WP 2 – BE and SLOD: SoA, Risks and human behavior

T.2.2 - SoA on SLOD (heat wave and pollution) in BE and their effect on health and wellbeing of its users. Methods for data collection and analysis (on medium/long term datasets). Correlation between pollution and climate data (e.g. wind, rain, fog). Current mitigation solution analysis. Identification of BE features and users' (inappropriate) behaviors modifying SLOD effects/risk levels. Development of indicators and relative weights for selected SLOD risk levels assessment

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Abstract

SLow Onset Disasters (SLOD) are responsible for the production of systemic effects on the urban ecosystem and can seriously harm people to be living in the cities. Therefore, the agents underpinning the SLODs must be carefully analysed to acquire a good knowledge of the effects that they may produce on the citizens and investigating how these agents are related to the Built Environment (BE) characteristics. Air pollution is one of the most critical agents which may produce severe SLODs. This report presents a set of analyses carried out on the open data provided by the Lombardy region on the main pollutant. These analyses allow to identify the trends of the most harmful pollutants enhanced by the BE typologies. For the city of Milan, the Particulate Matter (PM) concentration, CO, SO2, O3, NO2, black carbon and Volatile Organic Compounds (VOC) have been analyses in the period 2017-2020. These pollutants have been employed for the calculation of the US Environmental Protection Agency (EPA), Air Quality Index (AQI) in the same period. The analyses carried out in this report and the AQI calculation provides a sound basis for the definition of SLODs mitigation strategies and the further micro-scale measurements and analysis that will be carried out as the next step of the research.

Keywords

Slow-Onset Disasters, Built Environment; Pollution; Climate change, PM, CO, SO_2, O_3, NO_2, black carbon, VOC, Air Quality Index

Approvals

Role	Name	Partner
Coordinator	Enrico Quagliarini	UNIVPM

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Revision versions

Revision	Date	Short summary of modifications	Name	Partner
0.1	15.04.2020	Minor revision	Enrico Quagliarini	UNIVPM
			Michele Lucesoli	UNIVPM
1.0	10.04.2020	proofreading, required integrations to minor comments from the coordinator, editing	Graziano Salvalai	POLIMI

Summary

1. Introduction

The city of Milan is one of the most populated are of the Lombardy region. This is due both for its dimension and the great number of economic activities operating in this context and to the geographic location, reducing the wind circulation and therefore, facilitating the accumulation of pollutants. Milan is currently monitored by 7 Air Quality (AQ) stations (Figure 1) measuring different types of pollutants (Table 1). These stations are managed by the Agenzia Regionale per la Protezione dell'Ambiente (ARPA). The city is well equipped especially in the north/Eastern area, counting 6 AQ stations, while the South/Eastern area is the part where no stations are present. Moreover, most part of the AQ stations has been installed in high-traffic locations, apparently for monitoring the AQ in critical points for the emission of harmful pollutants.

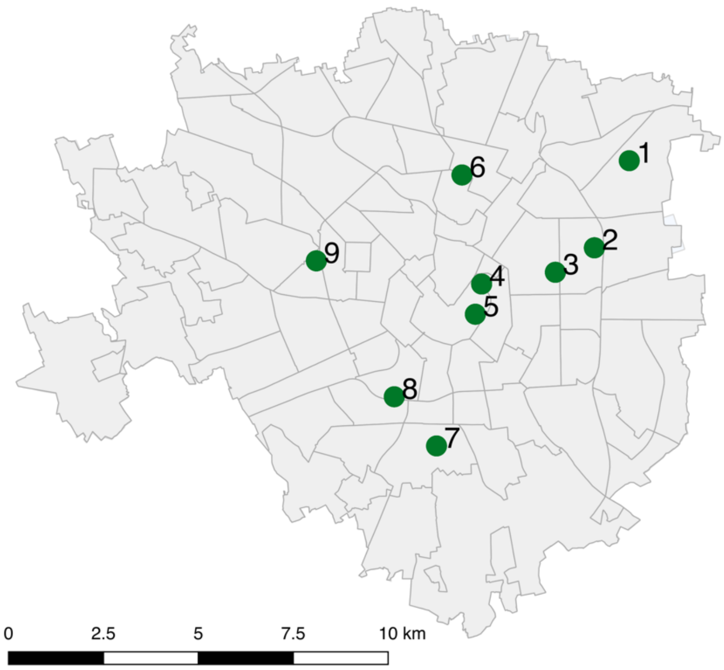

Figure 1: Map of the air quality stations in Milano. The numbers correspond to the IDs used in Table 1.

Table 1 lists the AQ stations and the available sensors for each of them. In this report, for each pollutant, the analysis of the historical series, most frequently registered values, count of the times each sensor detected values above the allowed thresholds have been done for the period 2017-february 2020. Analysing the historical data, the moving monthly average has been calculated. The moving average allows to smooth the short term fluctuations of the historical data, highlighting long-term trends (similar to what Paolini et al. (2016) did, but with a defined hour range instead).

However, it should be considered that not all the available sensors in the stations listed in Table 1 are properly working. When the sensors do not present any detected data, they are removed from the analyses.

After analysing the AQ in stations in the whole city of Milano, further insight has been done for the Pascal Città Studi AQ station. This is the closest station to the case study is that has been identified in the report D.2.1.2. Therefore, US Environmental Protection Agency (EPA) Air Quality Index (AQI) has been calculated. This provides an insight on which are the most severe pollutants and increases the knowledge of the data related to the case study area.

Table 1:Air quality parameters measured for each air quality station.

Map id	Station	Sensor code	Type of sensor
1	Milano - Parco Lambro		
		5722	Ozono (O_3)
		5550	Biossido di Azoto (NO_2)
		6340	Ossidi di Azoto (NO_x)
2	Milano - Pascal Città Studi		
		17126	Benzene (C_6H_6)
		20020	Ammoniaca (NO_3)
		10282	Ozono (O_3)
		12629	Benzo(a)pirene ($C_{20}H_{12}$)
		10278	Ossidi di Azoto (NO_x)
		12626	Cadmio (Cd)
		12627	Piombo (Pb)
		20004	BlackCarbon
		12624	Nikel (Ni)
		12625	Arsenico (As)
		10273	PM10 (SM2005)
		10283	PM2.5
		10279	Biossido di Azoto (NO_2)
		10280	Biossido di Zolfo (SO_2)
3	Milano - via Juvara		
		6637	Total PM
		6905	PM10 (SM2005)
		9874	PM2.5
		10269	Ammoniaca (NO_3)
		5625	Biossido di Zolfo (SO_2)
		5713	Ozono (O_3)
		5505	Biossido di Azoto (NO_2)
		6312	Ossidi di Azoto (NOx)
4	Milano - via Senato		
		12639	Cadmio (Cd)
		17122	Particelle sospese PM2.5
		12641	Benzo(a)pirene ($C_{20}H_{12}$)
		12638	Arsenico (As)
		6354	Ossidi di Azoto (NO_x)
		20005	BlackCarbon
		5834	Monossido di Carbonio (CO)
		5551	Biossido di Azoto (NO_2)
		10320	PM10 (SM2005)
		12637	Nikel (Ni)
		12640	Piombo (Pb)
		6057	Benzene (C_6H_6)
5	Milano - via Verziere		
		6956	PM10 (SM2005)
		5725	Ozono (O_3)
		5838	Monossido di Carbonio (CO)
		5531	Biossido di Azoto (NO_2)
		6366	Ossidi di Azoto (NOx)
		5647	Biossido di Zolfo (SO_2)
6	Milano - viale Marche		
		5827	Monossido di Carbonio (CO)
		17127	Benzene (C_6H_6)
		5651	Biossido di Zolfo (SO_2)
		6328	Ossidi di Azoto (NO_x)
		6641	Total PM
		5504	Biossido di Azoto (NO_2)

Map id	Station	Sensor code	Type of sensor
7	Milano - P.zza Abbiategrasso		
		5552	Biossido di Azoto (NO_2)
		5637	Biossido di Zolfo (SO_2)
		6344	Ossidi di Azoto (NO_x)
8	Milano - viale Liguria viale Toscana		
		5542	Biossido di Azoto (NO_2)
		6639	Total PM
		5823	Monossido di Carbonio (CO)
		6320	Ossidi di Azoto (NO_x)
		5628	Biossido di Zolfo (SO_2)
9	Milano - P.zza Zavattari		
		6062	Benzene (C_6H_6)
		5650	Biossido di Zolfo (SO_2)
		6372	Ossidi di Azoto (NO_x)
		6651	Total PM
		5506	Biossido di Azoto (NO_2)
		5841	Monossido di Carbonio (CO)

Figure 2 represents the main sources for the pollutants that have been analysed in the following paragraphs.

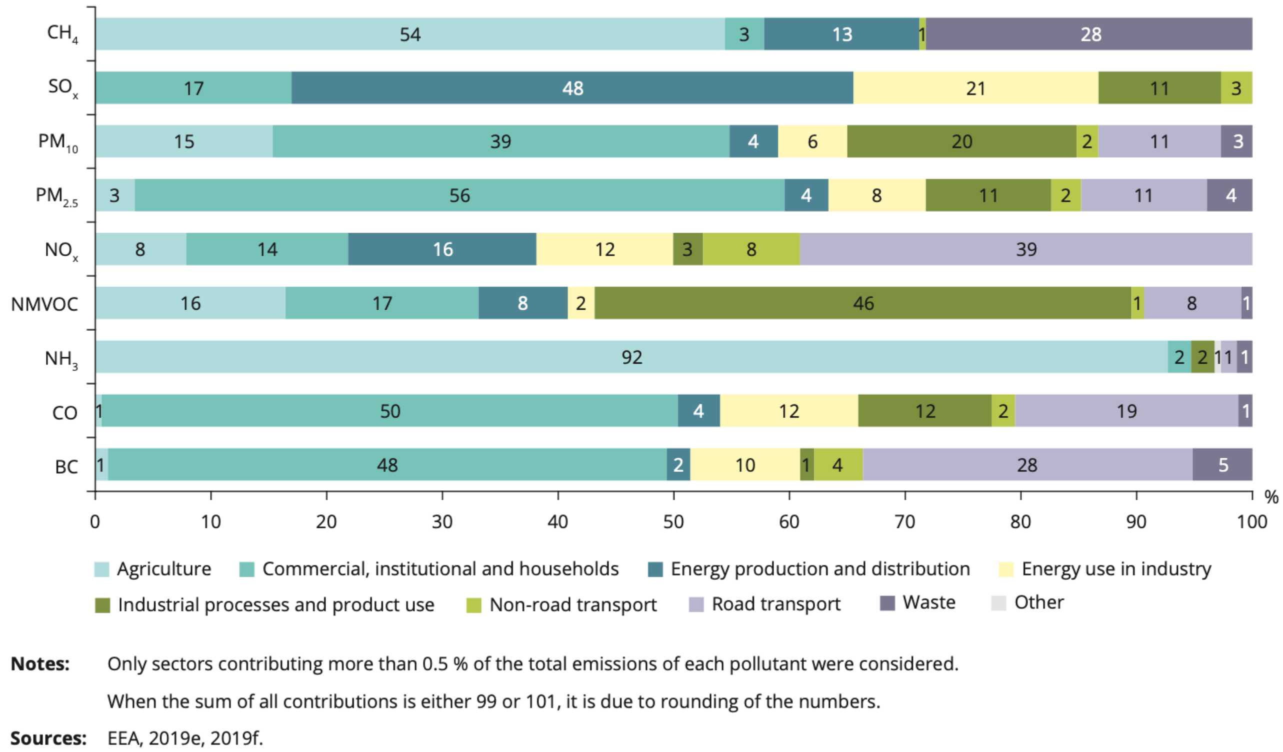

Figure 2: Contribution to EU-28 emissions from the main source sectors in 2017 of SOX, NOX, primary PM10, primary PM2.5, NH3, NMVOCs, CO, BC and CH4. Image is taken from the European Environment Agency (2019)

2. Air quality data collection and analysis

This section of the report provides the analyses related to the pollutants detected by the AQ stations in the Milan municipality. Data have been analysed in historical series, frequency of the detected value, frequency of detections above the allows threshold.

