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INTEGREEN

Action 5: Testing & Validation

D.5.3.1

Quantitative impact of eco-friendly traffic policies

Project Coordinating Beneficiary	Municipality of Bolzano
Project Associated Beneficiary n.2	TIS innovation park (TIS)
Project Associated Beneficiary n.3	Austrian Institute of Technology (AIT)

Città di Bolzano
Stadt Bozen

TiS innovation park

AIT AUSTRIAN INSTITUTE OF TECHNOLOGY

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1 Introduction

Action n.5 aims not only at verifying in a real scenario the first benefits and environmental impacts that the INTEGREEN system has produced through its first deployment. The long-term objective of this action, the last technical phase of the project execution, is in fact to identify the key advanced eco-friendly traffic policies that can be implemented on top of this novel system.

The activities of Action n.5 are organized in three different tasks, and very strictly connected to the ones completed in the previous project actions as illustrated in Figure 1. The comprehensive methodology followed for the technical implementation of the project is the V-model, which is a very common technique for (ITS) projects based on intelligent transportation systems (ITS).

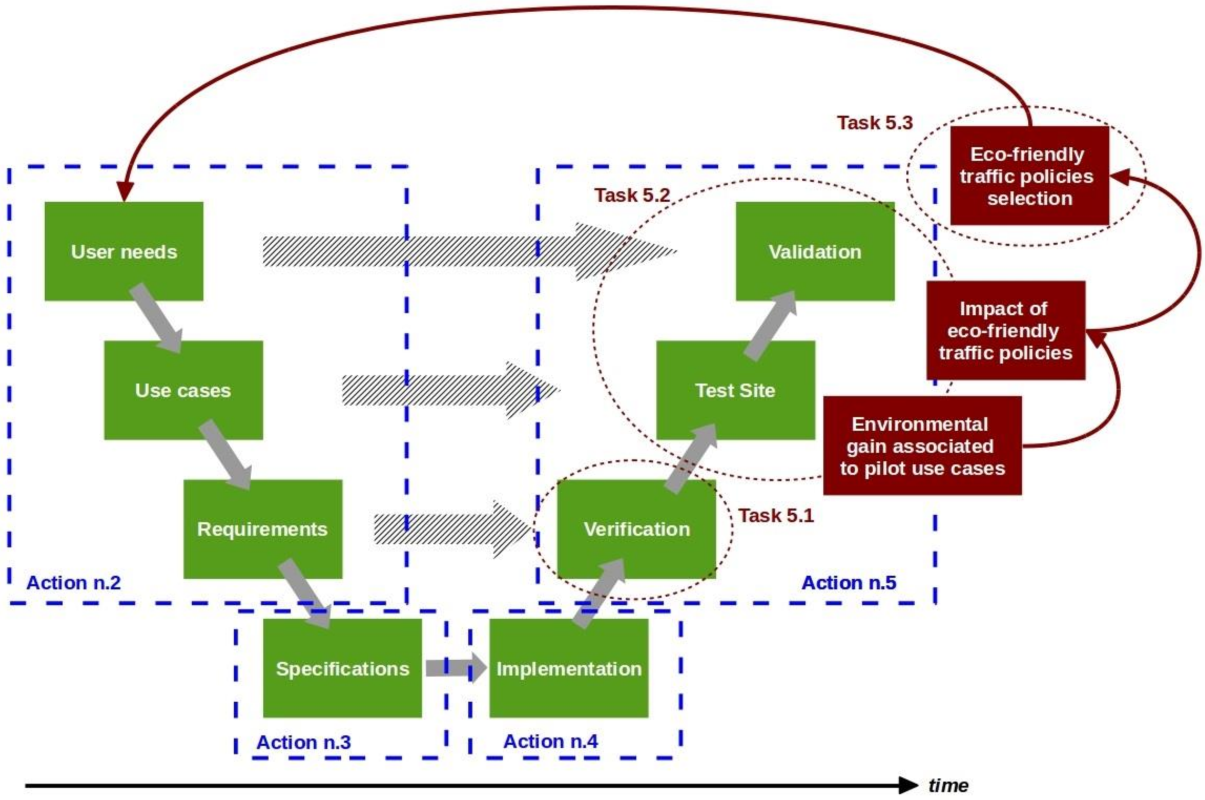

Figure 1: The V-model methodology followed in the technical implementation of the project and a graphical presentation of Action n.5 activities.

Action n.5 is organized in three different tasks:

- **Task 5.1** ("components tests"), in which system components are technically analyzed in order to verify that original system requirements are properly fulfilled.
- **Task 5.2** ("outdoor urban tests"), in which the INTEGREEN system is used empirically

within the city of Bolzano to quantify the environmental impact associated to a set of initial eco-friendly traffic policies introduced in the final part of the project, in particular by:

  - initially investigating the potential local environmental gain associated to a set of "pilot use cases", i.e. an empirical expression of the "ideal use cases" identified during the requirements' consolidation process;
  - finally experimenting the large-scale application of the initial eco-friendly traffic policies.

  Task 5.2 is also responsible to preliminary assess how far initial user needs have been satisfied.

- **Task 5.3** ("eco-friendly traffic policies"), in which the pilot experience of INTEGREEN is used to:
  - identify the most cost-effective strategies for reducing the environmental impact of urban traffic through dynamic traffic and mobility management policies;
  - consolidate the project contribution to the implementation of the enhanced EC policies in the field of environment and mobility governance.

The implementation of the future, selected eco-friendly traffic policies can furthermore represent the kick-off of a new cycle of the V-model, with an increasing engagement of local travelers and stakeholders in the calibration of the proposed measures.

1.1 Purpose of the document

The purpose of this document is to present the results of the first investigations related to the potential of different eco-friendly traffic policies in the city of Bolzano, based on the results presented in D.5.2.2 [1]. The preliminary studies on effective "soft" strategies to tackle urban pollution caused by motorized traffic that have been completed during the requirement process, and reported in D.2.1.1 [2], are updated based on the results obtained in the most promising initiatives carried out worldwide.

For a proper analysis of the contents that are presented, it is recommended to read this deliverable together with all the other outputs produced by Action n.5, i.e. not only D.5.2.2 but also D.5.1.1, in which the results of the system components are discussed [3] and D.5.2.1, in which the Test Bed plan activities are presented [4].

1.2 Document structure

This deliverable is structured as follows. In Chapter 2 an updated state-of-art of the most promising urban "environmental-oriented" traffic policies is given. Policies are classified in four main categories: (i) policies addressing vehicles' speed; (ii) policies addressing traffic flows; (iii) policies addressing urban navigation; (iv) policies addressing mobility management; and (v) policies addressing driving management. Chapter 3 presents a first selection of the most promising eco-friendly traffic policies to be introduced in the city of Bolzano, based on the empirical results of the field activities obtained in Task 5.2. Finally, in Chapter 4, the contribution that the INTEGREEN project experience can give to the improvement of the European policies in the field of urban environment and transport is discussed.

2 State-of-art of most promising urban environmental traffic policies

In D.2.1.1, a first investigation of the most relevant research project initiatives, mainly supported by financial instruments of the European Union such as the 7th Framework Programme (FP7) or the Competitiveness & Innovation Programme – ICT Policy Support Programme (CIP – ICT-PSP). This analysis was mainly performed with the intention to get useful inputs on how to design a technical system architecture capable of not only achieving the specific project objectives, but also sufficient scalable to deploy advanced (and more efficient) scenarios in the near future with reasonable efforts and investments.

During the project execution, most of the analyzed project initiatives have been concluded, and have given to the scientific community very important results about the potential to use advanced cooperative systems in order to reduce the environmental impact of urban traffic. These results can be very useful for INTEGREEN: the inputs received by the field operations tests related to the most promising approached to be deployed in Bolzano can provide the basis for a selection of the most interesting cooperative scenarios to be built over the technical INTEGREEN framework.

This chapter aims at putting the basis for such a “matching”. Results of the selected project initiatives are here summarized and reported, and where applicable enriched with additional pilot initiatives that based on the results of the INTEGREEN Test Bed are particularly interesting to be reported. This analysis is organized according to different environmental traffic strategies, according to the classification presented in Table 1. Such methodology has been defined according to what suggested at the state-of-art, in particular by taking in specific account the method proposed by Boltze and Lornauf in [5].

