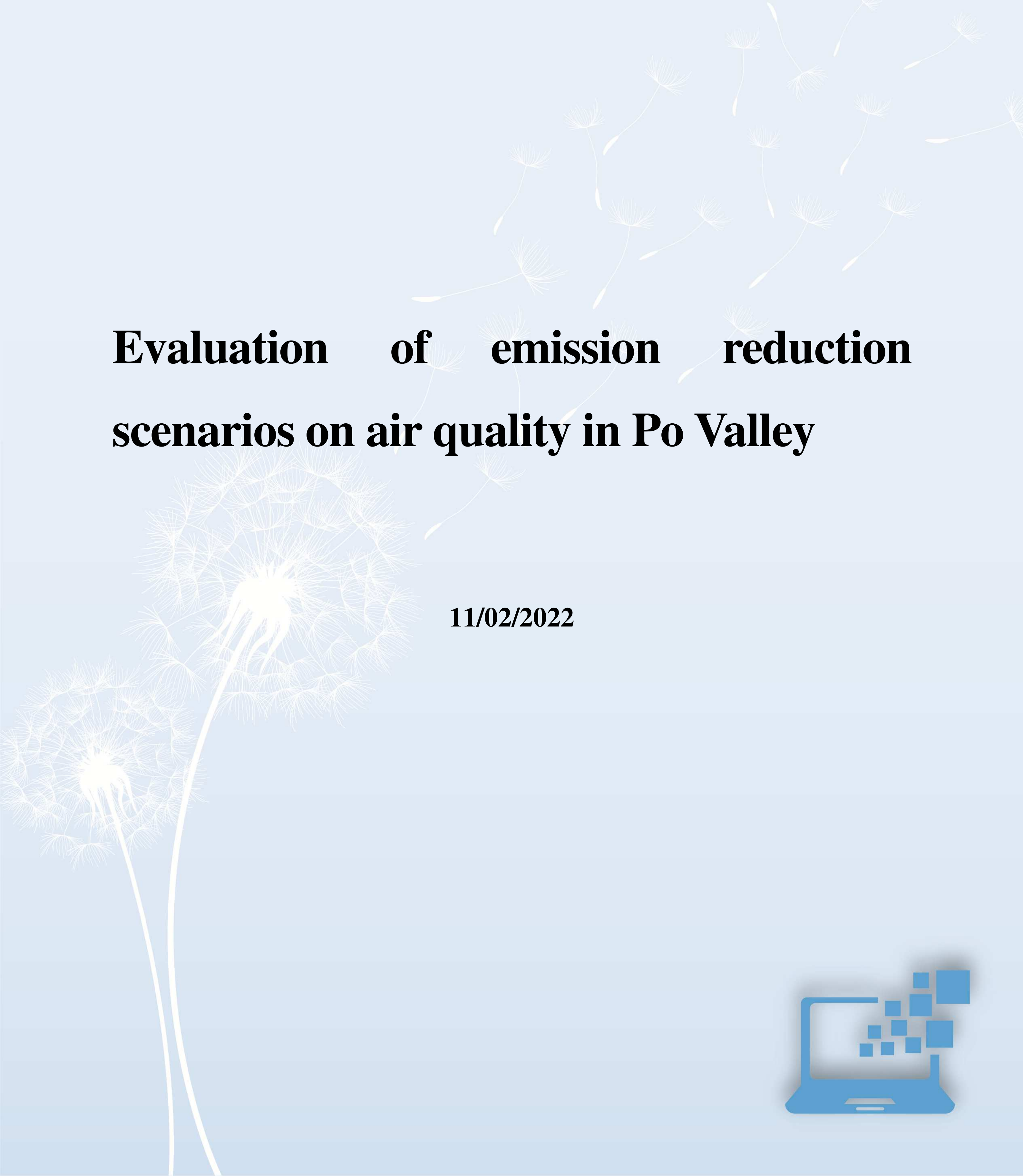
With the contribution
of the LIFE Programme
of the European Union

LIFE 15 IPE IT 013

Po Regions Engaged to Policies of Air

Evaluation of emission reduction scenarios on air quality in Po Valley

11/02/2022



With the contribution
of the LIFE Programme
of the European Union

LIFE 15 IPE IT 013

This document was produced within the project PREPAIR (LIFE 15 IPE IT 013) financed by the program LIFE 2014-2020 of the European Union.

Closing date of the report 11/02/2022

Authors:

Michele Stortini, Roberta Amorati, (ARPAE Emilia Romagna), Stefano Bande (ARPA Piemonte)

With the contribution of:

Giovanni Bonafè (ARPA Friuli Venezia Giulia), Elisabetta Angelino, Loris Colombo, Alessandro Marongiu, Guido Lanzani (ARPA Lombardia), Silvia Pillon (ARPA Veneto), Tiziana Magri (Arpa VDA) , Elisa Malloci, Gabriele Tonidandel (APPA Trento)

INDEX

INTRODUCTION

The Integrated project “Po Regions Engaged to Policies of Air” LIFE-IP PREPAIR supports the implementation of regional air quality plans (AQPs) and of Po Valley agreements on a larger scale, acting in a synergic way, so to strengthen the sustainability and durability of the results. The Po Valley, a densely populated and heavily industrialised area, represents a non-attaining zone for PM (Particulate Matter), NO_2 (Nitrogen Dioxide) and O_3 (Ozone). Since 2005 the Regions of the Po Valley adopted common actions on most polluting sectors on air quality (biomass combustion, transports, energy efficiency and agriculture) in order to reduce air pollution. These agreements, signed in 2005, 2007, 2013 and 2017, establish commitments for the implementation of measures and their funding for Regions and National Ministries. Following these agreements, the four Regions adopted air quality plans with measures to reduce the emissions for all the most polluting sectors. The regional plans contributed to the significant reduction of all pollutants in the Po Valley, e.g. achieving the annual limit for PM10 from 2018 and strongly reducing the number of daily exceedances. The experience gained through the activities led to the approval of the LIFE IP PREPAIR project, that is currently working on common actions on the over mentioned sectors in all the Regions, with the contributions of the Environmental Agencies, developing common tools for evaluating air quality and designing future scenarios on the whole area.

Many Member States exceeded environmental objectives for at least one pollutant and the Po Valley, due to its orographic and meteorological conditions, is one of the hot spots for pollution in Europe.

The WHO recently updated the global air quality guidelines, recommending new levels and interim targets for the atmospheric pollutants in order to protect the health of populations.

The aim of this work is to contribute to the discussion of the revision of European air quality rules. New limit introduction must be evaluated taking into account the technical feasibility and the timing for achieving new limits. However a preliminary assessment of the possibility of achieving the new air quality limits in the Po basin was carried out through several CTM simulations of targeted emission reduction scenarios. Currently, within the PREPAIR project, several CTM modelling systems are running operational. Among all these models, the NINFA modelling system implemented by Arpad was used.

In the following chapters the air quality modelling system is first briefly described (chap 1), then the results of scenario simulations are presented (chap 2) and finally discussed (chap 3).

1 AIR QUALITY MODELLING SYSTEM

1.1 NINFA

NINFA (Northern Italy Network to Forecast Aerosol pollution) is the operational air quality (AQ) model of the Environmental Agency of the Emilia-Romagna Region (Arpae). The model suite includes a Chemical Transport Model (CTM), a meteorological model and an emissions pre-processing tool. The chemical transport model is CHIMERE an eulerian-type numerical model, which simulates transport, dispersion, chemical transformations and deposition (dry and wet) of air pollutants and aerosols (http://www.lmd.polytechnique.fr/chimere/). In the model setup used in this study natural emission (biogenic, sea-salt and dust) as well as resuspension are taken into account. Starting from the emission data for the Po Valley, Slovenia (Figure 1) and the other regions/countries present in the model domain, (http://www.lifeprepair.eu/wp-content/uploads/2017/06/Emissions-dataset_final-report.pdf), the emissions are prescribed to the grid model by using specific proxy variables for each emission activity SNAP3[1] (i.e. road network for traffic emission, population and urban fabric for domestic heating, and so on).

