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A MODELLING CHAIN FOR ESTABLISHING A LOW EMISSION CORRIDOR THROUGH THE ALPS

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Abstract: The main objective of the EU-LIFE BrennerLEC project is to implement and validate a set of dynamic traffic control policies on the A22 highway stretch between Bolzano and Rovereto, to provide environmental benefits in terms of air quality. The reduction of air pollutant emissions is pursued by means of the dynamic management of the maximum allowed speed limits (i.e., variable speed limits, VSL), according to the current and predicted air quality situation, to prevent environmental conditions which can cause negative effects on the health of the population living near the motorway.

The estimation of NO_x and CO_2 emissions from traffic has been performed starting from an accurate characterisation of the vehicles fleet and traffic conditions on the A22 motorway. The combination of these data and the use of the European procedure COPERT V allow an accurate estimate of the emissions from traffic flowing on the highway.

A forecasting system has been implemented: meteorological forecasts obtained by means of a numerical weather prediction system, WRF, are combined with a local steady-state dispersion algorithm to evaluate the dispersion processes and the pollutants concentrations. The modelling chain has been calibrated by means of air quality data measured during the past years in the study area.

This forecasting system allows to predict, with enough time in advance, typically 24 hours, the occurrence of critical situations which require the introduction of reduced speed limits to reduce the air pollutants produced by traffic.

Key words: *environmental traffic management, traffic emissions estimation, air quality forecast*

INTRODUCTION

The implementation of Low Emission Zones (LEZs) is today a state-of-art measure that, especially in Europe, city authorities typically implement in order to tackle the high concentrations of air pollutants produced by urban traffic. 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, and in particular in mountainous regions like in the Alps, 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 NO_x emissions generated in the urban area (Antonacci et al. 2010). This is the reason why 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 are mainly based on the use of Variable Speed Limits (VSL), which particularly target diesel passenger cars. According to preliminary studies, 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 (Cavaliere et al., 2018) After five years of intense empirical testing, it is possible to provide a comprehensive assessment of the impact of the proposed measures. A dedicated elaboration chain is used to evaluate if VSLs are needed 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 yearly; (ii) forecast of the meteorological conditions, and in particular of the atmospheric stability; (iii) estimation of the NO_x/NO_2 concentrations, also supported by data-driven transit vehicles.

ESTIMATION OF POLLUTANTS EMISSIONS FROM TRAFFIC

The first step of the developed elaboration chain is the estimation of the NO_x and CO_2 emissions generated by the A22 highway traffic. This is achieved following the COPERT V procedure (Ntziachristos et al., 2018), which provides emissions of different pollutants from the main characteristics of a given vehicle: category, fuel supply, engine volume and EURO class. Therefore, the accuracy in the estimate of NO_x emissions strictly relies on the accuracy in the description of the fleet composition and speed.

Estimation of the circulating fleet composition

To obtain the best description of the effective circulating fleet on the A22 highway, a comprehensive data-driven analysis was performed. Different datasets were collected from multiple data providers: specifically, data from the highway operator A22, data from the Regional catalog of registered vehicles, data from the ACI (Automobile Club d'Italia) vehicle plates database, and data from the Austrian highway operator (Asfinag) for the heavy duty vehicles. This extensive dataset has been analyzed to obtain a reliable description of the circulating fleet composition during different typical days or periods. Indeed, the circulating fleet changes with the day of the week (business versus weekend days) and with the presence of tourists. A typical fleet composition for every typical generic period/day was then derived by identifying representative days in the available. Results from this analysis allow deriving the expected fleet composition in terms of circulation vehicle categories (i.e., light or heavy), fuel supplies, and EURO classes, for every typical day/period, to provide suitable information to the COPERT model, together with the traffic volumes and behaviour. Estimated emissions are then passed to the forecasting system controlling the VSL activation. Periodic studies carried out on a yearly basis clearly show that the renewal of the vehicles driving on the A22 highway is happening fast in terms of EURO class (Figure 2), 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.