Strategy	Description
Speed management	Solutions aiming at forcing vehicles at driving at certain “controlled” speeds over certain route stretches. As analyzed in the technical implementation of the emission model by considering all emission factors for all vehicle classes, at certain speeds the emission of pollutants generated is minimum [6].
Traffic control	Solutions aiming at controlling traffic flows in a way to reduce the overall number of stop&go situations. These conditions are one of the main drivers for pollution generated by urban traffic, as observed in the city of Bolzano as well thanks to the INTEGREEN system. Such strategies mostly cover the optimization of traffic lights intersections.
Urban navigation	Solutions aiming at optimally distributing traffic flows over the road network. Such strategies mostly cover the distribution of very real-time information to on-board users, mainly through on-board devices (e.g. satellite navigation units) or roadside equipment (e.g. Variable Message Signs (VMS)). In INTEGREEN however, due to the particular nature of the city with limited road infrastructure and the already excellent modal split equilibrium in “normal” traffic conditions, such strategies have demonstrated to have a significant impact only in case of perturbations of the normal traffic conditions. In most of these cases, what it is more interesting to

	explore are access management strategies to the city, which however can be already included in the mobility management strategies.
Mobility management	Solutions aiming at optimally managing the mobility demand of people and goods wanting to move within the city of Bolzano in a dynamic and flexible way. INTEGREEN has confirmed that for the city of Bolzano such strategies are the ones that can produce the most noticeable results in environmental terms. Three policies are particularly interesting to be explored: (i) **peak avoidance strategies**, in which commuters are induced to start motorized travels in certain periods of the day, based on the real-time traffic conditions, or to use alternative transport means; (ii) **restriction of high pollutant vehicles circulation**, at least during particular situations of environmental concern; (iii) **adaptation of conditions** (e.g. fees) for accessing the **public parking areas of the city**.
Driving management	Solutions aiming at improving the driving style so that the environmental footprint of a motorized urban trip is minimized, given the same boundary conditions. Most of the state-of-art strategies are based on on-board equipment, now more and more integrated in the vehicular systems, that help the drivers day by day to improve their eco-driving abilities.

Table 1: Eco-friendly traffic strategies categories.

2.1 Speed management strategies

Vehicle speed is one of the key factors for the total amount of emissions produced by motorized vehicles. As detailed in the design and implementation of the emission estimator engine of the INTEGREEN system [6], the minimum values of emissions factors are obtained at certain reference speeds, which are usually located in the interval 40-60 [km/h]. At very low or high speeds, these factors can increase several times with respect to these reference minimum values. Moreover, the increase of the generation of emissions is a direct function of the numbers and amplitude of accelerations.

Strategies can be therefore implemented in order to ensure that vehicular flows can transit at certain reference and constant speeds. The traditional approach is to use speed enforcement schemes or **Variable Speed Limits** (VSL), i.e. Variable Message Signs (VMS) indicating the current maximum admitted speed which is dynamically adjusted according to different criteria directly related to fundamental traffic parameters (Figure 2). In reality, the objective of these strategies, which are typically implemented in highways environments, are principally others, in particular the avoidance of accidents, the reduction of congestions and the increase of the reliability of journey times.

What are the typical environmental impacts of speed management strategies? Studies carried out in the European project COMPASS, related in particular to London highway M25, have demonstrated that the introduction of VSL has been responsible for a **reduction** of **CO_2 emissions estimated in the order of 2-8%** [7]. The reduction in the **levels of air pollutants concentrations** has been greater for **PM_x (about 8%)** than for **NO_x (about 1-2%)**. Several examples of VSL applications exist in Europe. VSL systems are implemented as advisory in Stockholm [8] or mandatory on German motorways (A5 Karlsruhe, A8 Munich, A3 Köln). In Austria, speed limits are automatically adjusted on highways as a function of weather and air pollution levels [9]. Studies indicate moreover that **enforcement** is necessary to achieve and maintain a sufficient level of acceptance. Results from empirical and simulation studies clearly show that driver compliance is an important factor and VSL performance quickly deteriorates as compliance rate drops. When such compliance is high, significant adjustments in driving behavior can be observed: more uniform speeds and reduced accelerations / decelerations, and significant reductions of excessive speeding patterns.

This is why **speed enforcement alone** can also have significant environmental effects. In **Rotterdam**, the introduction of a new speed control zone has determined an empirical **reduction of 15% of CO_2 emissions** [10].

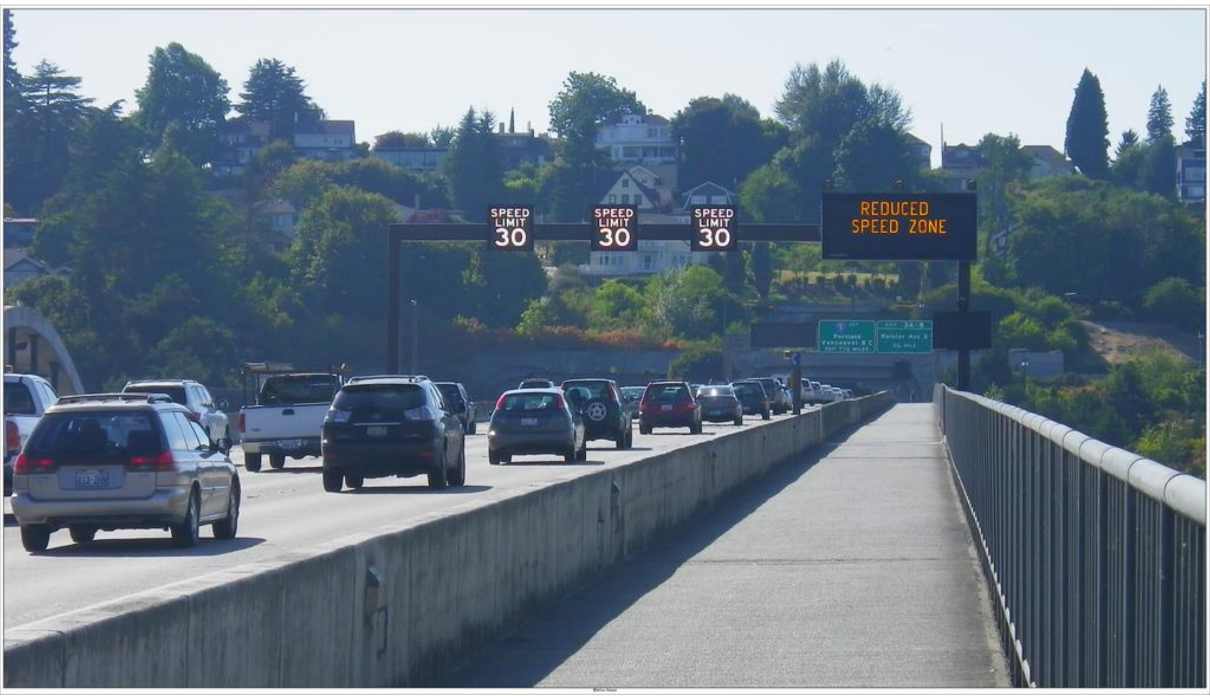

Figure 2: Typical VSL strategy implemented on a highway (Source: hdimagelib.com).

What about the potential of future cooperative scenarios, in which speed management measures can be implemented leveraging on the latest vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication technologies? Following applications could be introduced:

- **dedicated lanes** (similar to “high-occupancy vehicles” concept) **for “eco-drivers”**, i.e. who operate their vehicles in an eco-friendly way;
- **VSL** that are dynamically optimized as a function of the **environmental data** collected by **static and mobile monitoring stations**.

These measures can be combined with applications deployed inside the vehicles, i.e.:

- **eco-cooperative adaptive cruise control (ECACC)**, an evolution of the ACC function already included in most of the vehicles in commerce, which takes advantage of the information at disposal of other surrounding vehicles;

* **vehicle platooning**, i.e. a new cooperative concept developed in the European project SARTRE which is based on the idea that a platoon of vehicles can flow on the base of the instructions given by a leading vehicle, which could be for example driven by a professional driver implementing eco-driving concepts.

The possible overall scenario is the one presented in Figure 3. Preliminary researches related to the potential environmental improvements associated have evidenced that on a freeway the **reduction of speed limits** during days of high pollutants concentrations can produce **reductions of NO_x concentrations up to 17% over the 24-period** [11]. **Platooning concepts** can contribute to a further reduction of **8-16% of fuel consumption and CO_2 emissions** [12].

