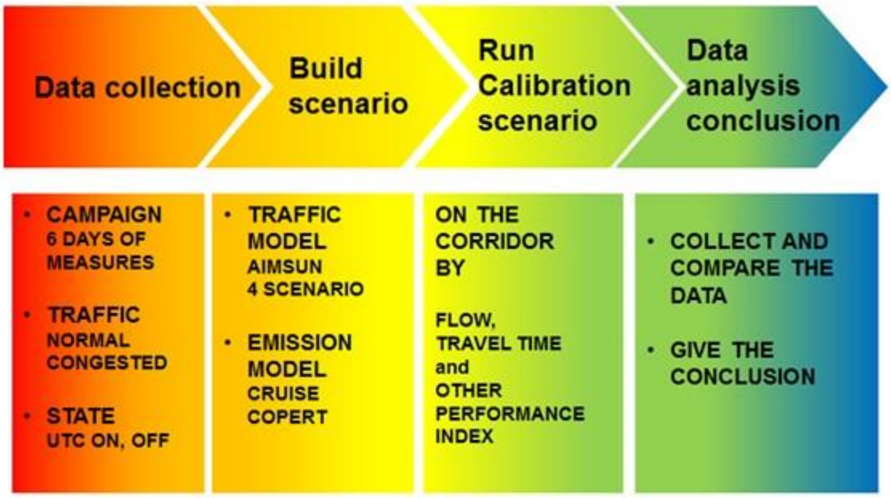


Figure 26: Turin's UTC process followed

A 6 days campaign of car measures was carried out by 5T for both normal and congested traffic situations, and considering the two system situations (UTC OFF and UTC ON). Four AIMSUN scenarios were built (at macro and micro level); in which the average demand of the campaign days was included. The GIPPS extended car following model, estimated with FIAT ecodrive data of standard user, was used in these scenarios.

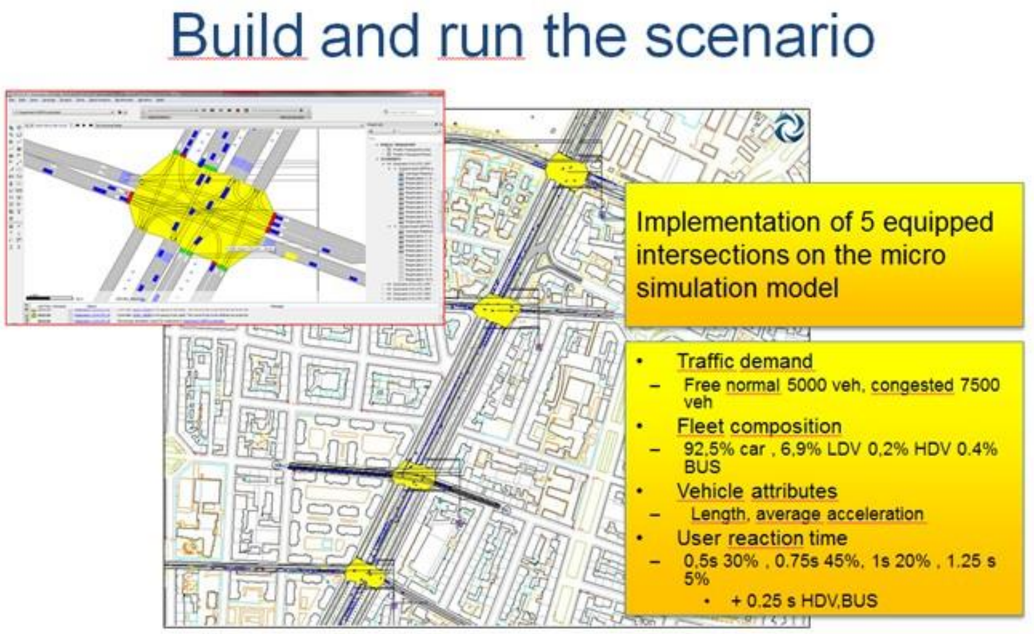


Figure 27: The scenario built

Scenarios

We consider two traffic conditions normal and congested involving a demand of 5000 and 7500 veh. per hour respectively.

Table 9: UTC: Turin case study. Scenarios considered at micro level

Scenario ID	Variables varying for each scenario			
	Traffic conditions	Penetration level	Number of replication	Fleet composition
4265	Normal	n/a	10	Turin 2013
887	Congested	n/a	10	Turin 2013

1.3.1.2. Results

Table 10: UTC: Turin case study. Results at micro level

Scenario ID	Fleet	Variation respect to the base case				
		CO2 abs kg	CO2 rel g/km	veh·km	veh·h	average speed km/h
4265	Turin 2013	-7.4%	-8%	0.4%	-11.3%	13.1%
887	Turin 2013	-3.5%	-4.5%	0.8%	-6.1%	7.4%

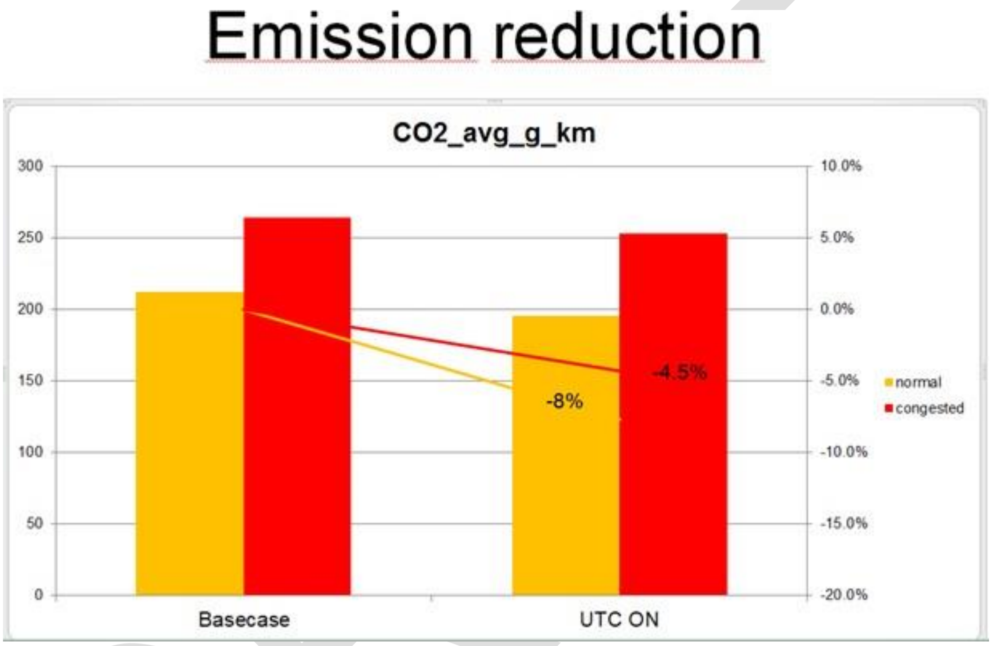


Figure 28: UTC: Turin case study. Emissions variation

The figure above shows the improvement in term of relative emission in g per Km comparing the cases UTC ON with UTC OFF. In the normal case the percentage of emission reduction in higher than in congested case (8% instead of 4,5%).

Comparing the travel time measured on the corridor we can say that the user save respectively 26. 5% in normal and 21% in congested.

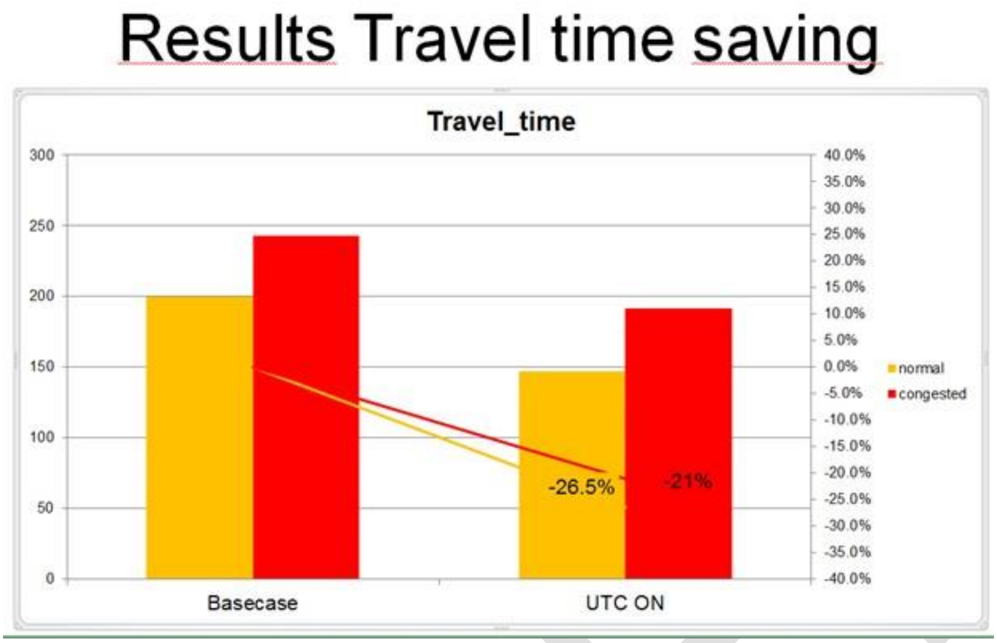


Figure 29: UTC: Turin case study. Travel time variation variation

With UTC activated, a higher number of vehicles can enter in the road network in the simulated scenario, as shown in Figure 26.

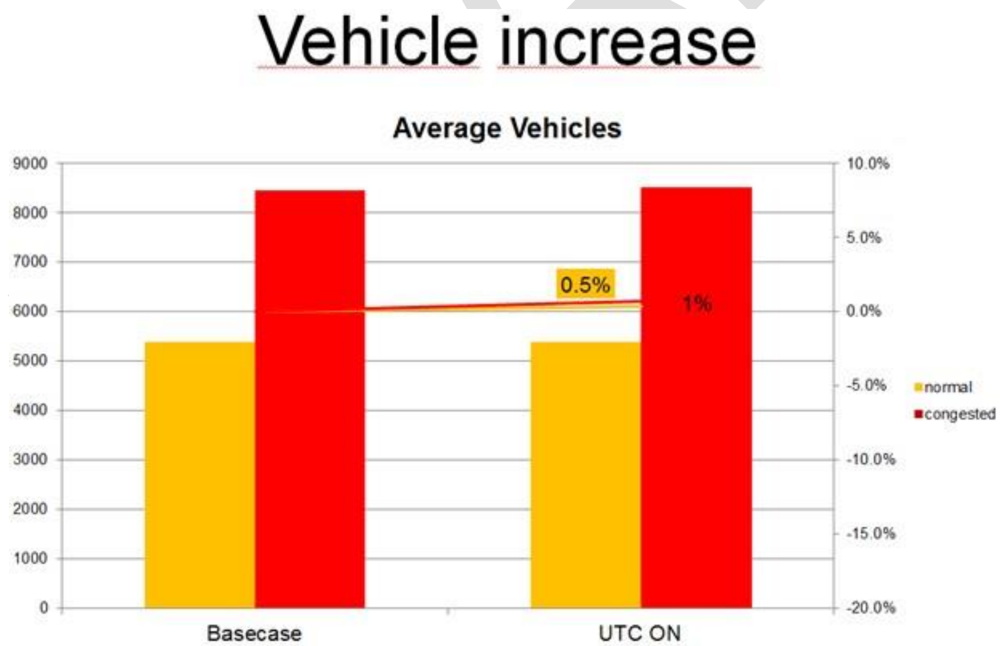


Figure 30: UTC: Turin case study. Traffic volume variation

We can conclude that UTC increases the level of service more when is applied in normal condition than in congested. It increases the capacity of the road, decreases the emission in both the cases normal and congested.

In general UTC is a good ICT measure in order to reduce the emission.

1.3.1.3. Urban Traffic Control – Comparison different fleet composition (advanced vehicles)

The influence and effectiveness of UTC may change when including a share of advanced vehicles such as hybrids or electrically driven cars in the fleet. Tests were done on the Turin test case, but with an older set of basecase and UTC on traffic simulations for congested conditions. The tested section is the same. At the older status of the traffic simulation the data were not fully correlated to real life tests. Some statistical parameters are different and the corresponding data are shown in the results section therefore.

For consideration of advanced vehicles a 10 % share of advanced vehicles was used. The advanced vehicles basically can be split into 2 types, vehicles that can be externally charged with electricity and vehicles with no external charging possibility.

Advanced vehicles that can be externally charged with electricity cover pure electric vehicles, range extenders, and plug in hybrids. For these vehicles it was assumed in the emission simulation that the entire trips were done on electrical energy only and no additional fuel is consumed. This fits to the target of this group that the typical distances in daily driving (working traffic) can be performed on electrical energy. The lower CO2 emission in absolute numbers is the optimum that can be reached therefore. The consumed electric energy is at the end converted into an equivalent CO_2 emission by considering the CO2 mix of the electrical currency and the charging efficiency. For the test case of Turin the CO2 mix was defined with 216.8 g CO2/kWh based on a carbon intensity of 2521 kg CO2/toe for Italy in the year 2010 (see Table). The charging efficiency was defined with 85% [2]

Advanced vehicles with no external charging possibility cover classical mild and full hybrids. At the simulation of these vehicles it is important to level out energy consumption. This means that the state of charge of the battery at the end of the simulation must be the same or at least very similar to the state of charge at the start of the simulation. This must be reached since all electrical energy must be produced by the combustion engine. For these vehicles the CO2 emission is determined based on the consumed fuel only, similar like it is done for conventional vehicles.

Table 11: Carbon Intensity and CO2 mix in Europe [1]

country	Carbon Intensity - kg CO2/toe			CO2 mix g/kWh		
Year	2005	2009	2010	2005	2009	2010
EU27	2494	2387	2372	214.4	205.2	204.0
Belgium	2607	2326	2281	224.2	200.0	196.1
Bulgaria	2631	2656	2723	226.2	228.4	234.1
Czech Republic	2829	2756	2699	243.3	237.0	232.1
Denmark	2831	2710	2626	243.4	233.0	225.8
Germany	2593	2505	2536	223.0	215.4	218.1
Estonia	3049	2824	3112	262.2	242.8	267.6
Ireland	3343	3002	2935	287.4	258.1	252.4
Greece	3978	3759	3752	342.0	323.2	322.6
Spain	2798	2587	2494	240.6	222.4	214.4
France	1615	1534	1519	138.9	131.9	130.6
Italy	2674	2540	2521	229.9	218.4	216.8
Cyprus	3845	3529	3501	330.6	303.4	301.0
Latvia	1959	1980	2123	168.4	170.2	182.5
Lithuania	1688	1579	2103	145.1	135.8	180.8
Luxembourg	2754	2689	2654	236.8	231.2	228.2
Hungary	2215	2023	2004	190.5	173.9	172.3
Malta	6962	8198	6603	598.6	704.9	567.8
Netherlands	2919	2769	2696	251.0	238.1	231.8
Austria	2376	2116	2124	204.3	181.9	182.6
Poland	3436	3229	3286	295.4	277.6	282.5
Portugal	2641	2444	2332	227.1	210.1	200.5
Romania	2766	2509	2462	237.8	215.7	211.7
Slovenia	2303	2281	2243	198.0	196.1	192.9
Slovakia	2239	2152	2132	192.5	185.0	183.3
Finland	1695	1675	1764	145.7	144.0	151.7
Sweden	1196	1223	1197	102.8	105.2	102.9
UK	2551	2535	2543	219.3	218.0	218.7

Scenarios

UTC with advanced vehicle fleet is considered for one condition only (congested). The scenarios considered for UTC with advanced vehicle fleet are shown in Table 12.

Table 12: UTC: Turin case study, advanced fleet, Scenarios considered

Scenario ID	Variables varying for each scenario				
	ICT measure	Advanced vehicle penetration rate	Traffic conditions	Number of replications	Fleet composition
4331_01	basecase	0%	congested	9	Turin 2013
887_01	UTC on			10	
4331_10	basecase	10%	congested	9	Turin 2013 10% Hybrid
887_10	UTC on			10	

Results

Table 13 shows the absolute value and the percentage of variation of each variable from the corresponding base case scenarios.

Table 13: UTC: Turin case study, advanced fleet, Results

Scenario ID	Absolute results			Variation with respect to the base case (0% start and stop)	
	CO2 abs kg	CO2 rel g/km	Average speed	CO2 abs kg	CO2 rel g/km
4331_01	294.6	247.26	22.25	0	0
887_01	251	214.01	27.51	-14.8	-13.45
4331_10	284.5	238.8	22.25	0	0
887_10	242.2	206.49	27.51	-14.87	-13.53

The improvement in CO2 emission due to UTC reaches nearly the same level independent from the fleet composition. This means that also in case of a larger share of advanced vehicles it is expected that introduction of UTC as ITS measure shows the same effectiveness with respect to CO2 emission.

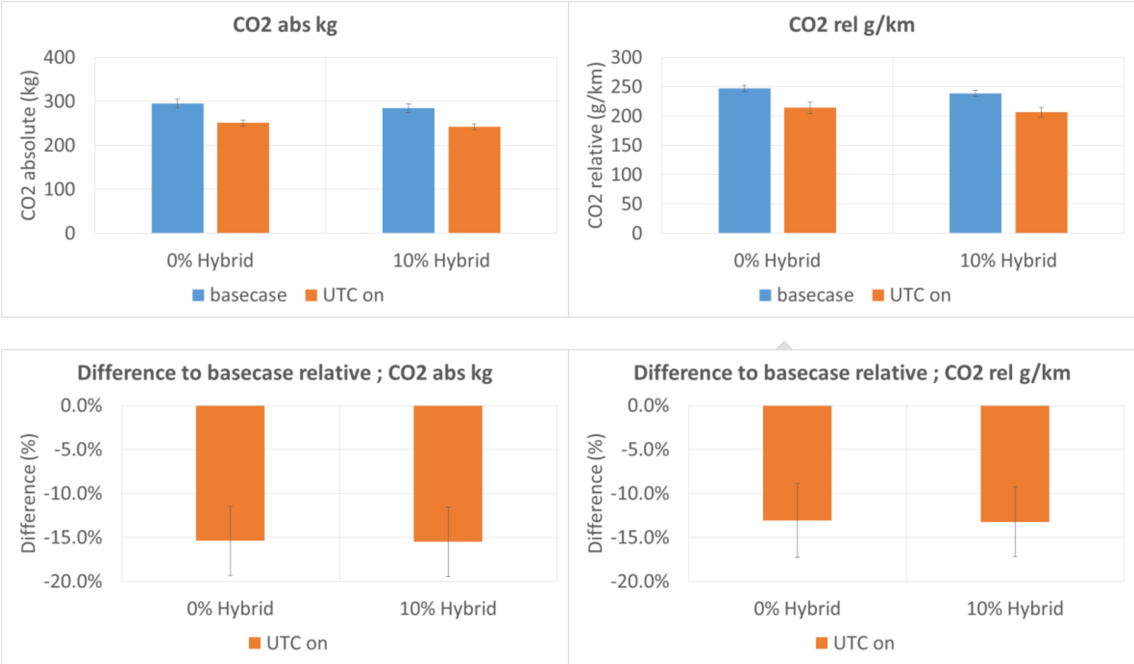


Figure 31: UTC: Turin case study. Advanced fleet: difference basecase and UTC on

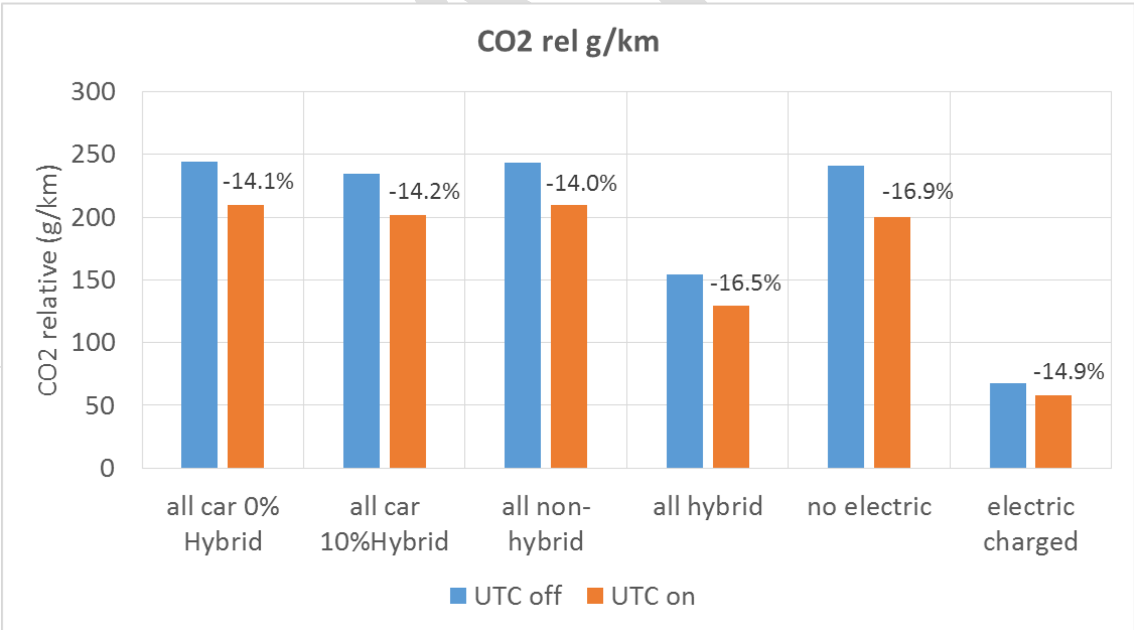


Figure 32: UTC: Turin case study. Advanced fleet: detailed results

More detailed information about the CO2 improvement between conventional and hybrid vehicles can be found in Figure 8. The results shown are for the group of the passenger cars only (no trucks and busses). All car 0% hybrid gives the result of the simulation case with no hybrid vehicles. This should be seen as reference. All car 10% Hybrid are the overall results for the 10% hybrid share (combined conventional and hybrid vehicles).

