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Urban SIS
D441.6.4.2 Use case air quality

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1. Introduction

Air quality is a pressing issue. Exposure to air pollution is known to reduce life expectancy, which gives as a consequence that the public awareness on the subject is rising, and legislation requiring lower limit values is being progressively introduced. However, improvement of air quality requires long term, extensive policies of emission reduction; these policies are linked, and sometimes conflicts, with those implemented to tackle climate change. Since meteorological conditions strongly affect air pollution, a long term assessment of the effectiveness of emission reduction policies should take into account how climate change will affect air quality in the forthcoming decades.

The city of Bologna is located in the southern boundary of Po Valley (Figure 1).

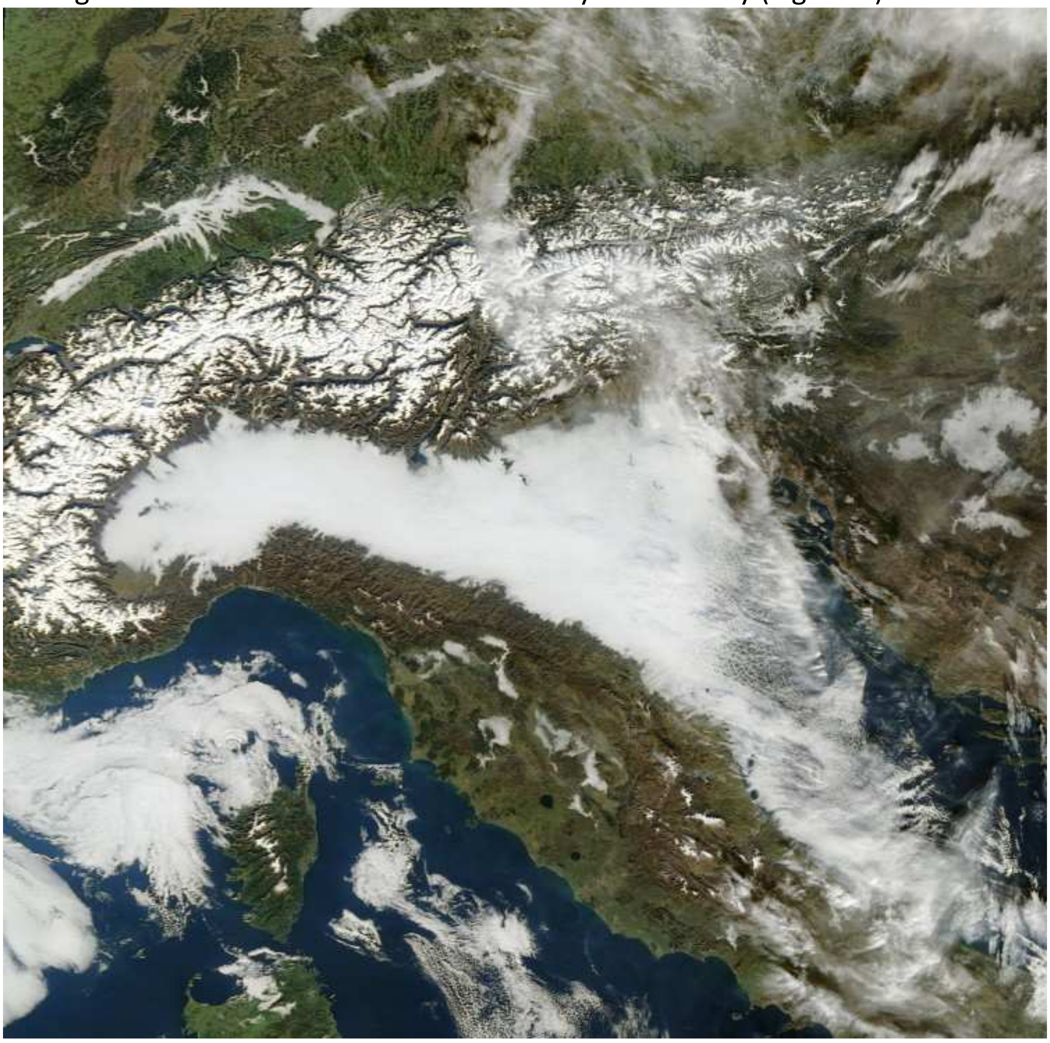

Figure 1 - Satellite view of Po Valley in a foggy winter day.