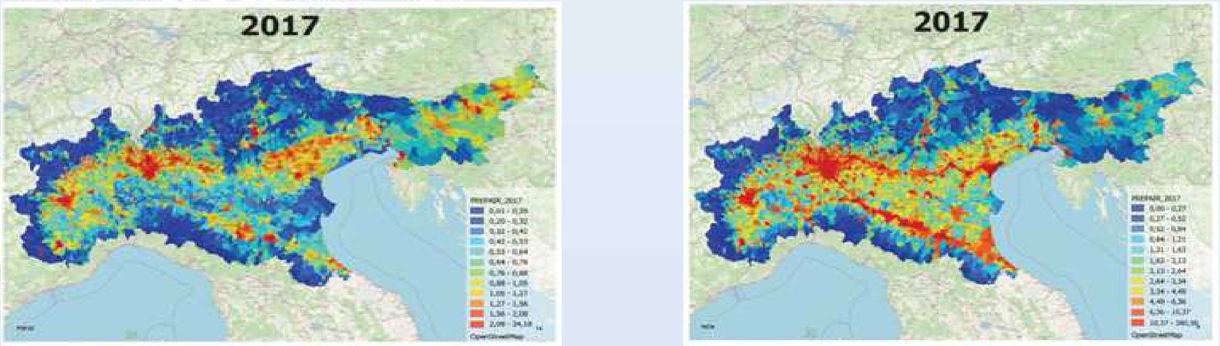


Figure 1 Emission maps at municipality level 2017 representing PM10 (left) and NOx (right)

---

[1] Acronym of Selected Nomenclature for Air Pollution, that was developed in the EMEP/EEA (Air Pollutant Emission Inventory Guidebook) project:
https://www.eea.europa.eu/themes/air/air-pollution-sources-1/emep-eea-air-pollutant-emission-inventory-guidebook

The meteorological hourly input is provided by COSMO, the National numerical weather prediction model used by the Italian National Civil Protection Department. COSMO[2] is a non-hydrostatic, limited-area atmospheric prediction model, based on the primitive thermo-hydrodynamical equations describing compressible flow in a moist atmosphere, with a variety of physical processes taken into account by dry and moist parameterization schemes. The initial and boundary conditions (IC/BC) in this study are provided by PrevAir European Scale Air Quality Service (http://www.prevair.org) project. The horizontal resolution of CTM simulations is 0.09×0.07 degree (around 5 km) and the modelling domain covers all of northern Italy.

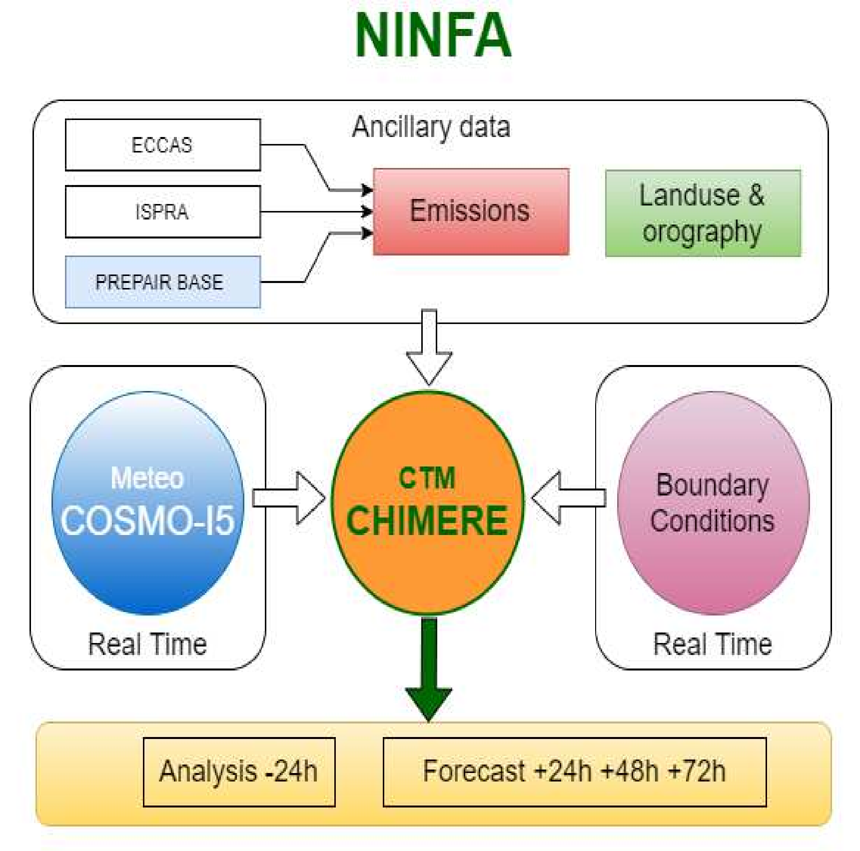


Figure 2 NINFA modelling system

---

[2] http://www.cosmo-model.org

1.2 Data fusion for adjustment with observations

The pollutant concentration output by the CTM NINFA can well represent the spatial distribution of pollutants while, on the other hand, in situ measurements are more quantitatively accurate.

The ratio f = *observation/simulation* represents the correct ratio between measurement and model estimate. A data fusion post processing is then applied to CTM simulations in order to get an adjustment factor field over the model domain at the model grid resolution. A Kriging with External Drift algorithm is applied in this work to spatialize the f factor, using the model itself and the elevation above the sea as a further spatial explanatory variable (KED, Wackernagel 2003[3], Ribeiro and Diggle, 2001[4]; Diggle and Ribeiro, 2007[5]).

For each pollutant the applied trend is selected among three possibilities: 1) linear model and elevation; 2) logarithmic model and linear elevation; 3) first order spatial trend. The trend type that minimises the one-leave-out mean standard error is chosen.

Let $f_i = observation_i \,/\, simulation_i$ at each point station i, a $f_{k,j}$ adjustment factor is obtained at each model cell (k,j). For every cell two simulations are therefore available: the model output (model RAW) and a model adjusted (model ADJUST).

The adjustment field, obtained from the base scenario (described below), is then applied to correct the reduction scenario simulations: $Model\_Adjust_{jk} = Model\_Raw_{jk} * f_{jk}$.

In this work the observed data refer to the year 2018 and are derived from the E1a data set, yearly reported to EEA (European Environmental Agency) by European Member States[6]. The background stations only are included for model adjustment. The annual average concentration is considered for all the examined pollutants (PM10, NO_2, PM2.5).

---

[3] Wackernagel H (2003) Multivariate geostatistics: an introduction with applications. Springer, Berlin

[4] Ribeiro JR, Diggle PJ (2001) geoR: a package for geostatistical analysis. R-NEWS 1(2):15–18

[5] Diggle P.J. and Ribeiro Jr. P. J. (2007) Model-based Geostatistics, Springer

[6] https://eeadmz1-cws-wp-air02.azurewebsites.net/index.php/users-corner/download-e1a-from-2013/

Some statistical indicators are calculated to evaluate the model performance. For the adjusted model, the one-leave-out method is used to retrieve the *f* factor which is used to adjust the model estimate. In the following table, the bias and the root mean square error are shown for both model and adjusted model. For all the pollutants the statistical scores improve by adjusting the model with observations.