All non-hybrid and all hybrid show the results for the 10% hybrid share test case for the conventional vehicles (all non-hybrid) and the hybrid vehicles (all hybrid). For the conventional vehicles the results are nearly identical to the test case without any hybrid vehicles. This is to be expected since the same fleet composition is considered. Small differences in the numbers are caused by the uncertainty of the results. Hybrid vehicles show in this example a larger reduction in CO2 emissions compared to the non-hybrid vehicles (-16.5% compared to 14.0%). In general the level of CO2 emissions is much smaller for the hybrid vehicles.

Looking even further in detail into the results by splitting the hybrid vehicles into vehicles that can be externally charged (electric charged) and hybrids with no external charging possibility (no electric) it becomes visible that the vehicles with no external charging possibility show a higher improvement in CO2 emission. However it has to be noted that due to the small number in vehicles existing on the market and used for the project these numbers are subject to change.

The results show also correspondingly large CO2 emissions for the hybrids with no external charging possibility. This is caused by the fact that one of the vehicles which is considered in the simulation is the Mercedes S-class, a very large vehicle which in this size is not considered in the conventional vehicles due to their small market share overall. However for hybrids it is expected and the current trend that hybrids are first introduced in large and expensive vehicle classes since buyers of this class of vehicles are less budget sensitive compared to small car buyers.

1.3.2. Rome

1.3.2.1. Modelling description

Rome test case is an important road itinerary (Via Appia) long 6,3 km and located in south-eastern side of the urban area as illustrated below. The itinerary is ruled by a 23 traffic lights coordinated by an UTC system that represents the main topic of the analysis. The test case was split in three different scenarios: in particular one refer to the base case condition (UTC off) while the other two simulate the effects of ICT measures as better illustrated below;

- in the first one, the environmental analyses have been carried out on the whole study area, simulating the effects of UTC-off condition only along Via Appia (Scenario ID = 102);

* In the second one, the same analyses have been carried out on the whole study area, simulating the effects of UTC-off condition on all the 22 different urban axes under UTC scheme, with a total length of 80 km (Scenario ID = 103).

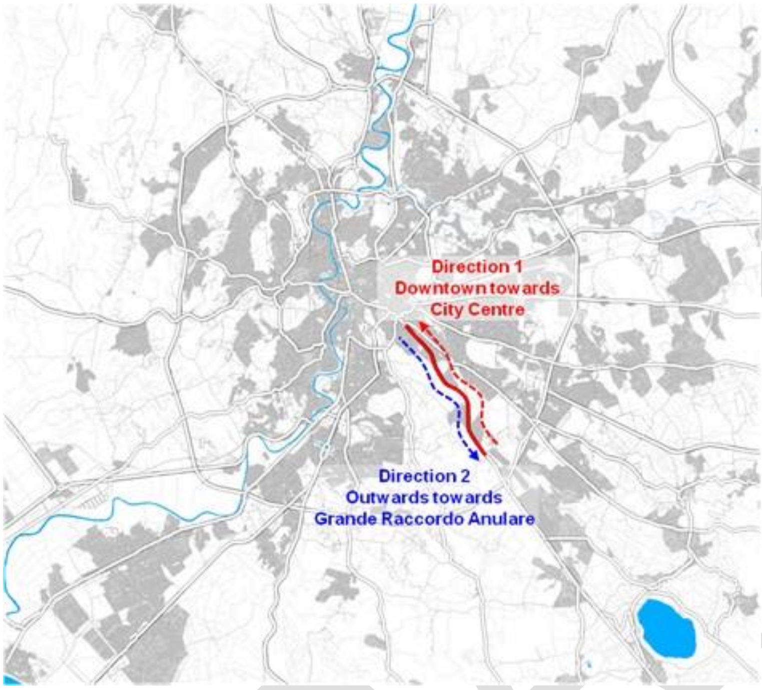


Figure 33: Location of Via Appia within the urban area

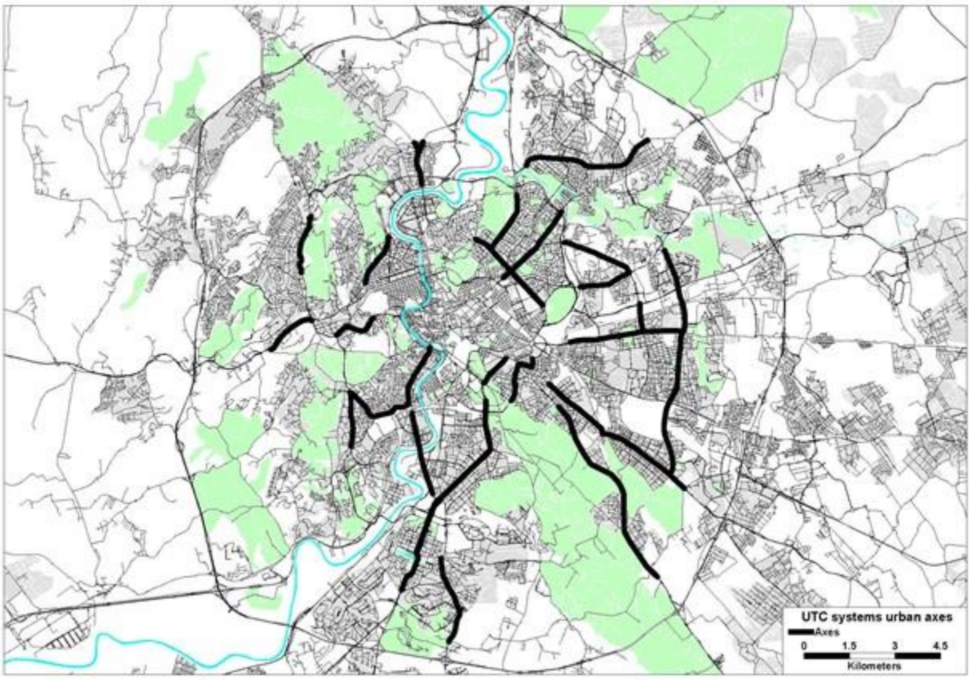


Figure 34: Urban axes with UTC systems

Modelling process description

The UTC effects were simulated both on micro and macro scale in order to develop a comprehensive methodology to assess the impacts of ITS measures on road transport CO2 emissions by taking into account the real-world driving and traffic behaviour in urban agglomerations.

The micro model has been built using VISSIM software that allows to represent in detail the "mobility process" of vehicles on the road since VISSIM uses the psycho-physical driver behaviour model where stochastic distributions of speed and spacing thresholds replicate individual driver behaviour characteristics. With this software it is possible to model accurately all the elements of the road network such as traffic lights controls, priority rules, reduced road sections, on street parking, on street bus stops, lateral distances between different classes of vehicles, etc.

The Via Appia micro model has been built so to consider all the characteristics of Rome's driving behaviour and all the particular conditions observed in the study area. For example, in Rome the usual behaviour of motorcycles and scooters when there is a queue at an intersection, is to "squeeze" through one vehicle and the other and reach the stop line where they wait for green signal. This behaviour has been taken into account by setting conveniently the parameters of lateral behaviour of these type of vehicles (two wheels). In addition, Via Appia micro model has been built to take into account all of the roads characteristics including several bottlenecks that are frequent and typical of a normal working day.

All these parameters were obtained by an accurate calibration process, an iterative process that consists of continuous adjustments to be done to the model's parameters and the following comparison of the modelled data with the observed data, being it traffic or travel times or other significant parameter, until this comparison shows a satisfactory representation of the observed data by the micro model.

Upscaling to macro traffic modelling

The UTC effects were also simulated in the Transcad macro assignment model in order to assess how it influences traffic flows conditions. These effects have been reproduced starting from the assumption that UTC-off situation mainly affects free flow speeds and road capacity.

Therefore a new set of parameters that modify Volume-Delay functions of links was defined, specifically taking into account road width and the effects of illegal parking on free flow speeds due to roadside activities, with resulting new free flow speeds, capacities and saturation flows for links.

Firstly this methodology was applied to the micro area study case (Via Appia), evaluating the global environmental effects. Finally, the parameter changes were applied to all UTC controlled main itineraries in order to simulate a wide area scenario UTC Off, assessing the environmental outcomes in the whole city.

Scenarios

Micro level

On the base of such issues, in the micro scale model two different scenarios were run:

Table 14: UTC: Rome case study. Scenarios considered at micro level

Scenario ID	Variables varying for each scenario			
	Traffic conditions	**ICT measure**	**Number of replications**	**Fleet composition**
303_2014	congested	UTC off	15	Rome 2014
313_2030	congested	UTC on	15	Italy 2030
303_2014	congested	UTC off	15	Rome 2014
313_2030	congested	UTC on	15	Italy 2030

The comparison has been carried out between the base case (with the entire network synchronized and optimized) and the UTC-off situation on Via Appia. Both scenarios were run for 2 different fleet compositions, Rome 2014 and Italy 2030.

Macro level

As above described on the macro model two different scenario were implemented:

- UTC measure active only on Via Appia: (Scenario 2)
- UTC measure active on the whole network: (Scenario 3)

For all the scenarios, the environmental analyses were based on the results obtained by the multimodal traffic assignment; starting from the total flows of each link of the network, total emissions were evaluated according to different fleet compositions, fuel types and emissions technologies. All scenarios were run for 2 different fleet compositions, Rome 2014 and Italy 2030.

Table 15: UTC: Rome case study, Scenarios considered at macro level

Scenario ID	Variables varying for each scenario	
	ICT measure	**Fleet composition**
102_2014	UTC on (Via Appia)	Rome 2014
102_2030	UTC on (Via Appia)	Italy 2030
103_2014	UTC on (whole Rome)	Rome 2014
103_2030	UTC on (whole Rome)	Italy 2030

1.3.2.2. Results

Micro level

At micro scale level, 15 different runs were carried out for each scenario, according to 15 different seeds. Four different parameters were used to assess the effects of UTC measures or transport system. As expected, base case condition (UTC off) involves an increase of traffic congestion confirmed by an increase of the total number of stops (+8.3%), average number of stops per vehicle (+9.6%) and average lost time per vehicle (+13.4%). At the same time the average speed in the whole network decreases (-7.5%).

Table 16: UTC: Rome case study. Micro model parameters

Parameters	UTC ON	UTC OFF	Abs.diff.	%
Average Network Speed [km/h]	20,3	18,7	+1,6	+7,5%
Total number of stops	105'888	114'720	+8'832	+8,3%
Average number of stops per vehicle	5,5	6,1	+0,5	+ 9,6%
Average lost time per vehicle [s]	204,9	232,2	+27,7	+ 13,4%

The environmental effects at the micro scale model were carried out comparing the results obtained with the actual fleet composition (Rome 2014) and the future one (Italy 2030). Following Table 16 shows the effectiveness of UTC system as the absolute CO_2 emissions and the relative CO_2 emissions (measured in g/km) decrease with the ICT measures switched on.

Table 17: UTC: Rome case study. Results at micro level.

Scenario ID	Fleet	Absolute results			Variation with respect to the base case (UTC off)	
		CO2 abs kg	CO2 rel g/km	percent stop time	CO2 abs kg	CO2 rel g/km
		kg	g/km	%	%	%
102_2014	Rome 2013	12795.5	332.21	35.52	-2.18	-4.84
102_2030	Italy 2030	11557.6	300.03	35.52	-1.72	-4.37

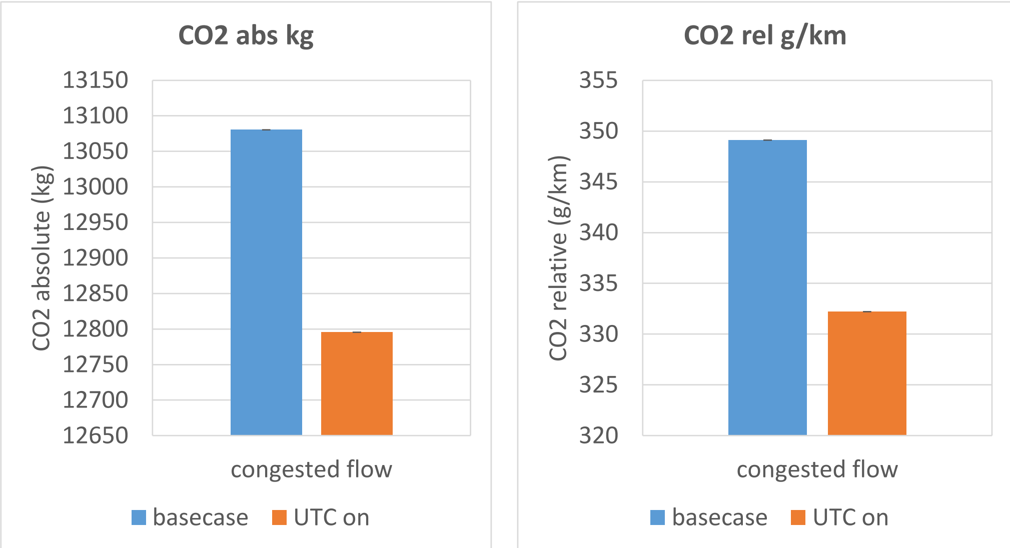


Figure 35: UTC: Rome case study, fleet 2013. Difference basecase and UTC on

Specifically, the decrease of absolute CO2 emissions and relative CO2 emissions are lower with the Italy 2030 fleet composition; it's probably due to the higher effectiveness of emission technologies that reduce the effects of ICT measures on the environment.

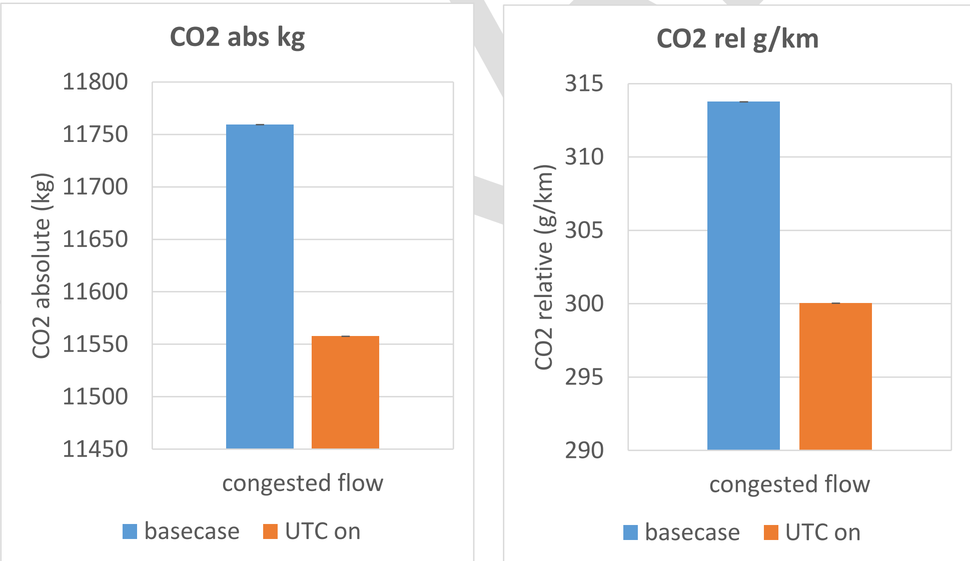


Figure 36: UTC: Rome case study, future fleet. Difference basecase and UTC

Macro level

With respect to the macro simulations, the one carried out with the UTC-on conditions along Via Appia, shows the effects of traffic lights synchronization and optimizations. The total travel times are 14% lower than base case condition. The environmental impacts, illustrated in Table 17 of the ICT on measures are small, mainly due to small size of the micro area where the UTC system effects were analyzed.

At the same time, the results provided by the upscaling process from test site to the whole city, show an increase of average speed with UTC on (+4%) and a global decrease of CO2 emissions, as illustrated in Table 18. The comparison between the results obtained with the actual fleet and the future one shows how the upgrade of emission technologies (future fleet) even in the base-case condition allows a reduction of CO2 emissions maintaining the same effectiveness of ICT measure regarding the environmental benefits (in terms of percentage).

Table 18: UTC: Rome case study. Results at macro level

MACRO MODEL		**Absolute value**				
Scenario ID	**Fleet**	**O2 abs kg**	**CO2 rel g/km**	**v·km**	**v·h**	**avg speed km/h**
102	2014	945,410	197	4,809,633	267,744	18.0
103	2014	944,945	197	4,808,264	267,519	18.0
102	2030	911,869	190	4,809,633	267,744	18.0
103	2030	911,421	190	4,808,263	267,519	18.0
MACRO MODEL		**Variation respect to the base case**				
Scenario ID	**Fleet**	**CO2 abs kg**	**CO2 rel g/km**	**v·km**	**v·h**	**avg speed km/h**
102	2014	-0.21%	-0.19%	-0.02%	-0.52%	0.50%
103	2014	-0.26%	-0.21%	-0.05%	-0.61%	0.56%
102	2030	-0.20%	-0.18%	-0.02%	-0.52%	0.50%
103	2030	-0.25%	-0.20%	-0.05%	-0.61%	0.56%

Table 19: UTC: Rome case study. Results at macro level: heavy trucks

MACRO MODEL		**Absolute value**				
Scenario ID	**Fleet**	**CO2 abs kg**	**CO2 rel g/km**	**v·km**	**v·h**	**avg speed km/h**
102	2014	53.341	679	78.570	6.179	12,71
103	2014	53.310	679	78.548	6.174	12,72
102	2030	53.054	675	78.570	6.179	12,71
103	2030	53.024	675	78.548	6.174	12,72
MACRO MODEL		**Variation respect to the base case**				
Scenario ID	**Fleet**	**CO2 abs kg**	**CO2 rel g/km**	**v·km**	**v·h**	**avg speed km/h**
102	2014	-0,24%	-0,22%	-0,02%	-0,52%	0,50%
103	2014	-0,30%	-0,25%	-0,05%	-0,61%	0,56%
102	2030	-0,23%	-0,21%	-0,02%	-0,52%	0,50%
103	2030	-0,29%	-0,24%	-0,05%	-0,61%	0,56%

Table 20: UTC: Rome case study. Results at macro level: light commercial vehicles

MACRO MODEL		**Absolute value**				
Scenario ID	**Fleet**	**CO2 abs kg**	**CO2 rel g/km**	**v·km**	**v·h**	**avg speed km/h**
102	2014	47.272	281	168.365	13.242	12,71
103	2014	47.247	281	168.317	13.231	12,72
102	2030	45.053	268	168.365	13.242	12,71
103	2030	45.030	268	168.317	13.231	12,72
MACRO MODEL		**Variation respect to the base case**				
Scenario ID	**Fleet**	**CO2 abs kg**	**CO2 rel g/km**	**v·km**	**v·h**	**avg speed km/h**
102	2014	-0,20%	-0,17%	-0,02%	-0,52%	0,50%
103	2014	-0,25%	-0,20%	-0,05%	-0,61%	0,56%
102	2030	-0,20%	-0,18%	-0,02%	-0,52%	0,50%
103	2030	-0,26%	-0,21%	-0,05%	-0,61%	0,56%

Table 21: UTC: Rome case study. Results at macro level: light commercial vehicles

MACRO MODEL		Absolute value				
Scenario ID	**Fleet**	**CO2 abs kg**	**CO2 rel g/km**	**v·km**	**v·h**	**avg speed km/h**
102	2014	844.797	185	4.562.697	248.323	18,37
103	2014	844.388	185	4.561.398	248.114	18,38
102	2030	813.762	178	4.562.697	248.323	18,37
103	2030	813.367	178	4.561.398	248.114	18,38
MACRO MODEL		**Variation respect to the base case**				
Scenario ID	**Fleet**	**CO2 abs kg**	**CO2 rel g/km**	**v·km**	**v·h**	**avg speed km/h**
102	2014	-0,21%	-0,19%	-0,02%	-0,52%	0,50%
103	2014	-0,26%	-0,21%	-0,05%	-0,61%	0,56%
102	2030	-0,20%	-0,18%	-0,02%	-0,52%	0,50%
103	2030	-0,25%	-0,20%	-0,05%	-0,61%	0,56%

1.4. ECO DRIVING

Measure description

Eco-driving is a way of driving that uses less fuel. The characteristics of eco driving are generally well defined and easily characterized. It involves following a set of techniques such as upshifting to avoid engine speeds over 2500 rpm, maintaining steady vehicle speed, anticipating traffic, accelerating and decelerating smoothly, and avoiding long idles.

The promotion of an energy-efficient style of driving is a measure that can have an important impact on fuel consumption.

Although most eco-driving techniques include to lower highway speed, it is most common for city or urban driving, where fuel savings can be achieved without lowering average speed or increasing travel times.

The eco-driving behaviour varies the attitude in setting speed and distance to the preceding vehicles. Speed and distance are parameters that influence, at the macroscopic level, the speed and density of traffic. The measure has to be simulated first of all at the micro level and the result can then be scale up to the macro.

Modelling scale

Eco-driving have been modelled at both micro level and macro level.