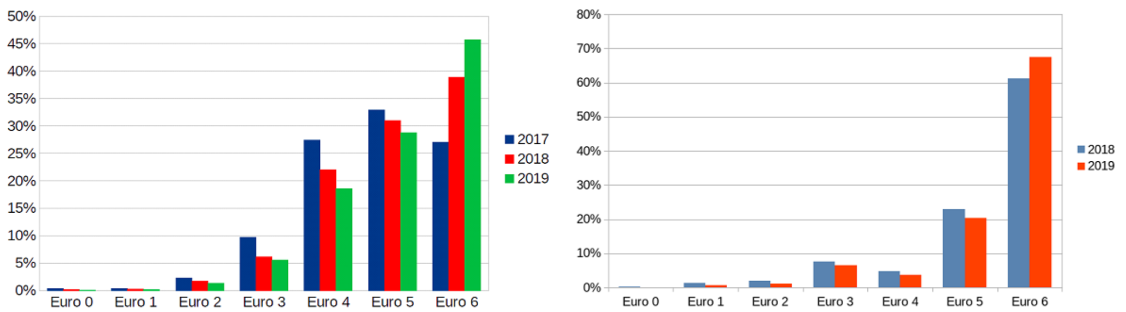

Figure 1: Evolution of the real circulating fleet on the A22 highway in the test stretch: light vehicles in the left and heavy duty vehicles on the right

Estimation of traffic volumes and traffic behaviour

The implemented traffic model is based on the analysis of historical data, collected from different inductive loops located inside the test stretch. The vehicles were grouped into three macro-classes: light vehicles, heavy duty vehicles and buses. For each macro-class it was possible to calculate the hourly forecast of vehicles' number and speed, diversified by day of the week and time of day. This implemented traffic model proved to be very reliable under normal motorway operating conditions, given the high repetitiveness of traffic flows. Since the outbreak of the COVID-19 pandemic, however, the restrictions adopted have led to a sharp drop in the traffic flow, especially for light vehicles. The implemented traffic model was then modified by introducing ad-hoc traffic forecasts drawn up by the motorway operator itself, with a frequency of 2/3 weeks. In addition, real time checks have been introduced into the modelling chain to prevent discrepancies in traffic forecasts from affecting the accuracy of air quality predictions.

DESCRIPTION OF THE ADVANCED FORECASTING SYSTEM

Once traffic emissions are available, it is possible to estimate pollutant concentrations with respect to one or more target points using an appropriate pollutant dispersion module. A forecasting system has been implemented: meteorological forecasts obtained by means of a numerical weather prediction model are combined with a local steady-state dispersion algorithm to evaluate the dispersion processes and the pollutants concentrations.

Meteorological Forecasting

The modelling chain implemented is based on the WRF model and is composed of three nested domains, with resolution of 9-3-1 km, respectively. In particular, the inner domain, presenting a rather high resolution for operational forecasts, covers the whole stretch of the A22 highway where VSL are implemented in the BrennerLEC project. Data from the Global Forecast System (GFS) global model are used as initial and boundary conditions, as well as measurements from local surface weather stations, which are assimilated to improve the representation of local meteorological conditions. Forecasts are run twice a day for 72 hours and input data for the dispersion model are provided at hourly intervals. Input data for the dispersion model include wind speed and direction at 10 m above ground level, air temperature at 2 m above ground level, incoming shortwave radiation, sensible heat flux and the Obukhov length.