During the Field Operational Tests of the European project **FOTsis**, for the large scale evaluation of close-to-market cooperative services in test areas of Spain, Portugal, Germany and Greece, the use of VSL has demonstrated to have less evident effects on travel times (-7.5% on average) and CO_2 emissions (about -1%)

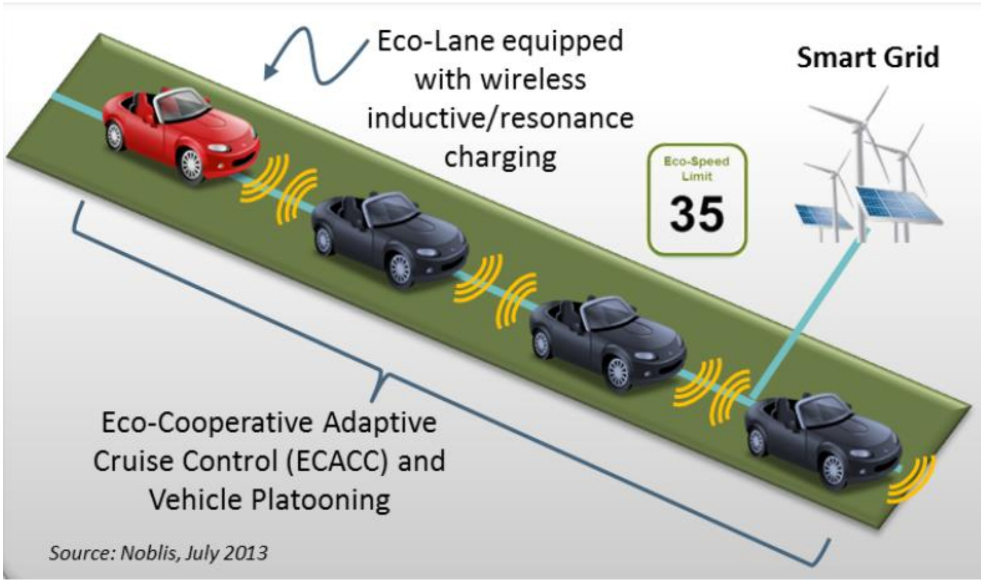

Figure 3: The eco-lanes operations scenario developed in the AERIS program by ITS-JPO [13].

Potential benefits can be summarized as follows:

Traditional speed management strategies coupling **VSL** and **speed enforcement systems** have demonstrated to produce reductions of emissions of up to 10-15%. The success of such measures however strongly depends on the driver compliance rate, i.e. on the percentage of drivers following the dynamic limits. These strategies can even produce in certain conditions a visible reduction of air pollutant concentrations at the roadside (about 2-8%), which is more visible for PM_x than NO_x.

New **cooperative concepts** based on **speed limits adjusted on the base of crowd-sourced environmental data** and **dedicated lanes**, coupled with **eco-cooperative**

adaptive cruise control and **platooning** applications, can produce larger environmental benefits. During high polluted days, the reduction of air pollutant concentrations can be over 10%. Emissions can be reduced of up 20%.

2.2 Traffic control management strategies

The first environmental traffic management strategies appeared at the state-of-art have been those related to the optimization of the traffic light cycles. The first attempts have been related to the **dynamic adaptation of cycles** based on **measured traffic data** in correspondence of a traffic intersection. Most complicated approaches include the **coordination of several traffic lights systems**. A study carried out in the German city of Cologne have demonstrated that the most remarkable results are obtained by dynamically adapting traffic lights cycles on the base of measured traffic data. Further optimization strategies have less significant impacts, but can contribute to reduce the NO_2 annual average concentrations of up 10% [14]. A more recent pilot project carried out by the Colorado Department of Transportation (CDOT) on an inter-urban section of about 13 [km] with 10 signalized intersections, hosting an average daily traffic of about 38.000 – 48.000 vehicles, has confirmed the added value of this measure in an area where unpredictable traffic jam conditions due to traffic patterns related to schools, tourists and weather are frequent. The project has demonstrated that by adapt dynamically traffic lights cycles with respect to the local traffic detections following results have been obtained: driver delays reduced by 39 per cent, improved travel times by 6 per cent; increased driver speeds an average of 7 per cent and number of stops reduced by nearly a third.

A **new generation of traffic light cycles optimization strategies** has recently started to appear. The idea is to adapt them not only on the base of the traffic conditions, but also on the **current meteorological status**. At the beginning of 2015, the city council of Copenhagen has announced to have approved an initial investment of 8 million Euros for the implementation of such a measure in the center of the city, that if successful, will be extended to the whole of it for a total planned investment of about 33 million Euros [15]. This important political commitment is based on some preliminary tests on the field in the city; detailed information of the obtained results have not been unfortunately released yet.

The proposed plan is actually much more ambitious. It aims to extend the monitoring capabilities of the city with respect to other **non-motorized modes** and to use this real-time information as well to improve such actuation plan. The idea is to collect anonymous information about travels of people via their smartphones and other connected mobile devices to street sensors, allowing traffic lights to change based on the number of pedestrians, cyclists and motorists on the road at that specific time. An important aspect of this measure is moreover the possibility to give "**green priority" to city buses** by letting traffic lights directly communicating with them. Such priorities can vary according e.g. if the bus is behind schedule or if it is full of passengers. Another important source of information is **events**: extended green lights could be exceptionally envisaged in order to facilitate the streaming out of the participants.

What about the potential of future cooperative scenarios, in which traffic control measures can be implemented leveraging on the latest vehicle-to-infrastructure (V2I) and vehicle-to-vehicle (V2V) communication technologies? A scientific answer has been produced by the results of the eCoMove project, but since results are strictly linked to urban navigation strategies, such considerations are reported in the correspondent paragraph below.

Empirical results for “cooperative” traffic lights related strategies have been produced in an increasing number of pilot projects all around the world. Probably, the most significant experience is the one carried out within the project **COMPASS 4D**, supported by the CIP – ICT-PSP programme. In the scope of these project, a pilot “**energy efficient intersection**” service (EEIS), aiming at reducing vehicle emissions at signalized intersections, has been deployed in a certain number of European pilot cities, including the Italian city of Verona, not far from Bolzano. Through this service, equipped vehicles will have the capability to present to drivers the “signal phase and timing information’” (SPaT), who therefore will have the opportunity to anticipate the current and upcoming traffic light phase.

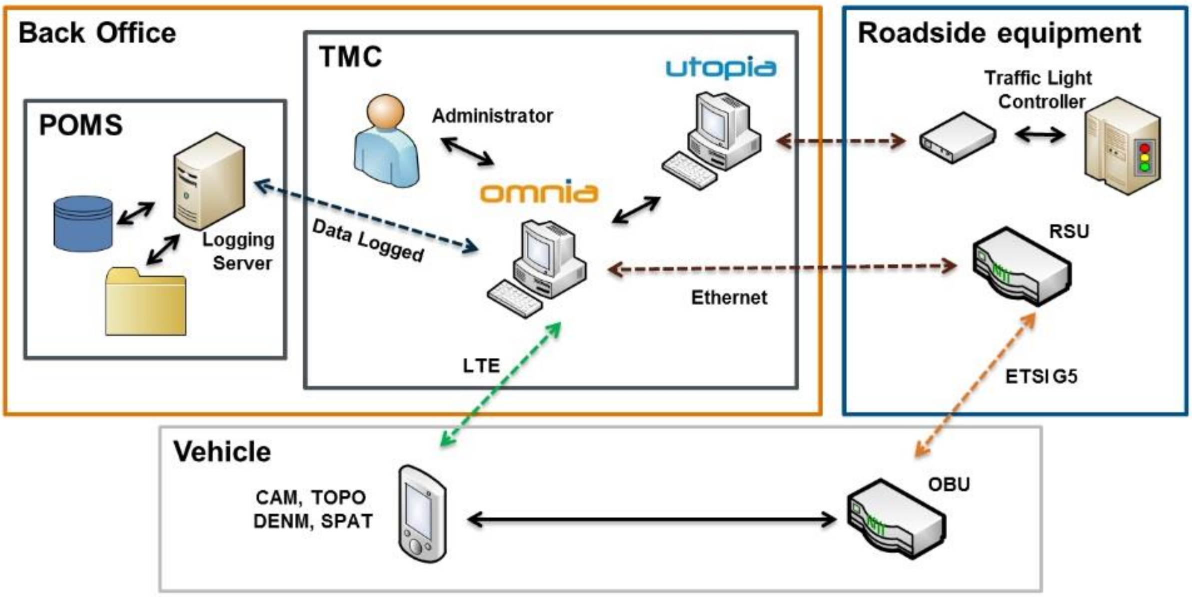

Figure 4: The architecture for the deployment of the EEIS in the city of Verona [16].

Following functions have been implemented:

- **Green Light Optimal Speed Advisory** (GLOSA): drivers receive traffic light phase information, and advice on the best deceleration strategy to approach the intersection at the most energy efficient speed.
- **Idling stop support**: ‘time-to-green’ information is used by the in-vehicle application for engine control and engine turn off.
- **Start delay prevention support**: ‘time-to-green’ information is used by the in-vehicle application to minimize time loss at the start of a green light phase due to reaction time.

- **Green priority**: heavy goods vehicles (HGV's), public transport vehicles, and emergency vehicles receive green priority at traffic lights. Different levels of green priority can be distinguished. The two outer limits are extension of the current phase or termination of the current phase to switch to the required phase. What level of green priority is appropriate depends on the vehicle type (e.g. HGV or emergency vehicle) and status (e.g. public transport vehicle on-time or behind schedule).