Pollutant	Averaging period	Legal nature and concentration	Comments
PM_{10}	1 day	Limit value: 50 μg/m³	Not to be exceeded on more than 35 days per year
	Calendar year	Limit value: 40 μg/m³	
$PM_{2.5}$	Calendar year	Limit value: 25 μg/m³	
		Exposure concentration obligation: 20 μg/m³	Average exposure indicator (AEI) (a) in 2015 (2013-2015 average)
		National exposure reduction target: 0-20 % reduction in exposure	AEI (a) in 2020, the percentage reduction depends on the initial AEI
O_3	Maximum daily 8-hour mean	Target value: 120 μg/m³	Not to be exceeded on more than 25 days/year, averaged over 3 years (b)
		Long-term objective: 120 μg/m³	
	1 hour	Information threshold: 180 μg/m³	
		Alert threshold: 240 μg/m³	
NO_2	1 hour	Limit value: 200 μg/m³	Not to be exceeded on more than 18 hours per year
		Alert threshold: 400 μg/m³	To be measured over 3 consecutive hours over 100 km² or an entire zone
	Calendar year	Limit value: 40 μg/m³	
BaP	Calendar year	Target value: 1 ng/m³	Measured as content in PM_{10}
SO_2	1 hour	Limit value: 350 μg/m³	Not to be exceeded on more than 24 hours per year
		Alert threshold: 500 μg/m³	To be measured over 3 consecutive hours over 100 km² or an entire zone
	1 day	Limit value: 125 μg/m³	Not to be exceeded on more than 3 days per year
CO	Maximum daily 8-hour mean	Limit value: 10 mg/m³	
C_6H_6	Calendar year	Limit value: 5 μg/m³	
Pb	Calendar year	Limit value: 0.5 μg/m³	Measured as content in PM_{10}
As	Calendar year	Target value: 6 ng/m³	Measured as content in PM_{10}
Cd	Calendar year	Target value: 5 ng/m³	Measured as content in PM_{10}
Ni	Calendar year	Target value: 20 ng/m³	Measured as content in PM_{10}

Notes: (a) AEI: based upon measurements in urban background locations established for this purpose by the Member States, assessed as a 3-year running annual mean.

(b) In the context of this report, only the maximum daily 8-hour means in 2017 are considered, so no average over the period 2015-2017 is presented.

Sources: EU, 2004, 2008.

Figure 3 – Air quality standards for the protection of health, as given in the EU Ambient Air Quality Directives (Image taken from the European Environment Agency (2019)).

It should be considered that, sometimes, sensor data are not complete for the period 2017-2020. Therefore, in these cases, the analyses should be carefully evaluated. In Lombardy and therefore in Milano, the same thresholds indicated by the European Environmental Agency (EEA) are accepted (Figure 3).
Data have been downloaded from the Lombardy Region's open data repository (ARPA Lombardia). This database is quite extensive and contains all the measures registered by the sensors, divided into yearly historical series. Each yearly dataset for each AQ station is composed approx. by 2.5M records. Therefore, data for all the available AQ sensors have been downloaded and cleaned, removing negative or absent values

and keeping only the validated (VA) records. This allows to accomplish the analysis increasing the data reliability, despite losing some part of the wide dataset.

1.1 Particulate Matter

The PM is a subset of an aerosol, defined as a mixture of solid or liquid particles suspended in a gas. Atmospheric particulate is defined as the complex set of particles, excluded water, suspended in the atmosphere for a sufficient amount of time for being transported and diffused. The PM is known to be one of the main pollutants in the atmosphere and its production is dependent mainly on commercial, household, institutional activities, production processes, agriculture and road transport. The following two paragraphs present the analyses carried out for the PM10 and PM2.5 from 2017 to February 2020.

PM10

Most of the PM10 comprehends the subset of particles small enough to pass through a size-selective inlet with a 50 % efficiency cut-off at 10 µm aerodynamic diameter (European Committee for Standardization 2014). PM10 is one of the most known pollutants recognized to be particularly harmful for human health (World Health Organization 2019). Figure 4 represents the trend of the PM10 concentration from 2017 to February 2020. Out of the 9 AQ station in the Milan municipality, only 3 of them are equipped with a PM10 sensor: via Verziere, via Senato and Pascal Città Studi. The trend shows clearly how the PM10 concentration is dependant on the heating period in Italy for climate zone E: 15th October to 15th April as stated by the DPR n. 74/2013.

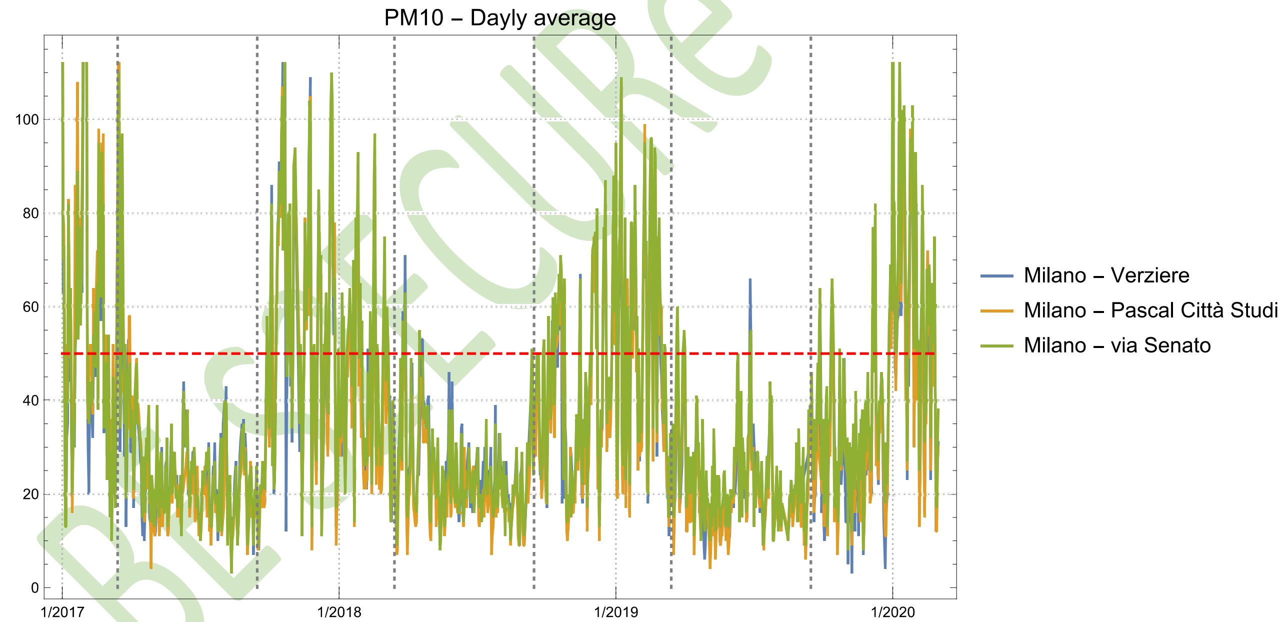

Figure 4: PM10 from 01/01/2017 to February 2020 detected by the three AQ stations of via Verziere, via Pascal Città Studi and via Senato.

Figure 5, Figure 6, Figure 7 represent the same analysis but for each of the sensors detecting PM10 in the respective AQ stations.

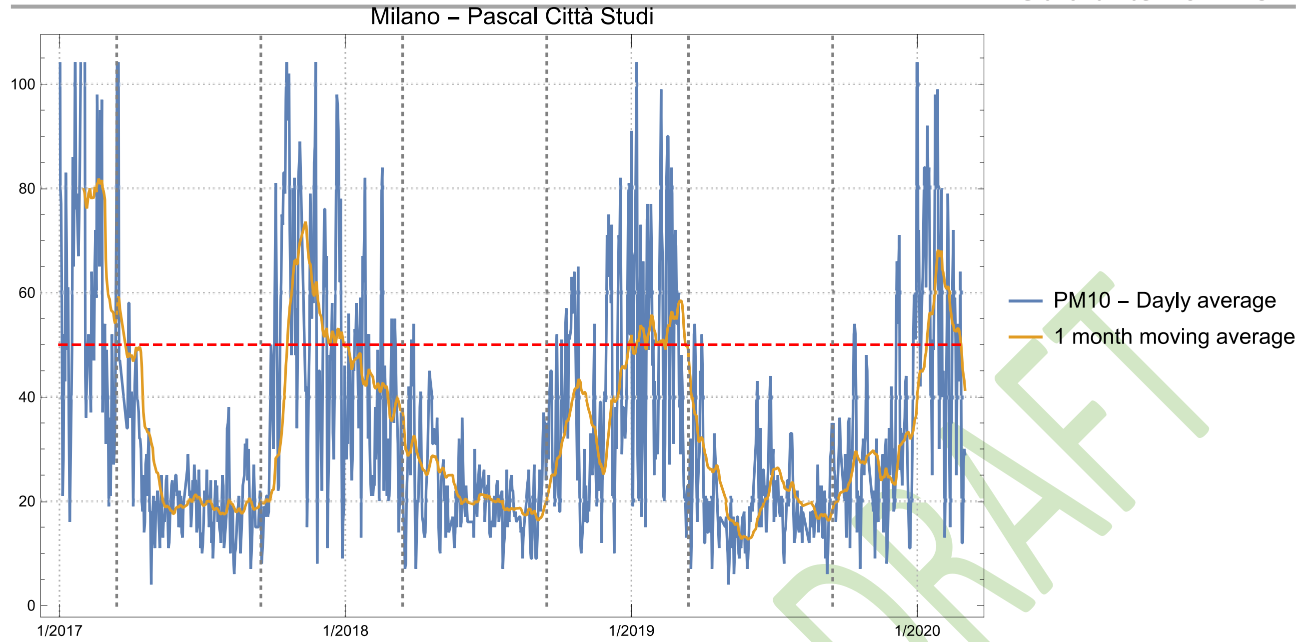

Figure 5: PM10 from 01/01/2017 to February 2020 registered by the AQ station Pascal Città Studi.