	PM10 bias	PM10 rmse	NO2 bias	NO2 rmse	PM2.5 bias	PM2.5 rmse
mod adjusted	0.06	2.76	0.24	4.54	0.14	2.81
mod raw	-4.16	6.09	-5.010	7.92	1.31	3.62

Table 1 Statistical scores bias and root mean square error, relative to PM10 NO2 and PM2.5, for model and model adjusted estimates vs observations (µg/m3)

In Figure 3 model simulations against observations are represented in scatter plots. In the graphs the model is depicted in blue and the adjusted model in red. The dashed lines represent the 50% relative uncertainty.

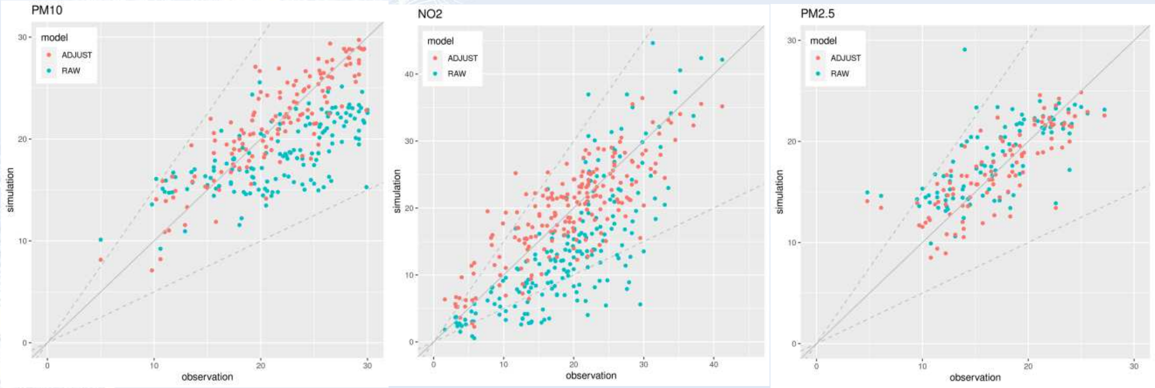


Figure 3 plot simulations vs observations (µg/m3), for model (blue) and model adjusted with observations (red). From left to right: PM10, NO2, PM2.5

2 SCENARIO SIMULATIONS RESULTS

A base case scenario and three hypothetical emission scenarios were simulated with the NINFA modelling system:

- *T1 scenario*: base case scenario, with the updated emission dataset developed in the Action D2, meteorological fields and IC/BC data referring to year 2018.
- *T7 scenario*: medium reduction scenario, with 50% reduction of all pollutants and precursors (NOx, VOC, NH3, PPM, SOx) over the whole modelling system domain, meteorological fields and IC/BC data referring to year 2018.
- *T8 scenario* : maximum reduction scenario, with 80% reductions of all pollutants and precursors (NOx, VOC, NH3, PPM, SOx) over the whole modelling system domain, meteorological fields and IC/BC data referring to year 2018.
- *T9 scenario:* minimum reduction scenario, with 10% reductions of all pollutants and precursors (NOx, VOC, NH3, PPM, SOx) over the whole modelling system domain, meteorological fields and IC/BC data referring to year 2018.

Scenarios are designed in evaluate the pollutant concentrations in Po Valley, resulting from more or less marked emission reductions, without any consideration about their socio-economic impact and feasibility of the actions necessary to achieve them

In order to make the pollutant model outputs more realistic and their spatial distribution more quantitatively representative, the adjustment factor retrieved from the base scenario T1 (ref paragraph 1.2), is applied to the annual average concentration produced by T7, T8, T9 scenarios (see Figure 7). The model results have been analysed taking into account the most critical indicators compared to the annual limit values established by the 2008/50/EC Directive and the new values proposed by WHO[7] :

---

[7] World Health Organization. (2021). WHO global air quality guidelines: particulate matter (PM2.5 and PM10), ozone, nitrogen dioxide, sulfur dioxide and carbon monoxide. World Health Organization. https://apps.who.int/iris/handle/10665/345329.

Pollutant	***Average time***	***Interim target 1***	***Interim target 2***	***Interim target 3***	***Interim target 4***	***AQG*** ***(air quality guidelines)***	***AAQ Directives*** ***(actual limit)***
PM2.5 $\mu g/m^3$	annual	35	25	15	10	5	25
PM10 $\mu g/m^3$	annual	70	50	30	20	10	40
NO_2 $\mu g/m^3$	annual	40	30	20	-	10	40

Table 2 *recommended annual AQG levels, interim target and EU 2008/50/EC Directive*

In the following Figures 4-6 the analysis results are presented in terms of the box plots of the observed values at each monitoring station stored in the observed dataset and the predicted concentration at each monitoring station for T7, T8 and T9 emission scenarios. The predicted value at each monitoring station j for the scenario k, Cp_{jk} was obtained from the following formula:

$$Cp_{jk}=C_j - D_{jk}*C_j$$

where:

C_j is the observed annual mean at the j monitoring stations,

$D_{jk}= (Cb_j- Cs_{jk})/Cb_j$ is the ratio at monitoring station j between the simulated concentration for the base case Cb_j and for the k scenario $Csjk$

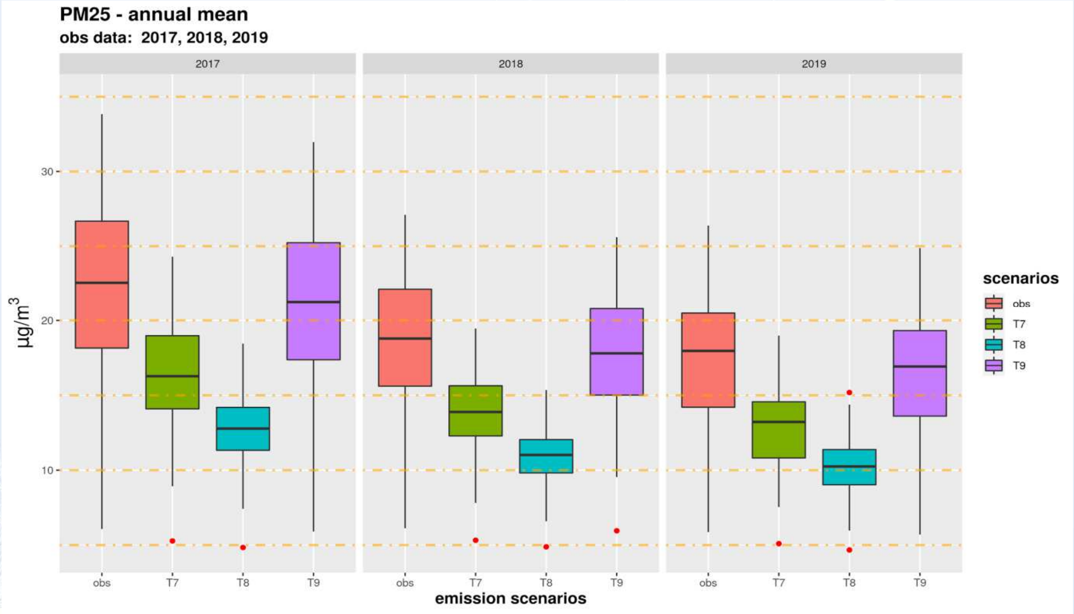
The observed dataset considers three years, i.e. 2017, 2018 and 2019 of annual averages of PM10, PM25 and NO_2 data and has been built from E1a annual statistics, exported from EEA's SQL database which stores primary validated assessment data reported by countries and successfully tested by automated QC[8]. The data related to the year 2020 and 2021 were not used in our analysis due to the considerable impact on air quality caused by COVID-19 pandemic. Figures 4a shows the boxplots of PM2.5 observed values for years 2017, 2018,

---

[8] https://eeadmz1-cws-wp-air02.azurewebsites.net/index.php/users-corner/statistics-e1a-table/

2019 at each monitoring station stored in observed dataset and the predicted concentration at each monitoring station for T7, T8 and T9 emission scenarios.