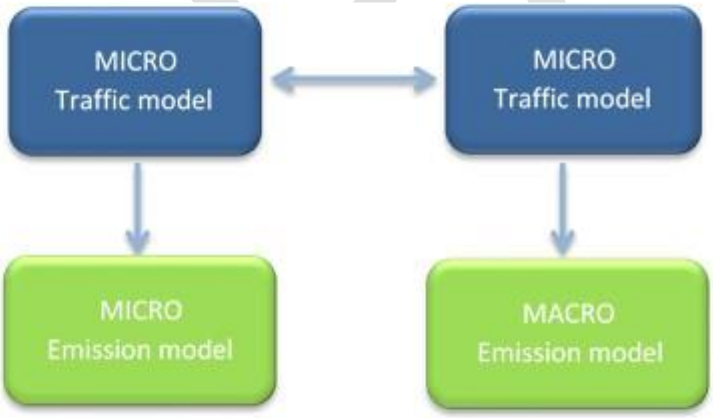


Figure 37: Eco-driving modelling scale

Different methodologies have been followed in each city for micro traffic simulation and for calculating the new speed intensity curves, but both results have been implemented in both macro traffic models. This was, as in the case study of Madrid eco driving was simulated for an urban highway while in Turin it was for an urban street, at the macro level we have simulated eco driving in both types of roads.

In the case of Madrid, the traffic software used has been PTV VISSIM and PTV VISUM, while in Turin it has been used AIMSUN for both micro and macro. Emissions have been calculated with either CRUISE (at micro level) or COPERT at the macro level).

Up scaling process to macro scale

Once the micro scenarios have been developed, micro results are used to calculate the new speed- intensity functions that will be used for simulating at a macro scale.

In this case, based on the different typology of the case studies, with Madrid's results it has been calculated new functions for highways, while in Turin for urban streets.

In the case of highways, the appreciated change is in terms of capacity but not in terms of free flow speed, while in the urban streets both capacity and free flow seem to vary with different penetration levels of eco drivers. This seems logical, due to different impact the effect of accelerating and braking have in urban streets compared to highways.

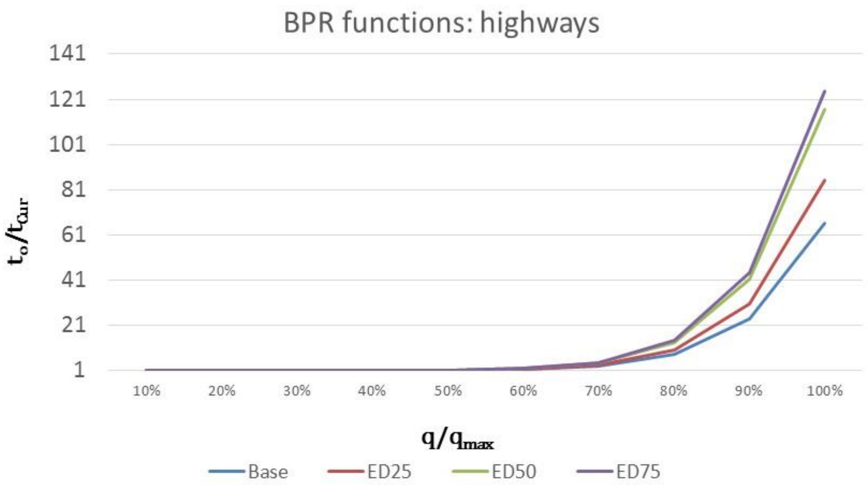


Figure 38: Changes in the fundamental diagram with different penetrattion levels of eco driving in urban highways

Table 22: Changes in BPR function parameters: Highways

% ECO	Capacity reduction	Δtime at 100% capacity
25 %	2.53%	29%
50 %	5.57%	76%
75 %	6.20%	88%

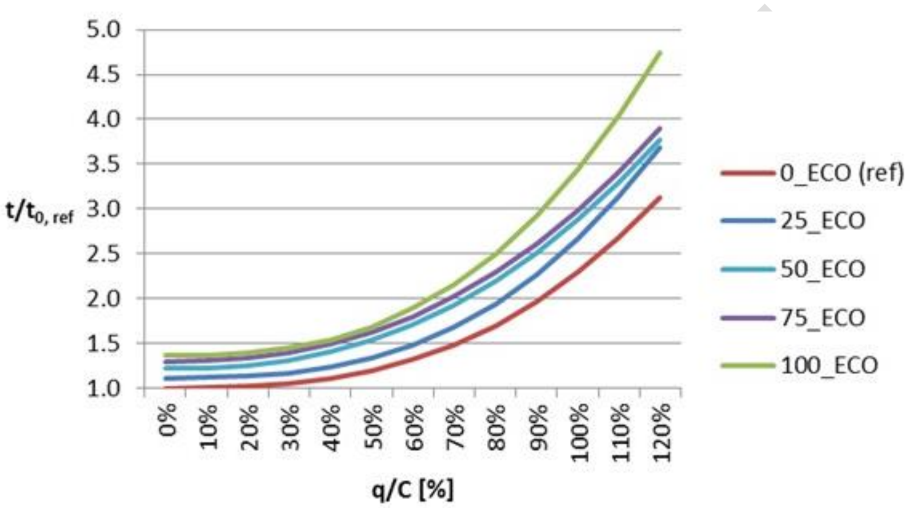


Figure 39: Changes in the fundamental diagram with different penetrattion levels of eco driving in urban streets

Table 23: Changes in BPR function parameters: Highways

% ECO	t_0	a	b	Δtime at t_0	Δtime at 100%capacity
0%	153	1.29	2.74	--	--
25 %	170	1.39	2.79	11%	16%
50 %	186	1.36	2.38	22%	26%
75 %	198	1.30	2.38	30%	30%
100 %	208	1.52	2.69	36%	50%

1.4.1. MADRID

1.4.1.1. Modelling description

The tested section is a 3 lanes motorway (southbound) with traffic intensity in the afternoon peak hours rounding 3,300 veh/h, (upstream) and with a length of 6.6 km. Most of the section is limited to 90 km/h, except the last 100 m., limited to 70 km/h. (tunnel entrance). The congestion is usually caused by the bottleneck situated in the M500 junction, as around 2,800 vehicles merge in the M30 in peak hour.

Figure 40 shows the tested section (marked in Figure 1 from A to B) with the Variable Message Signs (VMS) as well as the bottleneck junction where the congestion usually starts (M500).

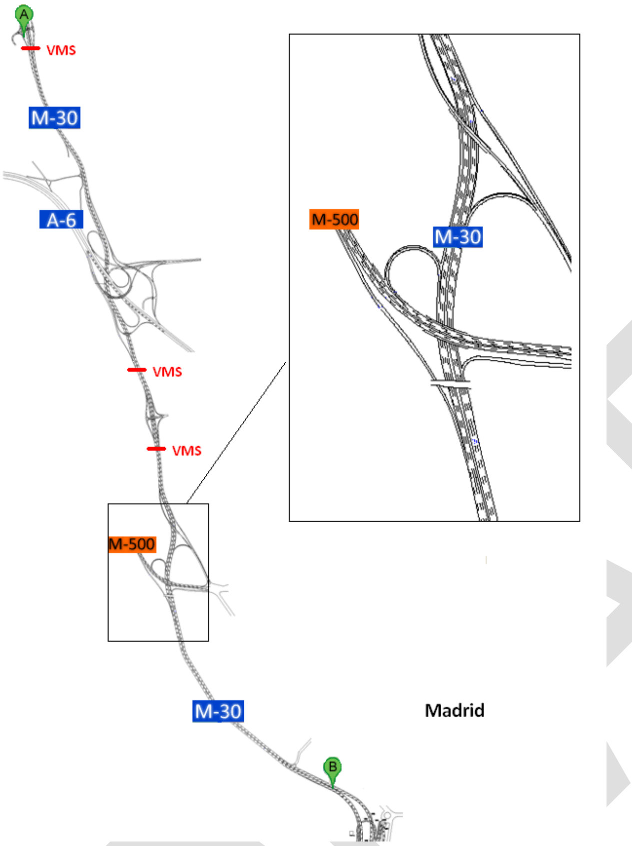


Figure 40: West section of the Madrid ring motorway.

Modelling process description

Analysis of real speed profiles

VISSIM software allows the users to change some of the parameters regarding the drivers´ behaviour: desired speed, desired acceleration and deceleration and other parameters regarding the car-following and lane change models.

First step in the modelling process has been the analysis of the speed profiles recorded at M30 ring motorway in Madrid. In particular for the case study of the West side southbound we recorded 41 trips driven normally and 37 trips driven following eco-driving rules. For these trips, we have analysed the following parameters, showing in Table 24 the variations between normal and eco-driving.

Table 24: Variation of selected speed profiles parameters comparing eco-driving with normal driving

Eco-driving motorway West	Normal Driving	Eco-driving	Reduction
95 Percentile of speed	93.0	92.7	0.3%
Average negative acceleration	-0.23	-0.21	8.6%
Average positive acceleration	0.25	0.21	16.0%

<u>Eco-driver definition and calibration in VISSIM</u>

The base case model has been calibrated (see Deliverable 6.2) using traffic and floating car data from the evening of Wednesday March 13th 2013. A new vehicle type has been created in order to reproduce the real conditions. This vehicle type has a specific route which is exactly the same as the floating cars during the test days.

The new "eco" vehicle type characteristics have been set following the variation in the parameters shown in Table 21. Desired speed distributions and desired acceleration and deceleration functions have been adapted accordingly. Figure 41 shows the normal and eco-driving acceleration curve for the car segment C-D:

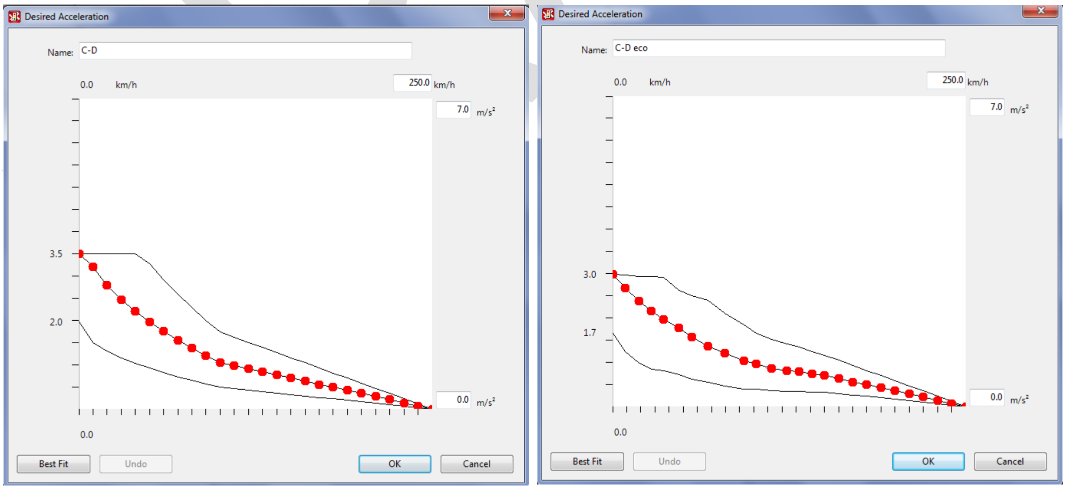


Figure 41: Normal and eco-driving acceleration functions for the vehicle types C-D and eco_C-D

Once the desired speed and acceleration functions have been set, safety distance and number of vehicles observed have been slightly increased to reproduce the eco-driving behaviour in reality.

Eco-driving model validation

We have added 1 vehicle every 15 minutes which runs exactly the same route as the floating cars. The validation consists in running first one scenario with these vehicles driving normally and then change their behaviour to eco-drivers.

The simulation results show savings of 4,5%, in line with measured savings of 5.3%.

Scenarios

A total of 18 scenarios have been considered for both either micro and macro simulations, though they are not coincident one by one.

At micro level, the variables producing this range of scenarios are:

- Traffic level: congested, medium and free flow
- Penetration rate: 5 – 20 – 25 – 50 and 75%

The only fleet composition considered for micro simulation has been 2014. At the macro level, apart from traffic level and penetration rate (25 -50 and 75%), it has also been considered the future fleet for 2030.

Table 25: Eco driving: Madrid case study. Scenarios considered at micro level

Scenario ID	**Variables varying for each scenario**			
	Traffic conditions	**Penetration rate**	**Number of replications**	**Fleet composition**
121_02	Low	5%	15	Madrid 2014
122_02	Normal	5%	15	Madrid 2014
123_02	Congested	5%	15	Madrid 2014
121_05	Low	20%	15	Madrid 2014
122_05	Normal	20%	15	Madrid 2014
123_05	Congested	20%	15	Madrid 2014
121_06	Low	25%	15	Madrid 2014
122_06	Normal	25%	15	Madrid 2014
123_06	Congested	25%	15	Madrid 2014
121_07	Low	50%	15	Madrid 2014
122_07	Normal	50%	15	Madrid 2014
123_07	Congested	50%	15	Madrid 2014
121_08	Low	75%	15	Madrid 2014
122_08	Normal	75%	15	Madrid 2014
123_08	Congested	75%	15	Madrid 2014
121_09	Low	100%	15	Madrid 2014
122_09	Normal	100%	15	Madrid 2014
123_09	Congested	100%	15	Madrid 2014

Table 26: Eco driving: Madrid case study. Scenarios considered at macro level

Scenario ID	Variables varying for each scenario		
	Traffic conditions	**Penetration level**	**Fleet composition**
1030100	Congested	25%	Madrid 2014
1030200	Congested	50%	Madrid 2014
1030300	Congested	75%	Madrid 2014
2030100	Medium	25%	Madrid 2014
2030200	Medium	50%	Madrid 2014
2030300	Medium	75%	Madrid 2014
3030100	Free	25%	Madrid 2014
3030200	Free	50%	Madrid 2014
3030300	Free	75%	Madrid 2014
1030101	Congested	25%	Madrid 2030
1030201	Congested	50%	Madrid 2030
1030301	Congested	75%	Madrid 2030
2030101	Medium	25%	Madrid 2030
2030201	Medium	50%	Madrid 2030
2030301	Medium	75%	Madrid 2030
3030101	Free	25%	Madrid 2030
3030201	Free	50%	Madrid 2030
3030301	Free	75%	Madrid 2030

1.4.1.2. Results

Micro level

At micro level, variables related to emissions, traffic and vehicle dynamics have been analysed. Table 27 shows the percentage of variation of each variable from the corresponding base case scenarios:

Table 27: Eco driving: Madrid case study. Results at micro level

Scenario ID	Absolute results			Variation with respect to the base case	
	CO2 abs kg	CO2 rel g/km	percent stop time	CO2 abs kg	CO2 rel g/km
121_02	1440.2	130.02	0.00	-0.89%	-0.89%
122_02	5465.8	149.56	1.28	4.37%	-1.53%
123_02	6324.0	173.89	4.65	0.93%	1.41%
121_05	1442.6	130.20	0.00	-0.72%	-0.75%
122_05	5449.7	150.28	1.50	4.07%	-1.06%
123_05	6481.0	179.41	5.34	3.43%	4.63%
121_06	1449.8	130.86	0.00	-0.23%	-0.25%
122_06	5474.8	151.30	1.61	4.55%	-0.38%
123_06	6527.3	181.38	5.73	4.17%	5.77%
121_07	1447.8	130.75	0.00	-0.37%	-0.33%
122_07	5485.1	152.64	1.96	4.74%	0.49%
123_07	6678.1	190.63	6.96	6.58%	11.17%
121_08	1477.7	133.46	0.00	1.69%	1.73%
122_08	5504.4	154.20	2.49	5.11%	1.53%
123_08	6721.7	194.58	7.51	7.28%	13.47%
121_09	1487.3	134.30	0.00	2.35%	2.38%
122_09	5529.2	156.14	3.29	5.59%	2.80%
123_09	6760.3	199.63	9.02	7.89%	16.42%

Table 27 shows that the progressive increment of eco-drivers influences negatively in the CO2 emissions. Eco-drivers tend to accelerate and brake smoothly, letting at the same time larger safety distances. These facts reduce the traffic density and, therefore, the capacity, producing longer queues and increasing travel times. Especially at the congested scenarios, the progressive input of eco-drivers produces an increment on stop times.

Relative positive effects can only be found with low levels of traffic and with eco-driving penetration rates smaller than 25%.

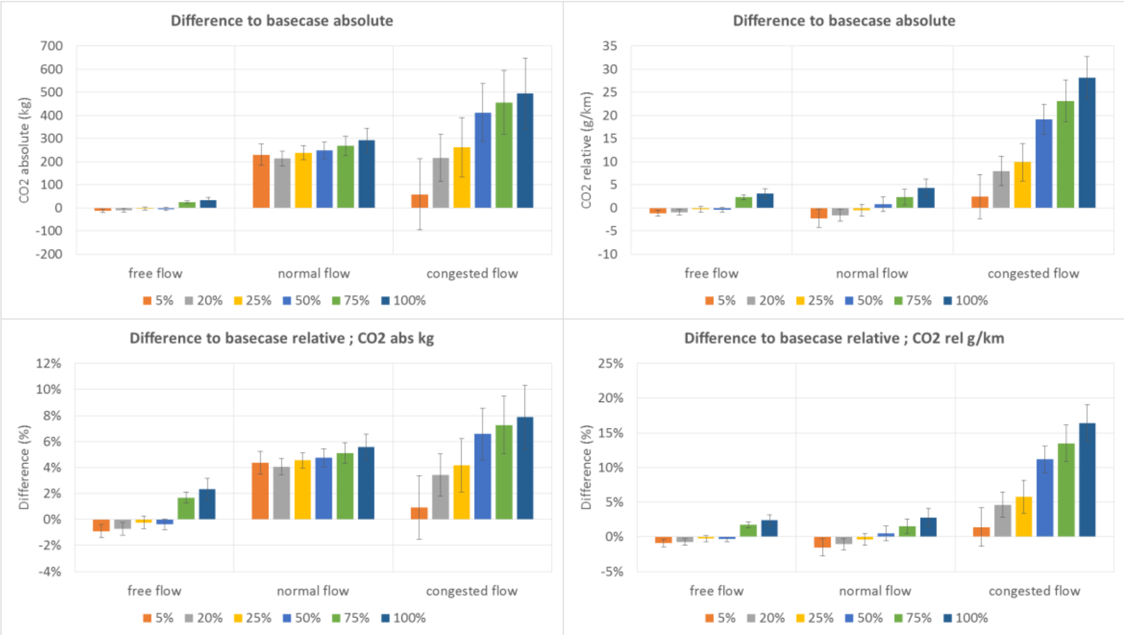


Figure 42: Eco-driving: Madrid case study. Difference basecase

Macro level

When upscaling to the macro level, we obtain there is a little benefit with low penetration levels but an increase either in veh-km and CO2 emissions with higher penetration ones.

Table 28: Eco driving: Madrid case study. Results at macro level

Scenario ID	Traffic	Fleet	Absolute values				
			CO2 abs kg	CO2 rel g/km	veh·km	veh·h	average speed km/h
1030100	Congested	Madrid 2014	1,074,722	182	5,901,526	95,556	62
1030200			1,094,714	184	5,952,811	101,836	58
1030300			1,103,247	185	5,973,023	104,553	57
2030100	Medium		791,739	180	4,403,989	59,823	74
2030200			802,299	181	4,434,283	62,808	71
2030300			808,534	182	4,452,025	64,379	69
3030100	Free		393,049	181	2,174,959	26,257	83
3030200			397,766	182	2,191,489	27,073	81
3030300			400,741	182	2,200,932	27,643	80
1030101	Congested	Madrid 2030	1,062,153	180	5,901,526	95,556	62
1030201			1,081,289	182	5,952,811	101,836	58
1030301			1,089,442	182	5,973,023	104,553	57
2030101	Medium		782,860	178	4,403,989	59,823	74
2030201			793,022	179	4,434,283	62,808	71
2030301			799,013	179	4,452,025	64,379	69
3030101	Free		388,437	179	2,174,959	26,257	83
3030201			392,981	179	2,191,489	27,073	81
3030301			395,836	180	2,200,932	27,643	80

Scenario ID	Traffic	Fleet	Variation respect to the base case				
			CO2 abs kg	CO2 rel g/km	veh·km	veh·h	average speed km/h
1030100	Congested	Madrid 2014	-0.55%	-0.83%	0.28%	-2.81%	3.19%
1030200			1.30%	0.14%	1.15%	3.57%	-2.34%
1030300			2.09%	0.58%	1.50%	6.34%	-4.55%
2030100	Medium		-0.37%	-0.35%	-0.03%	-1.44%	1.43%
2030200			0.96%	0.29%	0.66%	3.48%	-2.72%
2030300			1.74%	0.67%	1.06%	6.07%	-4.71%
3030100	Free		0.28%	0.09%	0.19%	0.62%	-0.43%
3030200			1.48%	0.53%	0.95%	3.75%	-2.69%
3030300			2.24%	0.85%	1.39%	5.93%	-4.29%
1030101	Congested	Madrid 2030	-0.49%	-0.77%	0.28%	-2.81%	3.19%
1030201			1.30%	0.15%	1.15%	3.57%	-2.34%
1030301			2.06%	0.56%	1.50%	6.34%	-4.55%
2030101	Medium		-0.35%	-0.32%	-0.03%	-1.44%	1.43%
2030201			0.94%	0.28%	0.66%	3.48%	-2.72%
2030301			1.71%	0.63%	1.06%	6.07%	-4.71%
3030101	Free		0.27%	0.08%	0.19%	0.62%	-0.43%
3030201			1.45%	0.49%	0.95%	3.75%	-2.69%
3030301			2.18%	0.79%	1.39%	5.93%	-4.29%

1.4.2. TURIN

1.4.2.1. Modelling description

At the micro level, models that describe the process by which drivers follow each other in a traffic stream are generally referred to as “car following” models.

Gipps model is one of the most widely studied and applied models for the microscopic simulation of traffic but it needed some improvement to properly simulate the “standard” drivers and the “eco-drivers”.

The original Gipps car-following model is divided in two parts: a first law “free speed” that manages the user’s behaviour at free flow, when the interactions between the vehicles are low, and a second law “following speed” that is derived from the assumption that the driver wants to keep a sort of safety distance, which manages the user’s behavior when it is engaged in following another vehicle.

