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The "lower emissions Brenner Digital Corridor": final empirical results of the BrennerLEC project

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Abstract

Apart from being one of the most important transportation axes of the European TEN-T network, the Brenner Corridor is today one of the most advanced roads in terms of research, development, testing and deployment of smart transportation technologies. This paper aims in particular to present the final results of one of the projects carried out by Autostrada del Brennero on the A22 highway in Italy, i.e. BrennerLEC, in which an extensive evaluation of the impacts of VSL applied for environmental and traffic control purposes and controlled by a complex ITS has been carried out. The results clearly demonstrate that VSL have a significant impact not only for reducing NO_2 concentrations, but also for increasing service levels in case of heavy traffic load. The measures are going to be exploited on the entire alpine stretch of the highway and extended in cooperative terms, leveraging on the C-ITS infrastructure under development.

Keywords:

Environmental traffic management, VSL, low emission corridor, gamification, C-ITS

Introduction

The implementation of Low Emission Zones (LEZs) is today a state-of-art measure that, especially in Europe[1], city authorities typically implement in order to tackle the high concentrations of air pollutants produced by urban traffic. LEZs are typically the expression of sensible areas that are protected by prohibiting or severely discouraging the access of the most pollutant vehicles. In London such restrictions are so strong that the new acronym ULEZ (Ultra LEZ) has been developed and used[2].

However, the concept of LEZ can be more effective if applied in big metropolitan areas, where urban traffic contributes to a large extent to air pollutant concentrations. In the case of smaller urban areas,

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[1] Please check the website: https://urbanaccessregulations.eu/low-emission-zones-main for more information about the current LEZs developments in Europe

[2] Details of the London's ULEZ are reported here: https://tfl.gov.uk/modes/driving/ultra-low-emission-zone

and in particular in mountainous regions like in the Alps characterized by a particular orography, alternative or additional solutions that are solely not limited to the urban infrastructure have to be designed. This is for example the case of the city of Bolzano, in the South Tyrol region in Italy, which is characterized by the transit of the A22 highway through the city. It is estimated that the highway traffic is responsible for about 20% of the overall NOx emissions generated in the urban area [1].

Figure 1 – A view of the city of Bolzano. The A22 highway crosses the urban area near the Adige river.

This is the reason why, after a preliminary project experience focused on policies targeted for the urban area [2], a local public – private consortium has decided in 2016 to start implementing the BrennerLEC project, co-funded by the European Commission under the LIFE programme, in which the focus is put on the highway traffic. In the scope of this project, a novel “Low Emission Corridor” (LEC) concept was coined. LEC is associated to a set of highway traffic control measures that have the clear goal of reducing the emissions of air pollutants generated by transit traffic, but without introducing particular restrictions for the circulation of vehicles. Such measures, which are extensively described in [3], are mainly based on the use of Variable Speed Limits (VSL), which particularly target diesel passenger cars. According to preliminary studies, shortly summarized in Figure 2, diesel vehicles account for about 76% of the entire fleet, and passenger cars for about 46% of the total emissions produced by the highway traffic.

After five years of intense empirical testing, in part already reported in [4] – [5], it is possible to provide a comprehensive assessment of the impact of the proposed measures and understand how they can evolve in the near future in light of the expected evolution of the circulating fleet, also in terms of cooperative and automated functionalities.