The concentrations observed in the year 2018 are at intermediate values between 2017 and 2019 and this situation is obviously reflected in the scenarios as well (Figure 4.a). In the more favourable year (2019) PM2.5 concentrations are between 5 and 15 µg/m³ in the T8 scenario, with the median of predicted concentration about 10 µg/m³; in the same scenario but in worst meteorological year (2017), PM2.5 concentrations are between 5 and 18 µg/m³. Analysing 2018 in more detail (see Figure 4.b) only in the T8 scenario one background station has a concentration value below 5 µg/m³, while all the other monitoring stations show concentrations between 5 and 15 µg/m^3.



.

Figure4 a PM2.5, annual averages: boxplots of observed and predicted concentration at each monitoring station in T7 (50%reduction), T8 (80% reduction) and T9 (10% reduction) emission scenarios, grouped by observation year.

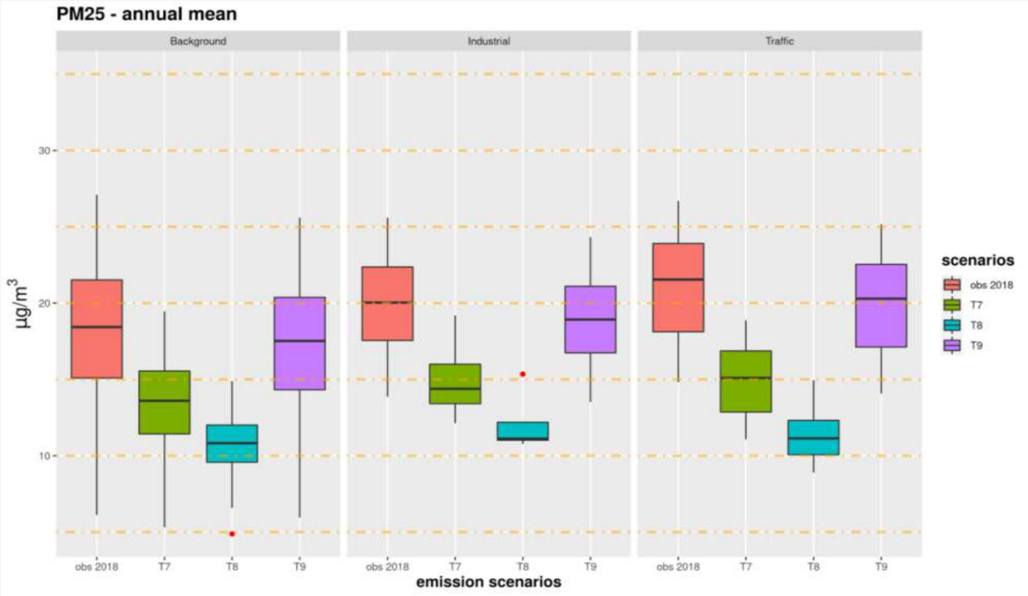


Figure4 b PM2.5 annual averages for the year 2018: boxplots of observed and predicted concentration at each monitoring station for T7 (50% reduction), T8 (80% reduction) and T9 (10% reduction) emission scenarios, grouped by station type classification (Background, Industrial, Traffic)

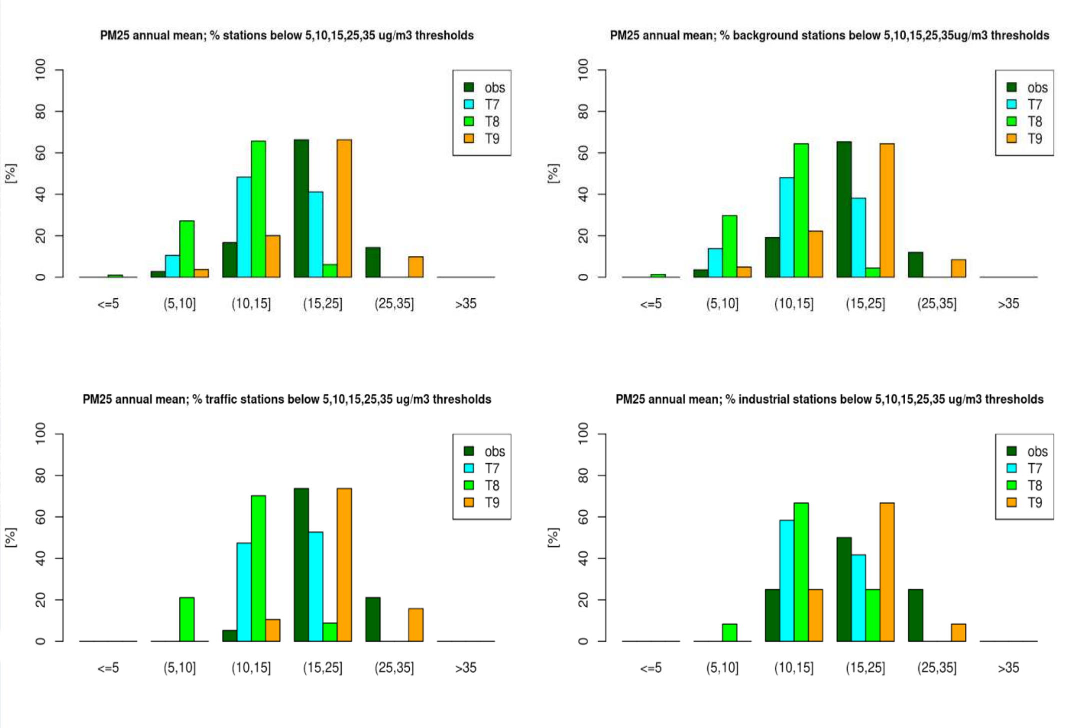


Figure4 c PM25, annual averages for year 2017, 2018, 2019: percentage of all stations below the interim target and AQG level observed (obs) and predicted data in T7, T8, T9 emission scenarios.

Figures 5a shows the boxplots of PM10 observed values for year 2017, 2018, 2019 at each monitoring station stored in observed dataset and the predicted concentration at each monitoring station for T7, T8 and T9 emission scenarios Also in this case concentrations observed in the year 2018 are at intermediate values between 2017 and 2019 and this situation is obviously reflected in the scenarios as well. PM10 concentrations are always between 5 and 25 µg/m³: in the best weather conditions (2019) the predicted distribution is centred around 15 µg/m³, around 18-20 µg/m³ in the worst case (2017). Analysing 2018 in more detail (see Figure.5.b) in the T8 scenario (80% reduction) almost all the monitoring background stations have concentrations below 20 µg/m³, in the 50% of monitoring background station the concentrations are below 15 µg/m³, and only few background stations show annual averages below 10 µg/m³; the concentration values are below 15 µg/m³ only in the 15% of monitoring traffic stations.