From a technical point of view, messages from the EEIS could come from a roadside unit communicating via 802.11p, or a traffic management centre communicating via 3G/4G. Depending on the system design and processing capabilities of the equipment, processing of signal phase and timing information, and the calculation of a speed and deceleration strategy, could be done by the infrastructure system or the in-vehicle system. Messages are visual and/or audible, and give a short and clear explanation of the warning. Potential benefits of cooperative "**eco-signal operations**" are however indicated in the numerous number of studies that the Intelligent Transportation Systems Joint Program Office (**ITS-JPO**) of the United States Department of Transportation (**USDOT**) is leading in the scope of its program "Applications for the Environment: Real-Time Information Synthesis" (**AERIS**), in particular [13]. The application bundle "eco-signal operations" include, among other:

- **Eco-Approach and Departure at Signalized Intersection**: basically equivalent to Compass4D's GLOSA, but includes the capability of vehicle-to-vehicle (V2V) communications for exchanging relevant Geographic Information Description (GID) messages. The on-board application is connected to the longitudinal vehicle control capabilities in the vehicle to support partial automation.

- **Eco-Traffic Signal Timing**: this application represent an advanced improvement of what is currently going to be deployed in the city of Copenhagen. Traffic lights collect data from vehicles, such as vehicle location, speed and emissions data using connected vehicle technologies, and develop dynamic signal timing with the purpose to reduce fuel consumption and overall emissions at the intersection.

- **Eco-Traffic Signal Priority**: basically equivalent to Compass4D's Green Priority.

Potential benefits can be summarized as follows:

Transforming a traffic light in an "**adaptive traffic light**", with cycles adapted as a function of real-time traffic data, the **emissions reduction can be in the order of up to 30%**. By **turning uncoordinated traffic lights in coordinated ones** (without any cooperative technology deployed), the additional benefit is estimated in the order of **8%**.

Cooperative applications like Eco-Approach and Departure at Signalized Intersection, can determine further improvements: (i) **5-10% benefit** in terms of fuel consumption and pollutant emissions for an **uncoordinated traffic light intersection**; (ii) an additional **4-5% benefit** if traffic lights are **coordinated**. Moreover, through a **combination** with **eco-driving behavior** on-board, the **overall benefit estimation is in the order of 22%.**

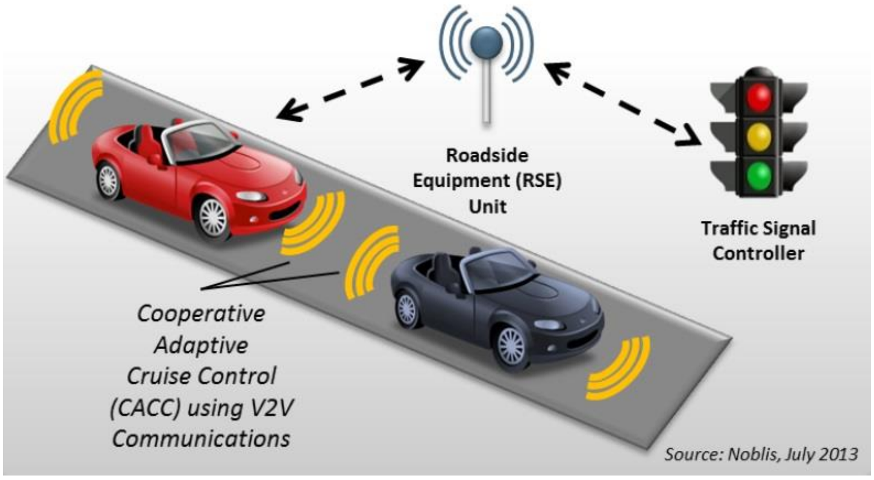

Figure 5: The eco-signal operations scenario developed in the AERIS program by ITS-JPO [13].

2.3 Urban navigation strategies

Another set of environmental traffic policies is the one related to the idea to better manage the traffic flows so that an overall balance in the usage of the road network is obtained, with consequent benefits from an environmental point of view.

The most interesting experiments evaluated in the scope of the project have been those carried out in the scope of the EU project **CARBOTRAF**, coordinated by the Mobility Department of AIT, involved in the requirements consolidation phase of INTEGREEN. CARBOTRAF is a research project which aims to deepen the idea to reduce the emissions of greenhouse gases (both CO_2 and black carbon) by **smart traffic management** (in particular by rerouting traffic accordingly), with the goal to develop methods and tools (including forecasts routines) for traffic operators to suggest the most cost / effective ITS measures according to the current situation. The evaluation of the potential of this approach has been carried out both through simulation analysis but also in a real-life operating scenarios, in particular in the cities of **Graz** and **Glasgow**.

Preliminary results were presented and together discussed during the second international workshop (June 2014) [17]. Of particular interest for the evaluation of the potential associated to urban navigation strategies have been the tests on urban navigation strategies organized in the city of Graz.

The reference scenario is briefly presented in Figure 6. The city of Graz is characterized by the possibility to enter the urban area through different highway gates (Graz South and Graz North), which are more or less equivalent from a traveling point of view. The purpose of the test was to suggest to drivers the best “eco-route” through the Variable Message Signs just before the gates, in order to incentivize drivers to take a certain route instead to the other one. The selection of the message and the choice of when displaying it has been taken on a real-time basis, on the base of the CARBOTRAF recommendations displayed through a decision support system (Figure 7).

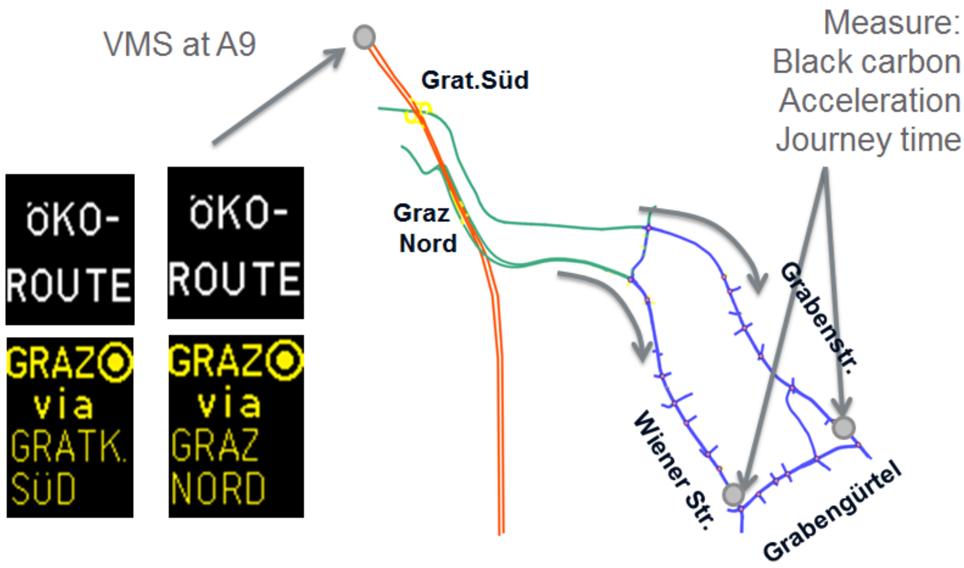

Figure 6: A schematic representation of the urban navigation strategy tested in the city of Graz in the scope of the CARBOTRAF project [17].