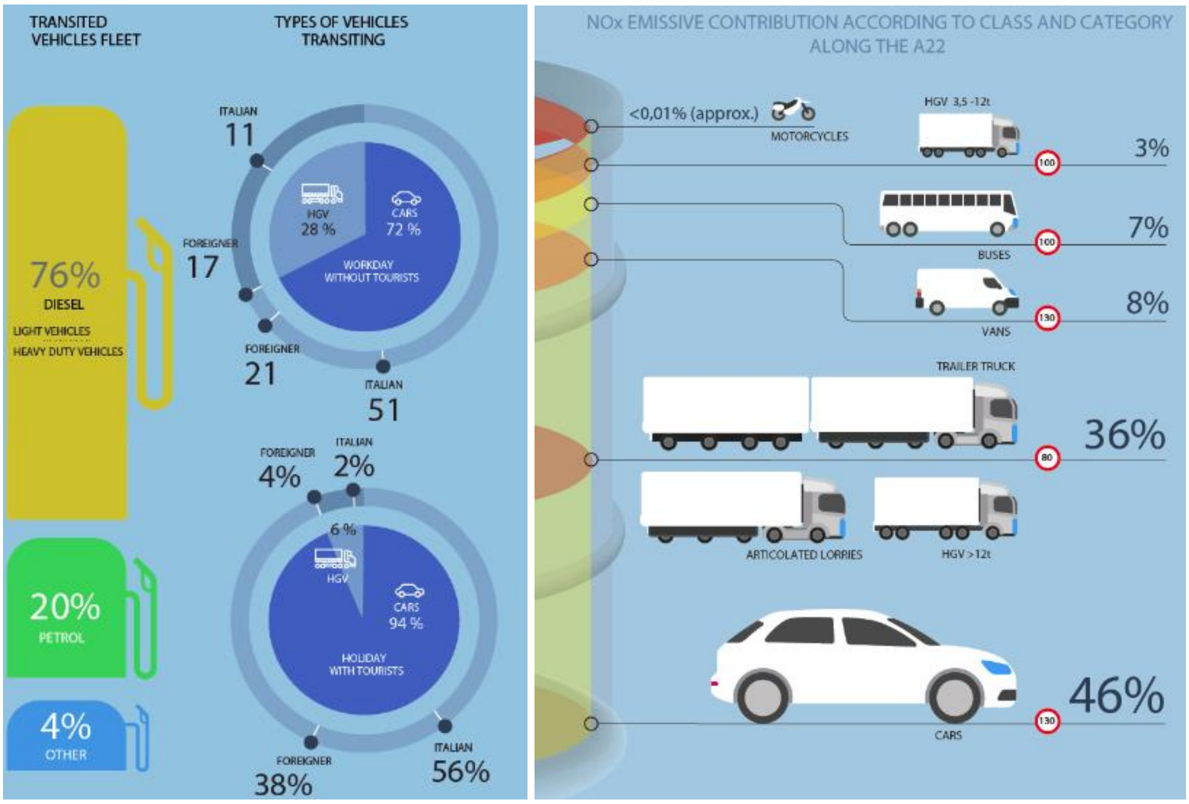

Figure 2 – Initial assessment of the circulating fleet on the A22 highway and its impact on NOx emissions.

The final configuration of the ITS system implemented

One of the main assumptions of BrennerLEC is that the activation of the measures must be proportioned to the effective impact that they may generate. This means, VSL should be activated when real-time and predicted traffic, meteorological and air quality conditions are favourable to obtain valuable benefits. In order to apply this approach, a complex ITS has been implemented so to let the Traffic Management Centre (TMC) of the A22 dynamically activate the target measures (Figure 3). The elaboration / forecasting logics take advantage of the data integration provided by the Open Data Hub[3], an open platform developed by NOI Techpark, in which all relevant sensor measurements are collected and harmonized. The so-called “traffic state machine” has the function to determine on a real-time basis the traffic conditions, and to suggest different VSL according to the congestion levels reached. A separate elaboration chain is used to evaluate if VSL are needed in order to tackle high NO_2 concentrations, based on the following steps: (i) estimation of the traffic-generated emissions, calibrated according to the last available information of the circulating fleet, which is updated on a yearly basis; (ii) forecast of the meteorological conditions, and in particular of the atmospheric stability; (iii) estimation of the NOx / NO_2 concentrations, also supported by data-driven assumptions of the background concentrations. The system implemented is also going to support the dynamic integrated management of traffic flows between the highway and the main urban centers of the region, e.g. for re-routing transit vehicles.