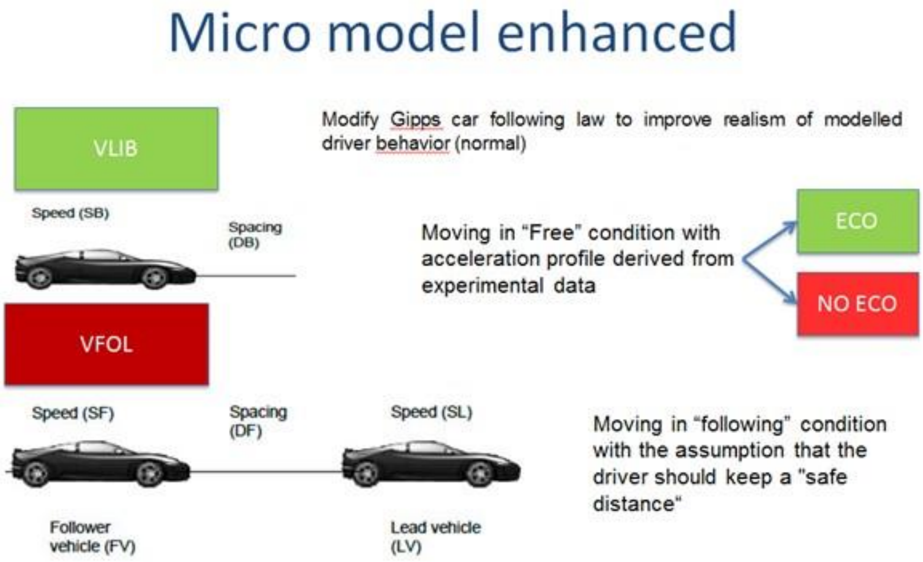


Figure 43: The car following model

The free speed is describe from the following expression:

"free speed" model is the following:

$$V_{lib}(t+T) = V(t) + \alpha \cdot a_n(1 - V(t)/V_d)(\beta + V(t)/V_d)^{\gamma} \qquad (1)$$

where:

T: delay time;

$V(t)$: speed of vehicle at time t;

$V_{lib}(t+T)$: free speed;

a_n: max acceleration;

V_d: max speed (the speed the driver would get if there are not constraints).

We calibrated the model on base of FIAT Ecodrive experimental data got this parameters

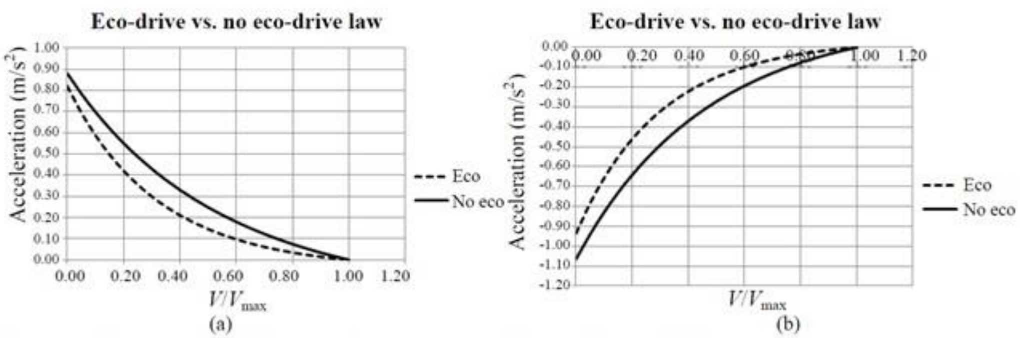


Fig. 8 (a) Acceleration and (b) deceleration function for eco-drive and "normal" driver.

Figure 44: Eco and not Eco driver free flow models

a_n = 5.21, α = 2.60, β=1.89, γ=-4.42 for ecodrive users and a_n = 2.95, α = 1.47, β = 1.91, γ = -2.47 standard users

The following speed part has showed below

The "following speed" model, based on safety distance concept, is as follow:

$$V_{fol}(t+T) = b_n \cdot T + \{b_n^2 \cdot T^2 - b_n[2(x_{n-1} - s_n - x_n) - V_n(t)T + V_{n-1}(t)^2/b_{n-1}]\}^{0.5} \quad (2)$$

where:

$V_n(t)$ and $V_{n-1}(t)$ are, respectively, the follower's and the leader's speed at time t;

n is the follower vehicle;

$n-1$ is the preceding vehicle;

x_n , x_{n-1} are vehicle n and $n-1$ positions;

b_n is the most severe braking that the driver of vehicle n (i.e., the follower) wishes to undertake;

b_{n-1} is the follower's estimate of the leader's maximum braking rate;

s_n is the length of vehicle n plus a safety margin.

The vehicle length + safety margin s_n and the breaking ratio b_n/b_{n-1} have been enhanced with two sub-models able to better describe the user behaviours:

$$s_n = s_{n0} + \gamma V^{\delta} \text{ (effective length)} \quad (3)$$

$$b_n/b_{n-1} = \alpha_0 \cdot (1 - V/V_{max})^{\lambda} \text{ (breaking ratio)} \quad (4)$$

where, s_{n0} is the vehicle length; V_{max} is the maximal speed of the vehicle; γ, δ, α_0, λ are parameters to be calibrated.

has been calibrated getting these parameters

$$\tau = 1 \text{ s}, \lambda = 0.3862$$

$$b = 4 \text{ m/s}^2, s_0 = 11 \text{ m}$$

$$V_{max} = 123 \text{ km/h}, \gamma = 2.561$$

$$\alpha_0 = 1.224, \delta = 0.3446$$

This parameter has been calculated supposing that micro behaviour (speed-distance law) must be coherent with traffic macro behaviour (fundamental diagram); we use the experimental data of a “average lane” of a road section belonging to a two lane motorway considering the fundamental diagram describe by the expression:

$$v = v_{ff}[1 - (k/k_j)^{\alpha}]^{\beta} \qquad (5)$$

where:

v_{ff}: free flow speed;

k: density;

k_j: jam density;

α, β: parameters to be calibrated.

The typical parameters for the traffic on two-lane highway are: v_{ff} = 123 km/h; k_j = 91 Veic/km; α = 1.4;

Modelling process description

The extended GIPPS models has been implemented in AIMSUN simulator by the micro SDK replacing the original GIPPS functions.

The tested section is a corridor of 1,6 km in Turin the same used for evaluate UTC measure.

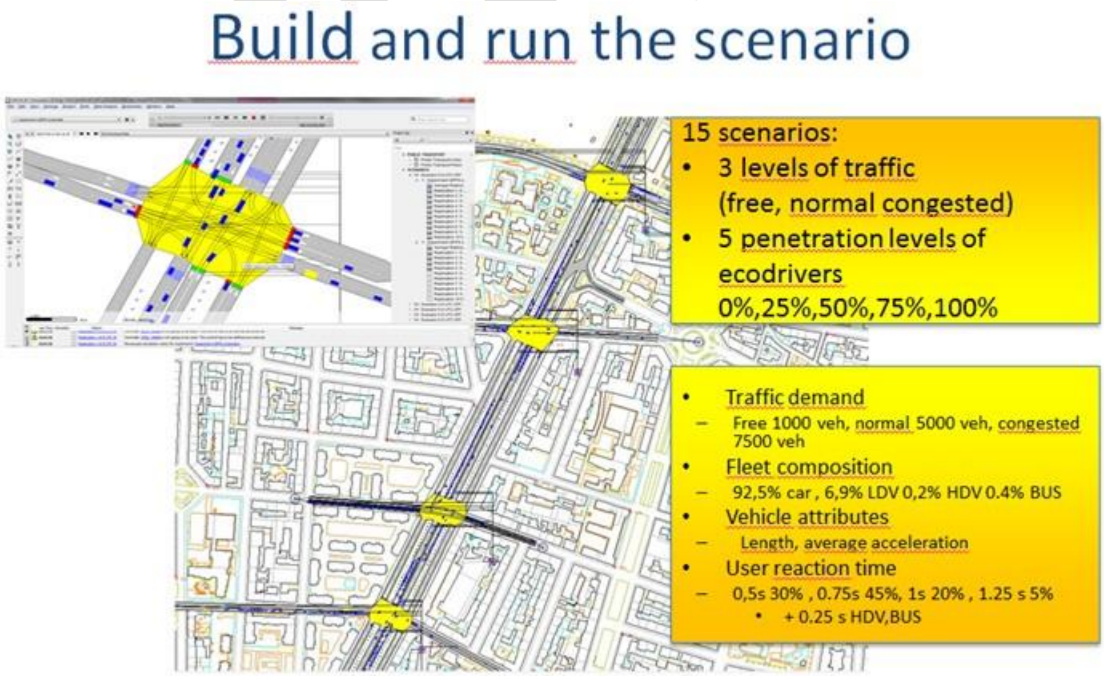


Figure 45: Ecodrive scenario built

Scenarios

We consider three traffic condition free normal and congested involving a demand respectively of 1000, 5000 and 7500 veh per hour and five penetration levels.

Table 29: Eco driving: Turin case study. Scenarios considered at micro level

Scenario ID	Variables varying for each scenario			
	Traffic conditions	Penetration level	Number of replication	Fleet composition
4334	Free	0%	10	Turin 2013
239933932		25%		
239934366		50%		
239934336		75%		
239934351		100%		
4192	Normal	0%		
239933996		25%		
239934208		50%		
239934193		75%		
239934381		100%		
4331	Congested	0%		
239933953		25%		
239934148		50%		
239934133		75%		
239934163		100%		

Table 30: Eco driving: Turin case study. Scenarios considered at macro level

Scenario ID	**Variables varying for each scenario**		
	Traffic conditions	**Penetration level**	**Fleet composition**
30142	Free	0%	Turin 2013 & 2030
30143		25%	
30144		50%	
30145		75%	
30146		100%	
30122	Normal	0%	
30123		25%	
30124		50%	
30125		75%	
30126		100%	
30114	Congested	0%	
30115		25%	
30116		50%	
30117		75%	
30118		100%	

1.4.2.1. Results

Micro level

Table 31: Eco driving: Turin case study. Results at micro level

Scenario ID	Basecase	Variation respect to the base case				
		CO2 abs kg	CO2 rel g/km	veh·km	veh·h	average speed km/h
239933932	4334	-3.8%	-4%	0.0%	4.4%	-4.2%
239934366	4334	-7.2%	-7.5%	0.4%	9.2%	-8.1%
239934336	4334	-12.2%	-11%	-1.2%	10.3%	-10.4%
239934351	4334	-14.7%	-15%	0.3%	16.1%	-13.6%
239933996	4192	-3.6%	-3.5%	0.0%	6.0%	-5.6%
239934208	4192	-7.7%	-7%	-0.9%	10.9%	-10.7%
239934193	4192	-9.4%	-9%	-0.8%	18.7%	-16.4%
239934381	4192	-11.5%	-10%	-1.5%	27.0%	-22.5%
239933953	4331	0.6%	-4%	-1.6%	12.6%	-12.6%
239934148	4331	0.1%	-7.5%	-3.8%	30.7%	-26.4%
239934133	4331	-3.3%	-11%	-8.6%	39.1%	-34.3%
239934163	4331	-6.5%	-15%	-9.6%	41.3%	-36.0%

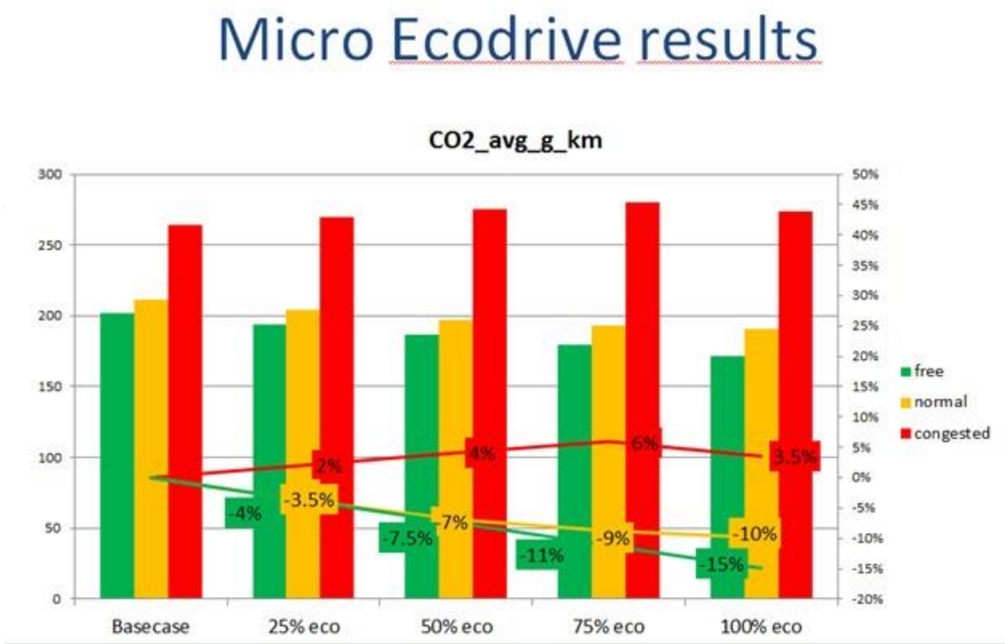


Figure 46: Eco drive: Turin case study. CO2 emissions variation

Basically these are the results in g for km of CO2 divided for level of traffic and penetration rate.

We can see that in case of free flow there is an improvement is consistence and arrive till 15% in case all the drivers drive in eco style. But the level of the traffic changes the situation, in case of traffic normal if there are all ecodrivers the percentage decrease from 15 to 10% and in proportional way in the other cases. In case of traffic congested there isn't any improvement, on the contrary the presence of ecodrivers worsen the situation

As it has been fully explained in the methodology deliverables we estimate the speed intensity curve in order to scale up the micro results at macro level.

Macro level

The analysis is developed on both the current (ACI 2013) and future (2030) fleet compositions, investigating how the ecodriver penetration rate affects traffic and CO2 emission in different traffic conditions.

The CO2 emission for the current fleet composition is reported in the following figures, in terms of g/km and kg respectively, as well as the comparison between current and future fleet compositions.

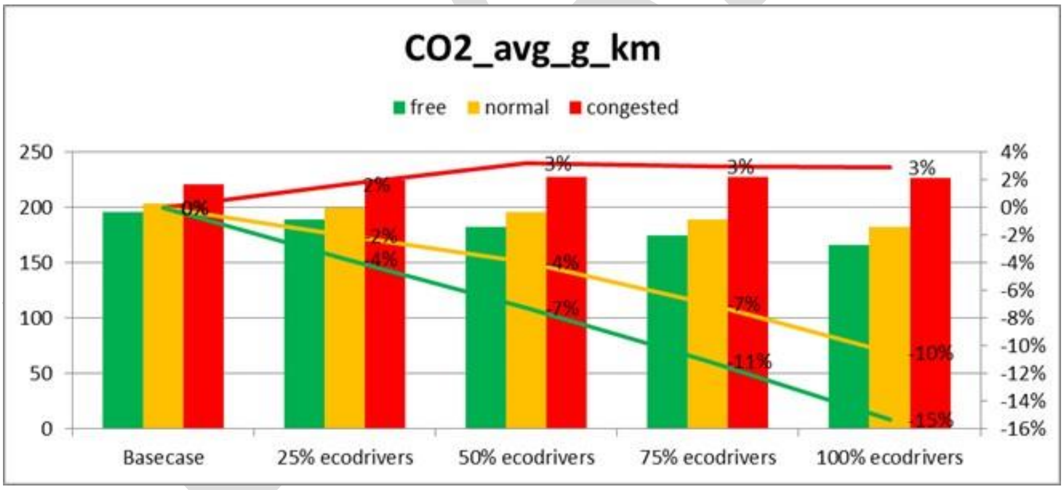


Figure 47: Eco drive: Turin case study. CO2 emissions variation

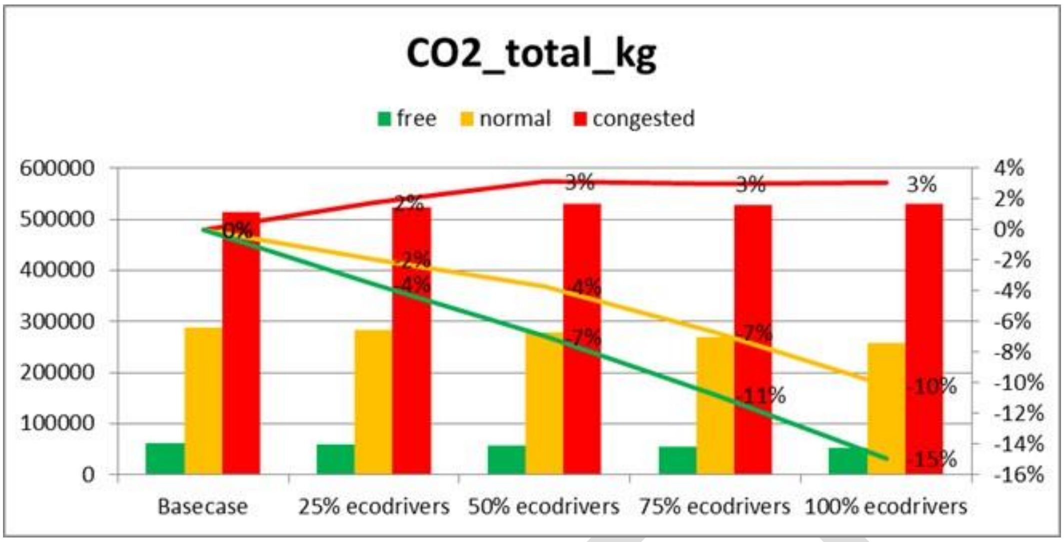


Figure 48: Eco drive: Turin case study. CO2 emissions variation

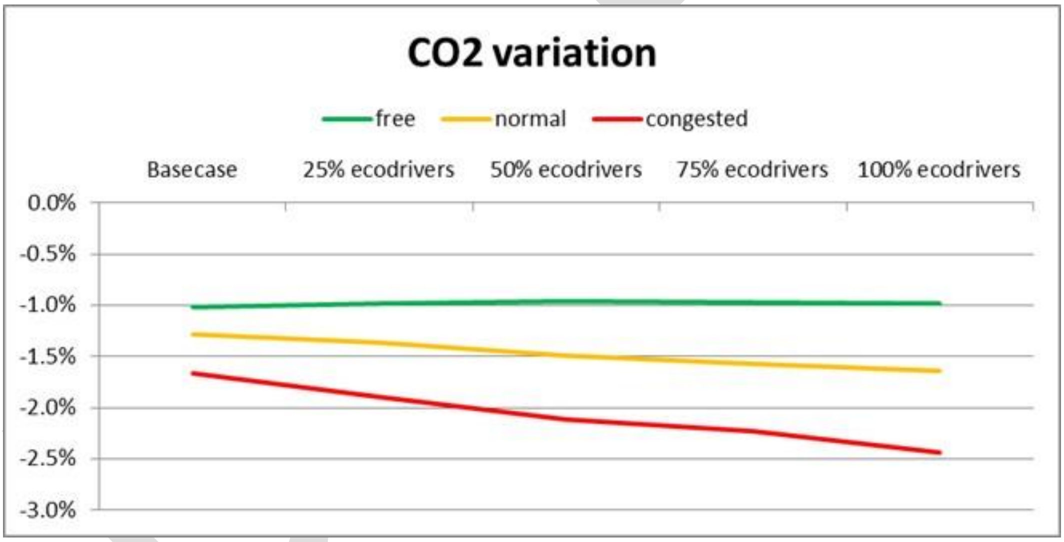


Figure 49: Eco drive: Turin case study. CO2 emissions variation

The ecodriver increase causes a reduction of the CO2 emission in free (-15% for 100% ecodrivers) and normal (-10% for 100% ecodrivers) traffic conditions whereas in congested traffic condition the CO2 emission increases (+3% for 100% ecodrivers). Considering the predicted future fleet composition, the CO2 emission would decrease according to an almost constant 1% rate in free flow condition, to a 1.3%-1.5% rate range in normal traffic condition and to a 1.7%-2.4% range in congested condition.

Table 32: Eco driving: Turin case study. Results at macro level

Scenario ID	Basecase	Variation respect to the base case				
		CO2 abs kg	CO2 rel g/km	veh·km	veh·h	average speed km/h
30143	30142	-4%	-4%	0%	11%	-10%
30144	30142	-7%	-7%	0%	22%	-18%
30145	30142	-11%	-11%	0%	30%	-23%
30146	30142	-15%	-15%	0%	36%	-26%
30123	30122	-2%	-2%	0%	12%	-11%
30124	30122	-4%	-4%	0%	24%	-19%
30125	30122	-7%	-7%	0%	32%	-24%
30126	30122	-10%	-10%	0%	39%	-28%
30115	30114	2%	2%	0%	13%	-12%
30116	30114	3%	3%	0%	25%	-20%
30117	30114	3%	3%	0%	32%	-24%
30118	30114	3%	3%	0%	42%	-30%

1.5. START AND STOP

Measure description

Start and stop is a vehicle specific ICT measure. In contrast to other ICT measure the traffic flow is not influenced, but only the local fuel consumption and CO2 emission is reduced by switching off the engine in case of idle conditions.

Modelling scale

Start and stop is simulated at micro level only. The traffic model used in Madrid and Rome is PTV VISSIM while AIMSUN for Turin. The emissions for start and stop are calculated using AVL CRUISE. Start and stop is considered for passenger cars only. Trucks and busses are simulated without start and stop, since trucks and busses are simulated using COPERT and no data for start and stop equipped trucks and busses are available inside COPERT.