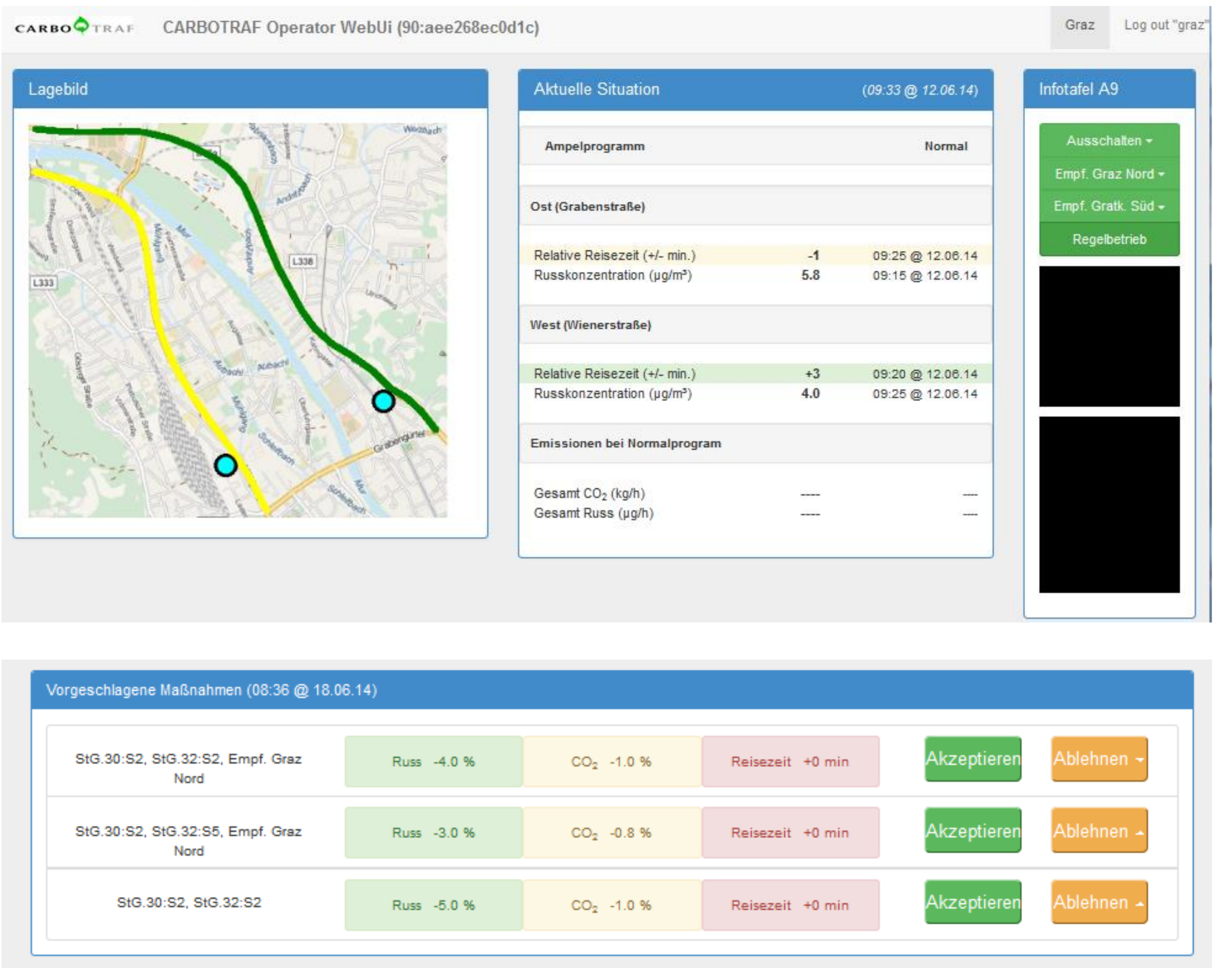

Figure 7: The decision support system developed in the CARBOTRAF project [17].

Preliminary results have shown that the **potential for emission reduction** is quite low, with the highest **improvements of up to 4%** in case of heavier traffic load. In case of low traffic, no appreciable improvements can be noticed.

Similar savings potentials have been demonstrated in the aforementioned eCoMove project. The assessment of such potential impact is linked to the "**ecoAdaptive Balancing and Control**" application, which looks at balancing traffic demand and network capacity by distributing traffic over a road network and facilitating this traffic locally with traffic light coordination. Vehicle-to-Infrastructure interaction plays a key role in acquiring real-time vehicle fuel consumption data to advise drivers about the optimal route choice and traffic light status. By taking advantage of real-time traffic information, road operators can propose alternative routes to drivers stuck in traffic, thus **reducing on average their estimated travel time by 5 % and emissions by 0.5 %**.

The impact of urban navigation strategies has been the specific target of several research initiatives in Europe. The preliminary results suggest that most of the **environmental improvements** (in the order of **up 5%**) that can be obtained by re-routing drivers through VMS or other on-board device can be obtained during **situations of heavy traffic**, but when the road network is not completely congested (i.e. when there are still other valid routing alternatives to be recommended).

2.4 Mobility management strategies

Mobility management strategies are probably the most promising and interesting ones, since they aim to change the plan of travel before a trip can take place, instead to intervene when a motorized travel is already taking place. In the scope of this analysis, the focus of this category of possible eco-friendly traffic policies has been restricted to two specific measures, which are particularly interesting for the particular needs of the city of Bolzano:

- the **dynamic pricing of parking fees**, which is automatically linked to the current traffic and air pollution conditions of the city;
- the introduction of benefits (in form of concrete **incentives**) to travelers who demonstrate to make **sustainable trip choices**, or at least to **avoid traffic peak hours**.

As far as the parking policy is concerned, during the last years, different experiments have been observed in several European cities. In **Madrid**, in 2014 the city council has decided to introduce parking fees which are directly related to the level of emissions of the vehicles. In particular, electric cars can park for free, while hybrid cars can pay 20% less than other conventionally-fueled vehicles. This policy is applied not only to parking areas, but also on parking slots near the roads: in this case, parking in empty streets will cost less, while parking in streets with few remaining parking spots left will charge up to 20% or more.

A similar initiative has started in the city of **Rotterdam**, in which a parking garage operator has started to offer discounted parking to low-emissions vehicles, in the order of 40%. In order to check if a vehicle is eligible or not for the discounting system, an Automatic Number Plate Recognition (ANPR) system has been installed in order to recognize the vehicle through its number plate, and check if emits less than 100 [g/km] of CO_2.

Another interesting initiative has been activated in the Swedish city of **Umea**, in which according to the indications defined in its Sustainable Urban Mobility Plan (SUMP) a new green parking purchase model has been developed and introduced. The basic idea is to give the possibility for property developers to build the 40% less of the new parking spaces needed in exchange for a commitment to change the travel behavior of tenants and reduce their car use by 40%. An initial experiment has demonstrated that this measure has the potential to create a potential modal shift e.g. from private cars to car pooling schemes of about 40%.

Other incentives to promote the reduction of the mobility demand during peak hours have been started to be piloted around the world. Probably one of the most interesting solutions is in test in Singapore, where in order to address the severe congestions during the peak time 8:00 – 8:45 AM incentives in form of "virtual points" have been introduced in order to foster local travelers to start a trip slightly before or later. These virtual points can be used in a raffle with the possibility to win cash. Travelers information are automatically recorded through smart cards and GPS data provided by public transportation vehicles, which can draw up a detailed overview of residents move with the local transport systems. The results of this new measure has demonstrated to reduce peak hour travel duration between 7% and 13%, with consequent environmental improvements that have however not been quantified. According however to the figures obtained during the validation of the INTEGREEN system, is possible to estimate that a reduction of peak hour travel times can determine emissions savings in the order of 5-10%, or even more in case additional factors determine a local increase of the local mobility demand.

What about the future potential associated to cooperative ITS technologies? The scenarios that are under investigation are directly link to an enhanced concept of **Low Emission Zone** (LEZ), defined as "*geographically defined areas that seek to incentivize "green transportation choices" or restrict specific categories of high-polluting vehicles from entering the zone*". The added value of cooperative technologies would be the possibility to know on a real-time basis the vehicle's engine emissions data, and assign incentives or not accordingly (Figure 8). Incentives like the one discussed for avoiding peak hour travels or inducing travelers to park in certain areas with respect to other ones, could be readapted according to this concept, which has been traditionally associated to congestion charging schemes.