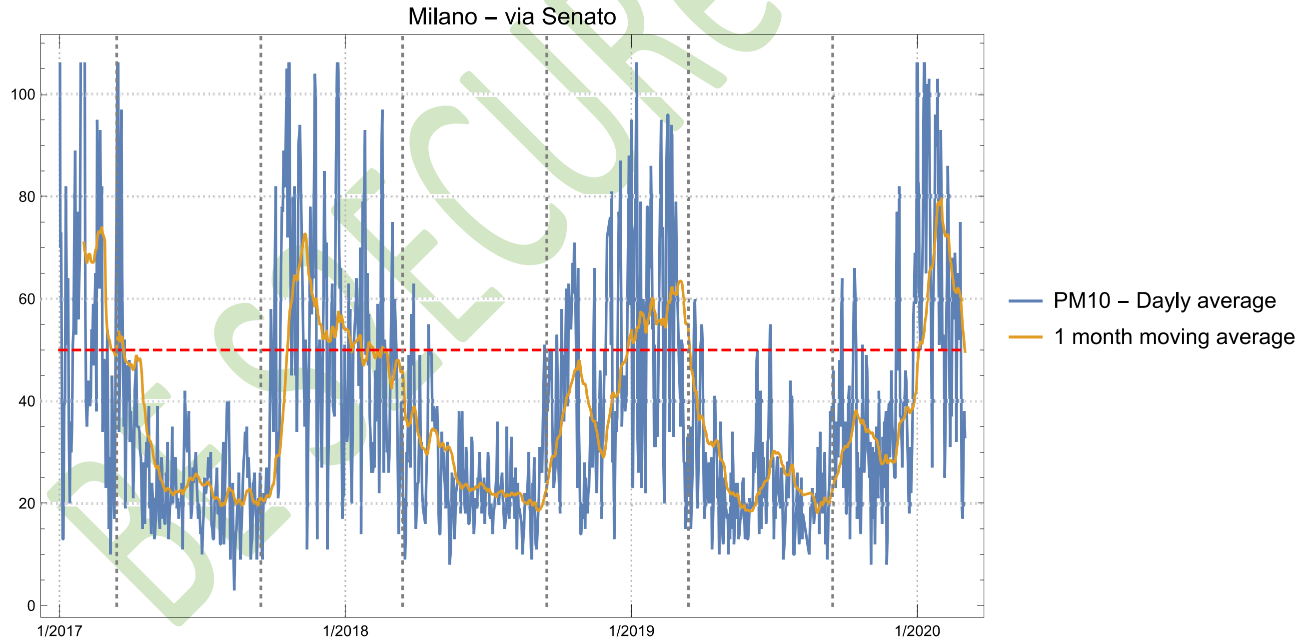

Figure 6: PM10 from 01/01/2017 to February 2020 registered by the AQ station via Senato.

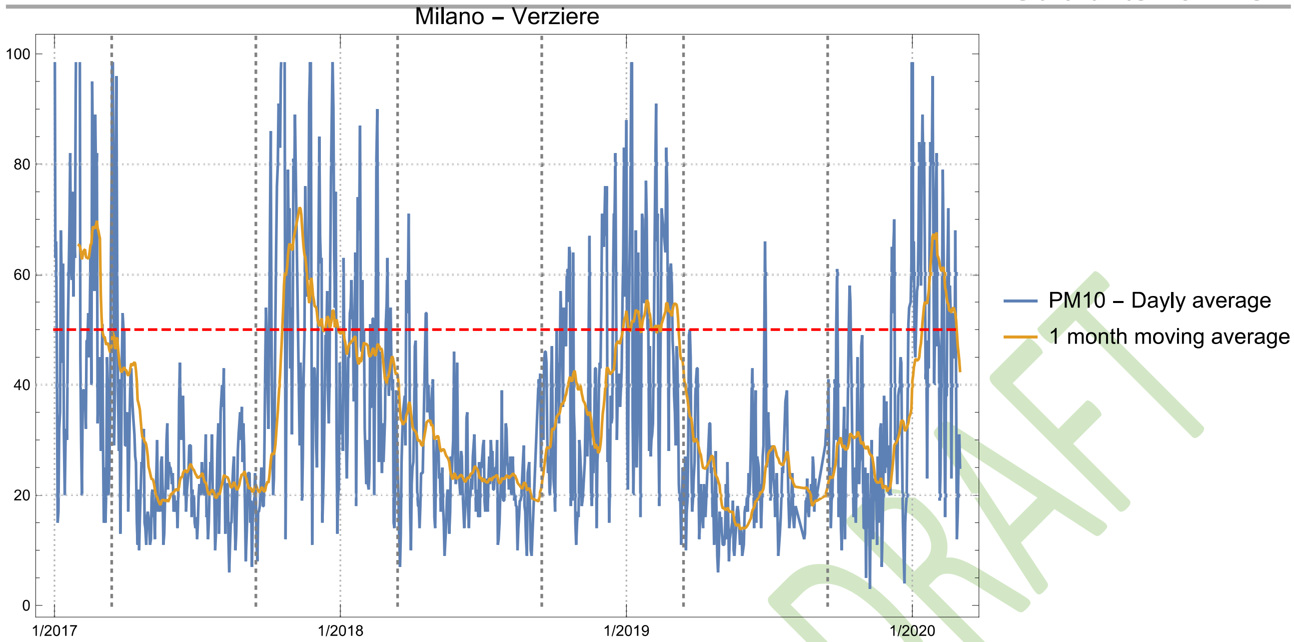

Figure 7: PM10 from 01/01/2017 to February 2020 registered by the AQ station Verziere.

During winter, the daily PM10 concentration exceeds largely the allowed threshold of 50 µg/m3, values reaching the highest measures during the coldest months (December/January). As the following stage of the analysis, a breakdown by AQ station has been done (Figure 8) and the count of the number of times that each PM10 sensor detected a value above the threshold has been done.

This analysis shows the highest number of values above the threshold for the via Senato sensor: one of the two located in the densest urban area (Senato and Verziere). Further analysis has been carried out to further investigate how the measures of the three stations are related to each other. Therefore Figure 9 represents the number of times a sensor in the correspondent AQ station has registered the highest value among the three detected by all the sensors in the AQ stations. For performing this analysis, only days in which the three measures were present have been considered.

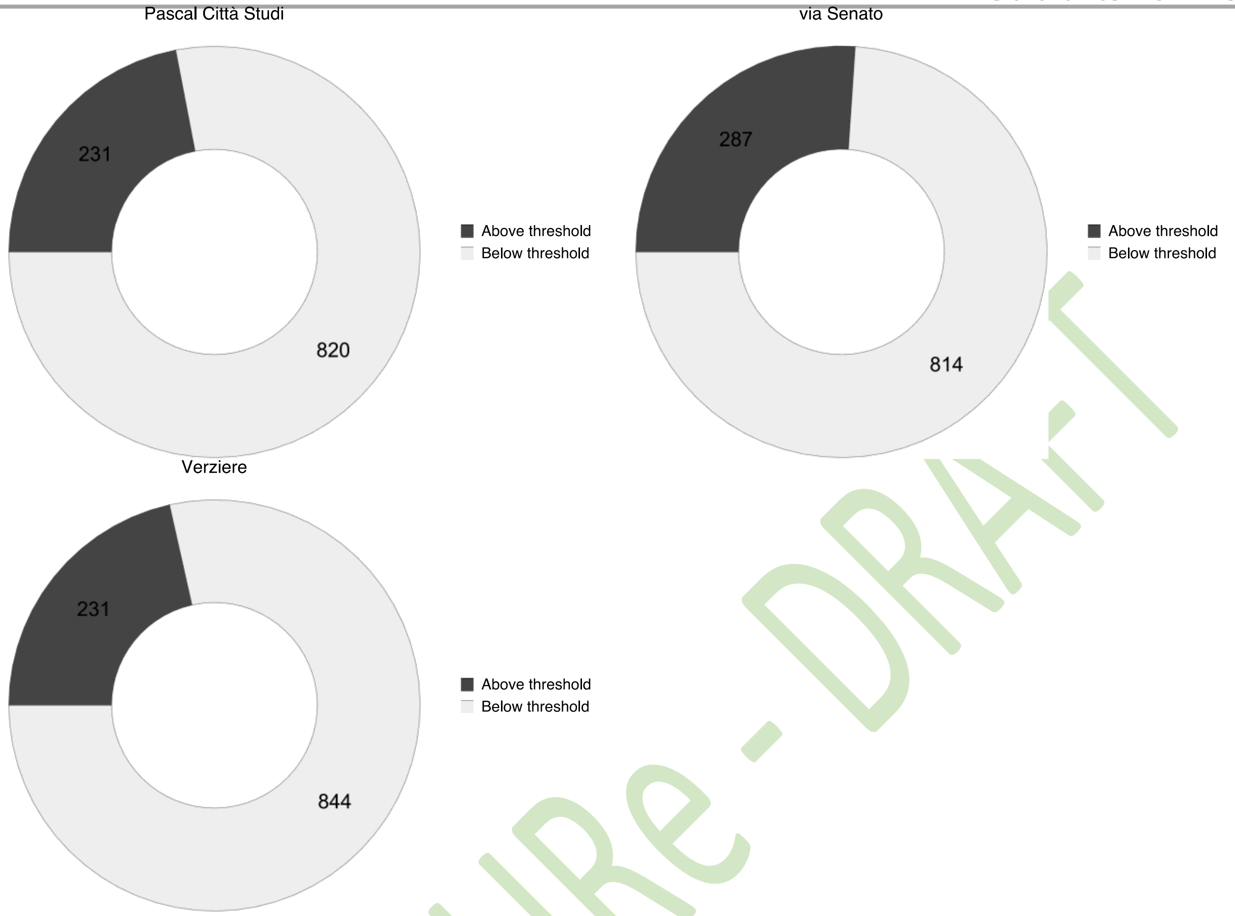

Figure 8: Frequency of PM10 above the threshold

The sensor in via Verziere measures the maximum PM10 values, i.e. is in the most polluted atmosphere in terms of particulate, more than twice the second most polluted area, the one in via Senato (Figure 9). Both sensors are in the city centre, a highly developed area, with a lot of traffic.

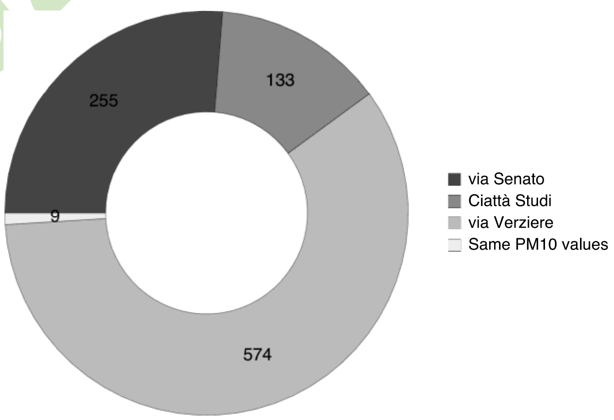

Figure 9: number of days a sensor recorded the max PM10 values

Noteworthy, sensor in via Verziere is close to a construction site for the new metro line 4 of the underground, where a lot of excavations are undertaken. This may be the reason for such a high presence of particulate.