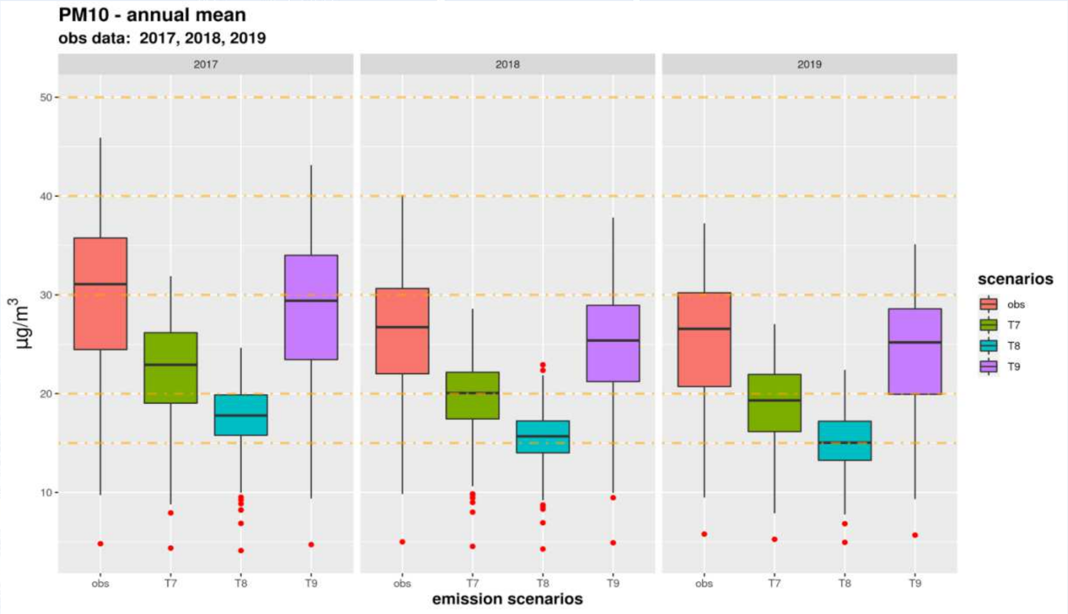


Figure5 a, PM10 annual averages: boxplots of predicted concentration at each monitoring station for T7 (50% reduction), T8 (80% reduction) and T9 (10% reduction) emission scenarios, grouped by year

.

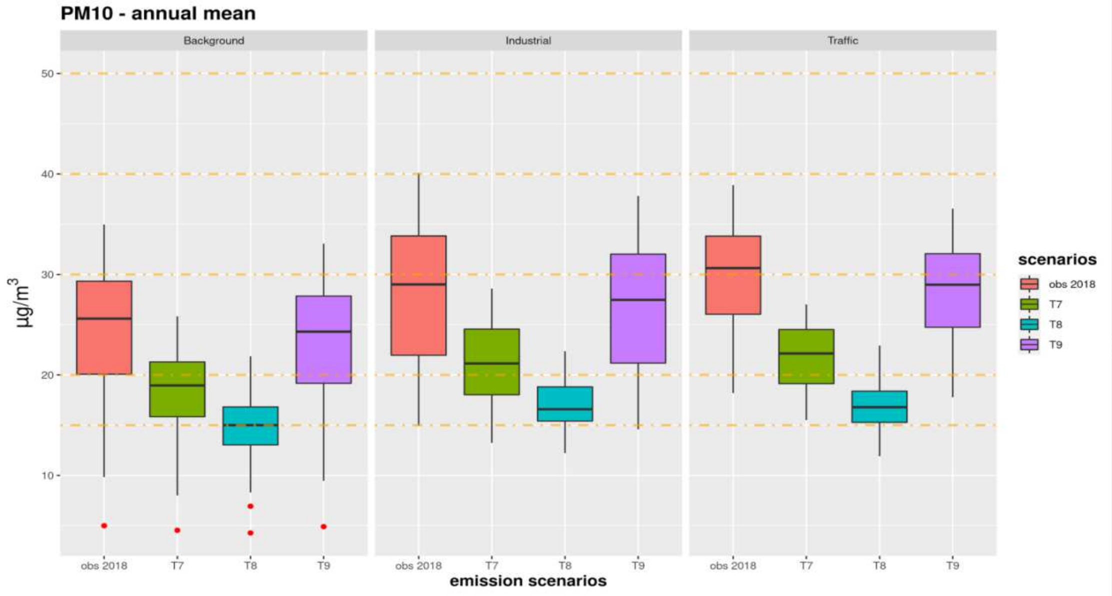


Figure5 bPM10, annual averages for the year 2018: boxplots of observed and predicted concentration at each monitoring station for T7 (50% reduction), T8 (80% reduction) and T9 (10% reduction) emission scenarios, grouped by station type classification

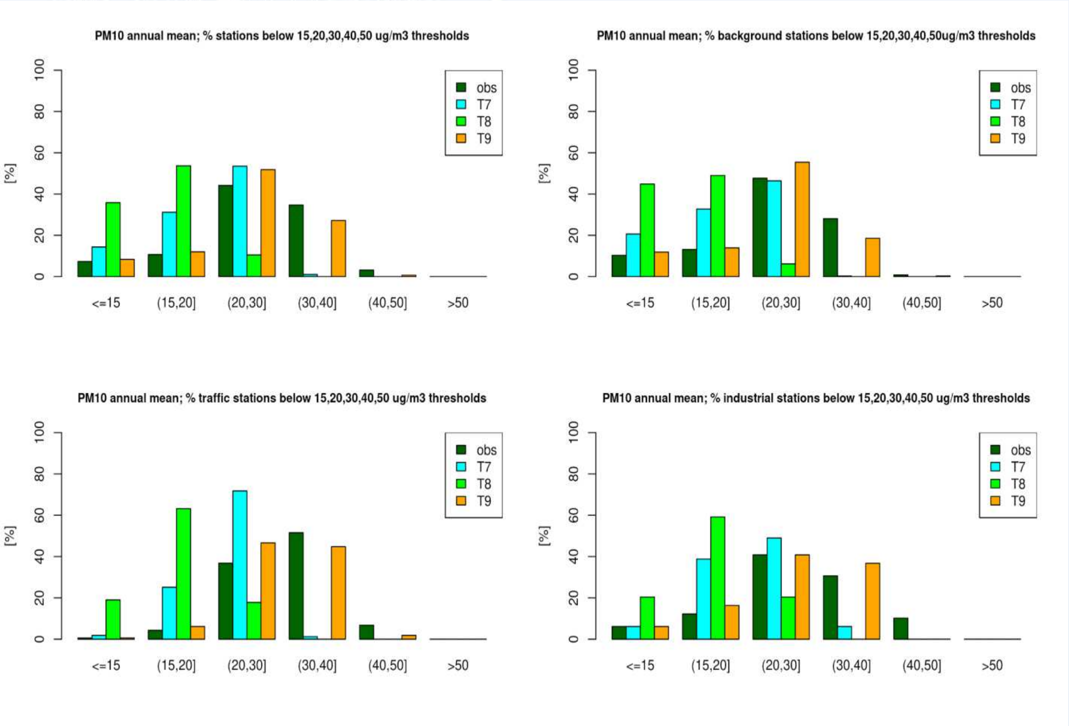


Figure5 c PM10, annual averages for year 2017, 2018, 2019: percentage of all stations below the interim target and AQG level for observed (obs) and predicted data in T7, T8, T9 emission scenarios.

Interannual variability is less evident for NO_2 annual averages (Figure 6.a): in the T8 scenario the higher values are below 15 µg/m³ for all years, while the median of concentrations is always below 10 µg/m³. Analysing in more detail the T8 scenario (Figure 6.b) for the year 2018, all background monitoring stations have concentrations below 10 µg/m³ and only a few traffic stations show annual averages above this threshold.