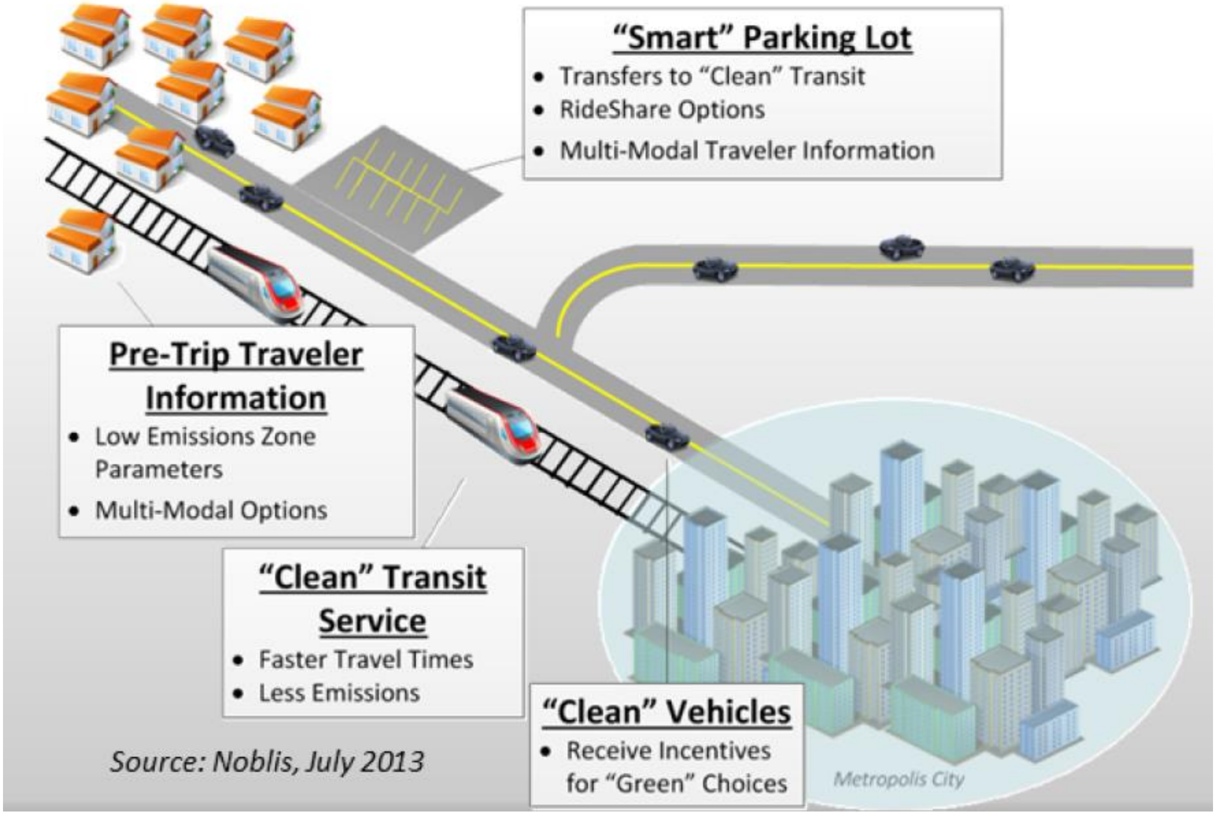

Figure 8: The enhanced cooperative concept of Low-Emission Zones [13].

Mobility management strategies include probably the set of policies with highest environmental improvements. **Parking or peak hour travel avoidance measures** can have direct impacts on the increase of sustainable transport options and for a more efficient temporal usage of the available road networks. **Emission savings can be more than 10%**, depending on the starting scenario and on the amplitude of periodic or occasional traffic congestion impacts. These measures have the potential to provide further improvements if combined in a novel concept of **Low Emission Zones**, which according to available studies and best-practices can have direct **effects in the order of 5% on the lowering on air pollution concentrations** in the area in which such zones are implemented.

2.5 Driving management strategies

Last but not least, environmental improvements can be obtained by introducing proper **driving management strategies**. The results of the baseline data collection process carried out in the scope of Action n.2 [2] have already given an empirical proof of how much an improper driving of a vehicle can dramatically increase its emission contributions.

Most of the new vehicles available for sale are now equipped with "**stand-alone" eco-driving support systems**, which teach day by day drivers on how to make best use of the gears, what speed to follow and other dynamic tips. Such on-board service can be combined with other functionalities such as automatic cruise control (ACC) in order to ensure a "smooth" driving experience even from an environmental point of view.

The scientific assessment of the benefits of eco-driving applications is the goal of several EU project, in particular of **eCoDriver**, whose results will be available in late 2015. Preliminary saving estimates have been completed again in the eCoMove project, in which the testing of eco driving support systems has demonstrated to very effective in order to strengthen the driver's awareness and the willingness to save fuel. Within the trial studies it has been possible to appreciate how highly dependent on the driving situations the fuel savings can be. Situations with the highest potential were often in urban surroundings (speed limit 50 – 70 [km/h]), in correspondence of traffic lights. Especially when approaching a red traffic light, which was about to switch to green, the information through an eco-driving support system, which is capable of communication with the traffic light, could lead to great fuel reductions close to or in some cases even above 20%, depending on the recommended target velocity [18]. Using these mechanisms unnecessary deceleration and acceleration and therefore unnecessary stops could be reduced substantially. In other situations it is questionable in which driving situations the drivers should be supported. There were some situations, e. g. curves, stop signs or roundabouts where the drivers were a little bit more skeptical about the support. A better quality check and approval of the information management within the on-board systems needs to be implemented for further studies.

According to available state-of-art studies, the environmental impact of **driving management strategies** can be very high, in particular if combined with policies governed on the central traffic management side through cooperative technologies. The highest improvements, in the **order of 20%**, can be obtained in urban surroundings in correspondence of traffic lights, but greater savings will be obviously noticeable if the starting driving behavior is characterized by a high level of inefficiency.

3 Eco-friendly policies for the city of Bolzano

The final objective of the project is to identify the most cost-effective strategies can guarantee to keep under control the environmental pollution generated by urban traffic, according to the empirical indications obtained during the final validation of the INTEGREEN project and to the most relevant international best-practices observed at the state-of-art. In particular, the aim is to build the ability for local decision-makers to avoid the need to adopt very hard measures in order to fight excessive pollution peaks, as recently carried out in Paris [19].

The results of all these investigation is qualitatively summarized in Table 2, in which the potential environmental impacts associated to the different analyzed and/or tested eco-friendly traffic policy classes is presented. This association takes in consideration two different cases: (i) the very common situation in which the urban traffic load is low and (ii) the much less frequent situation in which the urban traffic load is high. The classification has been made according to three different levels:

- **low impact**, i.e. in case the proposed policies are expected to have a nearly negligible effect on the traffic-produced emissions (i.e. up to 1-2%);
- **medium impact**, i.e. in case the proposed policies have shown the potential to determine a non-negligible effect on the traffic-produced emissions (i.e. in the order of 5-10%):
- **high impact**, i.e. in case the proposed polices have revealed a very high potential (i.e. in the order of 10-20%, or even more) environmental impact.

Eco-friendly traffic policy class	Impact with low traffic load	Impact with high traffic load
Speed management	Medium	Medium
Traffic control	Medium	High
Urban navigation	Low	Medium
Mobility management	High	High
Driving management	Medium	Medium

Table 2: Eco-friendly traffic policies categories: potential of improvement in the city of Bolzano.

The expected impact for each class of intervention and the recommended policy that can be now effectively deployed on top of the INTEGREEN system are going to be discussed in the following paragraphs, presented in form of a **SWOT** (*Strengths / Weaknesses / Opportunities / Threats*) analysis.

3.1 Speed management

The introduction of the **speed enforcement detectors** have revealed that speed management policies can be very effective even for cutting vehicular emissions, both with low and heavy traffic loads. The effect is particularly **high immediately soon after the detectors are installed**: drivers feel the risk to be controlled and the immediate consequence is that they tend to reduce their driving speed, at least in correspondence of the detectors. The field tests of INTEGREEN have demonstrated that this policy is much more effective is **several detectors are placed in series** on the same route, otherwise the effect of speed reduction is only limited in correspondence of the punctual point in which vehicular speeds are checked. Moreover, the **effect of similar speed management policies tend to decrease over time**, in particular if enforcement operations reveal to not be a good deterrent any more towards drivers.

Thanks to the INTEGREEN system and the actual ITS implementations in the city of Bolzano, it could be also possible to think to integrate in a near future a **dynamic management of admitted speed limits**, to be evaluated on top of the elaborations outputs of the INTEGREEN system. Dynamic speed limits could be visualized by drivers through roadside VMS or through proper information integration within the on-board devices.

The recommendation for the further extension of this pilot measure can be summarized as indicated in Table 3.

Strengths	**Weaknesses:**
• **emissions reduction potential** in the order of **10%**; • policy effective with both **low and heavy traffic loads**.	• the environmental effect tends to decrease in time; it is recommended to maintain a **high level of enforcement** coupled with this measure; • the effect of this measure is highest if **several detectors** are placed on all **most important routes** of the city (otherwise the impact could be nearly negligible);
Opportunities:	**Threats**:
• **dynamic management of admitted speed limits**, to be defined according to the elaboration outputs of the INTEGREEN system.	• proper **authorizations** could be necessary and eventually be obtained by the national stakeholders; • this policy has been **negatively accepted by local travellers**, with the need to properly and continuously communicate the positive impacts obtained thanks to this policy.

Table 3: Recommendation for the future implementation of speed management policies.

3.2 Traffic control

The first tests with the enhanced traffic lights system has demonstrated that the impact of adapting traffic light cycles can be not negligible, but with the most evident results to be associated to situation of **heavy traffic load** and in correspondence of a series of **enhanced traffic lights intersections**. According to state-of-art analysis, the passage from non-dynamic to dynamic changes of the phases of the traffic lights according to real-time traffic detections can produce the most relevant environmental savings.

Thanks to the INTEGREEN system and the actual ITS implementations in the city of Bolzano, it could be also possible to think to integrate in a near future more advanced policies in the dynamic actuation of traffic lights. The idea could be in other words to introduce **advanced coordinated traffic lights signaling plans**, dependent not only by **local traffic detections** but also on **current air pollution levels and meteorological conditions** as well. This is in ambitious policy which some European city is already exploring, and that now can be deployable in Bolzano with reasonable effort thanks to the INTEGREEN system, which promises to significantly reduce the environmental impact at traffic intersections in particular in case of situations of high traffic load (e.g. high tourist demand, bad weather, etc.).