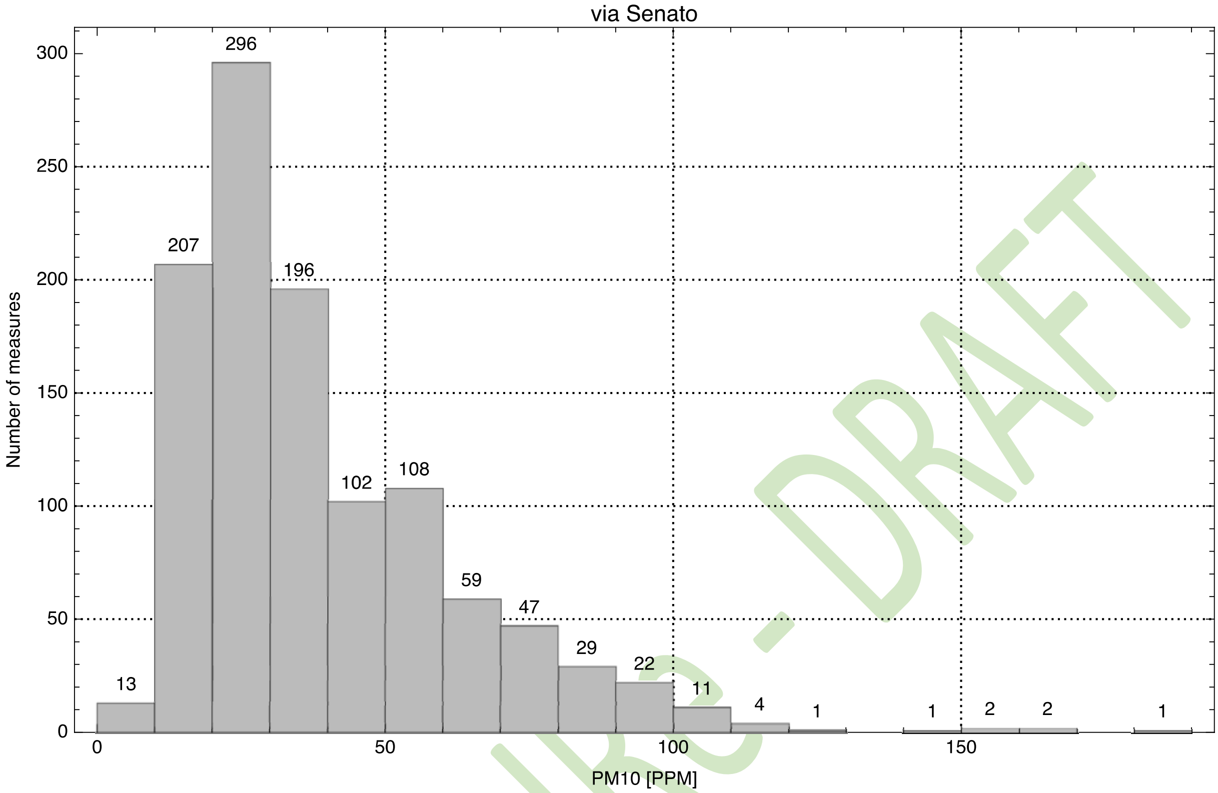

Figure 10: Number of PM10 measures for different PM10 values – via Senato

The following analysis represented in Figure 10, Figure 11 and Figure 12 concern the counting of the number of measures for each class of values (x-axis). This has been done for the three AQ stations, demonstrating that for most of the registered values, the measures are below the 50 µg/m3.

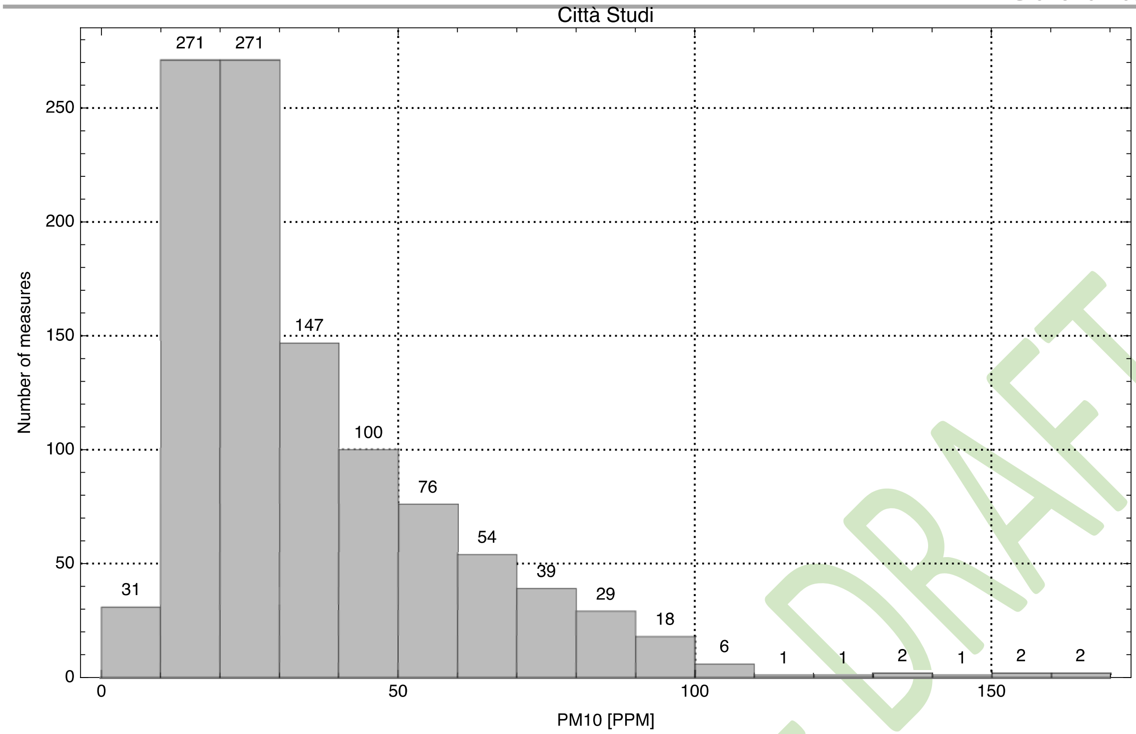

Figure 11: Number of PM10 measures for different PM10 values - Città Studi

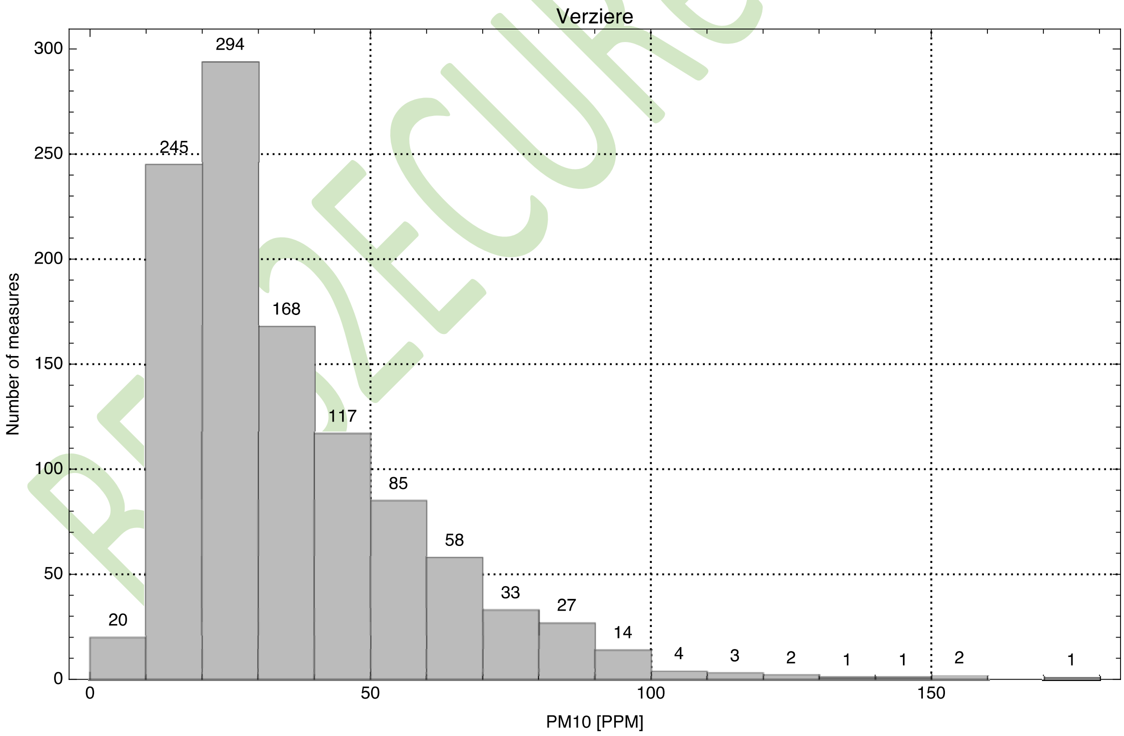

Figure 12: Number of PM10 measures for different PM10 values – via Verziere

PM2.5

The PM2.5 comprehends those particles small enough to pass through a size-selective inlet with a 50 % efficiency cut-off at 2.5 µm aerodynamic diameter. As described in the previous paragraph related to PM10, for PM2.5 the same analyses have been accomplished. In this case, the sensors measuring the PM2.5 concentration are located in the Pascal CIttà Studi and in the via Senato centrals. Figure 13, Figure 14 and Figure 15 represent the historic series trends for the data detected by the centrals in the period 1st January 2017 – February 2020. Data, once retrieved from the open data Lombardia portal have been cleaned removing negative and null values, and not validated rows. The PM2.5 concentration follows mainly the activation/deactivation cycles of the heating system in Lombardi, climate zone E: 15th October to 15th April as stated by the DPR n. 74/2013