[3] For more information about the Open Data Hub, please refer to the website https://opendatahub.bz.it/

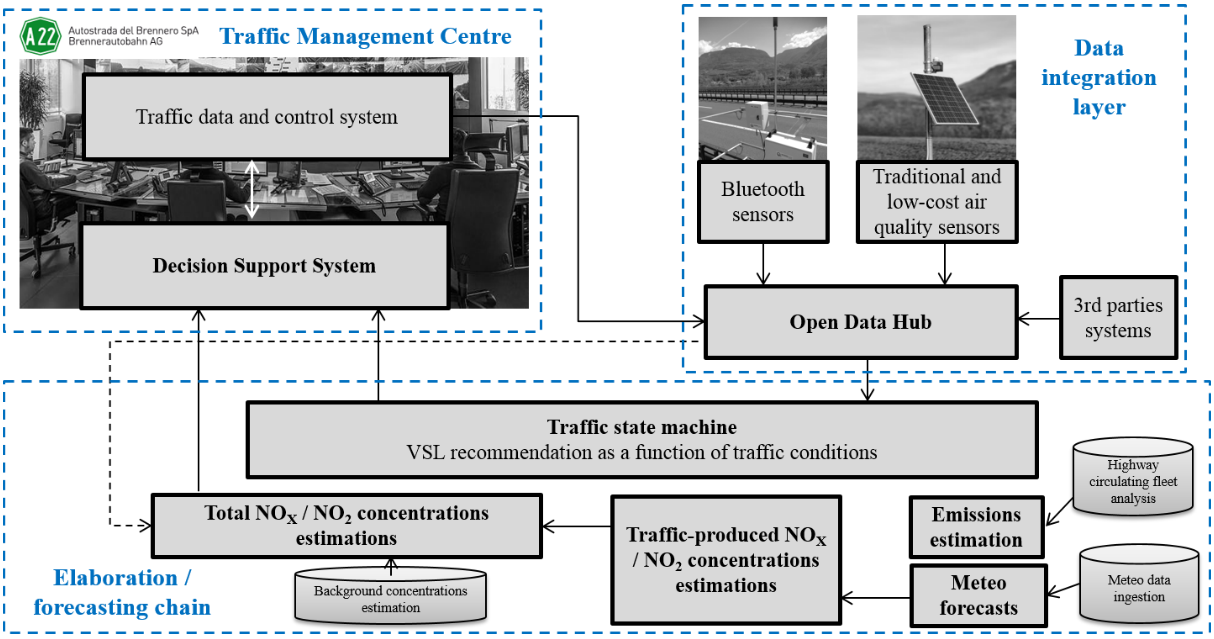

Figure 3 – The final system architecture implemented in the BrennerLEC project.

At present, in Italy the activation of VSL due to solely environmental reasons is not allowed. This fact has significantly limited the compliance rate of drivers, in particular in relation to certain test typologies. In order to address this challenge, an innovative solution was conceived and implemented. It is based on a rewarding APP, that automatically adds or subtracts points to drivers depending if they have respected the reduced speed limits on the highway. Users with the highest number of points can aspire to symbolic prizes which have been offered for this first competition, and which may be even more attractive in the future. Unfortunately, the restrictions caused by the COVID-19 pandemic have significantly influenced the evolution and the marketing of the competition. Despite this, a first group of nearly 200 active users has been already involved. The objective is to extensively test this approach during 2021, and to assess its impact on the level of compliance to VSL.

Results of the field operational tests

Field operational tests have been mainly divided between VSL triggered by poor air quality conditions (mainly characterized by the use of the recommended speed sign) and VSL triggered by congestion phenomena. The first typology of test has been more extensively evaluated, with more than 4’000 hours of VSL activation up to March 2020. Despite the current regulation, during the first testing phase the mandatory speed limit road sign was used. This has given the possibility to consolidate various robust emission reduction scenarios that are associated to the average drivers’ behaviour observed (Table 1). In particular, a robust comparison based on real data between the scenarios “business-as-usual” (in which no VSL are activated), suggested speed limit (with usage of the “recommended speed” signage) and mandatory speed limit (with usage of the “mandatory speed” signage) has been carried out. The estimation of the emissions is carried out through the COPERT methodology and emission factors and based on top of traffic data, in particular vehicles’ type and speed, and data related to the effective circulating fleet on the A22 highway. The latter data is derived from detailed assessments, carried out on a yearly basis, which investigate the motorisation of the vehicles during certain reference day types. The results obtained clearly demonstrate the effectiveness of this measure also for the reduction of greenhouse gas emissions. This analysis has been enriched by an evaluation of the possible added value of a section control system; in this case, the speed pattern profile has been completely simulated,. As far as the impact on roadside pollutant concentrations are concerned, air quality measurements carried out in particular in the first test phase have demonstrated a reduction of 14% of NO_2 emissions with an average speed reduction of 14 [km/h] (from 123 [km/h] without VSL activated to 109 [km/h]).