Po Valley is a well known hotspot in European air pollution, due to the heavy anthropization and to a combination of geographical and meteorological factors: it is surrounded by Alps and Appenines mountains, and it often experience weak winds and strong thermal inversions (figures 2 and 3).

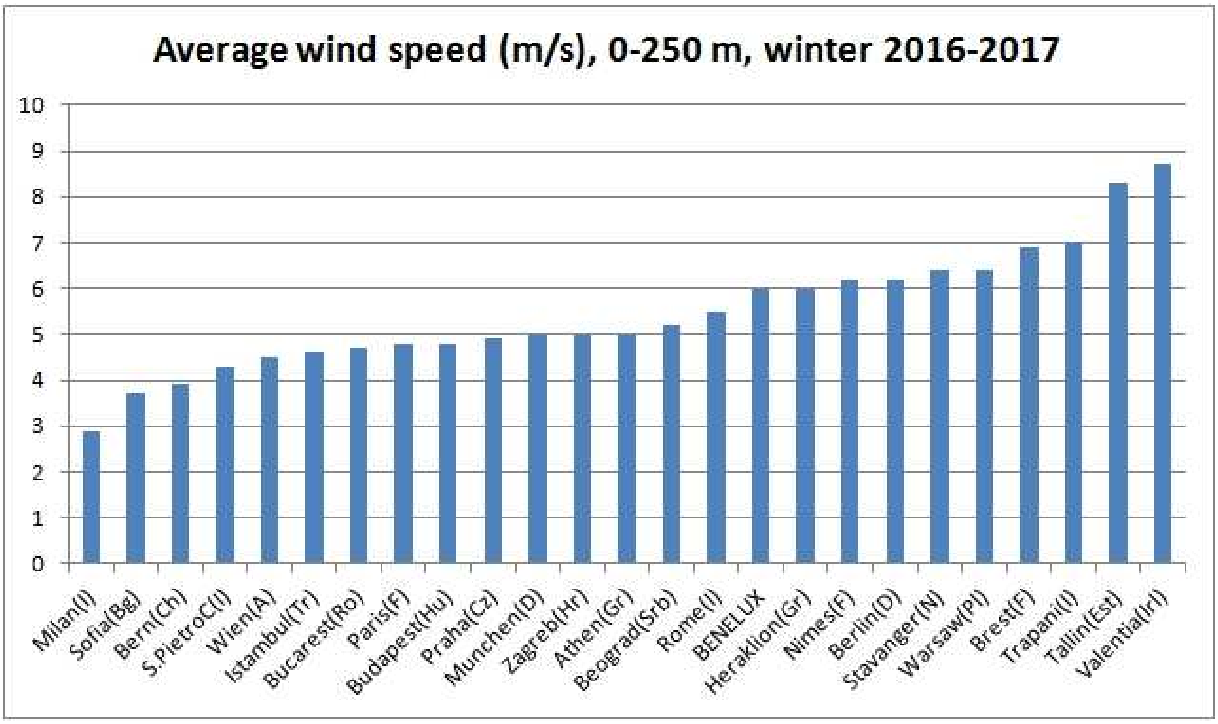

Figure 2 - Average wind speed in Europe during winter 2016-2017. Data from the GTS radiosounding network, average in the layer between surface and 250 m, from 01/10/2016 to 31/03/2017. Po Valley data are measured at Milan and S.Pietro Capofiume.