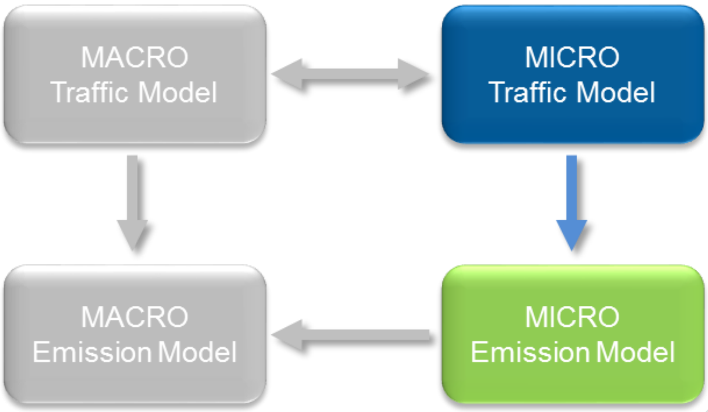


Figure 50: Start and stop modeling scale

1.5.1. Madrid

1.5.1.1. Modelling description

The tested section in the Madrid test case is the same section as used in the scenario for Variable Speed Limit (chapter 1.1).

Modelling process description

Since start and stop does not influence the traffic flow no specific traffic simulation needs to be carried out. Instead the traffic data from basecase and VSL on (see chapter1.1) are used. The application of start and stop is done inside the emission simulation. For the modelling process this means that only the emission simulation needs to be repeated for different penetration levels of start and stop, but no update of the traffic simulation is required. This has the positive side effect that the confidence interval is significantly reduced.

In the micro emission simulation start and stop is considered by separate vehicle models which include start and stop functionality. In this way different penetration levels can easily be considered. The assignment of start and stop vehicles in the entire fleet is done randomly.

Scenarios

Start and stop is considered for 4 different penetration levels of start and stop vehicles (0%, 10%, 50%, 100%). Simulations are carried out for basecase (free flow, normal, congested) and for VSL on conditions (normal and congested).

The scenarios considered for start and stop are shown in Table 3. All scenarios are run for 2 different fleet compositions, Madrid 2014 and Spain 2030.

Table 33: Start and stop: Madrid case study. Scenarios considered

Scenario ID	Variables varying for each scenario				
	Start/stop penetration rate	**ICT measure 2**	**Traffic conditions**	**Number of replications**	**Fleet composition**
101_01	0%	basecase	free	15	Madrid 2014 / Spain 2030
101_02	10%				
101_03	50%				
101_04	100%				
102_01	0%	basecase	normal	15	Madrid 2014 / Spain 2030
102_02	10%				
102_03	50%				
102_04	100%				
103_01	0%	basecase	congested	15	Madrid 2014 / Spain 2030
103_02	10%				
103_03	50%				
103_04	100%				
112_01	0%	VSL on	normal	10	Madrid 2014 / Spain 2030
112_02	10%				
112_03	50%				
112_04	100%				
113_01	0%	VSL on	congested	10	Madrid 2014 / Spain 2030
113_02	10%				
113_03	50%				
113_04	100%				

1.5.1.2. Results

The main important parameter beside the CO2 emission results for start and stop is the percentage of stop time. Since only during the stop time the engine can be shut off, only in this period a saving of fuel consumption and CO2 emission takes place.

Table 34 and Table 35 show the absolute value and the percentage of variation of each variable from the corresponding base case scenarios.

Table 34: Start and stop: Madrid case study. Fleet 2014: Results

Scenario ID	Fleet	Absolute results			Variation with respect to the base case (0% start and stop)	
		CO2 abs kg	CO2 rel g/km	percent stop time	CO2 abs kg	CO2 rel g/km
		kg	g/km	%	%	%
101_01	2014	2943.8	131.11	0	0	0
101_02	2014	2944	131.12	0	0.01	0.01
101_03	2014	2944.5	131.14	0	0.02	0.02
101_04	2014	2943.5	131.09	0	-0.01	-0.02
102_01	2014	5444.8	148.97	1.05	0	0
102_02	2014	5444.1	148.95	1.05	-0.01	-0.01
102_03	2014	5441.5	148.87	1.05	-0.06	-0.07
102_04	2014	5436.2	148.73	1.05	-0.16	-0.16
103_01	2014	6240.8	170.62	3.8	0	0
103_02	2014	6236.4	170.5	3.8	-0.07	-0.07
103_03	2014	6221.5	170.09	3.8	-0.31	-0.31
103_04	2014	6206.1	169.67	3.8	-0.56	-0.56
112_01	2014	5369.5	146.7	0.85	0	0
112_02	2014	5368.3	146.67	0.85	-0.02	-0.02
112_03	2014	5366.9	146.63	0.85	-0.05	-0.05
112_04	2014	5363.5	146.54	0.85	-0.11	-0.11
113_01	2014	6143.7	167.89	3.56	0	0
113_02	2014	6139.2	167.76	3.56	-0.07	-0.08
113_03	2014	6123.9	167.34	3.56	-0.32	-0.33
113_04	2014	6109.4	166.95	3.56	-0.56	-0.56

Table 35: Start and stop: Madrid case study. Fleet 2030: Results

Scenario ID	Fleet	Absolute results			Variation with respect to the base case (0% start and stop)	
		CO2 abs kg	CO2 rel g/km	percent stop time	CO2 abs kg	CO2 rel g/km
		kg	g/km	%	%	%
101_01	2030	2756.8	122.78	0	0	0
101_02	2030	2756	122.74	0	-0.03	-0.03
101_03	2030	2756.5	122.77	0	-0.01	-0.01
101_04	2030	2755.7	122.73	0	-0.04	-0.04
102_01	2030	5034.1	137.73	1.05	0	0
102_02	2030	5032.8	137.69	1.05	-0.03	-0.03
102_03	2030	5030.6	137.63	1.05	-0.07	-0.07
102_04	2030	5025.3	137.48	1.05	-0.17	-0.18
103_01	2030	5717	156.29	3.8	0	0
103_02	2030	5717.8	156.32	3.8	0.01	0.02
103_03	2030	5702.8	155.91	3.8	-0.25	-0.24
103_04	2030	5685.6	155.44	3.8	-0.55	-0.54
112_01	2030	4969.1	135.76	0.85	0	0
112_02	2030	4970.1	135.79	0.85	0.02	0.02
112_03	2030	4967.7	135.72	0.85	-0.03	-0.03
112_04	2030	4964.4	135.63	0.85	-0.09	-0.1
113_01	2030	5634.6	153.97	3.56	0	0
113_02	2030	5632.9	153.93	3.56	-0.03	-0.03
113_03	2030	5619.3	153.56	3.56	-0.27	-0.27
113_04	2030	5604.3	153.15	3.56	-0.54	-0.53

The improvement in CO2 emission due to start and stop in the Madrid test case is small. This is caused by the small percentage of stop time, which is zero for free flow conditions and reaches only 3.8% for congested condition.

It is visible that the improvement in CO2 emission increases with higher penetration rate of start and stop vehicles. In general a linear trend can be expected, the non-linearity seen in the data is caused by the confidence interval of the simulation results (see Figure 51 to Figure 54).

For the Madrid case implementation of start and stop is for basecase and VSL on equally effective. This is caused by the fact that due to implementation of VSL the stop time is only marginally influenced and therefore the effect on the CO2 emission is small.

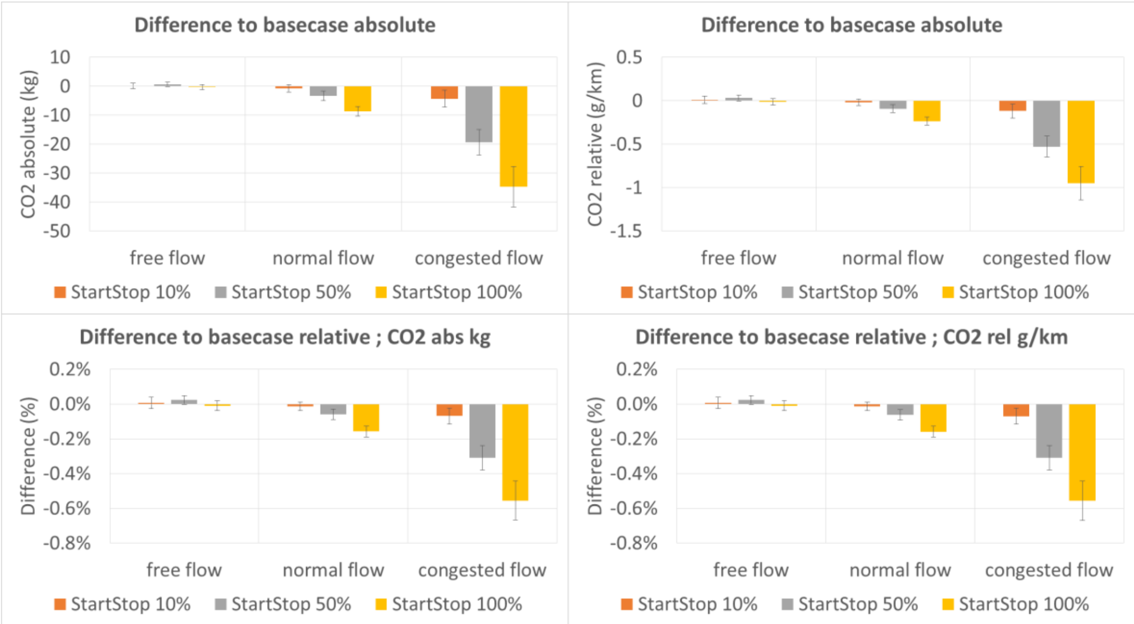


Figure 51: Start and stop: Madrid case study, Fleet 2014, Difference basecase

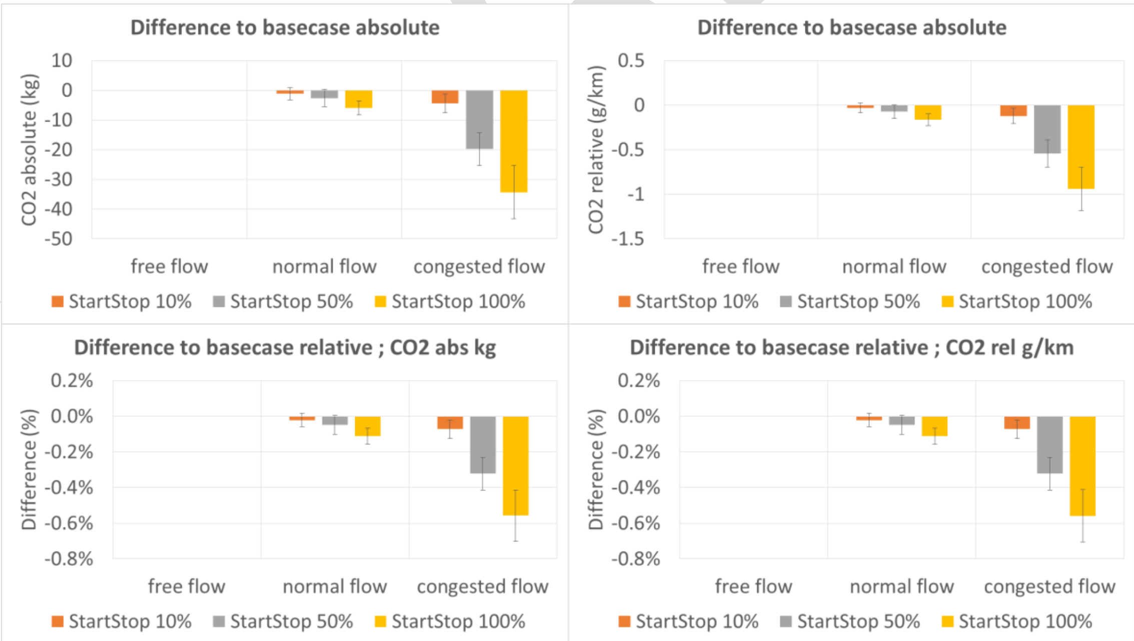


Figure 52: Start and stop: Madrid case study, Fleet 2014, Difference VSL on

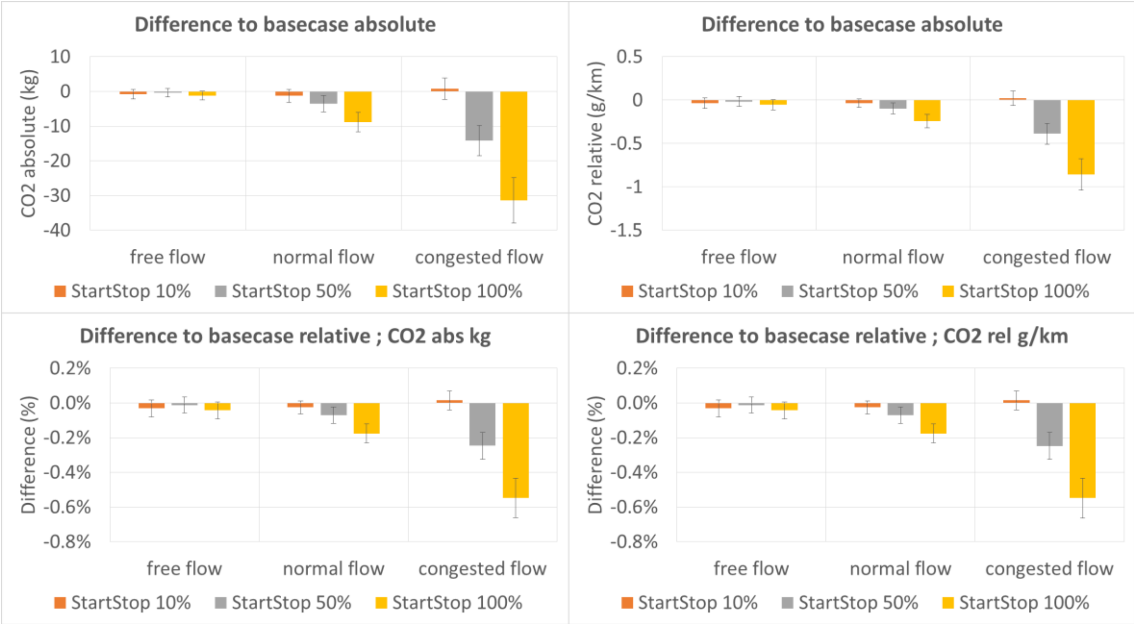


Figure 53: Start and stop: Madrid case study, Fleet 2030, Difference basecase

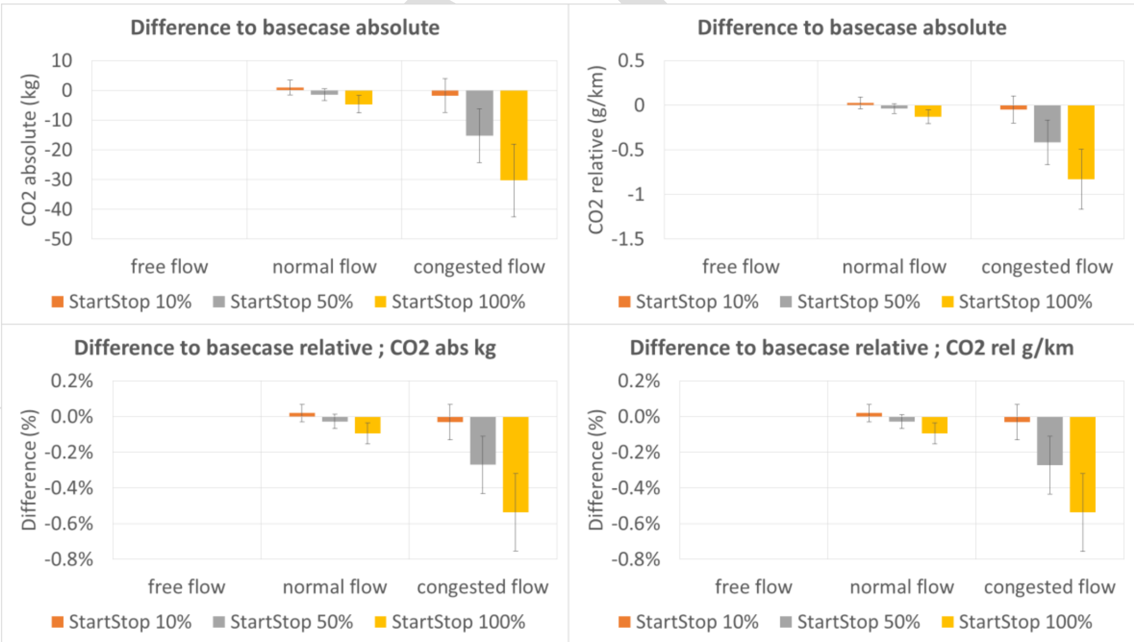


Figure 54: Start and stop: Madrid case study, Fleet 2030, Difference VSL on

As it can be seen from Figure 55 the relation between stop time and CO2 improvement is nearly linear for small stop time percentages. Differences from this trend can be observed and are caused by the confidence interval as well as by the working principle of the start/stop control. At a 2nd short stop directly after another one the engine is often not stopped since a delay time must be reached to stop the engine after a previous start.

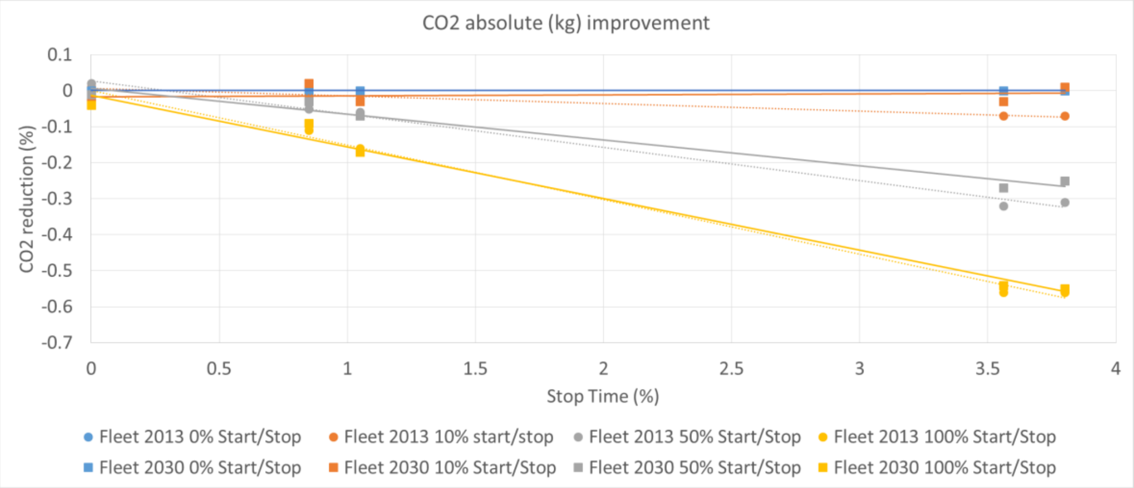


Figure 55: Start and stop: Madrid case study, CO2 improvement versus stop time

1.5.2. Turin

1.5.2.1. Modelling description

Modelling process description

Since start and stop does not influence the traffic flow no specific traffic simulation needs to be carried out. Instead the traffic data from basecase and UTC on (see chapter 1.3) are used. The application of start and stop is done inside the emission simulation. For the modelling process this means that only the emission simulation needs to be repeated for different penetration levels of start and stop, but no update of the traffic simulation is required. This has the positive side effect that the confidence interval is significantly reduced.

In the micro emission simulation start and stop is considered by separate vehicle models which include start and stop functionality. In this way different penetration levels can easily be considered. The assignment of start and stop vehicles in the entire fleet is done randomly.

Scenarios

Start and stop is considered for 4 different penetration levels of start and stop vehicles (0%, 10%, 50%, 100%). Simulations are carried out for all three traffic conditions (free, normal, and congested) for basecase and for normal and congested flow for UTC on conditions. Free flow for UTC on conditions is not considered since during that time of the day UTC is not active.

The scenarios considered for start and stop are shown in Table All scenarios are run for 2 different fleet compositions, Turin 2013 and Italy 2030.

Table 36: Start and stop: Turin case study. Scenarios considered

Scenario ID	Variables varying for each scenario				
	Start/stop penetration rate	ICT measure 2	Traffic conditions	Number of replications	Fleet composition
4334_01	0%	basecase	free	10	Turin 2013 / Italy 2030
4334_02	10%				
4334_03	50%				
4334_04	100%				
4192_01	0%	basecase	normal	10	Turin 2013 / Italy 2030
4192_02	10%				
4192_03	50%				
4192_04	100%				
4331_01	0%	basecase	congested	10	Turin 2013 / Italy 2030
4331_02	10%				
4331_03	50%				
4331_04	100%				
4265_01	0%	UTC on	normal	10	Turin 2013 / Italy 2030
4265_02	10%				
4265_03	50%				
4265_04	100%				
887_01	0%	UTC on	congested	10	Turin 2013 / Italy 2030
887_02	10%				
887_03	50%				
887_04	100%				

1.5.2.2. Results

Micro level

The main important parameter beside the CO2 emission results for start and stop is the percentage of stop time. Since only during the stop time the engine can be shut off, only in this period a saving of fuel consumption and CO2 emission can take place.

Table 37 and Table 38 show the absolute value and the percentage of variation of each variable from the corresponding base case scenarios.