Table 1 – Emissions’ reduction associated with different reference scenarios. The reductions are compared to the reference Business-As-Usual scenario (no VSL)

Scenario	NO_x emissions scenario / BAU emissions scenario [%]	CO_2 emissions scenario / BAU emissions scenario [%]
Scenario “**business-as-usual**” (BAU)	100.0%	100.0%
Scenario phase 3 – **suggested** speed limit (real)	95.8% (-4.2%)	98.1% (-1.9%)
Scenario phase 1 - **binding** speed limit **without** section control (real)	88.0% (-12.0%)	93.9% (-6.1%)
Scenario **binding** speed limit **with** section control (simulated)	74.6% (-25.4%)	87.1% (-12.9%)

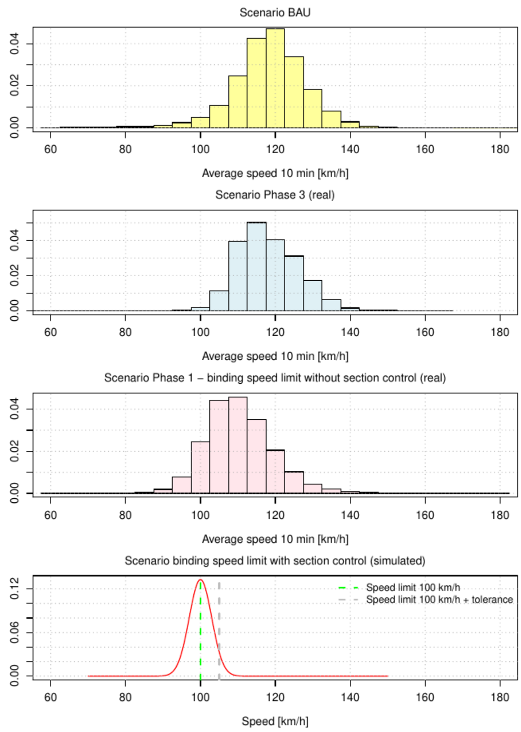

Figure 4 – VSL triggered by poor air quality conditions in different testing conditions: suggested speed limit (on the left) and mandatory speed limit (on the right) .

The second typology of test has been carried out less frequently, since congestion phenomena are typically limited to spring and summer weekends (e.g. due to foreign travellers coming in Italy for holidays) and to the Christmas period. Despite this, up to February 2020 it has been possible to execute more than 700 hours of tests and get solid results about the benefits of this measure as well. The most significant indications in that respect were collected during the summer 2020, when, due to the COVID-19 limitations, it was not possible for the TMC of A22 to carry out tests, despite traffic levels occasionally reached the typical pre-COVID levels observed in the previous years. In particular, a comparison between the overall levels of service observed with and without VSL activated (years 2019 and 2020, respectively) during days which showed similar traffic volumes has been carried out (Figure 5). In most of the cases observed, days with VSL activated, characterized by greater traffic volumes in the same time period (8-20), showed remarkable reductions of the travel times. During 2021 the final testing phase will be carried out on top of a more consolidated version of the Decision Support System (DSS) made available to the TMC’s operators, and these preliminary results will be furthermore enriched and extended also to other relevant KPIs, in particular the emissions of air pollutants and greenhouse gases.