The recommendation for the further extension of this pilot measure can be summarized as indicated in Table 4.

Strengths • **emissions reduction potential** in the order of **20%**;	**Weaknesses:** • the environmental effect tends to be greatest with **heavy traffic loads**, which is however the less frequent one in Bolzano;
Opportunities: • **adapt traffic lights cycles** according to **environmental information** as well (air pollution and meteorological conditions).	**Threats**: • the increase of traffic flowing could foster an **increase of traffic levels** in the city. Therefore this measure must be coupled with policies continuously promoting sustainable mobility habits.

Table 4: Recommendation for the future implementation of traffic control policies.

3.3 Advanced end-users services and incentives program

The launch of the first advanced applications for the local travelers has **not shown significant environmental improvements**, but is already demonstrating important **positive impacts**, as for example the general reduction of the occurrence of traffic congestions in the city. These services are going to become more and more important in order to **increase the stability** of the urban mobility system with respect to external influencing factors, in particular bad weather information and sudden increase in the occasional mobility demand.

The recommendation is therefore to **further improve and promote the advanced services destined to local travelers**, which will be foster more and more intelligent mobility choices by occasional and non-occasional users. The services must be improved in order to provide in an easier way the **recommendation for the best trip in Bolzano based on the current conditions**. As indicated by the feedbacks of the users' survey, these services will have a more relevant added value if they will be able to **notify only real-time issues** affecting the mobility system of the city. As demonstrated even in other pilot initiatives investigated in this analysis, **most of the efficiency is in the time and mode of a travel**, and less on the **selection of the route**. This is particularly emphasized for the city of Bolzano, where the road network is quite limited in extension and the possibility for navigation alternatives quite limited.

End-users applications will moreover represent the opportunity to inform travelers about:

- **new incentives schemes for non-entering in the city during peak hours**;
- **dynamic policies** related e.g. to the **change of the prices of the parking areas in the city according to current load for accessing the historical city centre**.

The recommendation for the further extension of this pilot measure can be summarized as indicated in Table 5.

Strengths	**Weaknesses:**
• **emissions reduction potential** in the order of **20%**; • policy effective with both **low and heavy traffic loads**.	• the policy takes some time to be environmentally-effective, since a certain penetration in the local community of travellers must be created. Proper activities of users' (and stakeholders') involvement are therefore recommended in order to speed up this process.
Opportunities:	**Threats**:

• **evolution of the end-users services**:
  ○ best **real-time trip option** automatically suggested;
  ○ **notifications** only delivered to users;
  ○ combination with **incentives policies** concerning the management of peak times travels and parking offer.
	• the incentives policies can determine political and social opposition by users and stakeholders. It is therefore recommended to involve all interested parties in the calibration of these policies in order to find the best acceptable compromise which can at the same guarantee the expected environmental outcomes.

Table 5: Recommendation for the future implementation of incentives programs based on advanced end-users services.

3.4 Advanced Low Emission Zones concepts

Low Emission Zones (LEZ) are a consolidated policy in urban areas which are conventionally defined as "*areas where access to certain polluting vehicles is restricted or deterred*".

The main purpose of this policy is primarily to **improve air quality**, but actually they can be considered as a powerful instrument to better manage traffic flows in the city. Many examples of LEZ are available in Europe and in Italy as well, and are organized for different purposes and on the base of different criteria, covering the following variables:

- type of **pollutant vehicles** that are not allowed to transit in the LEZ;
- **operating mechanisms** (e.g. permanent / temporary);
- type of **enforcement mechanisms** used to verify the observance of the access mechanisms;
- integration with other **road charging principles**.

A reference state-of-art example could be the one of **Milano**, in which the "Area C" scheme is in function. It is an example of combined LEZ and urban road charging scheme, where vehicles are charged to enter, but only if they present a minimum emissions standard. This scheme, that has significantly evolved during time, and which is electronically controlled by an ANPR scheme, has shown to be able to produce significant environmental results: according to data presented during the 2014 conference of the CIVITAS network, there has been a **reduction of 50% of pollutant vehicles, a reduction of about 20% of nitrogen oxides, and a reduction of about 35% of carbon dioxide** [20].

An important aspect is related to the economical sustainability of this solution: thanks to the new incomes, more funding are available for sustainable mobility modes.

In Bolzano, thanks to the new ITS implementation that the Municipality of Bolzano has been introducing (enforcement system for the automatic control of the vehicular access to the historical city centre, ANPR installations in residential areas), the purpose is to develop a completely new LEZ operating mechanism to be enhanced in:

- **time**, since access criteria could change dynamically as a function of current (and predicted) traffic and environmental conditions;
- **space**, since access criteria could take in active consideration the current situation in neighboring road networks such as the regional one and the A22 highway and could be virtually extended in these areas.

The basic idea is that most of the environmental benefits could be obtained in a reduced amount of time, avoiding to maintain strict limitations even if this is not strictly necessary. This assumption is supported by several state-of-art studies available in the literature, carried out primarily in highway domain.

The recommendation for the implementation of this pilot measure can be summarized as indicated in Table 6.

Strengths	**Weaknesses:**
• direct improvements of the **air pollution concentrations** where the LEZ is implemented, with **decrease in the order of up 30%**; • significant **reduction of high pollutant vehicles** traveling through the city (of about one half).	• the costs for implementing such a measure are not negligible. To be effective, new system components to INTEGREEN must be added (e.g. predictive tools, integration with neighbouring traffic management systems, etc.). The demonstration of a LEZ could be the focus of a new follow-up project.
Opportunities:	**Threats**:
• development of a **completely new LEZ concept** that other urban areas could replicate, and that can provide a more acceptable compromise between traveling needs / environmental protections goals.	• the introduction of a LEZ is a complex process that touches the interest of several involved parties. It is therefore recommended to involve all interested parties from the conception of this measure in order to guarantee the maximum level of acceptance by all target groups

Table 6: Recommendation for the future implementation of the advanced LEZ concept.

4 Contributions to the implementation of new EU policies

During the implementation of the INTEGREEN project, it has been possible to verify how the proposed approach of integrating both traffic and air pollution information in order to better manage urban traffic from an "environmental" point of view has become more and more widespread not only in Europe but also worldwide. Just to name a few project initiatives, the following best-practices are mentioned:

uTRAQ project

From official sources of Transport Research Laboratory (TRL):

*"The **Urban Traffic Management and Air Quality** (uTRAQ) project uses satellite-generated atmospheric data to help local authorities devise **traffic management strategies for reducing pollution levels and hotspots**. The project is part funded by the European Space Agency (ESA) and led by the UK's Transport Research Laboratory (TRL) in collaboration with TSS-Transport Simulation Systems (TSS) and the University of Leicester in the UK's Midlands.*

*The uTRAQ project breaks new ground by bringing **air quality and weather monitoring systems, modelling and traffic forecasting tools, and adaptive management systems into one single, user-centric intelligent integrated solution**. An intelligent decision support tool enables a traffic control operator to implement traffic control strategies that can be used to mitigate the effects of local traffic air pollution, reduce pollution hotspots and exceed air quality thresholds.*

Developed under the ESA's Advanced Research in Telecommunications Systems' (ARTES) 20 Integrated Applications Program (IAP) , the uTRAQ project aims to:

- *demonstrate and promote how space applications can be used for the management of traffic and air quality;*
- *provide city-wide data for traffic and air quality for the support of policy decisions at an operational level;*
- *develop a new operational service in close participation with local authorities for managing their traffic and air quality through broad participation by key factors, such as local authorities, SMEs, and other industrial businesses;*
- *demonstrate a manual/automatic monitoring and decision support tool to aid traffic management at an operational level, considering a range of policy level objectives.*

The uTRAQ system integrates software components that enhance an existing UTC (Urban Traffic Control) system, in this case SCOOT (Split Cycle Offset Optimization Technique), in order to allow the optimization of traffic signal timings for both improved air quality and traffic *flow, instead of just for optimal traffic flow.*

Traffic data, air quality data and meteorological data integrates with a modular traffic management system that collects, filters, processes and analyses the data feeds. A key feature of the project is its use of the latest air quality and traffic software models to generate test strategies: TSS' Aimsun Online is the real-time, simulation-based traffic prediction module providing live forecasts for upcoming traffic conditions, while the University of Leicester team is providing the air quality (AQ) module, which will identify AQ data feeds and generate real world forecasts, 'now-casts' and emissions profiles from the traffic model for each test strategy. The combination of feeds will enable uTRAQ to identify points, routes or areas where AQ is a problem.