Table 37: Start and stop: Turin case study. Fleet 2013: Results

Scenario ID	Fleet	Absolute results			Variation with respect to the base case (0% start and stop)	
		CO2 abs kg	CO2 rel g/km	percent stop time	CO2 abs kg	CO2 rel g/km
		kg	g/km	%	%	%
4334_01	2013	299.4	201.76	36.51	0	0
4334_02	2013	297.8	200.68	36.51	-0.53	-0.54
4334_03	2013	290.5	195.78	36.51	-2.97	-2.96
4334_04	2013	281.9	190.02	36.51	-5.85	-5.82
4192_01	2013	1223.7	211.9	39.32	0	0
4192_02	2013	1215.4	210.46	39.32	-0.68	-0.68
4192_03	2013	1181.8	204.64	39.32	-3.42	-3.43
4192_04	2013	1139.8	197.37	39.32	-6.86	-6.86
4331_01	2013	2633.2	264.16	56.45	0	0
4331_02	2013	2599.6	260.78	56.45	-1.28	-1.28
4331_03	2013	2465.9	247.35	56.45	-6.35	-6.36
4331_04	2013	2299.3	230.61	56.45	-12.68	-12.7
4265_01	2013	1133.3	195.54	35.51	0	0
4265_02	2013	1125.9	194.27	35.51	-0.65	-0.65
4265_03	2013	1099.7	189.73	35.51	-2.96	-2.97
4265_04	2013	1065.4	183.83	35.51	-5.99	-5.99
887_01	2013	2541.2	252.83	54.66	0	0
887_02	2013	2511.9	249.91	54.66	-1.15	-1.15
887_03	2013	2390.3	237.8	54.66	-5.94	-5.94
887_04	2013	2239.8	222.82	54.66	-11.86	-11.87

Table 38: Start and stop: Turin case study. Fleet 2030: Results

Scenario ID	Fleet	Absolute results			Variation with respect to the base case (0% start and stop)	
		CO2 abs kg	CO2 rel g/km	percent stop time	CO2 abs kg	CO2 rel g/km
		kg	g/km	%	%	%
4334_01	2030	261.8	176.47	36.51	0	0
4334_02	2030	260.4	175.52	36.51	-0.53	-0.54
4334_03	2030	255.2	172.02	36.51	-2.52	-2.52
4334_04	2030	248.6	167.57	36.51	-5.04	-5.04
4192_01	2030	1064	184.23	39.32	0	0
4192_02	2030	1057.1	183.04	39.32	-0.65	-0.65
4192_03	2030	1031.5	178.62	39.32	-3.05	-3.05
4192_04	2030	1000.8	173.3	39.32	-5.94	-5.93
4331_01	2030	2269.7	227.68	56.45	0	0
4331_02	2030	2244.3	225.13	56.45	-1.12	-1.12
4331_03	2030	2145	215.16	56.45	-5.49	-5.5
4331_04	2030	2021.4	202.73	56.45	-10.94	-10.96
4265_01	2030	989.2	170.68	35.51	0	0
4265_02	2030	984.2	169.81	35.51	-0.51	-0.51
4265_03	2030	963.3	166.2	35.51	-2.62	-2.62
4265_04	2030	938.9	162	35.51	-5.08	-5.09
887_01	2030	2194.7	218.35	54.66	0	0
887_02	2030	2172	216.09	54.66	-1.03	-1.04
887_03	2030	2081.3	207.06	54.66	-5.17	-5.17
887_04	2030	1969.6	195.94	54.66	-10.26	-10.26

The improvement in CO2 emission due to start and stop in the Turin test case reaches up to 13% for congested condition at basecase for the fleet 2013. Similar as in the Rome test case the improvement is smaller for the fleet 2030 reaching only 11 %. The total improvement is higher compared to the Rome test case since also the percentage of stop time is higher in Turin. While for Rome the stop time reached about 40% in congested condition, it reaches close to 60% in the Turin test case. Stop times for normal and free conditions in Turin are in the same range as the values for congested condition in Rome. The visible improvements are for these comparable cases also similar.

It is visible that the improvement in CO2 emission increases with higher penetration rate of start and stop vehicles. In general a linear trend can be expected, the non-linearity seen in the data is caused by the confidence interval of the simulation results (see Figure 56 to Figure 59).

For the Turin case implementation of start and stop at UTC is less effective compared to the basecase. This is caused by the fact that due to implementation of UTC the stop time is reduced and therefore the effect on the CO2 emission is reduced.

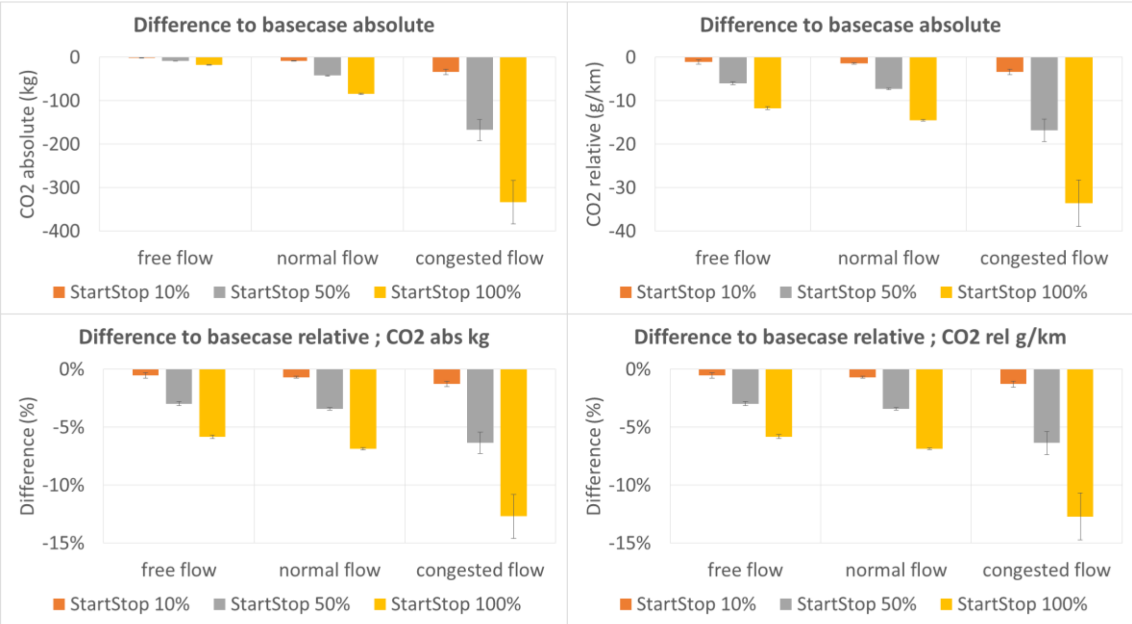


Figure 56: Start and stop: Turin case study. Fleet 2013: Difference basecase

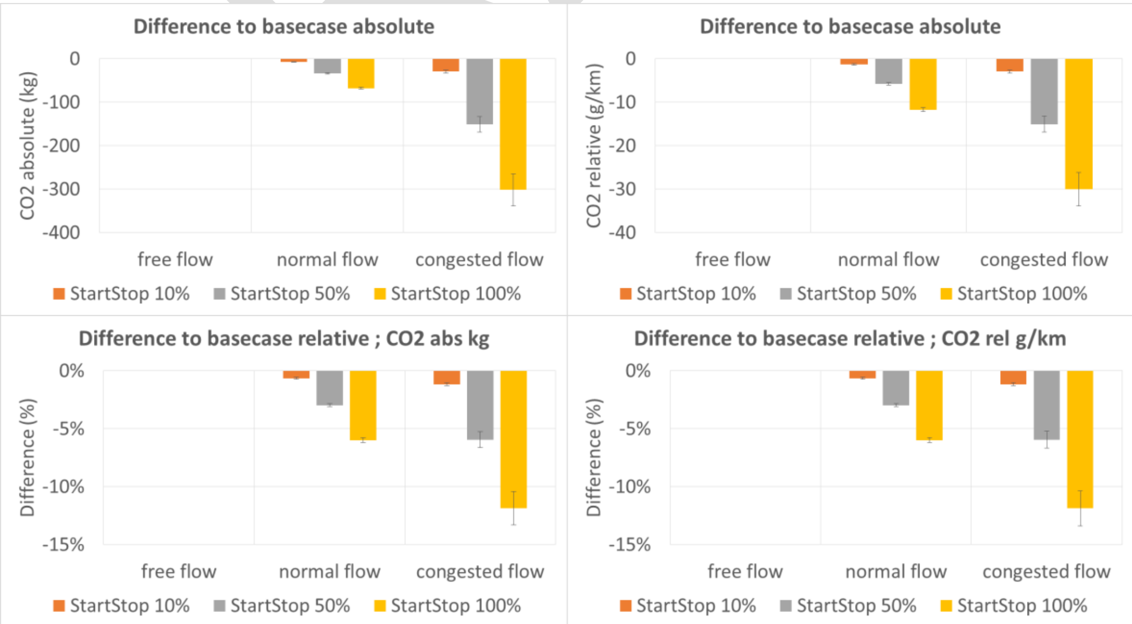


Figure 57: Start and stop: Turin case study. Fleet 2013: Difference UTC on

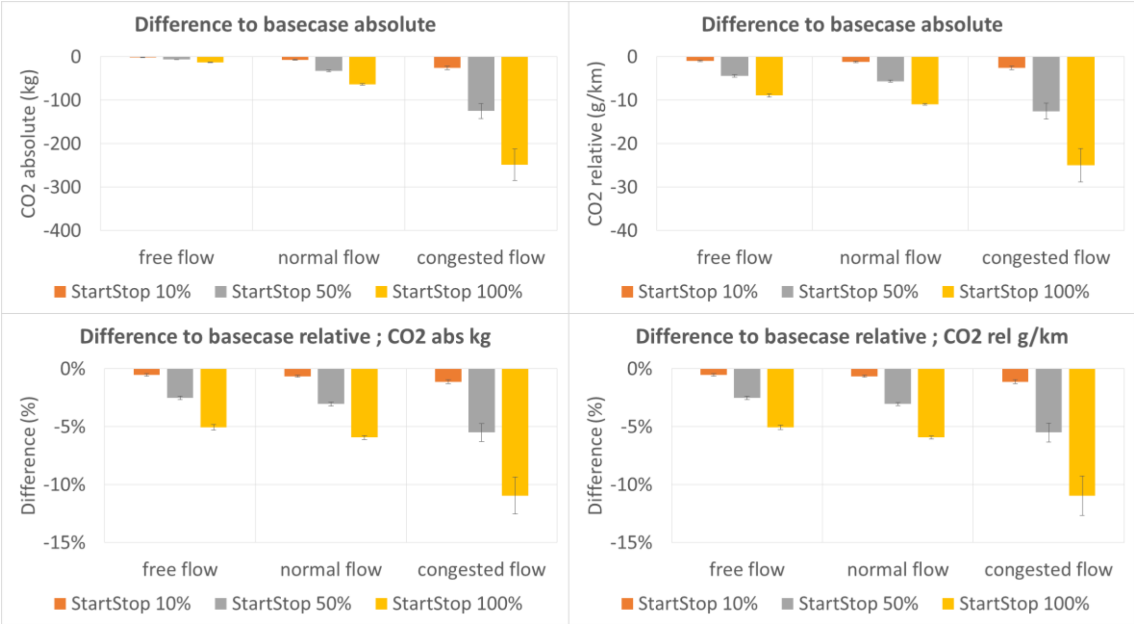


Figure 58: Start and stop: Turin case study. Fleet 2030: Difference basecase

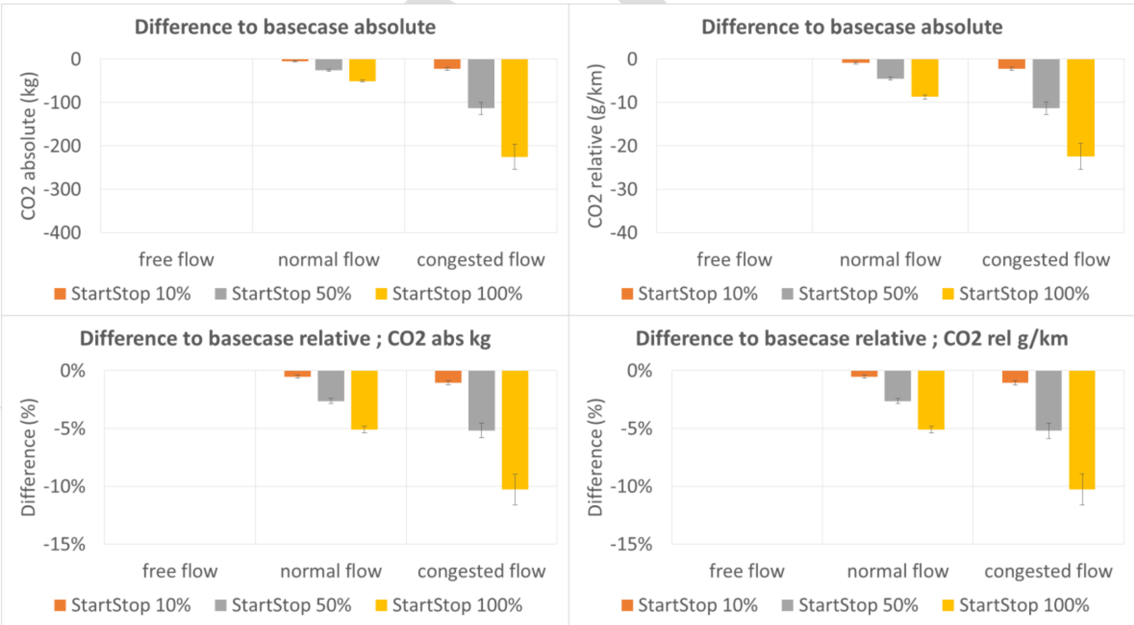


Figure 59: Start and stop: Turin case study. Fleet 2030: Difference UTC on

As it can be seen from Figure 60 the relation between stop time and CO2 improvement is not linear anymore when considering an additional point that for 0% stop time there is no CO2 reduction. The trend line shown considers a polynomic shape 2nd order.

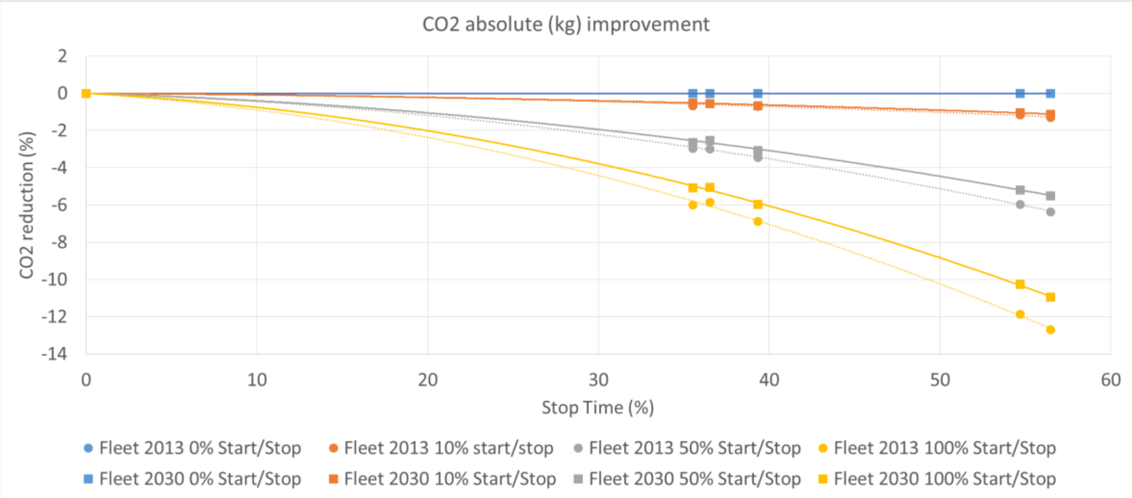


Figure 60: Start and stop: Turin case study. CO2 improvement versus stop time

1.5.3. Rome

1.5.3.1. Modelling description

Modelling process description

Since start and stop does not influence the traffic flow no specific traffic simulation needs to be carried out. Instead the traffic data from basecase and UTC on (see chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**) are used. The application of start and stop is done inside the emission simulation. For the modelling process this means that only the emission simulation needs to be repeated for different penetration levels of start and stop, but no update of the traffic simulation is required. This has the positive side effect that the confidence interval is significantly reduced.

In the micro emission simulation start and stop is considered by separate vehicle models which include start and stop functionality. In this way different penetration levels can easily be considered. The assignment of start and stop vehicles in the entire fleet is done randomly.

Scenarios

Start and stop is considered for 4 different penetration levels of start and stop vehicles (0%, 10%, 50%, 100%). Simulations are carried out for congested conditions only for basecase and for UTC on conditions.

The scenarios considered for start and stop are shown in Table All scenarios are run for 2 different fleet compositions, Rome 2013 and Italy 2030.

Table 39: Start and stop: Rome case study. Scenarios considered

Scenario ID	Variables varying for each scenario				
	Start/stop penetration rate	**ICT measure 2**	**Traffic conditions**	**Number of replications**	**Fleet composition**
303_01	0%	basecase	congested	15	Rome 2013 / Italy 2030
303_02	10%				
303_03	50%				
303_04	100%				
313_01	0%	UTC on	congested	15	Rome 2013 / Italy 2030
313_02	10%				
313_03	50%				
313_04	100%				

1.5.3.2. Results

The main important parameter beside the CO2 emission results for start and stop is the percentage of stop time. Since only during the stop time the engine can be shut off, only in this period a saving of fuel consumption and CO2 emission takes place.

Table 40 and Table 41 show the absolute value and the percentage of variation of each variable from the corresponding base case scenarios.

Table 40: Start and stop: Rome case study. Fleet 2013: Results

Scenario ID	Fleet	Absolute results			Variation with respect to the base case (0% start and stop)	
		CO2 abs kg	**CO2 rel g/km**	**percent stop time**	**CO2 abs kg**	**CO2 rel g/km**
		kg	g/km	%	%	%
303_01	2013	13080.5	349.1	39.25	0	0
303_02	2013	13005.2	347.08	39.25	-0.58	-0.58
303_03	2013	12703.4	338.94	39.25	-2.88	-2.91
303_04	2013	12329.2	328.84	39.25	-5.74	-5.8
313_01	2013	12795.5	332.21	35.52	0	0
313_02	2013	12730.5	330.51	35.52	-0.51	-0.51
313_03	2013	12477.4	323.9	35.52	-2.49	-2.5
313_04	2013	12156	315.49	35.52	-5	-5.03

Table 41: Start and stop: Rome case study. Fleet 2030: Results

Scenario ID	Fleet	Absolute results			Variation with respect to the base case (0% start and stop)	
		CO2 abs kg	CO2 rel g/km	percent stop time	CO2 abs kg	CO2 rel g/km
		kg	g/km	%	%	%
303_01	2030	11759.3	313.75	39.25	0	0
303_02	2030	11705.9	312.32	39.25	-0.45	-0.46
303_03	2030	11489.9	306.49	39.25	-2.29	-2.31
303_04	2030	11227.6	299.41	39.25	-4.52	-4.57
313_01	2030	11557.6	300.03	35.52	0	0
313_02	2030	11514.6	298.91	35.52	-0.37	-0.37
313_03	2030	11331.9	294.13	35.52	-1.95	-1.97
313_04	2030	11106.6	288.24	35.52	-3.9	-3.93

The improvement in CO2 emission due to start and stop in the Rome test case reaches up to 6% for the fleet 2013. For the fleet 2030 the improvement is smaller and reaches only 4.6% at max. The higher improvement compared to the Madrid test case is caused by the higher percentage of stop time which reaches 40% in Rome.

It is visible that the improvement in CO2 emission increases with higher penetration rate of start and stop vehicles. In general a linear trend can be expected, the non-linearity seen in the data is caused by the confidence interval of the simulation results (see Figure 61 and Figure 62).

For the Rome case implementation of start and stop at UTC is less effective compared to the basecase. This is caused by the fact that due to implementation of UTC the stop time is reduced and therefore the effect on the CO2 emission is reduced.