Air quality Forecasting and Monitoring

The R-line model (Snyder et al. 2013) was implemented in the modelling chain to evaluate the dispersion of pollutants. R-line is a steady-state, line-source dispersion model, developed for impacts from mobile source emissions of primary, chemically inert air pollutants in near-road environments. The concentration from a finite line source in R-LINE is calculated by summation of a series of point sources. Each point source is simulated using a Gaussian plume. The model calibration has been performed by means of data collected by passive air quality sensors installed within the project. The appropriate calibration coefficients have been identified and adopted inside the modelling chain. NO_2 concentration has been calculated by using Romberg formula. Measured concentration data alongside the highway are provided by a network of 12 low-cost sensors (AirQino, hereinafter AQ, Gualtieri et al., 2017). Two field campaigns were carried out to calibrate the AQ sensors. The first field calibration was carried out in June 2018 on the rooftop of an operational air quality station managed by the Environmental Protection Agency of the Autonomous Province of Trento, in the city of Trento, close to a major suburban road. The AQ sensors were installed side by side and data were collected during the whole month of June 2018. A second period of calibration was required to test the sensors under a wider range of climatic conditions. It took place in the first two weeks of February 2019 and the AQ sensors were installed on the roof of a reference station installed alongside the highway and managed by the Environmental Protection Agency of the Autonomous Province of Bolzano. The double calibration allowed to apply a multivariate regression with two temperature-dependent classes of coefficients (Bisignano et al. 2021). The performance of the calibrated sensors was then tested again reference air quality stations. Figure 2 shows an example of the average diurnal cycles of NOx for each day of the week measured by an AQ sensor and a reference station, throughout a year-long validation.

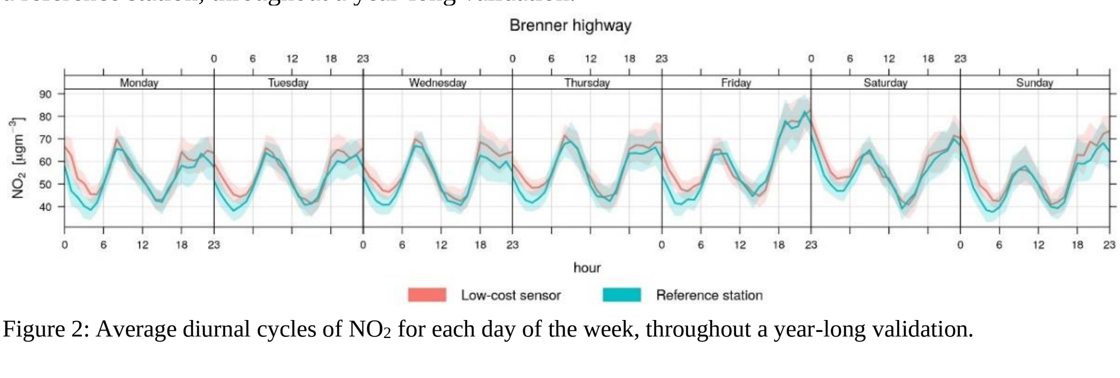

Figure 2: Average diurnal cycles of NO_2 for each day of the week, throughout a year-long validation.

Figure 3 shows an example of the comparison between simulated and measured concentration of NO_2. The modelling chain can also work in diagnostic mode, using measured traffic data as input. Hence, in Figure 3, NO_2 R-Line forecasts with measured and predicted traffic data are shown on the top and on the bottom panel, respectively. Obviously, the uncertainty associated with the estimate of the circulating fleet, the emissions produced by traffic and with the meteorological forecasts remains, but in this way, it is possible to carry out a correct calibration of the air quality model and verify the predictive capacity of the modelling chain. The use of diagnostic mode was particularly useful during the COVID-19 emergency period when the correct prediction of the traffic flows was very difficult.