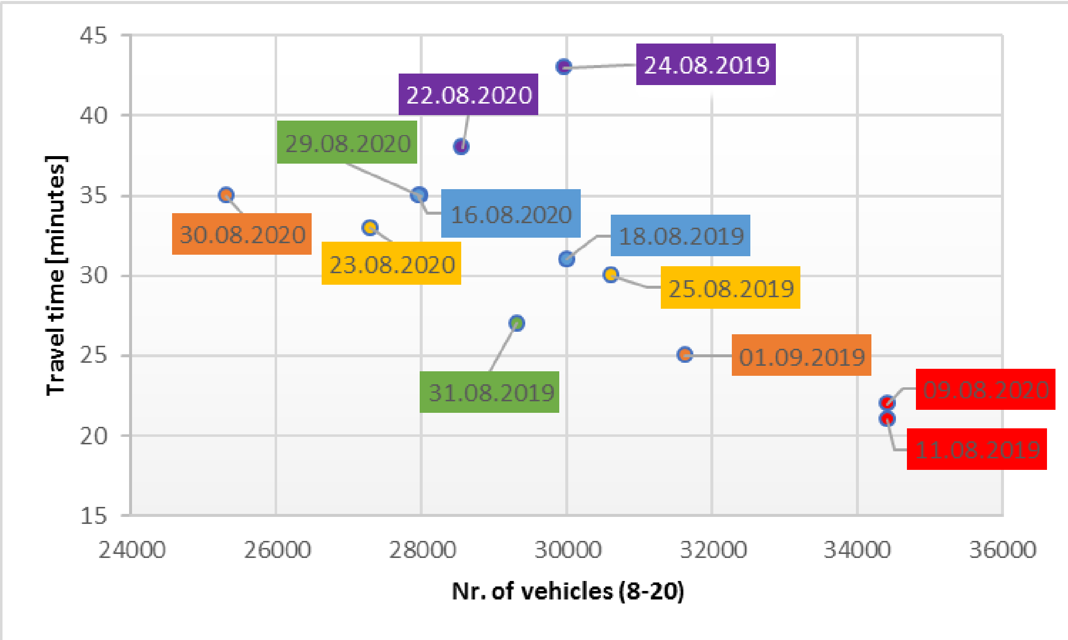

Figure 5 – Comparison between target days of heavy seasonal traffic between summer 2019 (with activation of VSL) and 2020 (without activation of VSL).

Replication perspectives

These results are promising in view of the exploitation of such measures along the entire alpine stretch of the A22 highway and – more ambitiously – on the entire Brenner Corridor. The long-term perspective is to build a so-called “lower emissions Brenner Digital Corridor”, in which the BrennerLEC measures are applied and extended (also for managing heavy traffic) by taking leverage of the C-ITS hybrid infrastructure that has been deployed, in particular in the scope of the C-ROADS Italy and 5G-Carmen projects (Figure 6). More specifically, through one of the Day-1 applications (i.e. in-vehicle signage / speed limits), future connected and automated vehicles (CAVs) will be able to automatically receive the information of an active VSL and adapt their speed accordingly. Such cooperative scenarios are under research and development, and first pilot tests have been already carried out on limited stretches of the A22.

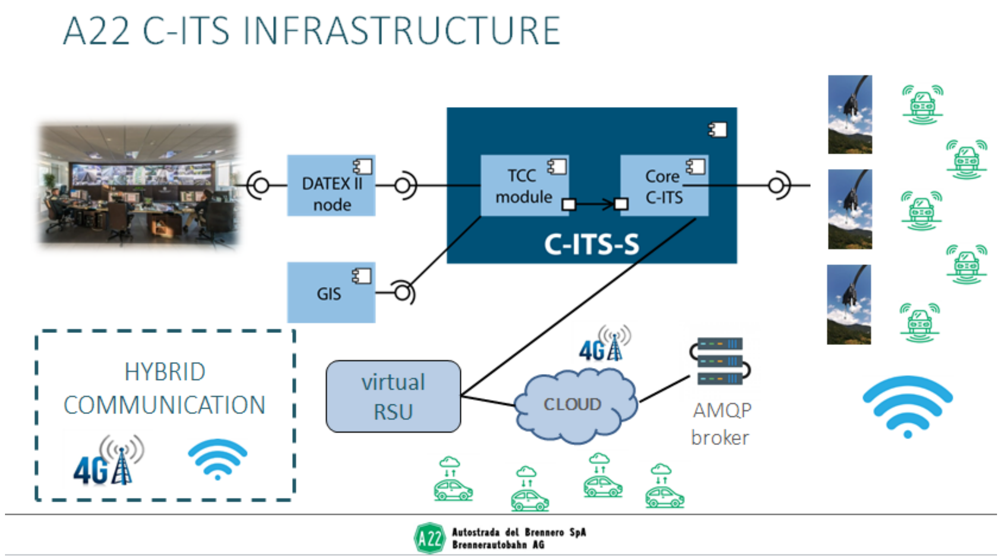

Figure 6 – Screenshot example of the back-end system of A22 generating the cooperative messages for the connected vehicles.