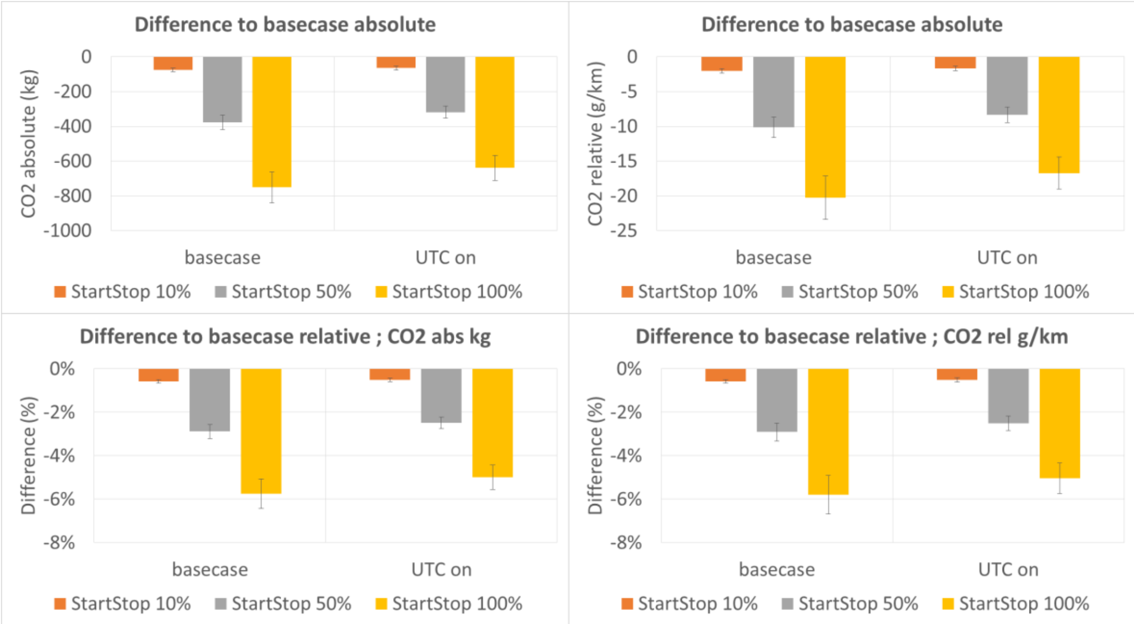


Figure 61: Start and stop: Rome case study. Fleet 2013: Difference basecase and UTC on

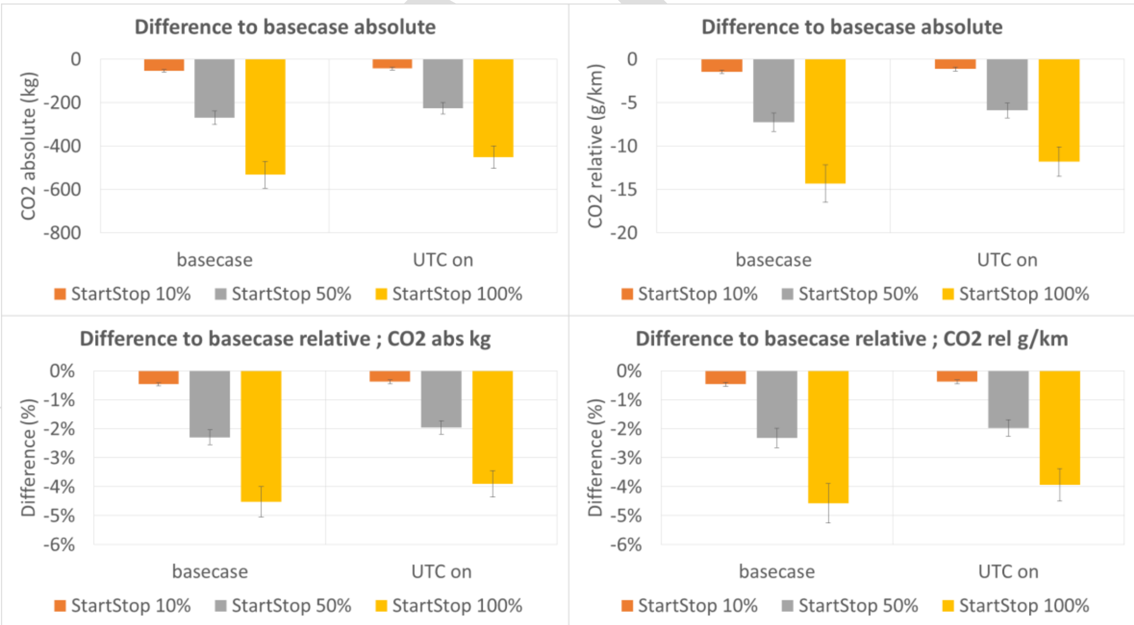


Figure 62: Start and stop: Rome case study. Fleet 2030: Difference basecase and UTC on

As it can be seen from Figure 63 the relation between stop time and CO2 improvement is nearly linear. Differences from this trend can be observed and are caused by the confidence interval as well as by the working principle of the start/stop control. At a 2nd short stops directly after another one the engine is often not stopped since a delay time must be reached to stop the engine after a previous start.

This effect is also illustrated when putting together the numbers for all 3 test sites (Madrid, Rome, Turin; see Figure 64). The polynomic trend line is matched by the results of all 3 cities. It is also visible that the reduction is CO2 emission is smaller for the newer fleet (2030). Extrapolating the trend line also an additional point could be found since for 100% stop time the CO2 reduction would be exactly 100% (engine is stopped all the time).

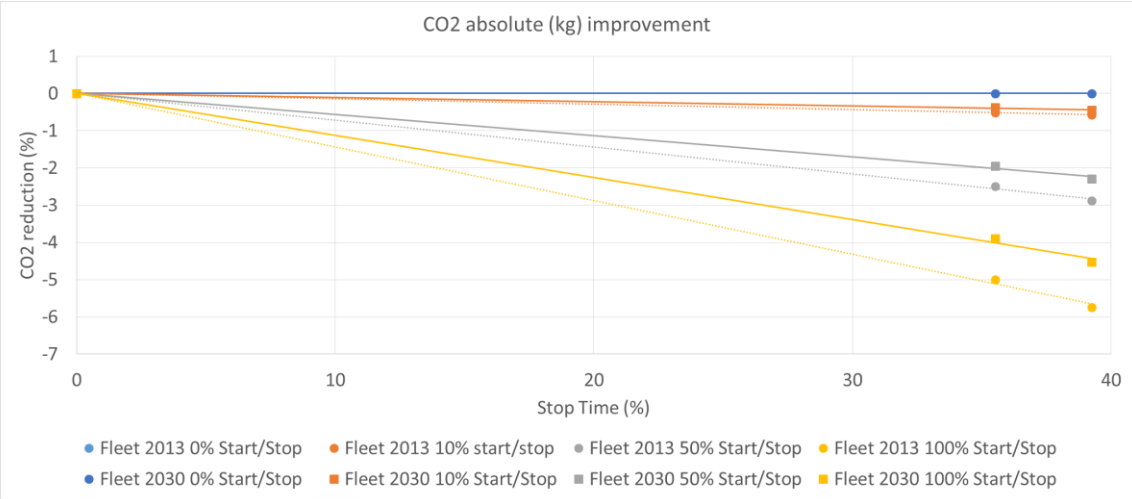


Figure 63: Start and stop: Rome case study. CO2 improvement versus stop time

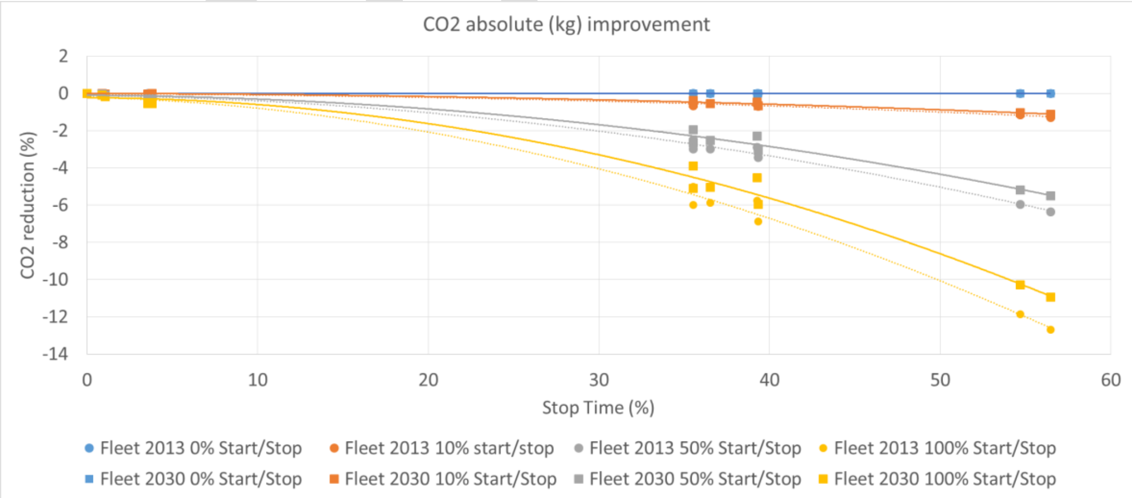


Figure 64: Start and stop: All case studies (Madrid, Rome, Turin). CO2 improvement versus stop time

1.6. ADAPTIVE CRUISE CONTROL SYSTEMS

Measure description

Adaptive Cruise Control (ACC) is an Advanced Driver Assistance System (ADAS) which controls the velocity of a vehicle subject to the distance to the vehicle in front in an automatic way. For measuring the distance, radar sensors are usually used whereas in newer systems camera technology or lidar sensors are used. If the measured distance is larger than a safe distance to the vehicle in front, which is specified by the driver, the vehicle is automatically accelerated. In turn, if the vehicle gets closer and closer to the safe distance the vehicle is decelerated.

As the acceleration behaviour of a vehicle has a big impact on its emissions, Adaptive Cruise Control can reduce the vehicle emissions if the controllers implemented in the corresponding Electronic Control Units (ECUs) in the vehicle are parameterized in a way that harsh and frequent accelerations are avoided.

Modelling scale

As ACC influences the speed profiles of single vehicles inside a traffic simulation, it is particularly interesting to investigate this technology on a microscopic scale. For this, only the blocks Vehicle control micro model, MICRO Traffic model and MICRO Emission model of the integrated simulation platform are considered (see Figure 65).

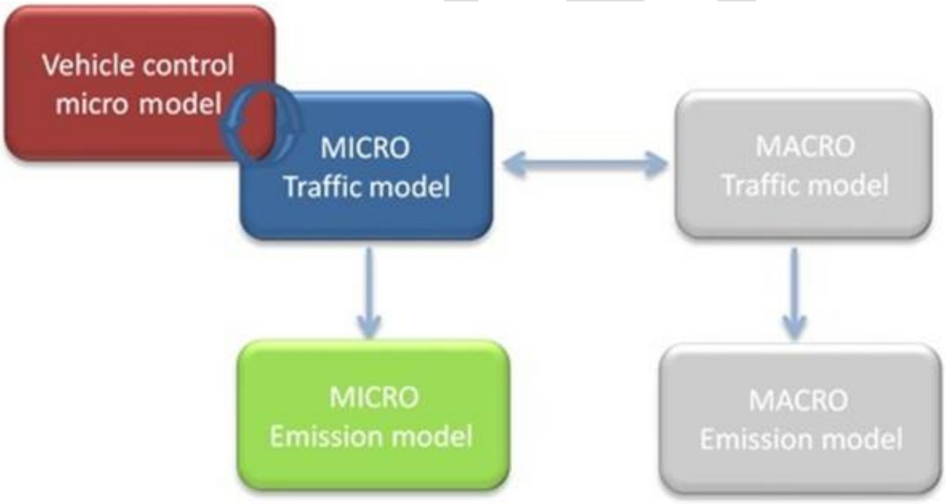


Figure 65: ACC modelling scale

1.6.1. MUNICH

1.6.1.1. Modelling description

Modelling process description

The ACC technology is integrated in a microscopic traffic simulator such as Aimsun or SUMO via plugins which are developed in the ICT-Emissions project. The plugins (sensor model) establish a connection to the software platform MESSINA, which provides the models for ACC and for the physical and mechanical constraints of a vehicle's powertrain (see Figure 66).

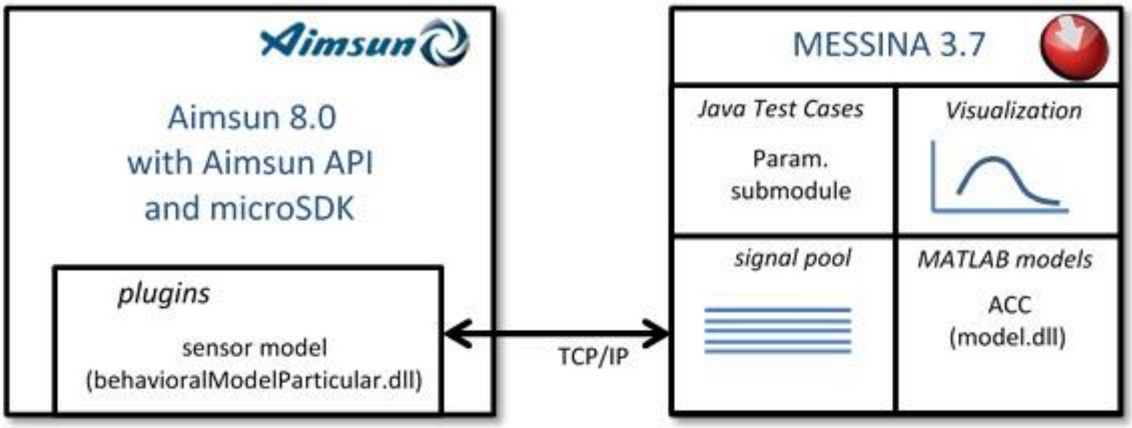


Figure 66: Main components of the ACC simulator

The Vehicle control model interacts with the MICRO Traffic model on-line when a simulation is executed and computes the speed profiles of the vehicles in the simulation in real-time subject to their environment. The emissions are computed from the speed profiles by the MICRO Emission model after the simulation has finished.

In each simulation step information about the velocities of the vehicles in the traffic simulation as well as about the distances to the preceding vehicles is transmitted to the ACC model in MESSINA. The latter computes from this data the velocities of the vehicles for the next simulation step. Hence, there is a continuous exchange of information between the traffic simulator and the vehicle simulator in MESSINA.

For the scientific analysis of the ACC technology inside the traffic simulation a parameterization submodule in MESSINA is used. In the parameterization submodule test cases can be implemented using the programming language Java. The test cases specify important parameters for the simulation, such as the road network, the traffic level and also the share of ACC vehicles in the microscopic traffic simulation. The ACC vehicles are distributed in a random way among all vehicles in the scenario, which can have stochastic effects on the speed profiles and, hence, on the emissions. To this end, the parameterization submodule provides the possibility to execute several replications of the same test case automatically. Moreover, different test cases including different parameterizations can also be executed in an automated fashion. Hence, simulations can run over night or over the weekend.

Scenarios

For the investigation of the ACC technology in microscopic traffic simulations two urban scenarios are selected. The first scenario is part of an urban ring road in Munich (Mittlerer Ring Nord) with multiple access roads (see Figure 67). The second scenario is part of the city quarter Schwabing in Munich (see Figure 68), which exhibits several crossroads partly controlled by traffic lights.

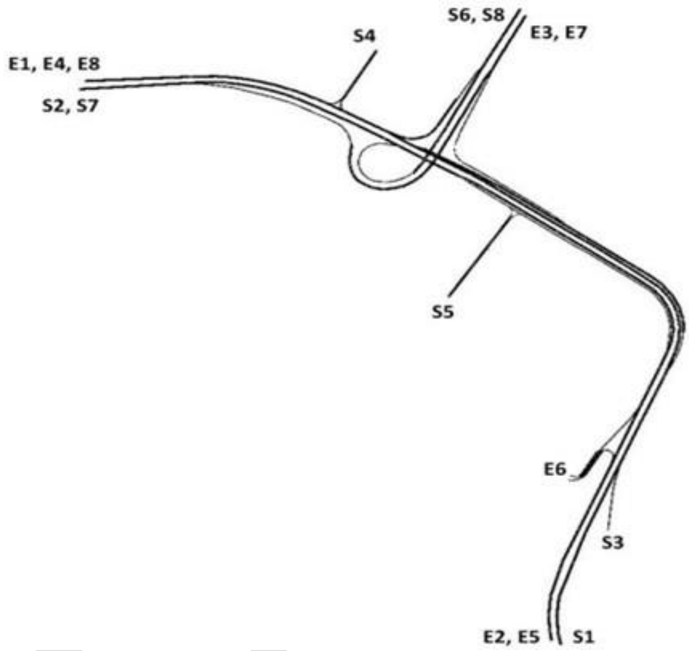


Figure 67: Scenario 1 - Urban ring road

Figure 68: Scenario 2 - City quarter

In the ring road scenario the major traffic flow is on the ring road. There are only minor traffic flows on the access roads. In the city quarter scenario the traffic flow is almost equal over the whole road network.

In both scenarios two traffic levels are considered – a low traffic level with approx. 8 veh / km and a medium traffic level with approx. 14 veh / km. There are 200 vehicles in the traffic scenarios, except in the low traffic density case in the city quarter scenario. Here, there are only 100 vehicles in the scenario, which also results in a lower amount of absolute CO2 emissions over all ACC penetration rates in Section 1.4.1.2.

Furthermore, in both scenarios the penetration rate of ACC vehicles is increased in discrete steps from 0% to 100%. For a given penetration rate multiple replications are executed and the mean value is computed from the results obtained from the different replications.

The different parameterizations which are investigated in the simulations are summarized in Table 42:

Table 42: ACC: Munich case study. Scenarios

Scenario ID	Scenarios		
	Penetration rate	Traffic conditions	Number of replications
141_01	0%	Urban ring road, low traffic level	30
141_02	20%		
141_03	40%		
141_04	60%		
141_05	80%		
141_06	100%		
142_01	0%	Urban ring road, medium traffic level	30
142_02	20%		
142_03	40%		
142_04	60%		
142_05	80%		
142_06	100%		
143_01	0%	City quarter, low traffic level	30
143_02	20%		
143_03	40%		
143_04	60%		
143_05	80%		
143_06	100%		
144_01	0%	City quarter, medium traffic level	30
144_02	20%		
144_03	40%		
144_04	60%		
144_05	80%		
144_06	100%		

1.6.1.2. Results

The absolute amounts of CO2 emissions which result from the simulations are shown in Table 43. Mean values over all replications are given for the absolute CO2 emissions. Furthermore, the relative amount of CO2 emissions per kilometre is given. Moreover, for both the absolute and the relative amount of CO2 emissions the reduction of CO2 emissions with respect to the basecase is given. The basecase is the respective scenario with 0% ACC vehicles.

Table 43: ACC: Munich case study. Results

Scenario ID	Absolute results		Variation with respect to the base case (0% ACC)	
	CO2 abs kg	CO2 rel g/km	CO2 abs kg	CO2 rel g/km
	kg	g/km	%	%
141_01	59.74	144.7	-	-
141_02	58.86	142.5	-1.48	-1.48
141_03	57.71	139.7	-3.40	-3.40
141_04	56.58	137.0	-5.30	-5.30
141_05	55.86	135.3	-6.49	-6.49
141_06	54.48	131.9	-8.81	-8.81
142_01	59.96	145.2	-	-
142_02	59.04	143.0	-1.54	-1.54
142_03	58.24	141.0	-2.87	-2.87
142_04	57.29	138.7	-4.46	-4.46
142_05	56.19	136.1	-6.28	-6.28
142_06	55.52	134.4	-7.42	-7.42
143_01	19.84	200.4	-	-
143_02	19.79	199.9	-0.27	-0.27
143_03	19.67	198.7	-0.84	-0.84
143_04	19.57	197.7	-1.35	-1.35
143_05	19.52	197.1	-1.63	-1.63
143_06	19.42	196.2	-2.10	-2.10
144_01	47.92	242.0	-	-
144_02	47.51	240.0	-0.85	-0.85
144_03	47.56	240.2	-0.76	-0.76
144_04	47.38	239.3	-1.12	-1.12
144_05	47.22	238.5	-1.47	-1.47
144_06	47.23	238.5	-1.45	-1.45

As the results in Table 40 show, the reduction of CO2 emissions increases if the share of ACC vehicles in the traffic scenarios is increased. Considering the urban ring road scenario the largest CO2 reduction results from a low traffic level and 100% ACC vehicles. If the traffic level is increased the CO2 reduction is not as large but still prominent. This can be explained from the fact that vehicles entering the ring road via the access roads slightly disturb the traffic flow on the ring. This results in speed profiles which are not as flat as in the case of a low traffic density.

The reduction of CO2 emissions in the city quarter scenarios, in turn, is smaller than in the urban ring road scenarios. This is due to the fact that the vehicles in the city scenario often have to stop at the crossroads and re-accelerate again. This disturbs the traffic flow.

1.6.2. TURIN

1.6.2.1. Modelling description

For the simulation of ITS measures which are based on modern vehicular technology (such as ADAS vehicle) a specific behaviour of the vehicle need to be simulated and a detailed model of the vehicles in the traffic scenarios is necessary.

The simulation of mechanisms which control the velocity of the cars and influence the car-following behaviour rely on the real-time interaction between the micro traffic simulator and the vehicle simulator, since in each simulation step the context of a vehicle influences its acceleration behaviour in the next simulation step.

The run-time processing loop between the micro traffic model and the vehicle simulator and presents the architecture of a system which is designed for a neat interaction between these two modules.

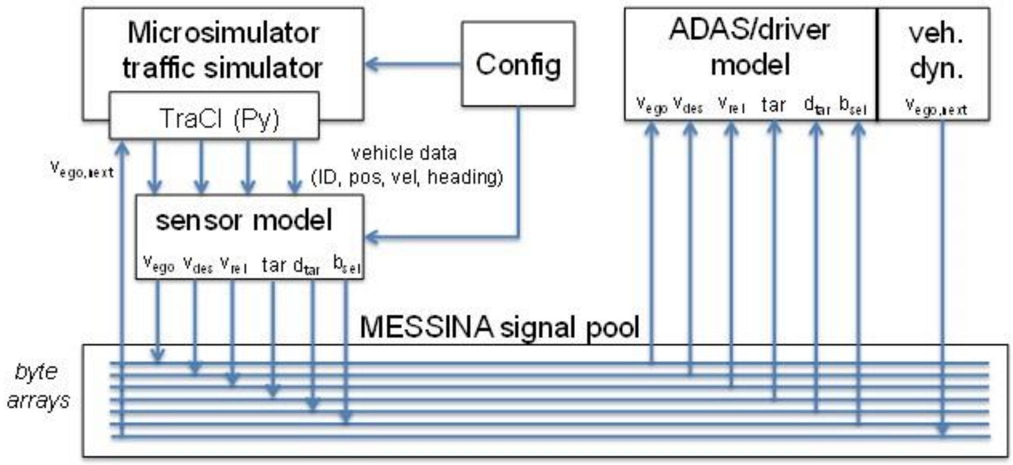


Figure 69: Micro traffic and ADAS submodel integration

The micro traffic simulator and the vehicle simulator exchange information via the signal pool of MESSINA. MESSINA has been developed as a test framework for automotive electronic control units (ECUs). The signal pool mimics the bus systems which nowadays are part of the electrical system of almost all vehicles and serve as a communication entity for the ECUs.