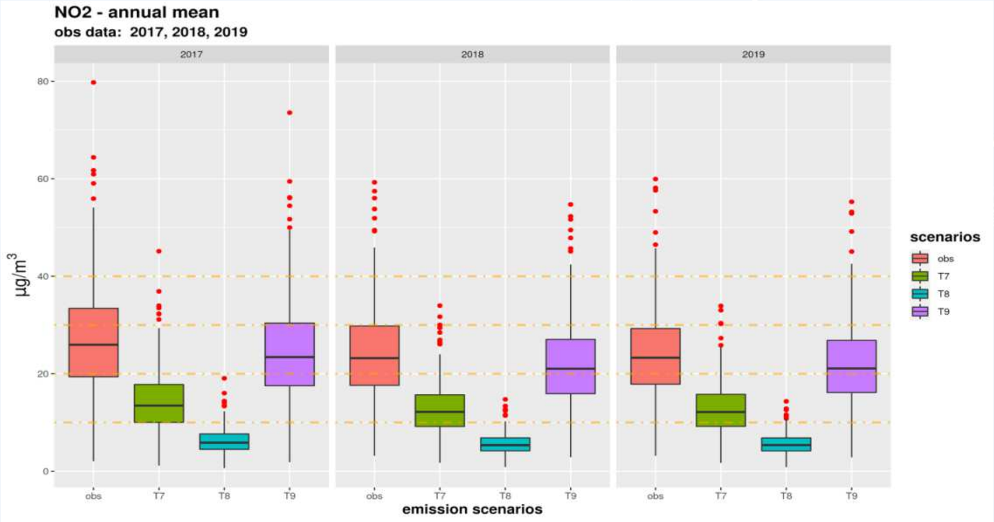


Figure6 a NO2, annual averages: boxplots of predicted concentration at each monitoring station for T7 (50% reduction), T8 (80% reduction) and T9 (10% reduction) emission scenarios, grouped by year.

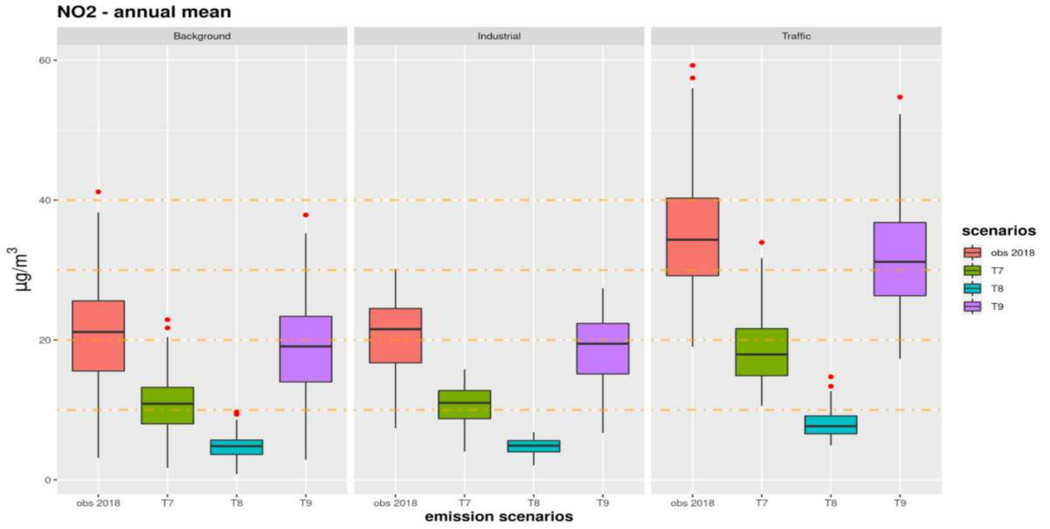


Figure6 b NO2 annual averages for the year 2018: boxplots of observed and predicted concentration at each monitoring station for T7 (50% reduction), T8 (80% reduction) and T9 (10% reduction) emission scenarios, grouped by station type classification.

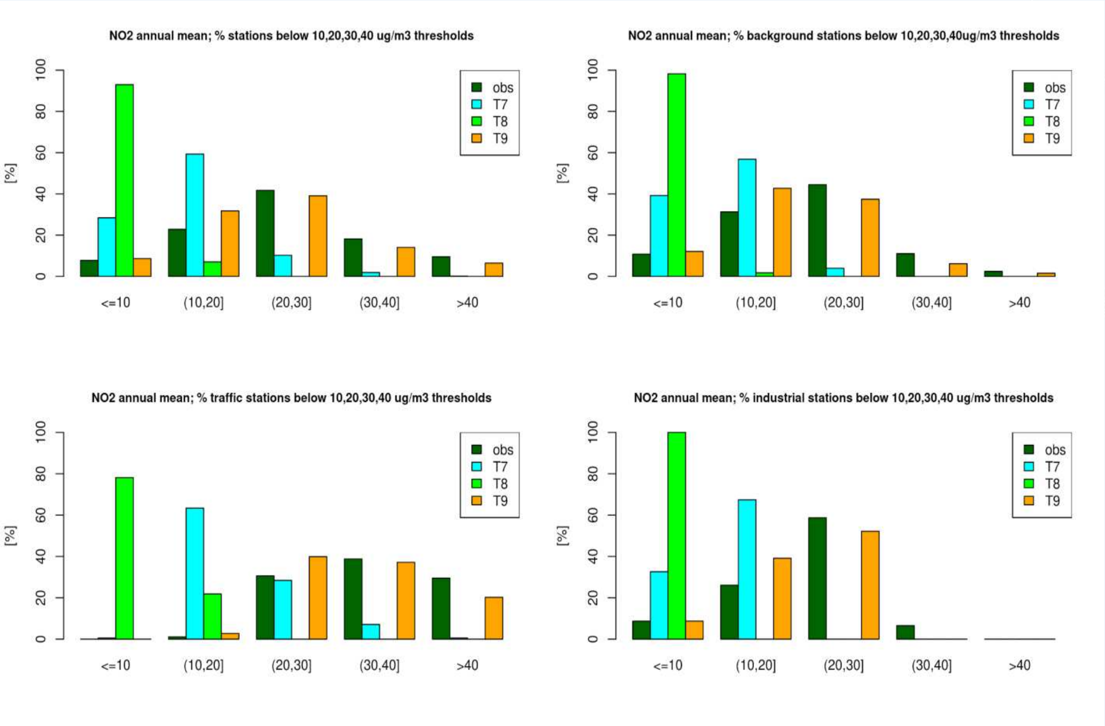


Figure6 c NO2 annual averages: annual averages: for year 2017, 2018, 2019: percentage of all stations below the interim target and AQG level for observed (obs) and predicted data in T7, T8, T9 emission scenarios.

Figure 7 shows a comparison of predicted annual averages (year 2018) in T1 (base case), T7, T8, T9 emission scenarios for the three different modelling system outputs: DMO (direct model output, without data fusion), KED (model output with observation data fusion), OBS_C (predicted data with the algorithm described above), in the T1 scenario OBS_C is equal to observed (2018) data. KED and OBS_C results are almost the same, while DMO output shows underestimates in the base case and therefore even in the emission scenarios.