But what about the replication of the VSL measures along the A22, given the current and forecasted air quality and traffic levels and considering external factors such as the changes in the mobility habits caused by the COVID-19 pandemic and the evolution of the circulating fleet driving on the highway? The periodic aforementioned studies on the effective fleet driving along the A22 highway (Figure 7) clearly show that the renewal of the vehicles driving on the A22 highway is happening fast in terms of EURO class, but without significant variations in terms of the share of combustion engine type. For instance, diesel light vehicles have confirmed to be the majority of the transit vehicles, with a share that passed from 75% in 2017 to 82% in 2019. A remarkable increase of “clean” vehicles (e.g. newer EURO-6, hybrid or full electric passenger cars) is however to be expected in the next years; this trend must be however verified also in the following years, and in particular in 2020 and 2021, in order to also consider the possible effects of the COVID-19 pandemic.

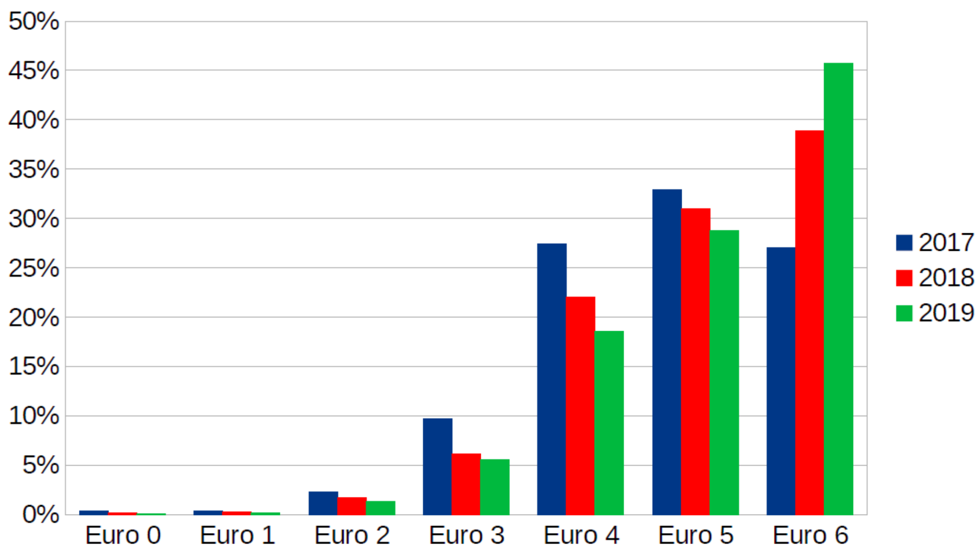

Figure 7 – Evolution of the real circulating fleet on the A22 highway in the test stretch (detail of light vehicles).

The exploitation plan which is proposed for the extensive application of the VSL takes in consideration these challenges and aims to define a concrete replication output that is expression of an optimized balance between expected impacts and investments needed. As far as the VSL for air quality purposes are concerned, the following methodology is proposed:

- calculation of a detailed map (resolution 2 x 2 [km^2]) of the average background pollutant concentrations, i.e. without the contribution produced by the traffic on the A22 highway;
- evaluation of the average air quality conditions in correspondence of the highway:
    - (i) if they exceed a certain reference threshold, the stretch must be managed with VSL; for NO_2, this threshold is at present set to 32 [$\mu g/m^3$], corresponding to the upper assessment threshold of the annual limit value for the protection of human health set by the Directive 2008/50/EC;
    - (ii) if not, the presence of significant residential structures near the highway must be considered and the total average concentrations experienced at this distance must be calculated. The contribution to local concentrations of the A22 highway is spatially modelled through a negative exponential curve, calibrated through field data. In this case, VSL are foreseen in cases in which estimated air quality levels exceed the reference annual limit value of 40 [$\mu g/m^3$] set by the Directive 2008/50/EC.