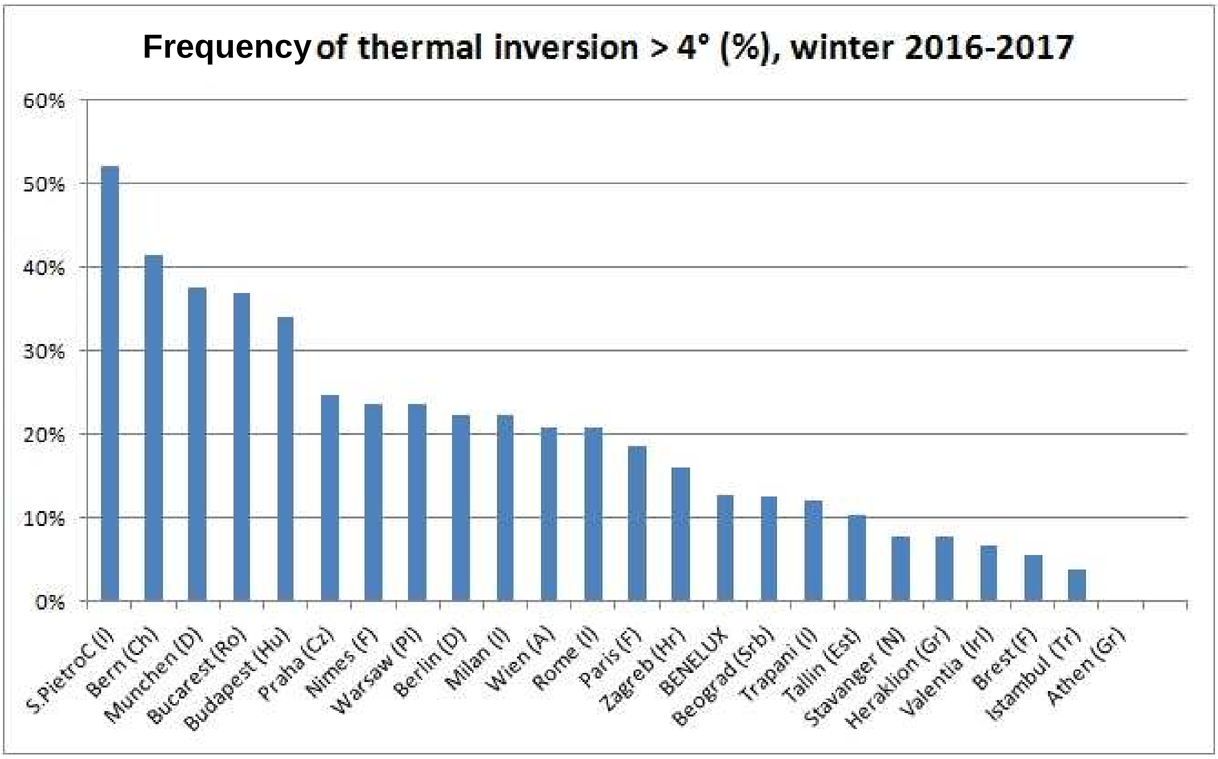

Figure 2 - Frequency of occurrence of thermal inversions > 4° in Europe during winter 2016-2017. Data from the GTS radiosounding at 00GMT, from 01/10/2016 to 31/03/2017. Temperature inversion is calculated as the difference between the highest temperature in the profile and surface temperature. Po Valley data are measured at Milan and S.Pietro Capofiume.

Moreover, Po Valley is located in the Mediterranean area, where the consequences of climate change are expected to be particularly important. It is therefore an ideal area to study how climate change and emission reduction policies will affect air quality in future years.

Air pollution in Po Valley is strongly dependent on the season: in winter months concentrations of PM10, PM2.5 and NO2 are almost twice higher than in summer, while O3 usually reaches high values during summer months.

In recent years, concentrations of most pollutants in Po Valley have gradually decreased, thanks to technological improvements and policies of emission reduction. In the next decades, this trend of concentration reduction is expected to continue, due to ongoing policies and legislation. Climate change will change the way in which pollutants are dispersed and transported in the atmosphere, thus affecting future air quality: the magnitude of this effects, and even if air quality will improve or worsen, is largely unknown, and may depend on the geographical area and on the pollutant considered. Since emission reduction policies aim at stably reducing air pollution, the assessment of their effectiveness should take into account also the consequences of climate change.