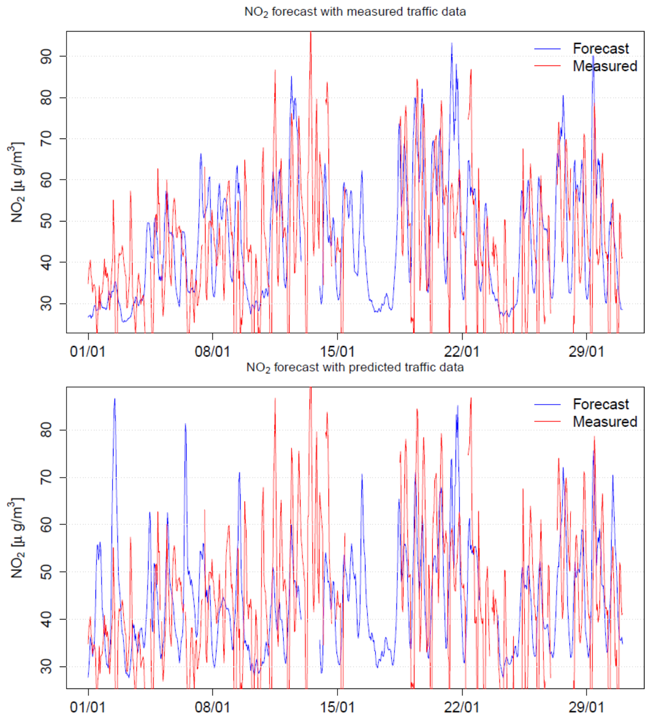

Figure 3: Comparison beetwen R-Line forecasts (with measured traffic data on the top panel and with predicted traffic data on the bottom panel) and low-cost sensor meaurements of NO2 concentration.

DESCRIPTION OF THE VSL ARCHITECTURE SYSTEM

One of the principal guidelines followed in the BrennerLEC project 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. The elaboration / forecasting logics take advantage of the data integration provided by the Open Data Hub, 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. The activation of VSL is suggested to the TMC 24 hours in advance and is based on a comparison between concentrations' forecasts and a reference threshold, which is set so as to reach a certain environmental goal (i.e., average annual NO_2 concentration at a certain distance from the highway) by considering a maximum number of annual hours in which such measure can be activated. Such upper limit is currently set as 30% of the total annual hours. During the operations by the TMC, the elaboration/forecasting chain evaluates on a real-time basis the traffic and air quality situation on the monitored road and foresees the possibility to change the VSL activation plan accordingly. VSL are not activated if traffic volumes or NO_2 concentrations from AQ sensors are significantly lower (more than 50%) than the forecasts for a certain time (3 consecutive hours). At present, no full automation has been implemented in the TMC, because traffic operators do want to keep full control of the messages published on the variable message signs; in future it will be however possible to automate the activation/deactivation of VSL in advance, after a preliminary control and acceptance of the proposed activation plan.

RESULTS

Field operational tests have been extensively evaluated, with more than 4'000 hours of VSL activation up to March 2020. During the first phase of the project, in order to assess the impact of reduced speed limits on NO_2 roadside concentrations, air quality measurements performed in a stretch of the highway where VSL were implemented were compared against observations performed in a close stretch where the maximum speed limit was not modified. This analysis highlighted that, on average, a reduction of the vehicle speed of 14 km h^{-1} lead to a decrease of NO_2 concentrations in the order of 6 µg m^{-3}, equal to about 10% of the typical concentrations measured close to the highway. The average hourly differences between the concentrations measured in these two stretches of the highway during the implementation of the VSL are reported in Figure 4. Positive values (green bars) indicate a reduction of the concentrations thanks to the implementation of VSL, whereas negative values (red bars) indicate higher NO_2 concentrations in the stretch of the highway where VSL were adopted. This Figure clearly highlights that the reduction of NO_2 concentrations induced by VSL was significant especially in the afternoon and in the evening. Smaller reductions were found during night-time, since traffic volumes are usually low at night and thus the reduction of the emissions induced by VSL is less significant.

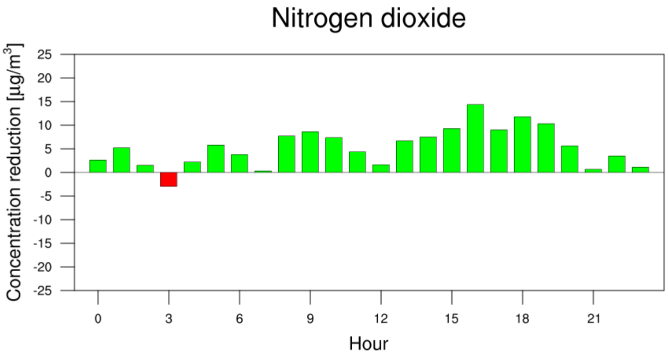

Figure 4: Average hourly differences of roadside NO_2 concentrations due to the application of VSL. Positive values (green bars) indicate a reduction, whereas negative values (red bars) indicate higher NO_2 concentrations.

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