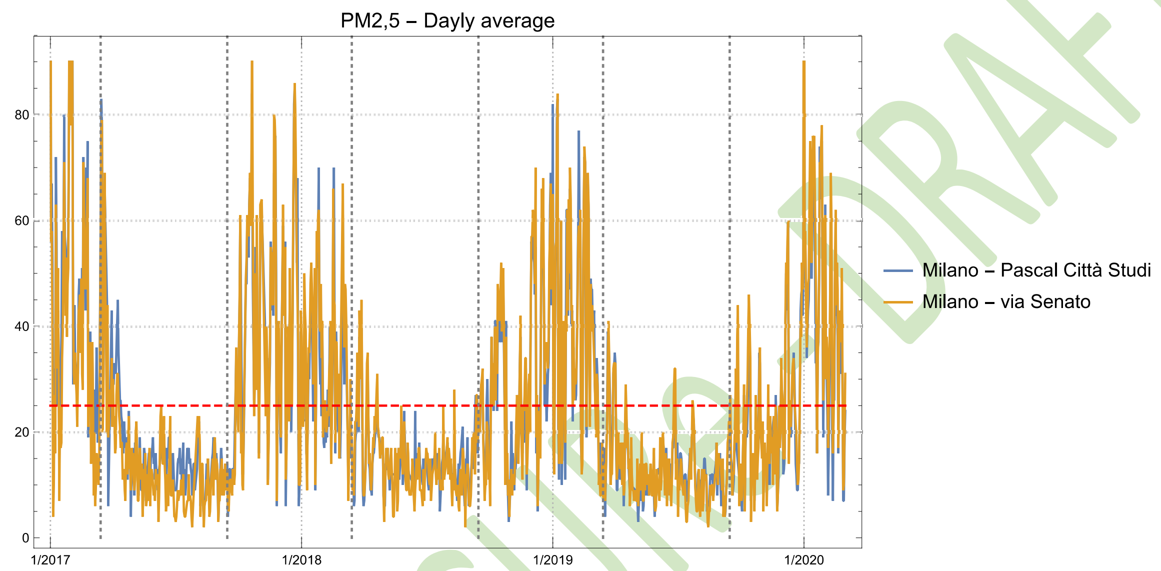

Figure 13: PM2,5 from 01/01/2017 to February 2020

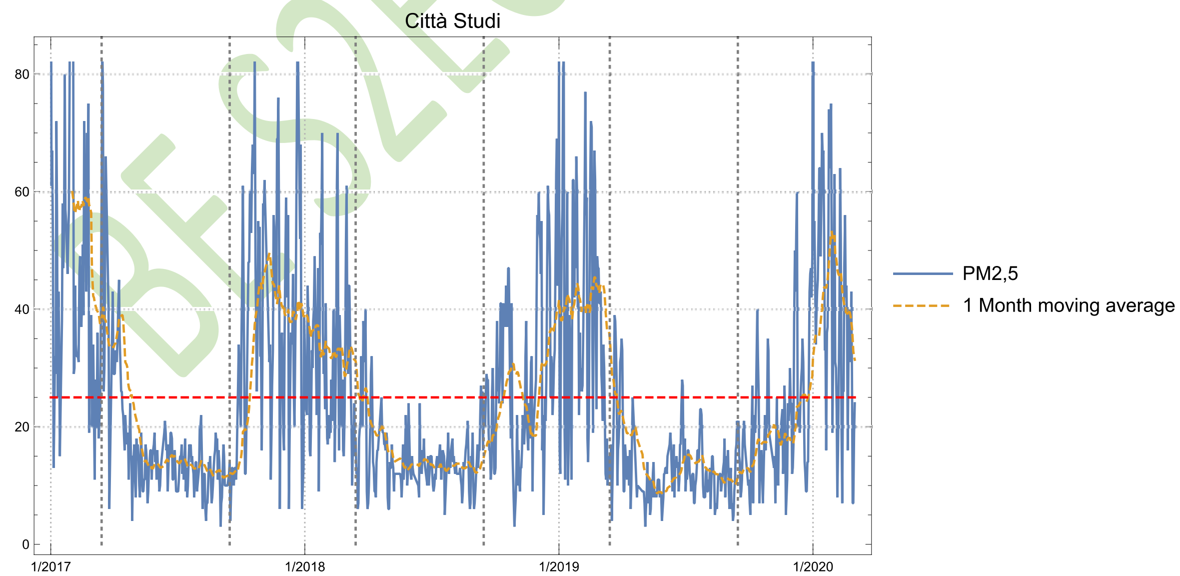

Figure 14: PM2,5 from 01/01/2017 to February 2020 measured by Pascal Città Studi AQ station.

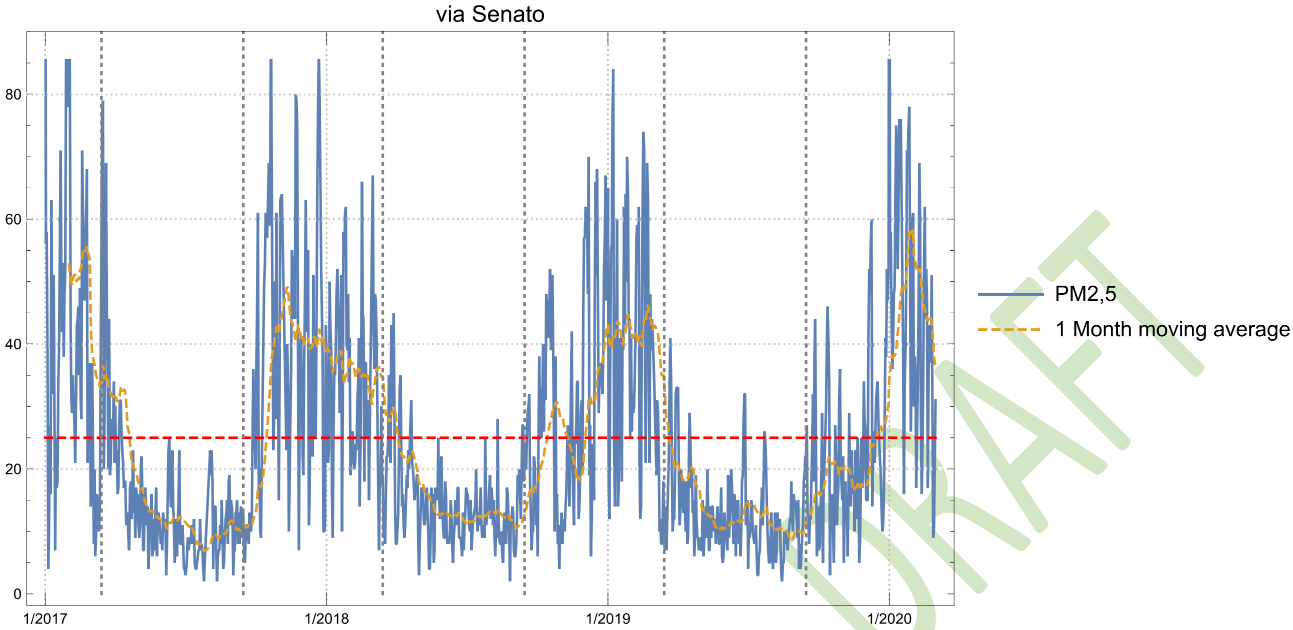

Figure 15: PM2,5 from 01/01/2017 to February 2020 measured by Pascal via Senato AQ station.

The further data analysis step concerns the calculation of the frequency each sensor has registered values above the allows threshold of 25µg/m3 Figure 16. This analysis demonstrated that the sensors detected approximately the same amount of values above the threshold, with a surplus of 23 detections for the via Senato sensor.

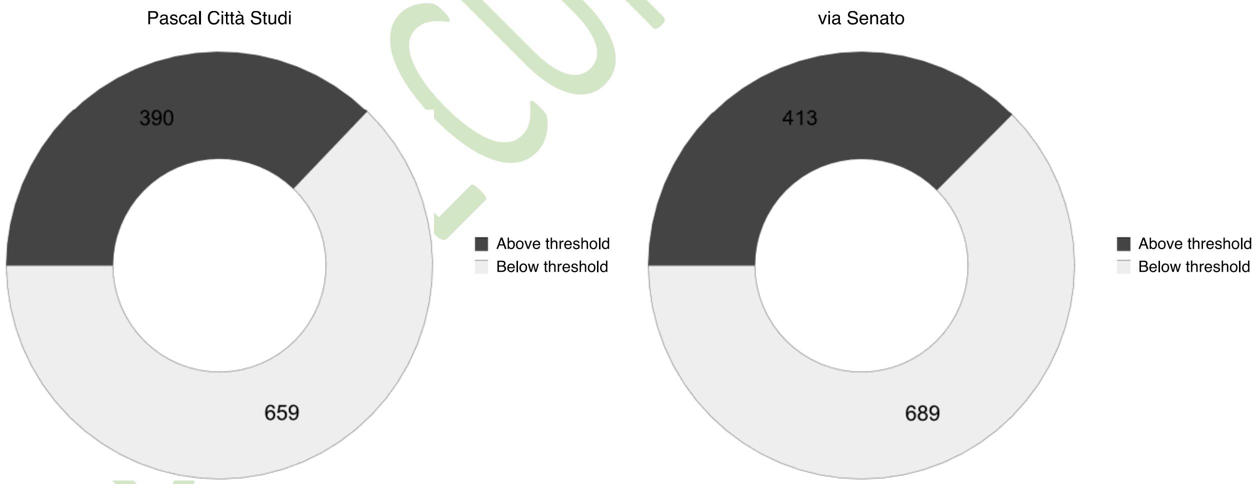

Figure 16: Frequency of PM2,5 above the threshold

Also the following analysis confirmed the similarity in the values detected by the two sensors. Figure 17 represents the number of times a sensor registered the maximum value out of the two sensors considered for the study.

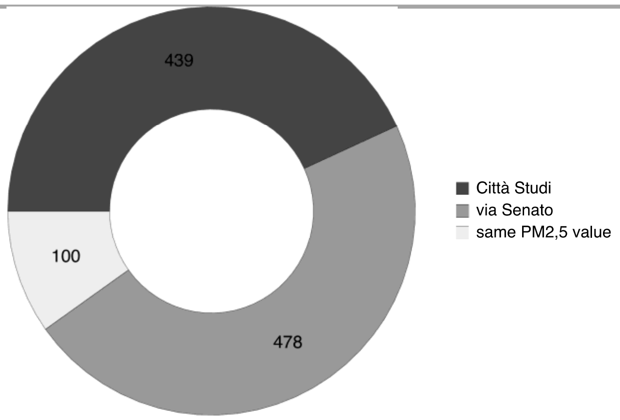

Figure 17: PM2,5 Number of max

In conclusion, Figure 18 and Figure 19 represent the subdivision of the measured values in classes and the count of the values within each class. The most detected values both for the Pascal Città Studi AQ station and for the via Senato station sit in the class 10-20 µg/m3 namely the class immediately before the allowed threshold of 25 µg/m3. Indeed, the PM2.5 a pollutant that shows the most critical concentrations among the ones analyses in this report.