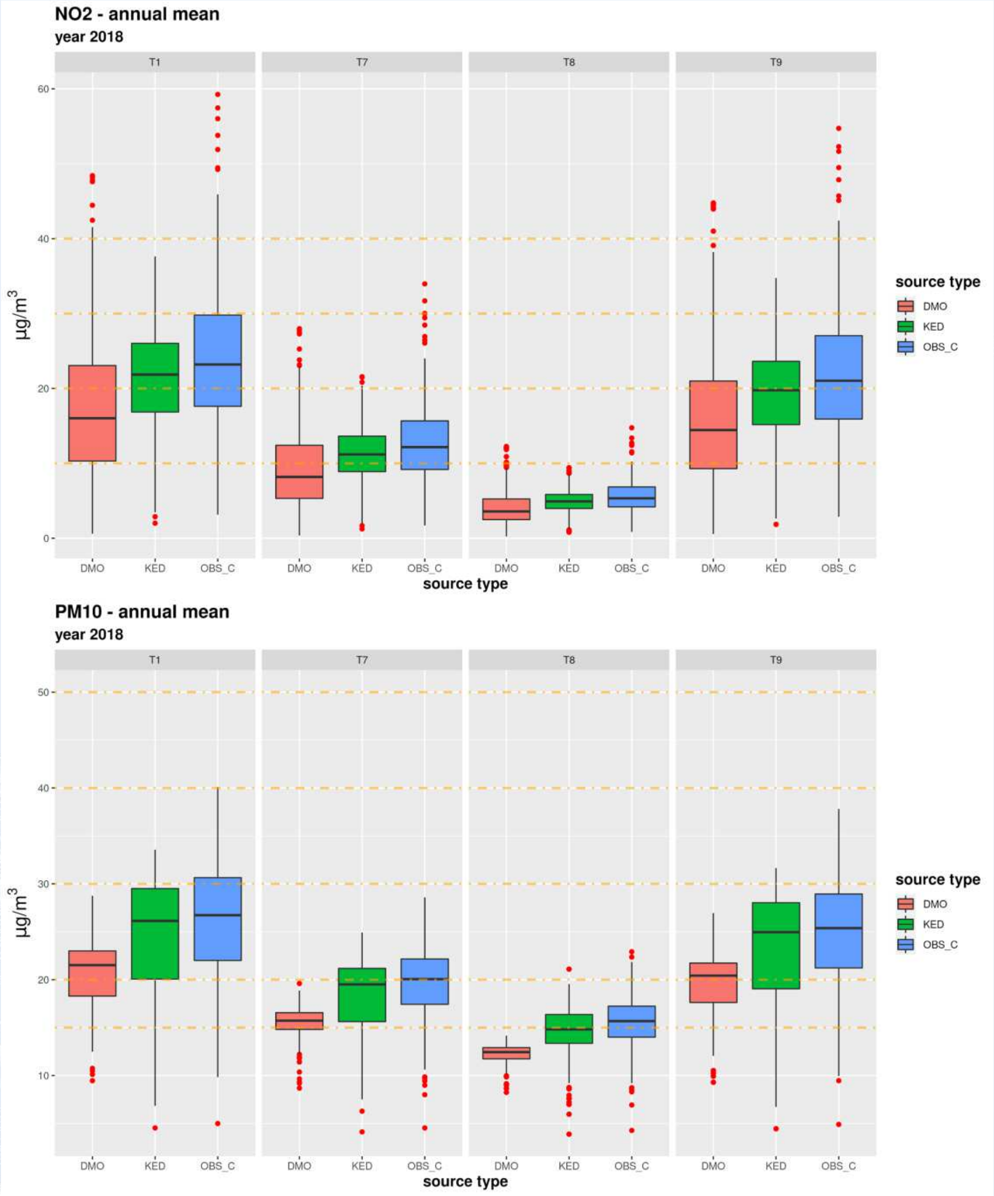


Figure7 Comparison of predicted annual average example (year 2018) in T1 (base case), T7, T8, T9 emission scenarios for the three different modelling system outputs: DMO (direct model output, without data fusion), KED (model output with observation data fusion), OBS_C (predicted data with the algorithm described above).

The spatial distribution of PM2.5, PM10, NO_2 annual average related to the year 2018 for the more effective T8 emission scenario are presented in the following figures. The year 2018 is the reference for the meteorological driver COSMO and, as described in the previous analysis, it shows an intermediate behaviour between year 2017 and year 2019. As mentioned above, if the emissions of all primary pollutants and precursors (NOx, VOC, NH3, PPM, SOx) decreased by 80% in almost the entire Po Valley the annual mean of PM2.5 (Figure 8.a) would be between 5 and 15 µg/m^3, while PM10 concentration (Figure 8.b) would be between 15 and 20 µg/m^3 and NO_2 (Figure 8.c) would be below 10µg/m^3. It should be underlined that the lack of sea monitoring stations and the boundary conditions always referred to the year 2018 may lead to a higher uncertainty of the modelling results in the border areas of the Po Valley and in particular in the coastal areas.

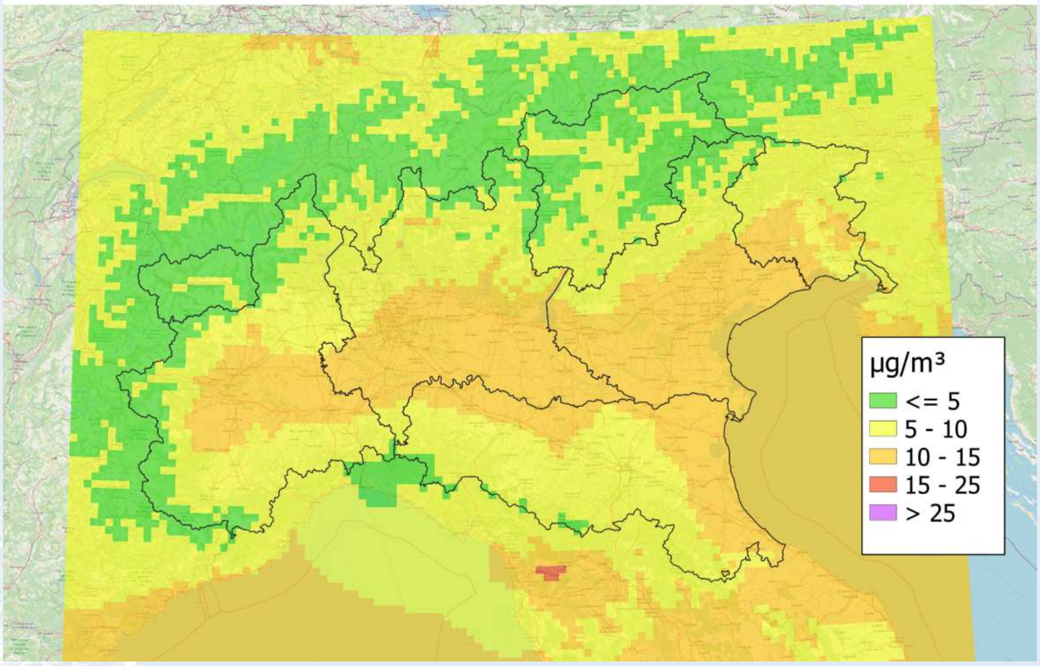


Figure 8a Annual average PM2.5 concentration field (T8 scenario – 80% reduction)

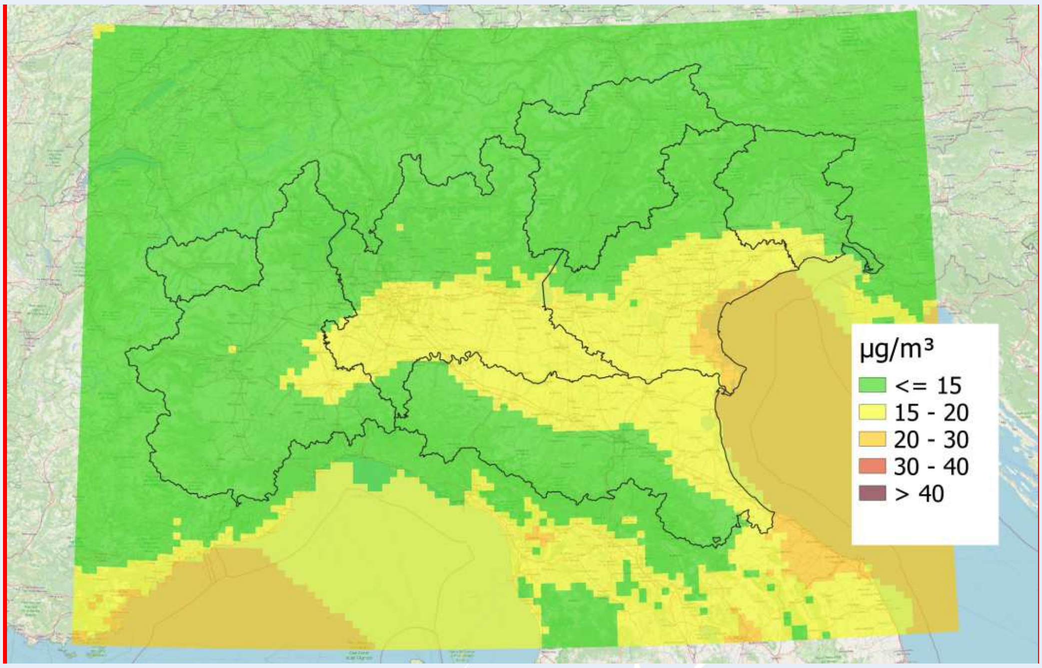


Figure 8 b Annual average PM10 concentration field (T8 scenario – 80% reduction)