The application of this methodology results in the activation of such VSL mostly in correspondence of the most populated areas (e.g. crossing of urban areas), where the most significant air quality issues are located (Figure 8). The red stretches are those which do not pass the control (i), while the orange ones are those related to buildings near the highway with average concentrations above the reference annual limit value (control (ii)). In order to check possible critical solutions near this threshold reference also stretches with concentrations greater than 38 [$\mu g/m^3$] have been highlighted in yellow. The green stretches are those which do not suffer from any environmental concern in terms of NO_2 concentrations. The final definition of the stretches in which VSL have to be applied or not, reported in Figure 8 as well, is based on a post-processing work, which takes into account mainly the relevance and the type of the buildings near the highway (in case of building outside residential zones these cells are marked as "green", otherwise as "red") and the current infrastructure setting, by considering factors such as the presence of VMS or the positioning of the toll gates.

As far as the VSL in case of heavy congestion levels are concerned, the plan is strongly based on the ambition of A22 to equip the infrastructure with hard should running (HSR) in both directions of travel between the toll gates of Bolzano South and Verona North, that are placed at a distance of about 140 [km], with a dense network of Variable Message Signs (VMS) of different type, in order to properly manage the lanes opening and associated VSL in different steps of activation and deactivation. An analysis of the traffic volumes and characteristics has already evidenced that this type of measure can be justified from Bolzano South up to the connection with the A4 highway, south of Verona. Inside this long stretch, different sub-stretches can be defined, with different calibration settings and trigger parameters for activating VSL. The junction stretch that connects to Austria (Brenner – Bolzano

South), of about 100 [km], has completely different characteristics and patterns, and, being mostly placed on viaducts, it is quite unfeasible to foresee an adequate network of VMS. In this stretch, it could be however possible in the future to applicate VSL in a “virtual” way, thanks to the remote connection between the TMC of the A22 and the CAVs driving on the highway.