2. The UrbanSIS interface

Data available on UrbanSIS web interface cover a wide range of applications. For air quality, several groups of ECVs (Essential Climate Variables) and indicators are provided: concentrations of the main pollutants, population exposure and mortality rates, as well as several meteorological parameters.

For each product, UrbanSIS interface provides 3 sets of data:

- ***historical***: Reanalysis, covering 5 years in recent past
- ***present***: Output of model simulations in present climate; these data do not take into account observations. 5 full years of data are provided, representative of one "typical" and 4 "extreme" meteorological conditions (see ANNEX in D441.3.4 for more details on how the Urban SIS five years were selected).
- ***future***: Output of model simulations in future climate, with the same type of output of the present dataset. Emissions of pollutants in future dataset are reduced according to established environmental policies.

Historical data are used to evaluate model performance for a specific location and parameter; to estimate future air quality conditions, the difference between present and future should be considered.

For each ECV, UrbanSIS interface provide different products: it is always possible to download the raw data (hourly time series of values and maps), but a set of "final" products are also provided. This is a very useful feature, since it allows to easily screen the data and draw quick conclusions, but also to refine the analysis on the most interesting indicators and to compare results with external sources of data. UrbanSIS interface can therefore be used by both end users with limited technical capabilities, as well as by advanced end users who have interest in more sophisticated data processing.

From an end-user point of view, the interface is well designed; it also contains some very useful features, such as the possibility to download gridded data on sub-domains and to make straightforward comparisons of pollution levels with legislation thresholds. Tutorials and on-line documentation are concise, but it contains all relevant information.

For practical use some minor difficulties have emerged, and a set of improvements are suggested:

- It is sometimes difficult to download long series of raw data (hourly time series of ECVs for multiple years, or long time series of gridded data), especially if the local computer is not very performant, or if internet connection is not very fast. It would be useful if an alternative way to download raw data (eg. ftp server) were provided.

- A straightforward way to save pictures and charts from the screen would be useful.

- If the interface must be reloaded (due to errors in processing, connection timeouts, request of too heavy processing), all the work and configuration done (eg. saved probes and saved views) is lost: it would be useful to have the possibility to save "projects", either locally or on the remote server.

3. Outcomes of the Bologna air quality use case

For air quality, 4 ECVs has been selected (Table 1):
- PM_{10}: annual average, limit value 40 µg/m^3
- $PM_{2.5}$: annual average, limit value 25 µg/m^3
- NO_2: annual average, limit value 40 µg/m^3
- O_3: 93.15th percentile of max of 8-hour running averages (same as 25 exceedances per year of the 120 µg/m^3 threshold)

Table 1 - Values of selected air quality ECVs in the Bologna city centre (longitude 11.343, latitude 44.494). Historical, present and future data are averages over the 5 years provided by UrbanSIS; observations are taken from Bologna urban background monitoring stations, and are average over years 2012-2016.

	PM10	PM2.5	NO2	O3
Observations (2012-2016)	24	16	25	
Historical	20	16	26	122
Present climate	21	15	26	116
Future climate	13	10	22	108

Model performance is satisfactory, although ozone concentrations are probably underestimated. In recent years, urban background concentrations of NO2, PM10 and PM2.5 in Bologna have usually been below EU limits. The limit for PM_{10} daily values is exceeded at roadside stations and also in background locations in years with particularly unfavorable meteorological conditions. It should nevertheless be noted that PM is considered harmful even at low concentrations, and that there is widespread discussion about making legislation limits stricter (eg. by reducing thresholds, introducing limits on PM1 or on aerosol components such as black carbon).

In the future scenario, concentrations of every pollutant are predicted to decrease, by almost 40% for aerosols, and by around 10% for O_3 and NO_2.