The task of the sensor model is to acquire the context of the vehicles, i.e. to measure distances to other vehicles and to provide information about the vehicle's own velocity. To get this data, the sensor model makes use of an application programming interface (API) which allows for the extraction of relevant vehicle data from the traffic simulation. An API is offered by almost all common traffic simulators such as AIMSUN or SUMO.

ADAS submodule is responsible for the control of the vehicles' longitudinal dynamics, i.e. their acceleration and braking behavior. It provides two options.

One option is that the vehicle dynamics is supposed to be controled by a human driver. In this case, the Gipps model, as an established model for human driving behavior, is applied. Another option is that the vehicle dynamics are determined from an automatic control mechanism such as Adaptive Cruise Control.

Modelling process description

The tested section is always the corridor of 1,6 km in Turin the same used for evaluate UTC and Ecodrive measure

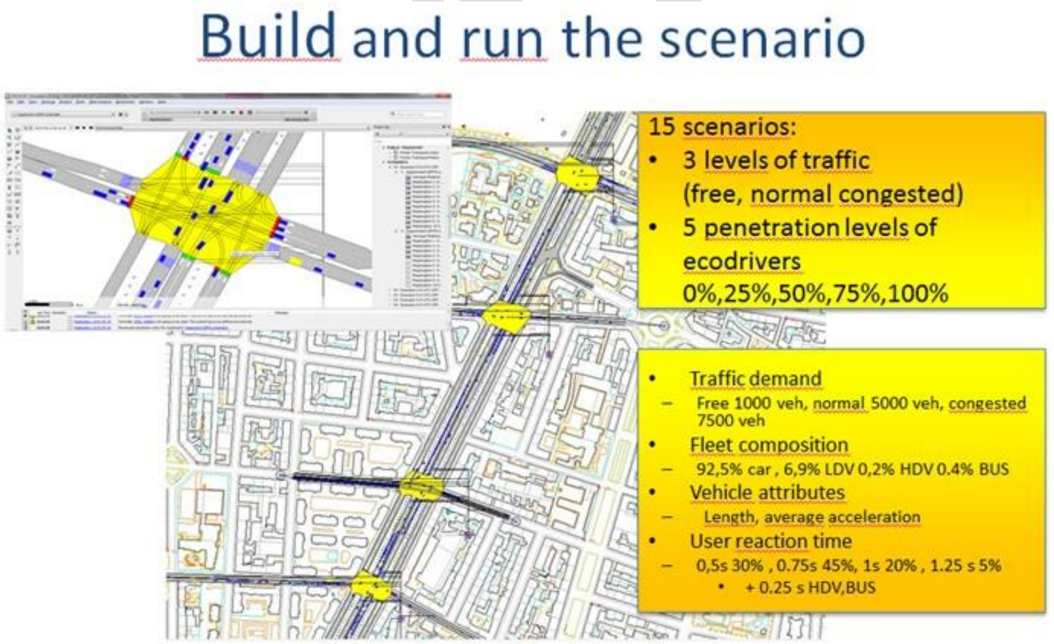


Figure 70: Adaptive CRUISE Control scenario built

B&M develop the integration between AIMSUN and MESSINA, then provide the SW to CNH that set the traffic scenario and run traffic and emission models. Six scenario has been built taking the free traffic flow case with six level of ADAS penetration vehicles (0,20,40,60,80,100 %). The last phase consist in collect and analyze the data and give the conclusion.

Scenarios

We consider a traffic condition free flow and six penetration level:

Table 44: ACC: Turin case study. Scenarios considered

Scenario ID	Variables varying for each scenario			
	Traffic conditions	Penetration level	Number of replication	Fleet composition
4334_01	Free	0% ADAS	1	Turin 2013
4334_02	Free	20% ADAS	1	Turin 2013
4334_03	Free	40% ADAS	1	Turin 2013
4334_04	Free	60% ADAS	1	Turin 2013
4334_05	Free	80% ADAS	1	Turin 2013
4334_06	Free	100% ADAS	1	Turin 2013

1.6.2.2. Results

Micro level

Table 45 ACC: Turin case study. Results

Scenario ID	Fleet	Variation respect to the base case				
		CO2 abs kg	CO2 rel g/km	veh·km	veh·h	average speed km/h
4334_02	Turin 2013	-0.1%	-0.2%	0.0%	0.0%	0.0%
4334_03	Turin 2013	-1.1%	-1.0%	0.6%	-0.6%	0.6%
4334_04	Turin 2013	-1.3%	-1.3%	0.8%	-0.8%	0.8%
4334_05	Turin 2013	-2.2%	-2.3%	1.1%	-1.1%	1.1%
4334_06	Turin 2013	-2.2%	-2.2%	1.4%	-1.3%	1.4%

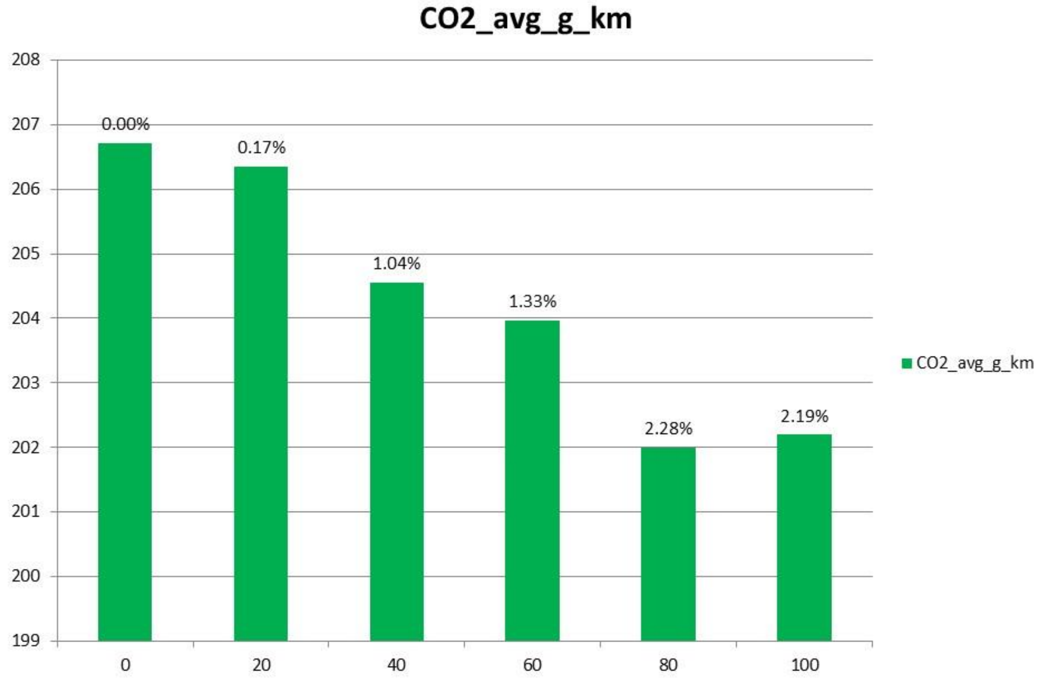


Figure 71: Adaptive CRUISE Control scenario built

Figure 71 shows the benefit in term of reduction of emission increasing the percentage of ADAS in the scenario. These percentage got are coherent with those got in Munich scenario, in case of city quarter, by B&M.

2 SUMMARY AND CONCLUSIONS

Table 43 summarizes all the results presented in chapter 1.

Table 46: ALL Scenarios: summary of results

Variation with respect to the base case			Micro				Macro				
Measure	**City**	**Fleet**	**Scenario ID**		**CO2 abs kg**	**CO2 rel g/km**	**Fleet**	**Scenario ID**		**CO2 abs kg**	**CO2 rel g/km**
VSL	Madrid	Madrid 2014	112_01	Normal	-1.40%	-1.50%	Madrid 2014	2020000	Medium	-0.06%	-0.09%
			113_01	Congested	-1.60%	-1.60%		1020000	Congested	-0.10%	-0.04%
							Madrid 2030	2020001	Medium	-1.37%	0.17%
								1020001	Congested	-1.40%	0.20%

Variation with respect to the base case			2014			2030		
Measure	**City**	**Scenario description**	**Scenario ID**	**CO2 abs kg**	**CO2 rel g/km**	**Scenario ID**	**CO2 abs kg**	**CO2 rel g/km**
GN	Madrid	10%-Congested	1010100	-2.22%	1.48%	1010101	-2.31%	1.39%
		25%-Congested	1010200	-4.89%	3.09%	1010201	-5.08%	2.88%
		50%-Congested	1010300	-7.07%	4.78%	1010301	-7.37%	4.44%
		75%-Congested	1010400	-7.92%	5.78%	1010401	-8.28%	5.36%
		90%-Congested	1010500	-8.16%	6.19%	1010501	-8.54%	5.74%
		10%-Medium	2010100	-1.13%	0.49%	2010101	-1.14%	0.47%
		25%-Medium	2010200	-2.24%	1.58%	2010201	-2.32%	1.50%
		50%-Medium	2010300	-3.18%	2.94%	2010301	-3.34%	2.77%
		75%-Medium	2010400	-4.08%	3.79%	2010401	-4.29%	3.57%
		90%-Medium	2010500	-4.66%	4.23%	2010501	-4.89%	3.98%
		10%-Free	3010100	-5.91%	-0.07%	3010101	-5.90%	-0.05%
		25%-Free	3010200	-6.83%	-0.08%	3010201	-6.80%	-0.05%
		50%-Free	3010300	-7.85%	0.00%	3010301	-7.81%	0.05%
		75%-Free	3010400	-8.93%	0.01%	3010401	-8.88%	0.07%
		90%-Free	3010500	-9.47%	0.02%	3010501	-9.41%	0.08%

Variation with respect to the base case			Micro				Macro			
Measure	**City**	**Fleet**	**Scenario ID**	**Traffic**	**CO2 abs kg**	**CO2 rel g/km**	**Scenario ID**	**Traffic**	**CO2 abs kg**	**CO2 rel g/km**
UTC	Turin	Turin2013	4265	Normal	-7.40%	-8.00%				
		Turin2013	887	Congested	-3.50%	-4.50%				
		Turin2013	887_01		-14.28%	-13.35%				
		Turin2013Hybrid10%	887_10		-14.87%	-13.53%				
	Rome	Rome2013	102_2014	Congested	-2.18	-4.84	102	Congested	-0.21%	-0.19%
		Rome2013					103		-0.26%	-0.21%
		Italy2030	102_2030	Congested	-1.72	-4.37	102		-0.20%	-0.18%
		Italy2030					103		-0.25%	-0.20%

Variation with respect to the base case			Micro			Macro					
Measure	**City**	**Traffic and penetration level**	**Scenario ID**	**CO2 abs kg**	**CO2 rel g/km**	**Scenario ID**	**CO2 abs kg 2014**	**CO2 rel g/km 2014**	**Scenario ID**	**CO2 abs kg 2030**	**CO2 rel g/km 2030**
ECODriving	Madrid	5%-Free	121_02	-0.89%	-0.89%						
		5%-Normal	122_02	4.37%	-1.53%						
		5%-Congested	123_02	0.93%	1.41%						
		20%-Free	121_05	-0.72%	-0.75%						
		20%-Normal	122_05	4.07%	-1.06%						
		20%-Congested	123_05	3.43%	4.63%						
		25%-Free	121_06	-0.23%	-0.25%	3030100	0.28%	0.09%	3030101	0.27%	0.08%
		25%-Normal	122_06	4.55%	-0.38%	2030100	-0.37%	-0.35%	2030101	-0.35%	-0.32%
		25%-Congested	123_06	4.17%	5.77%	1030100	-0.55%	-0.83%	1030101	-0.49%	-0.77%
		50%-Free	121_07	-0.37%	-0.33%	3030200	1.48%	0.53%	3030201	1.45%	0.49%
		50%-Normal	122_07	4.74%	0.49%	2030200	0.96%	0.29%	2030201	0.94%	0.28%
		50%-Congested	123_07	6.58%	11.17%	1030200	1.30%	0.14%	1030201	1.30%	0.15%
		75%-Free	121_08	1.69%	1.73%	3030300	2.24%	0.85%	3030301	2.18%	0.79%
		75%-Normal	122_08	5.11%	1.53%	2030300	1.74%	0.67%	2030301	1.71%	0.63%
		75%-Congested	123_08	7.28%	13.47%	1030300	2.09%	0.58%	1030301	2.06%	0.56%
		100%-Low	121_09	2.35%	2.38%						
		100%-Normal	122_09	5.59%	2.80%						
		100%-Congested	123_09	7.89%	16.42%						

Variation with respect to the base case				Micro			Macro		
Measure	**City**	**Fleet**	**Traffic and penetration level**	**Scenario ID**	**CO2 abs kg**	**CO2 rel g/km**	**Scenario ID**	**CO2 abs kg**	**CO2 rel g/km**
ECODriving	Turin	Turin 2013	25%-Free	239933932	-3.80%	-4.00%	30143	-4.00%	-4.00%
			50%-Free	239934366	-7.20%	-7.50%	30144	-7.00%	-7.00%
			75%-Free	239934336	-12.20%	-11.00%	30145	-11.00%	-11.00%
			100%-Free	239934351	-14.70%	-15.00%	30146	-15.00%	-15.00%
			25%-Normal	239933996	-3.60%	-3.50%	30123	-2.00%	-2.00%
			50%-Normal	239934208	-7.70%	-7.00%	30124	-4.00%	-4.00%
			75%-Normal	239934193	-9.40%	-9.00%	30125	-7.00%	-7.00%
			100%-Normal	239934381	-11.50%	-10.00%	30126	-10.00%	-10.00%
			25%-Congested	239933953	0.60%	-4.00%	30115	2.00%	2.00%
			50%-Congested	239934148	0.10%	-7.50%	30116	3.00%	3.00%
			75%-Congested	239934133	-3.30%	-11.00%	30117	3.00%	3.00%
			100%-Congested	239934163	-6.50%	-15.00%	30118	3.00%	3.00%

Variation with respect to the base case				2014		2030	
Measure	**City**	**Penetration level and traffic**	**Scenario ID**	**CO2 abs kg**	**CO2 rel g/km**	**CO2 abs kg**	**CO2 rel g/km**
START & STOP	Madrid	10%-Free	101_02	0.01%	0.01%	-0.03%	-0.03%
		50%-Free	101_03	0.02%	0.02%	-0.01%	-0.01%
		100%-Free	101_04	-0.01%	-0.02%	-0.04%	-0.04%
		10%-Normal	102_02	-0.01%	-0.01%	-0.03%	-0.03%
		50%-Normal	102_03	-0.06%	-0.07%	-0.07%	-0.07%
		100%-Normal	102_04	-0.16%	-0.16%	-0.17%	-0.18%
		10%-Congested	103_02	-0.07%	-0.07%	0.01%	0.02%
		50%-Congested	103_03	-0.31%	-0.31%	-0.25%	-0.24%
		100%-Congested	103_04	-0.56%	-0.56%	-0.55%	-0.54%
		VSL-10%-Normal	112_02	-0.02%	-0.02%	0.02%	0.02%
		VSL-50%-Normal	112_03	-0.05%	-0.05%	-0.03%	-0.03%
		VSL-100%-Normal	112_04	-0.11%	-0.11%	-0.09%	-0.10%
		VSL-10%-Congested	113_02	-0.07%	-0.08%	-0.03%	-0.03%
		VSL-50%-Congested	113_03	-0.32%	-0.33%	-0.27%	-0.27%
		VSL-100%-Congested	113_04	-0.56%	-0.56%	-0.54%	-0.53%

Variation with respect to the base case				2014		2030	
Measure	City	Penetration level and traffic	Scenario ID	CO2 abs kg	CO2 rel g/km	CO2 abs kg	CO2 rel g/km
START & STOP	Turin	10%-Free	4334_02	-0.53%	-0.54%	-0.53%	-0.54%
		50%-Free	4334_03	-2.97%	-2.96%	-2.52%	-2.52%
		100%-Free	4334_04	-5.85%	-5.82%	-5.04%	-5.04%
		10%-Normal	4192_02	-0.68%	-0.68%	-0.65%	-0.65%
		50%-Normal	4192_03	-3.42%	-3.43%	-3.05%	-3.05%
		100%-Normal	4192_04	-6.86%	-6.86%	-5.94%	-5.93%
		10%-Congested	4331_02	-1.28%	-1.28%	-1.12%	-1.12%
		50%-Congested	4331_03	-6.35%	-6.36%	-5.49%	-5.50%
		100%-Congested	4331_04	-12.68%	-12.70%	-10.94%	-10.96%
		UTC-10%-Normal	4265_02	-0.65%	-0.65%	-0.51%	-0.51%
		UTC-50%-Normal	4265_03	-2.96%	-2.97%	-2.62%	-2.62%
		UTC-100%-Normal	4265_04	-5.99%	-5.99%	-5.08%	-5.09%
		UTC-10%-Congested	887_02	-1.15%	-1.15%	-1.03%	-1.04%
		UTC-50%-Congested	887_03	-5.94%	-5.94%	-5.17%	-5.17%
		UTC-100%-Congested	887_04	-11.86%	-11.87%	-10.26%	-10.26%

Variation with respect to the base case				2014		2030	
Measure	**City**	**Penetration level and traffic**	**Scenario ID**	**CO2 abs kg**	**CO2 rel g/km**	**CO2 abs kg**	**CO2 rel g/km**
START & STOP	Rome	10%-Congested	303_02	-0.58%	-0.58%	-0.45%	-0.46%
		50%-Congested	303_03	-2.88%	-2.91%	-2.29%	-2.31%
		100%-Congested	303_04	-5.74%	-5.80%	-4.52%	-4.57%
		UTC-10%-Congested	313_02	-0.51%	-0.51%	-0.37%	-0.37%
		UTC-50%-Congested	313_03	-2.49%	-2.50%	-1.95%	-1.97%
		UTC-100%-Congested	313_04	-5.00%	-5.03%	-3.90%	-3.93%

Variation with respect to the base case			Micro			
Measure	**City**	**Fleet**	**Scenario ID**	**Scenario description**	**CO2 abs kg**	**CO2 rel g/km**
ACC	Munich		141_02	RingRoad-20%-Low traffic	-1.48%	-1.48%
			141_03	RingRoad-40%-Low traffic	-3.40%	-3.40%
			141_04	RingRoad-60%-Low traffic	-5.30%	-5.30%
			141_05	RingRoad-80%-Low traffic	-6.49%	-6.49%
			141_06	RingRoad-100%-Low traffic	-8.81%	-8.81%
			142_02	RingRoad-20%-Medium traffic	-1.54%	-1.54%
			142_03	RingRoad-40%-Medium traffic	-2.87%	-2.87%
			142_04	RingRoad-60%-Medium traffic	-4.46%	-4.46%
			142_05	RingRoad-80%-Medium traffic	-6.28%	-6.28%
			142_06	RingRoad-100%-Medium traffic	-7.42%	-7.42%
			143_02	CityQuarter-20%-Low traffic	-0.27%	-0.27%
			143_03	CityQuarter-40%-Low traffic	-0.84%	-0.84%
			143_04	CityQuarter-60%-Low traffic	-1.35%	-1.35%
			143_05	CityQuarter-80%-Low traffic	-1.63%	-1.63%
			143_06	CityQuarter-100%-Low traffic	-2.10%	-2.10%
			144_02	CityQuarter-20%-Medium traffic	-0.85%	-0.85%
			144_03	CityQuarter-40%-Medium traffic	-0.76%	-0.76%
			144_04	CityQuarter-60%-Medium traffic	-1.12%	-1.12%
			144_05	CityQuarter-80%-Medium traffic	-1.47%	-1.47%
			144_06	CityQuarter-100%-Medium traffic	-1.45%	-1.45%
	Turin	Turin2013	4334_02	20%-Free	-0.10%	-0.20%
			4334_03	40%-Free	-1.10%	-1.00%
			4334_04	60%-Free	-1.30%	-1.30%
			4334_05	80%-Free	-2.20%	-2.30%
			4334_06	100%-Free	-2.20%	-2.20%

After analysing all these previous scenarios, we can conclude that impacts vary not only with the measure itself but of course with the penetration level, the traffic situation the type of road or the citizen's driving profile. Therefore, it is difficult to quantify the expected impacts an ICT measure may have.

A clear example of this is start and stop, where we can observe how results vary not only from the case of Madrid to Turin or Rome, which are different type of roads, but also between Turin and Rome, being both urban streets.

What it is clear is that these measures do have a positive impact, though not always for all traffic situations, and of course geographical distribution may not be homogeneous. For example, in VSL, we can see that the positive impact is displaced from the road with VSL ON to other ring roads. In the case of Green Navigation, as length has an important weight in minimizing CO2 emissions, drivers follow shorter routes, which sometimes cross city centres, therefore producing an increase of veh-km in these areas and decreasing traffic of peripheral roads.

This is an important aspect to highlight because it means that, though being positive for CO2 emissions, which have a global effect, may be negative for other environmental aspects.

In most of the measures, CO2 emissions decrease is below 3%, which means none of these measures represents a turning point in solving the problem of increasing CO2 emissions, but all of them, implemented correctly, may help to tackle it.

Also, some of the results bring up questions which may ask ourselves if it is realistic to assume citizens are willing to accept these consequences, such as the time increase in the case of green navigation.

Measures affecting directly the vehicle do not seem to have a negative impact, as there is no change interfering with the rest of drivers. But measures affecting either the driving profile or the route choice have consequences not only in the driver's individual behaviour but in the rest of drivers at the moment, which may at the end produce non expected effects. A clear example of this is eco driving, where we can see that individual saving of only one eco driver is higher that with higher penetration levels of eco drivers.

Therefore, a strong effort in investigating these measures needs to be made, as they have a potential to reduce CO2 but there are many variables interfering which need to deepen in their knowledge in order to provide assessment to implement them in practice.