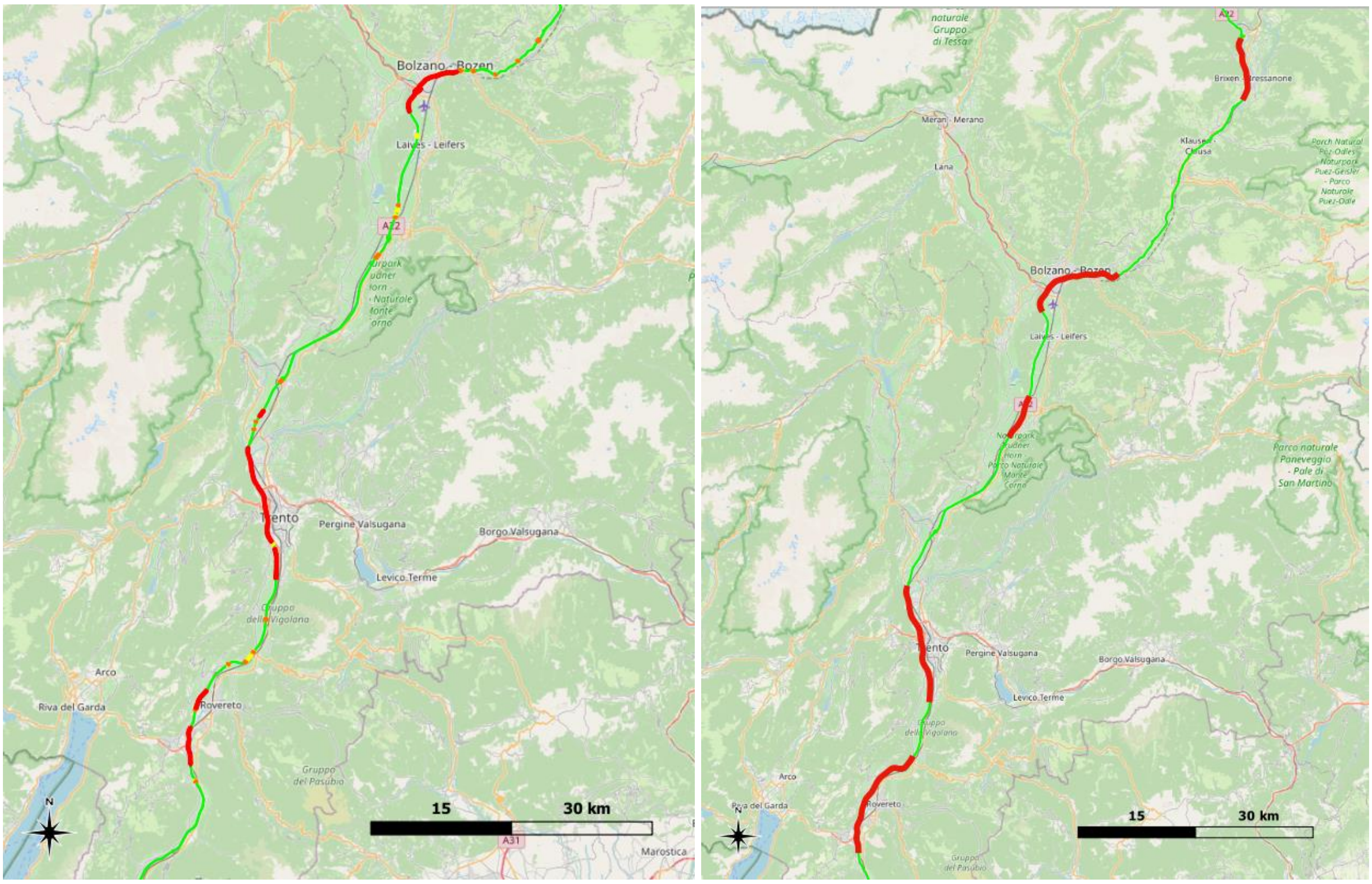

Figure 8 – Stretches between the cities of Bolzano and Rovereto (in red) satisfying the criteria for the introduction of VSL for air quality purpose (on the left: before final post-processing; on the right after final post-processing).

In order to promote a replication of these measures, in particular in the Italian context, the project is currently finalizing precise guidelines and instructions on how these replication logics can be applied almost on every highway, independently from the presence of specific local boundary conditions. The current process of updating the Italian rules of the road, which should soon allow VMS to be used also for environmental reasons, is clearly an essential factor for fostering this type of replicability.

Conclusions

After five years of intense testing of VSL applications on the A22 highway with about 4’700 hours up to February 2020, and despite external issues such as the COVID-19 pandemic, as well as the current Italian regulation, it has been possible to collect in the scope of the EU-LIFE BrennerLEC project solid empirical evidences related to the benefits of this kind of measure on both the reduction of the associated environmental issues (in particular, NO_2 and black carbon concentrations, CO_2 emissions) and the increase of the levels of service of the highway during heavy congestion situations. Additional empirical evidences related to the summer season 2021 will be presented as well during the conference. It is important to underline that these measures have also increased the already high road safety levels, with almost no accidents during the test activities. The field results strongly depend on the level of user compliance obtained: the more the drivers respect VSL and have a smoother driving behaviour, the more significant are the benefits observed. The possible added value of enforcement systems has been also evaluated through simulated scenarios. Despite this evidence, the project experience has outlined the need to foster a driving attitude which observes the proposed VSL independently from the presence of enforcement systems. A rewarding initiative based on a gamification APP, probably a first attempt of this kind worldwide in the highway domain, has been demonstrating the enormous potential associated to an optimal mix between “stick and carrot” policies to obtain the desired compliance.

The BrennerLEC results are the basis for the concretization of the low-emission Brenner Digital Corridor, which aims to extensively replicate these and other measures on the entire A22 highway, also benefitting from the C-ITS hybrid infrastructure that is under deployment. A concrete exploitation methodology is proposed in order to find out the most suitable highway stretches to be managed with the BrennerLEC measures, so to optimize the balance between expected benefits and necessary roadside ITS investments (e.g. VMS). This replication work is going to be exploited and harmonized on the entire Brenner Corridor, in cooperation with the reference Austrian and German operators (Asfinag and Autobahndirektion Südbayern respectively). Additional relevant topics are going to be explored, such for example the usage of harmonized ramp metering logics for controlling the entering / leaving traffic flows between the highways of competence. This harmonization work between the current highway situation present in different Member States is also highlighting the need to upgrade / implement the reference EU regulation, so that drivers can get a uniform experience while driving on the entire Brenner Corridor. Topics to be developed are for instance:

- the regulation of the emergency lane or corridor in case of accident, which is managed in different ways from Member State to Member State;
- the interoperability of the toll systems, in the perspective of “toll gates-free” highways (Directive EC 2019/520);
- the implementation of rewarding systems in the road (highway) domain, with the possibility to convert mobility credits in cash value to be used for different incentivizing purposes.

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