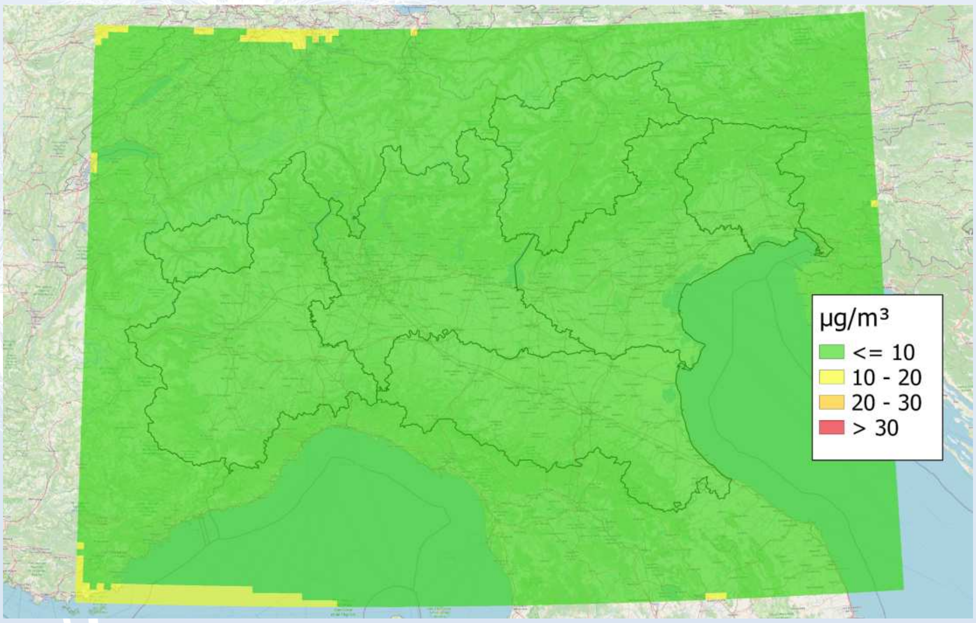


Figure 8 c Annual average NO2 concentration field (T8 scenario – 80% reduction

3 DISCUSSION

This report briefly shows the emission reductions necessary to achieve the targets indicates in the new WHO guidelines in the PO Valley. The present study shows that despite a considerable and hardly achievable in short time emission reductions (-80%), the recommended level (AQG level) will not be respected in many areas of the Po Valley. Table 3 summarises the compliance with the limits proposed by WHO and EU for each pollutant and for the T7 and T8 scenarios.

In the case of PM2.5 the scenario T7 (50% emission reduction) leads to compliance with the interim target 2 while interim target 3 would be achieved with scenario T8 (-80% emission reduction). The PM10 concentrations in both scenarios T7 (-50%) and T8 (-80%) are between interim target 3 and interim target 4. Finally, for NO$_2$ the concentrations in traffic stations are significantly higher than in background ones. Halving the emission (scenario T7) is not enough to comply the interim target 2. On the other hand, in all background stations the more ambitious AQG level could be respected reducing the emission of 80% (scenario T8).

Pollutant	Interim target 1		Interim target 2		Interim target 3		Interim target 4		AQG (air quality guidelines)		AAQ Directives (actual limit)	
PM2.5	35	🟩 T7	25	🟩 T7	15	🟥 T7	10	🟥 T7	5	🟥 T7	25	🟩 T7
µg/m3		🟩 T8		🟩 T8		🟩 T8		🟥 T8		🟥 T8		🟩 T8
PM10	70	🟩 T7	50	🟩 T7	30	🟩 T7	20	🟥 T7	10	🟥 T7	40	🟩 T7
µg/m3		🟩 T8		🟩 T8		🟩 T8		🟨 T8		🟥 T8		🟩 T8
NO2	40	🟩 T7	30	🟨 T7	20	🟨 T7	-		10	🟥 T7	40	🟩 T7
µg/m3		🟩 T8		🟩 T8		🟩 T8				🟨 T8		🟩 T8

Table 3 summary of achievement of the WHO recommended AQG levels, interim target and EU 2008/50/EC Directive for T7 and T8 scenarios. The green/red background highlights respectively achievement/non achievement of selected target, while yellow background means achievement at most monitoring stations.

THE PROJECT PREPAIR

The Po Basin represents a critical area for the quality of air, as the limit values of fine powders, nitrogen oxides and ozone set by the European Union are often exceeded. The northern Italian regions are included in this area as well as the metropolitan cities of Milan, Bologna and Turin.

This area is densely populated and highly industrialized. Tons of nitrogen oxides, powders and ammonia are emitted annually into the atmosphere from a wide variety of polluting sources, mainly related to traffic, domestic heating, industry, energy production and agriculture. Ammonia, mainly emitted by agricultural and zootechnical activities, contributes substantially to the formation of secondary powders, which constitute a very significant fraction of total powders in the atmosphere.

Because of the weather conditions and the morphological characteristics of the basin, which prevent the mixing of the atmosphere, the background concentrations of the particulate, in the winter period, are often high.

In order to improve the quality of the air in the Po Valley, since 2005 Regions have signed Program Agreements identifying coordinated and homogeneous actions to limit emissions deriving from the most emissive activities.

The PREPAIR project aims at implementing the measures foreseen by the regional plans and by the 2013 Po Basin Agreement on a wider scale, strengthening the sustainability and durability of the results: in fact, the project involves not only the regions of the Po valley and its main cities, but also Slovenia, for its territorial contiguity along the northern Adriatic basin and for its similar characteristics at an emissive and meteoclimatic level.

The project actions concern the most emissive sectors: agriculture, combustion of biomass for domestic use, transport of goods and people, energy consumption and the development of common tools for monitoring the emissions and for the assessment of air quality over the whole project area.

DURATION

From February 1st, 2017 to January 31, 2024.

TOTAL BUDGET

17 million euros available to invest in 7 years: 10 million of which coming from the European Life Program.

COMPLEMENTARY FUNDS

PREPAIR is an integrated project: over 850 million euros coming from structural funds and from regional and national resources of all partners for complementary actions related to air quality.

PARTNERS

The project involves 17 partners and is coordinated by the Emilia-Romagna Region – General directorate for the territorial and environmental care

www.lifeprepair.eu – info@lifeprepair.eu

Regione Emilia-Romagna
Regione del Veneto
Regione Lombardia
Regione Piemonte
Regione Autonoma Friuli Venezia Giulia
Provincia Autonoma di Trento

arpae agenzia prevenzione ambiente energia emilia-romagna
arpav Agenzia Regionale per la Prevenzione e Protezione Ambientale del Veneto
Arpa Piemonte Agenzia Regionale per la Protezione Ambientale
ARPA Lombardia Agenzia Regionale per la Protezione dell'Ambiente
ARPA Valle d'Aosta
arpa FVG agenzia regionale per la protezione dell'ambiente del friuli venezia giulia

ARSO ENVIRONMENT Slovenian Environment Agency
Comune di Bologna
Comune di Milano
Città di Torino
ART-ER Attrattività Ricerca Territorio
FLA Fondazione Lombardia per l'Ambiente