Over the course of the next year, the uTRAQ system will be tested at three locations:

- *the first is in cooperation with Leicestershire County Council and involves the **A6 corridor**, which approaches the city from the south east and is considered one of the busiest stretches of road in the county;*
- *the second test site is **Northampton**, where the uTRAQ team will model up to 66 road junctions, most of which have SCOOT, and can use GNSS data from the city's buses (pictured) to fine-tune performance;*
- *the final site is in the **city of Leicester**, including some adjacent sites in the county, with control available through 122 controlled junctions with access to intensive AQ monitoring facilities and data such as Airviro.*

Leicester currently has the worst air quality in the UK and the ninth worst in the EU, in terms of numbers of days exceeding minimum acceptable levels".

"Green Vision" initiative

From official releases of the city of San Josè (USA)

The city of San José and Intel Corporation are collaborating on a public-private partnership (P3) to further the city's 'Green Vision' goals. The project, known as 'Smart Cities USA', is expected to help drive San José's economic growth, foster 25,000 clean-tech jobs, create environmental sustainability and enhance the quality of life for residents. The pilot program in San José is Intel's first smart city implementation in the USA, with the scalability of the company's architecture expected to enable the city to quickly deploy a range of smart systems to improve: air and water quality; traffic and parking management; noise pollution, public transportation efficiency; communications systems; and other city infrastructure.

The pilot project will give San José residents real-time, local data that can inform their personal decisions. For example, the community will better understand how they can help 'Spare the Air' on poor air quality days. When there is a local air quality alert, residents can choose to take public transit, bicycle or carpool to get to work and thus reduce emissions and *improve air quality. Known as the Capital of Silicon Valley, the city is installing a network of sensors to create a 'sustainability lens' that uses Intel technology to measure various characteristics, such as particulates in the air, noise pollution and traffic flow. The measurement data will produce meaningful insights that will lead to improvements in air quality, noise, transportation efficiency, environmental sustainability, health and energy efficiency. San José has installed a sensor demonstration platform using Intel's Gateway Solutions for the Internet of Things, with the company's Quark processor and third-party sensors. Each gateway incorporates Wind River's Intelligent Device Platform software with McAfee security features connected to Intel's Hadoop distribution in the cloud.*

4.1 Air pollution policy

The implementation of the INTEGREEN project has confirmed its contribution for actively supporting the implementation of the **EU Environment Action Programme** [21] and the further development of the EU legislative framework, indicated in the **EU Air Quality Strategy 2030** .

INTEGREEN represents a clear application of one of the key measures identified to deliver air quality compliance, which is to "*foster enhanced technical and management capabilities*".

In particular, "*Member States, regions and cities with notable air quality problems are encouraged to consider the use of these funds [2014-2020 European Structural and Investments Funds (ESIF) and the new LIFE instrument for 2014-2020] where relevant, to implement actions to reduce air pollutions, not least through the promotion of innovative technologies. LIFE will support the temporary additional efforts that may be needed to improve overall air quality governance and help leverage more substantial additional finance from other funding sources*."

The added values of the project, proofed by empirical evidence, can be summarized as follows:

- **accurate monitoring** system capable to **jointly measure traffic and air pollution conditions directly at the emission source** (i.e. the road), and thus the possibility to exactly assess the environmental impact of a specific measure / policy;
- capability to carry out specific evaluations about the **localized presence of air pollution peaks** through the **low-cost mobile probe**, and thus enhance the comprehension of the dispersion phenomena near these linear sources;
- the **integrated real-time traffic / air pollution conditions assessment**, which could significantly improve not only the way urban traffic is typically managed and controlled, but also the traffic-related policies which are typically proposed by air quality experts in order to face the pollution issues facing the urban environments. INTEGREEN could thus represent a very valuable instrument for further **approaching the traffic and the environmental community**.

4.2 Urban transport policy

As far as the transportation EU policies and targets are concerned, the new reference strategy is the one presented in the **White Paper** "*Roadmap to a Single European Transport Area - Towards a competitive and resource efficient transport system*", published in 2011 and which:

"*makes the case for transforming the European transport system into a sustainable and competitive system that will further improve mobility and continue to support economic growth and employment. It sets ambitious objectives for reducing Europe's dependence on imported oil, improving the environment, reducing accidents and sharply cutting greenhouse-gas emissions. These objectives have to be seen in the context of a continuous growth in transport demand, differences in the evolution of transport modes, demographic changes and a dwindling investment capacity of public authorities*."

Through a recent Communication of the EC, a first stocktaking of research and innovation in the EU transport sector has been defined. Key points are in particular:

- the development of user-oriented integrated transport;
- the introduction of new generations of urban transport vehicles and schemes;
- the convergence between distinct fields such as transport, information and telecommunications services, environment;
- the creation of new innovation spiral in which a new generation of talents, innovators and entrepreneurs can be attracted.

The INTEGREEN project has managed to identify a certain number of traffic measures catalogue, evaluated from their environmental impact potential. The knowledge of these impacts, and the further analysis of the ex-ante/ ex-post conditions associated to the introduction of the selected policies thanks to the INTEGREEN framework, can with no doubt represent an added value for the EU transport policy in terms of:

- advanced **monitoring of the impacts of urban traffic strategies**;
- **recommendation of most cost-effective solutions deployed** (based on empirical and qualitative results).

It is important to finally underline the added value of the project in terms of **local contribution of the achievement of the indicated European targets**.

Conclusions

This report has covered the analysis of the potential of several eco-friendly traffic policies to be introduced in the city of Bolzano on top of the INTEGREEN system.

First of all, an analysis of the different classes of the eco-friendly strategies based on state-of-art results has been completed. The most relevant results are summarized in Table 7.

Eco-friendly traffic policy class	Target	Potential environmental benefit
Speed management	Control vehicular speeds in order to ensure that the quantity of emissions is minimum.	Emissions reduction in the order of 10-15%, air pollution concentrations of 2-8%.
Traffic control	Optimize the regulation at signalized intersections.	Initial “automation” of traffic lights can determine a reduction of traffic emissions up to 30%. Additional benefits up to further 20% are possible through new cooperative approaches based on direct communications traffic lights – driver.
Urban navigation	Optimize the distribution of vehicular traffic over the road network.	Limited environmental improvements (in the order of 5% emission reductions, obtained in particular in case of heavy traffic).
Mobility management	Influence the mobility demand of people and goods so that the efficiency in the usage of the road network and the mobility services is maximum.	Emissions savings can be potentially huge (even more than 20%) if policies determine modal split changes. The highest benefits can be obtained during traffic congestion situations. Measures which are linked to novel Low Emission Zones concepts can have direct impacts on air pollution concentrations, in the order of 5% or even more.
Driving management	Improve the driving styles so that the environmental footprint of a motorized urban trip is minimized	Highest improvements are in urban surroundings in correspondence of traffic lights, and can be responsible for emission savings in the order of 20%. The improvement is however much more greater if the initial driving style is very inefficient.

Table 7: Summary of the potential impacts of the different eco-friendly traffic policy classes, according to state-of-art information.

On the base of these inputs and the preliminary empirical results of the policies tested in the city of Bolzano, whose results are reported in deliverable D.5.2.2, it has been possible to identify the level of impact that each strategy can have in the particular environment of the city of Bolzano, as summarized in Table 2.

On the base of these assessment results, the following package of policies has been identified for short-term implementation.

- **large scale installation of speed detectors**;

- **introduction of advanced coordinated traffic lights signaling plans**, with potential linkage to the current air pollution levels and meteorological conditions;
- **further improvement and promotion of the advanced services destined to local travelers**, with the possibility to introduce new incentives e.g. for non-entering in the city during peak hours, or to promote most effective parking strategies in the city centre, with e.g. the possibility to dynamically change the prices of the parking areas in the city according to current load for accessing the historical city centre.
- **introduction of a new advanced Low-Emission Zone concept**, that aims to dynamically manage the transit of high pollutant vehicles (in particular, heavy ones) to and across the city. The idea is to manage restrictions in a non-fixed way, depending on the current (and possibly forecasted) traffic and air quality conditions in the city.

The report has finally carried out an evaluation of the project contribution to the EU policies. The project not only represents a local effort to implement the EU policies in the field of sustainable urban transport and the management of air pollution issues. The main added value of the project is that it is one of the attempts at European level to approach the traffic and the environmental community by creating a unique system capable to measure both conditions on a real-time basis. The project supports even the idea to include some new technologies like the mobile system prototype for detecting the localized presence of air pollution peaks. From a transportation point of view, the INTEGREEN system represents an interesting solution for quantitatively assess the performance of the selected traffic strategies, with the opportunity to significantly improve the monitoring capabilities concerning the level of achievement of reference EU targets.

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