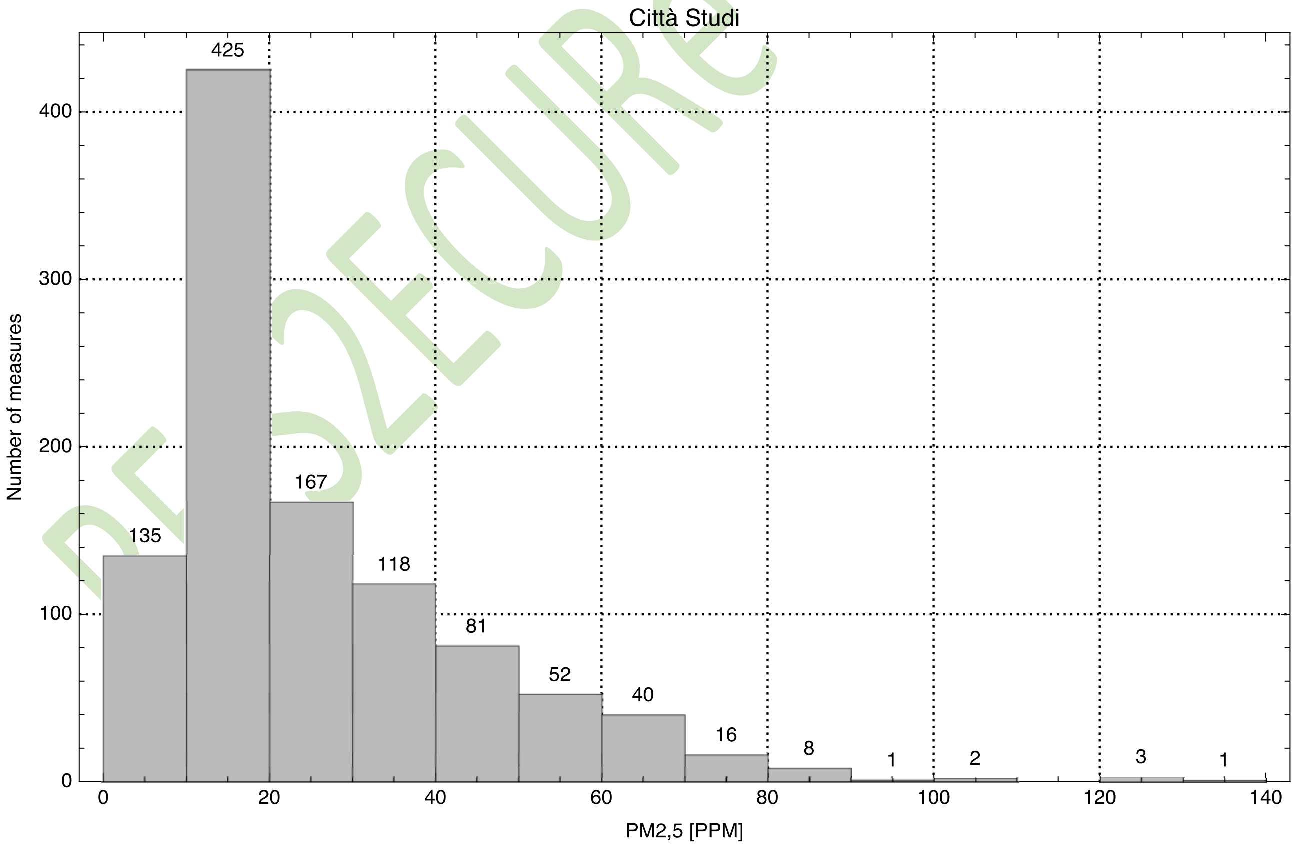

Figure 18: Number of PM2,5 measures for different PM2,5 values - Città Studi

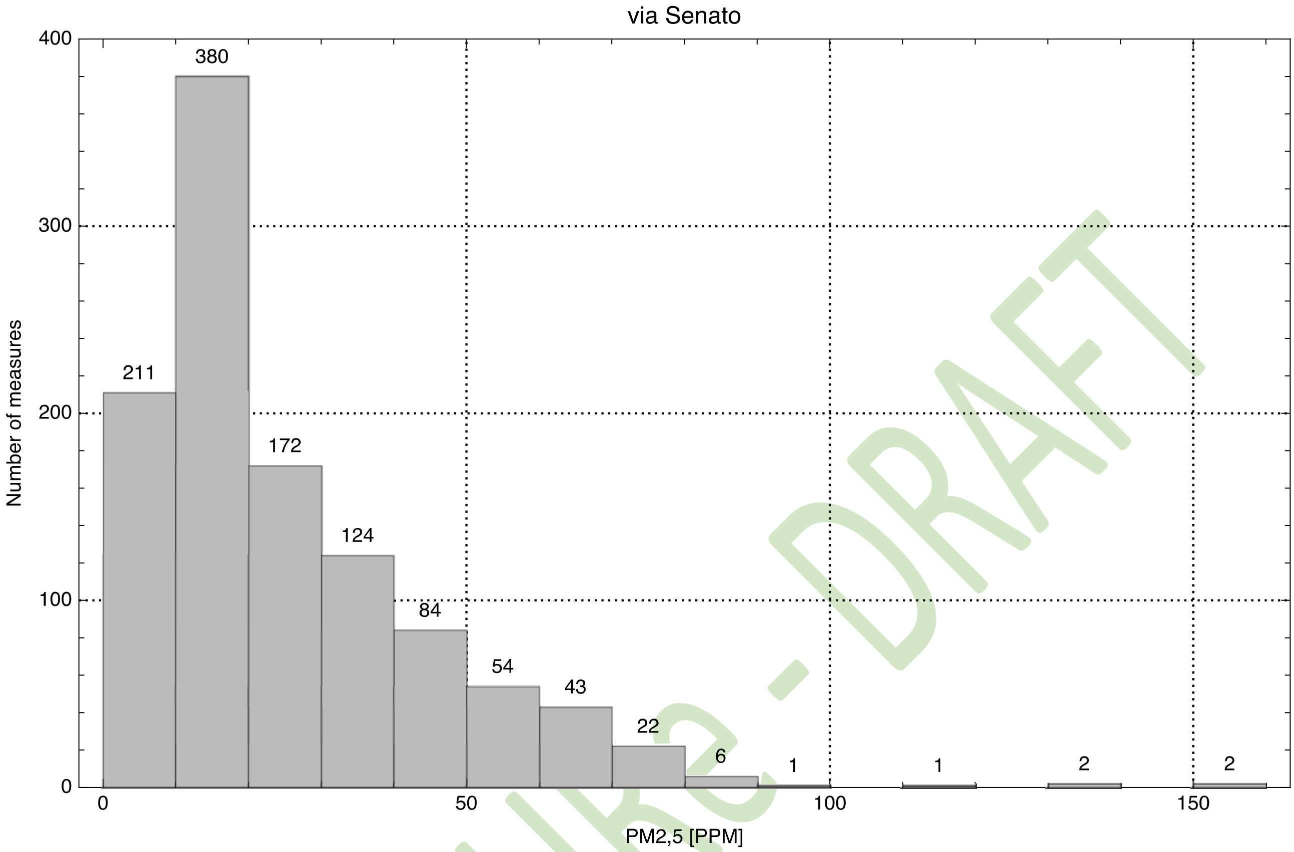

Figure 19: Number of PM2,5 measures for different PM2,5 values – via Senato

1.2 CO

The carbon monoxide is a colourless, odourless and inflammable gas, highly toxic that is produced in combustions with the scarce presence of air (ARPA Lombardia). The carbon monoxide mixes well with air, forming explosive atmospheres. It can react with oxygen, acetylene, chlorine, fluorine, nitrogen oxides. It is a predominantly primary pollutant, emitted directly from all processes of incomplete combustion of carbon compounds. The main anthropogenic sources are household, institutional and commercial activities and, in minor but consistent part, vehicular traffic (European Environment Agency 2019).
The same analyses presented before, have been accomplished for this pollutant, except for the counting each sensor detected a value over the allowed threshold of 10 mg/m³. Fortunately, the limit value in the period 2017-2020 has been exceeded in none of the active sensors Figure 20. ARPA AQ stations measuring the concentration of this pollutant are via Senato, viale Marche and viale Toscana Figure 21, Figure 22, Figure 23.

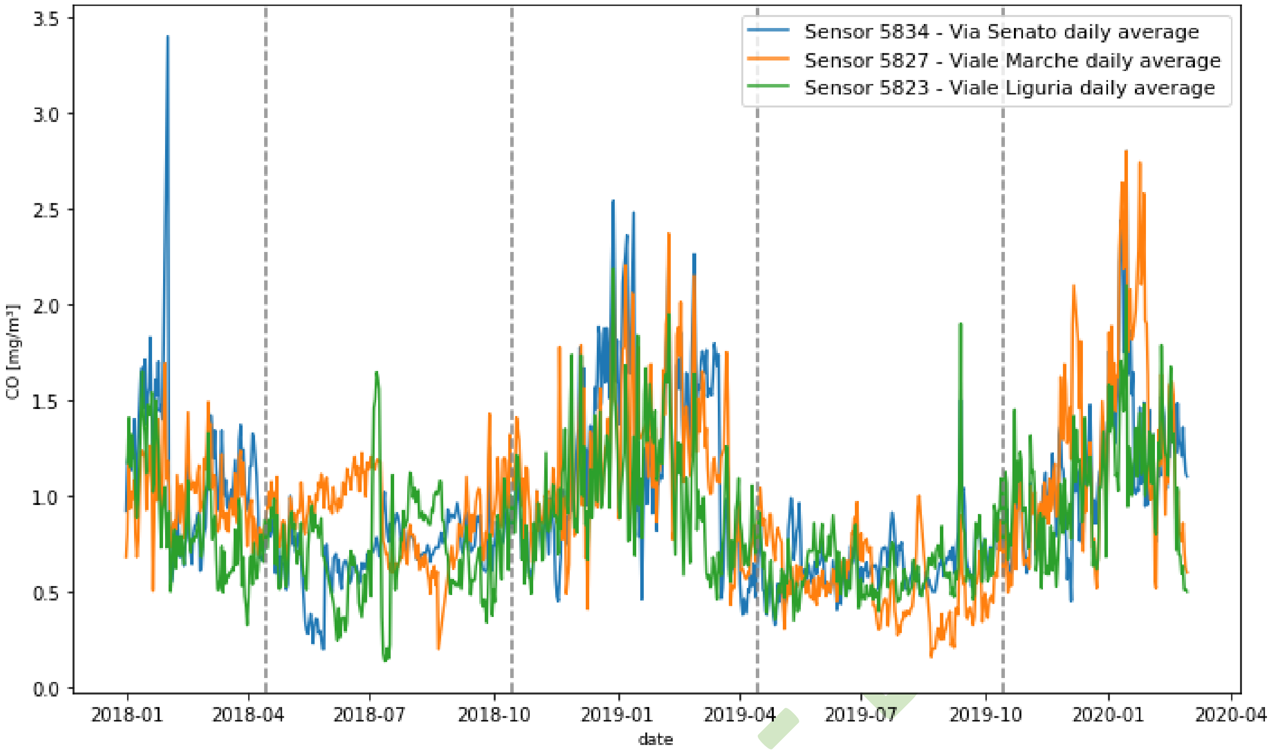

Figure 20: CO detected by the active sensors (simultaneously detected)