To estimate the net effect of changes in atmospheric dispersion associated with climate change, a set of meteorological parameters linked with AQ have been selected (Table 2):

- ***WS***: average 10 m wind speed (m/s)
- ***Hmix***: average boundary layer height (m)
- ***Rain***: accumulated precipitation (mm)
- ***Tmax***: average of daily maximum temperatures (°C)
- ***Vent***: average "ventilation index" (product of wind speed and boundary layer height; m2/s)
- ***CDW***: percentage of "winter critical days" (days with ventilation index < 800 m2/s and accumulated precipitation < 0.3 mm). This parameter is an indicator of meteorological conditions that inhibit the dispersion of pollutants during winter months, and it has proven a good predictor of seasonal averages of PM10 concentrations in Emilia Romagna.
- ***CDS***: percentage of "summer critical days" (days with maximum temperature > 30 °C). This parameter is an indicator of meteorological conditions that favor ozone production in Emilia Romagna during summer months: high maximum temperatures usually occur during sunny days with anticyclonic conditions.

Table 2 - Values of the selected meteorological ECVs, for the grid point of Bologna city centre (longitude 11.343, latitude 44.494). Historical, present and future data are averages over the "normal" years (i.e. the year out of five considered as normal in terms of temperature and precipitation); observations are taken from Bologna urban meteorological station, and refer to the same year of the historical data.

	Observations (2012)						
	WS	Hmix	Rain	Tmax	Vent	CDW	CDS
year	2,4	318	618	19,4	932		
summer	2,8	406	289	26,9	1297		37%
winter	2,0	230	329	12,0	567	54%	
	Historical (reanalysis 2012)						
	WS	Hmix	Rain	Tmax	Vent	CDW	CDS
year	2,7	647	858	20,1	1967		
summer	3,1	820	385	27,7	2716		43%
winter	2,3	474	472	12,4	1219	28%	
	Present climate (2005)						
	WS	Hmix	Rain	Tmax	Vent	CDW	CDS
year	2,8	507	634	18,7	1612		
summer	3,1	688	291	26,3	2210		30%
winter	2,5	325	344	11,1	1010	43%	
	Future climate (2050)						
	WS	Hmix	Rain	Tmax	Vent	CDW	CDS
year	2,6	488	711	21,4	1493		
summer	2,9	655	251	30,1	1996		55%
winter	2,3	321	460	12,7	987	51%	
	Climate change difference (2050 – 2005)						
	WS	Hmix	Rain	Tmax	Vent	CDW	CDS
year	-7%	-4%	12%	2,7	-7%		
summer	-5%	-5%	-14%	3,8	-10%		84%
winter	-8%	-1%	34%	1,6	-2%	18%	

Wind speed and boundary layer height are expected to slightly decrease in all seasons; maximum temperatures will increase significantly, especially in summer; the number of days with "unfavourable" meteorological conditions will increase both in summer and winter.

4. Conclusions

In Urban SIS, the standard approach of processing entire climatological time series (>30 years) would have been unfeasible, due to the computing times for simulations with the high spatial and temporal resolution required. Instead, for each scenario a small set of “representative” years has been selected and processed in detail. This approach turned out to be feasible and practical, but the selection of the “representative” years is somehow subjective. Moreover, it can be impossible to find a set of years that are representative for all required ECVs: it may therefore be necessary either to restrict the set of ECVs or to select independent set of years for the different classes of ECVs. In Urban SIS the representative years were selected according to temperature and precipitation: the introduction of selection criteria tailored on air quality may be beneficial.

For the Bologna use case, there are indications that climate change will likely have a negative impact on air quality. Both wind speed and mixing height are predicted to decrease by around 5% (1 to 8%) in all seasons, reducing atmospheric dispersion and increasing the chance of episodes of strong pollution. Although the magnitude of the reduction is limited, the number of days with “unfavorable” meteorological conditions for air quality during winter will increase by almost 20%, making it more difficult to attain the fulfillment of legislation requirements and increasing the short-term effects of pollution.

In summer months, maximum temperatures in Bologna centre are expected to increase by almost 4 degrees, and the number of days with T>30° will almost double. Ozone peaks will likely be more frequent and long-lasting. Concentrations of pollutants will nevertheless decrease, thanks to the policies of emission reduction, but the benefits will be partly compensated by the reduction of atmospheric dispersion, especially for ozone pollution in summer months.