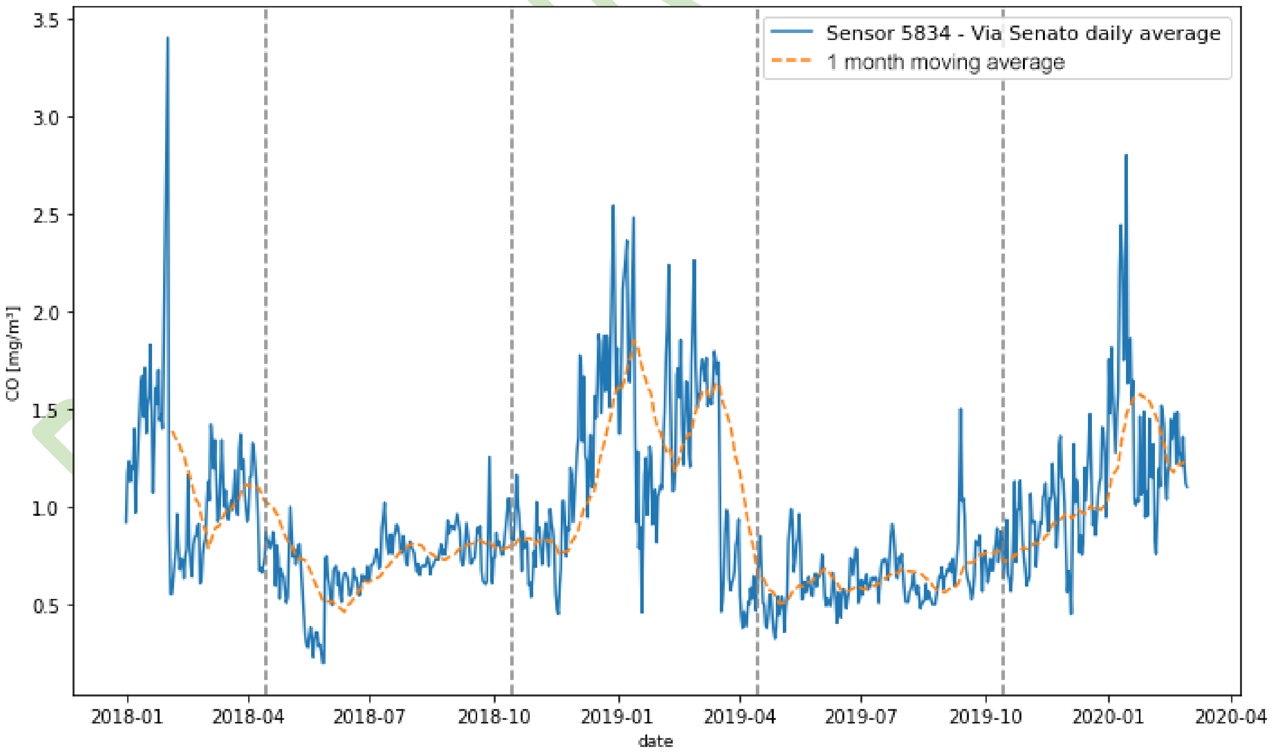

Figure 21:CO detected by Via Senato AQ station.

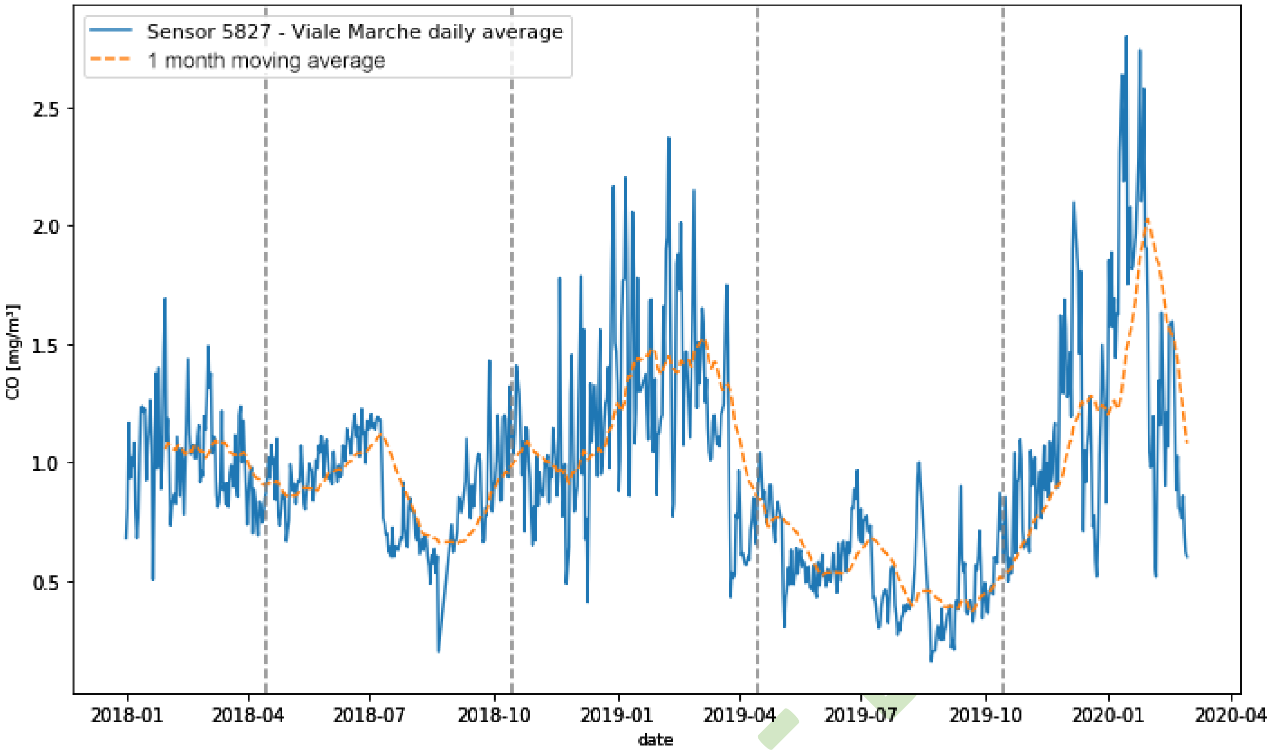

Figure 22: CO detected by Viale Marche AQ station.

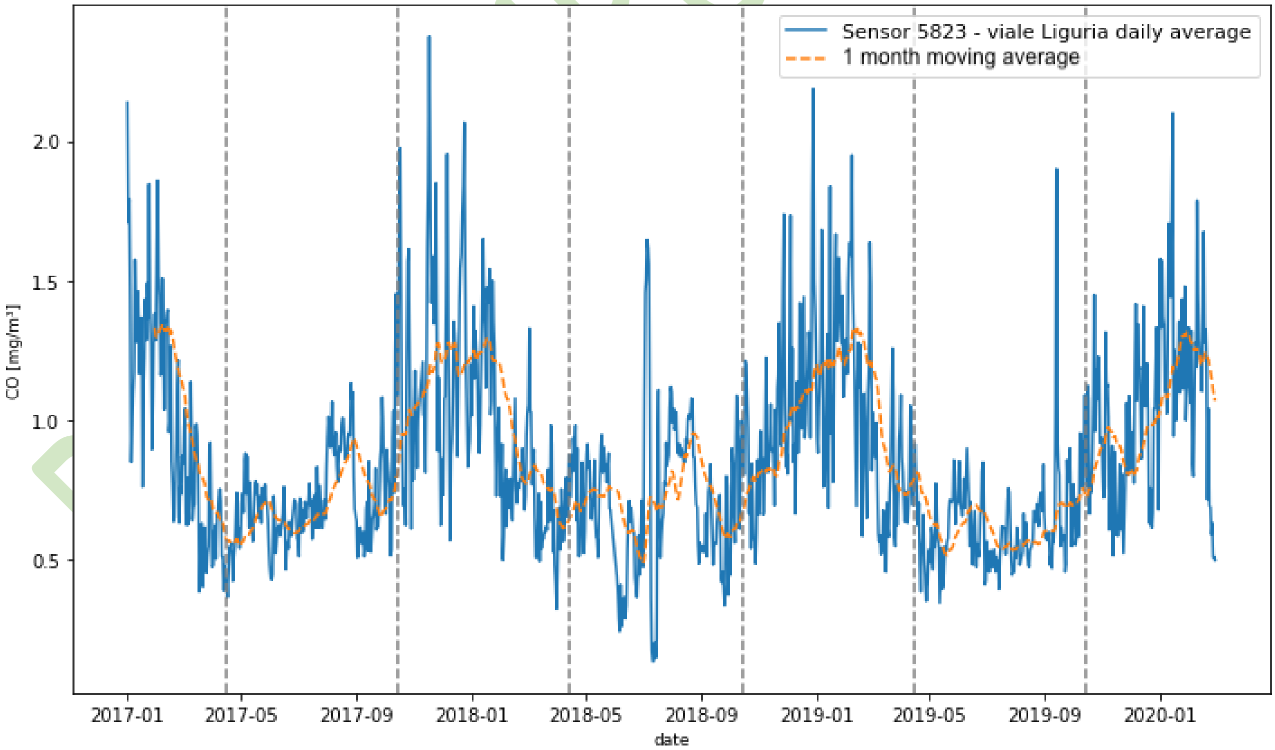

Figure 23: CO detected by viale Liguria AQ station.

The following analysis concerns the classification of the detected values for each AQ station and the counting of the number of measures for each class. The most part of the values are below 2 mg/m^3, a value way below the allowed threshold of 10 mg/m^3. However, a different distribution in classes of the measured values is registered the three active sensors. This is likely to be due to their location: the viale Marche sensor is located in an area where every day the intense road traffic is registered. The same can be stated for the viale Liguria sensors. This may motivate the higher CO concentration values for the viale Marche and viale Liguria AQ station, compared to the values registered by the via Senato sensors.

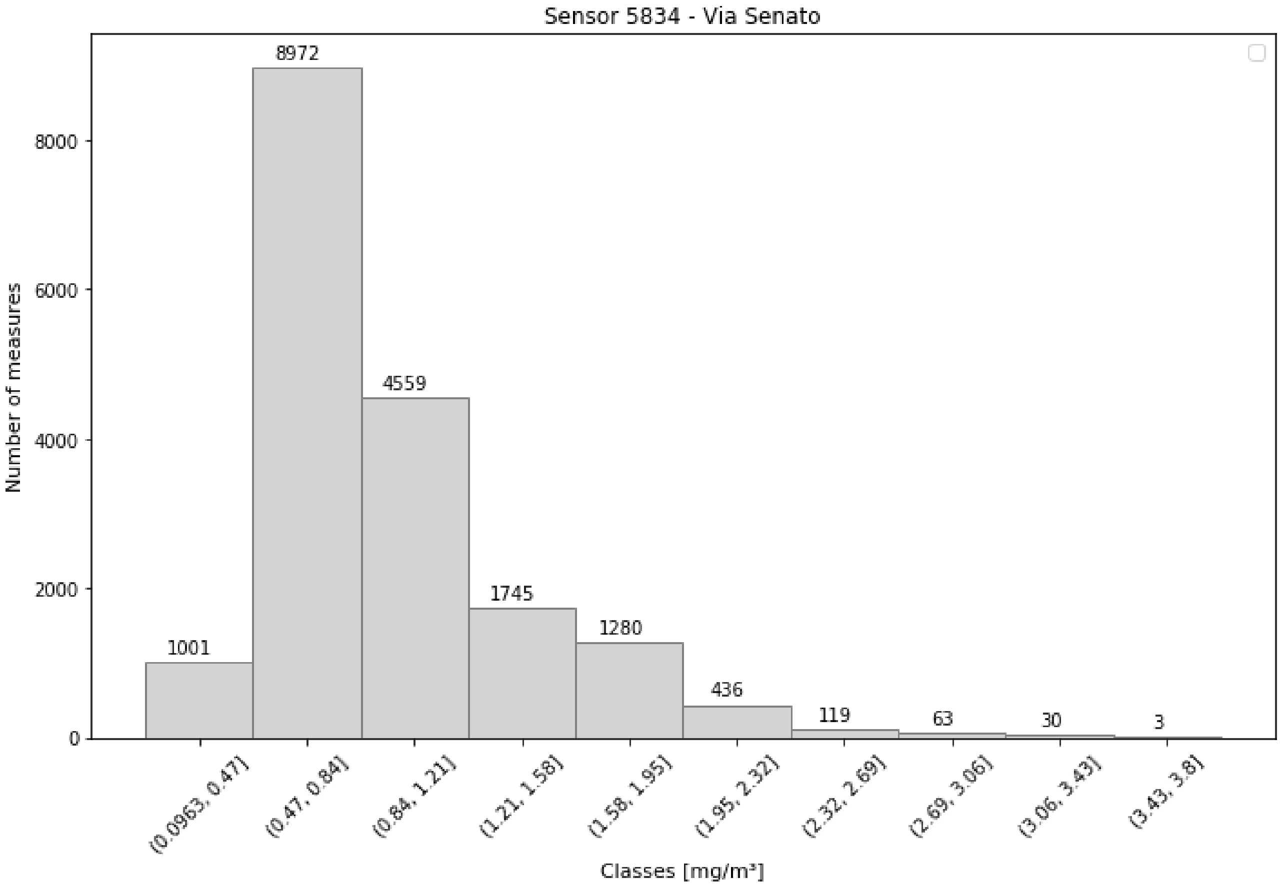

Figure 24: Number of CO measures for different classes of CO values – via Senato.

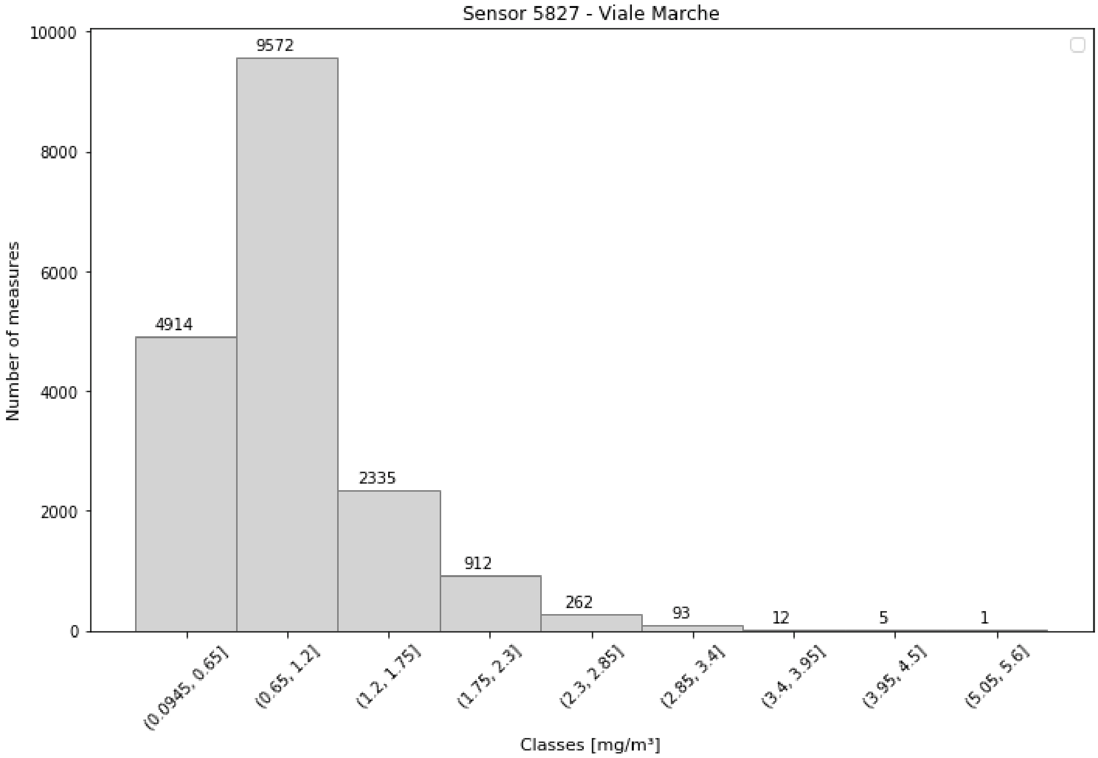

Figure 25: Number of CO measures for different CO values – viale Marche

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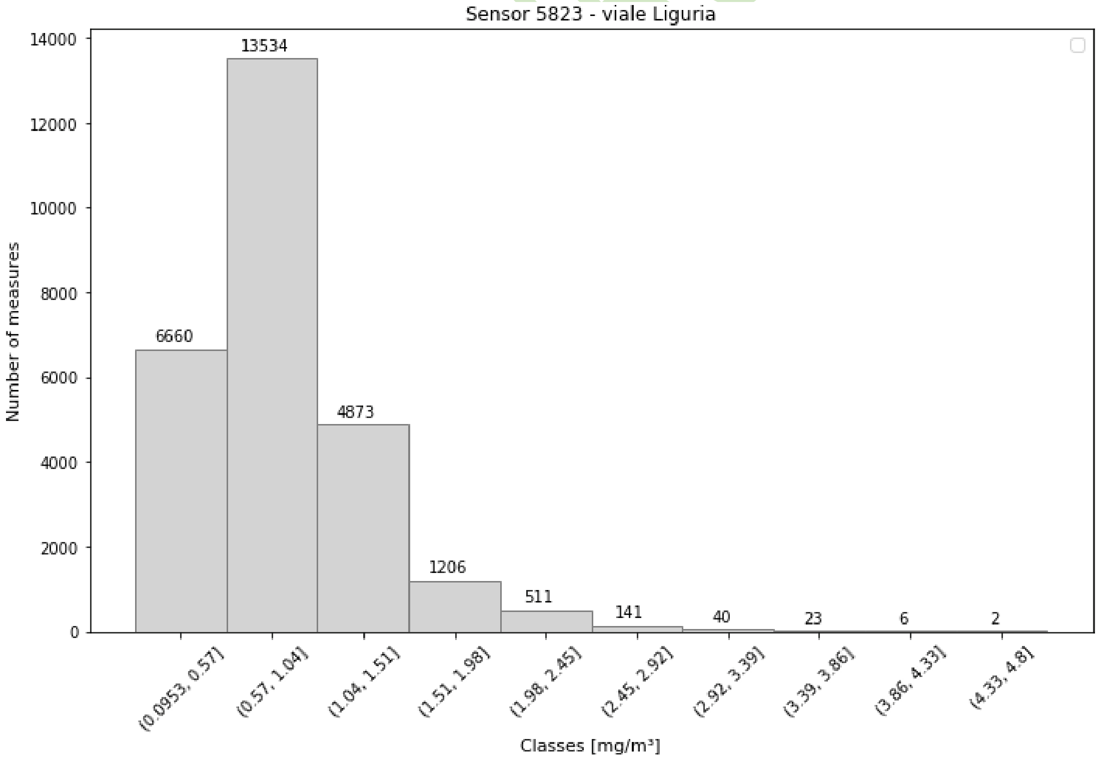


Figure 26: Number of CO measures for different CO values – Viale Liguria.

1.3 SO_2

The analyses on the SO_2 have been carried out for the historical series 2017-2020, only on data registered by the pascal Città Studi sensor, the only data available on the Regione Lombardia Open Data portal. Other 4 SO_2 sensors are located in the via Senato, via Verziere, viale Marche, viale Liguria and Piazza Zavattari AQ stations. Unfortunately, for these sensors data are unavailable.

"Sulphur dioxide reacts violently with ammonia and amines, acetylene, alkali metals, chlorine, ethylene oxide and in the presence of water or water vapour can attack many metals, including aluminium, iron, steel, brass, copper and nickel. Liquefied, it can corrode plastics and rubber. The SO_2 presence in the atmosphere is mainly due to the combustion of fossil fuels (coal and petroleum derivatives) in which sulphur is present as an impurity. In nature it is mainly produced by volcanic activity while the main human sources are heating and energy production plants fuelled by diesel, coal and fuel oils" (ARPA Lombardia).

For the only sensor considered for the analyses, the daily limit of 125 µg/m³, has never been exceeded. Moreover, registered values are largely under the allowed limit: the maximum level in the considered period is 12.9 µg/m³.

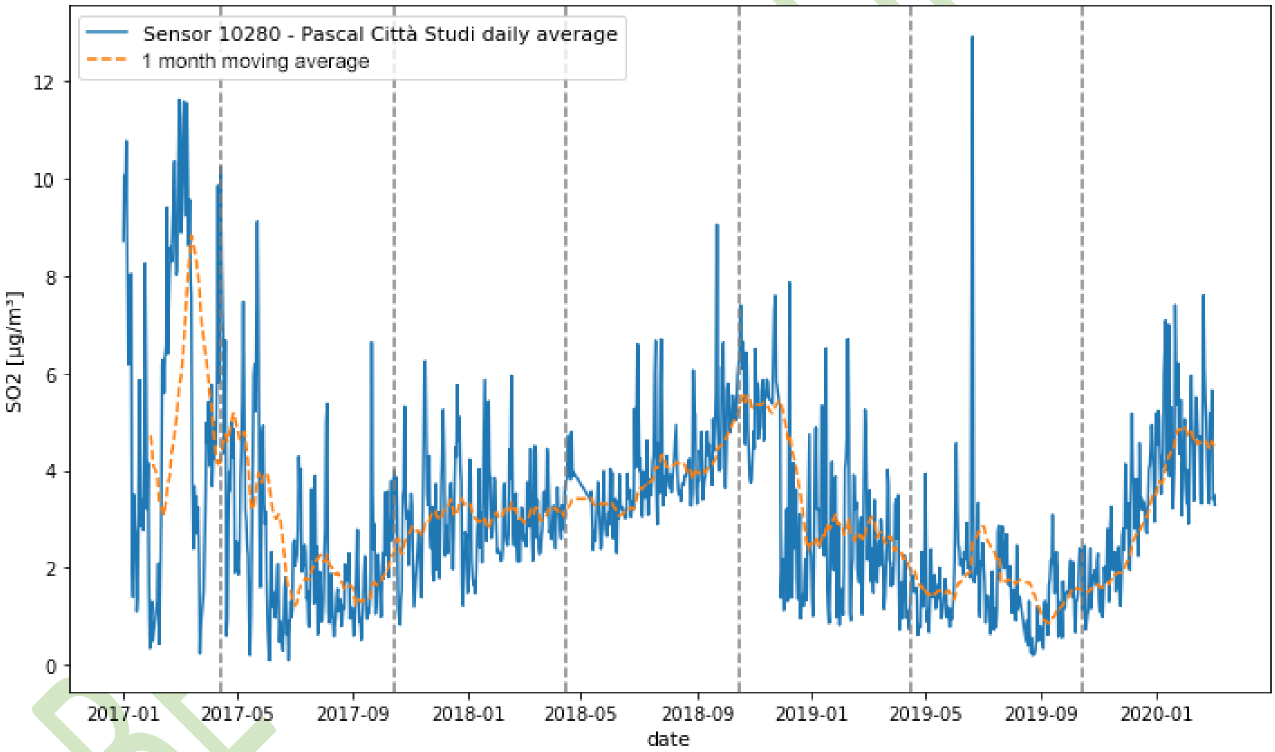


Figure 27: SO2 detected by Pascal Città Studi AQ station.

The further step in of the analysis concerns the subdivision in classes, as already seen for other pollutants and the counting of the number of detected measures, whose values are comprehended in the defined classes Figure 28. The chart demonstrates that the most part of the detected values are comprehended in the classes below 5.11, as a further confirmation of the low values registered for this pollutant, overall.

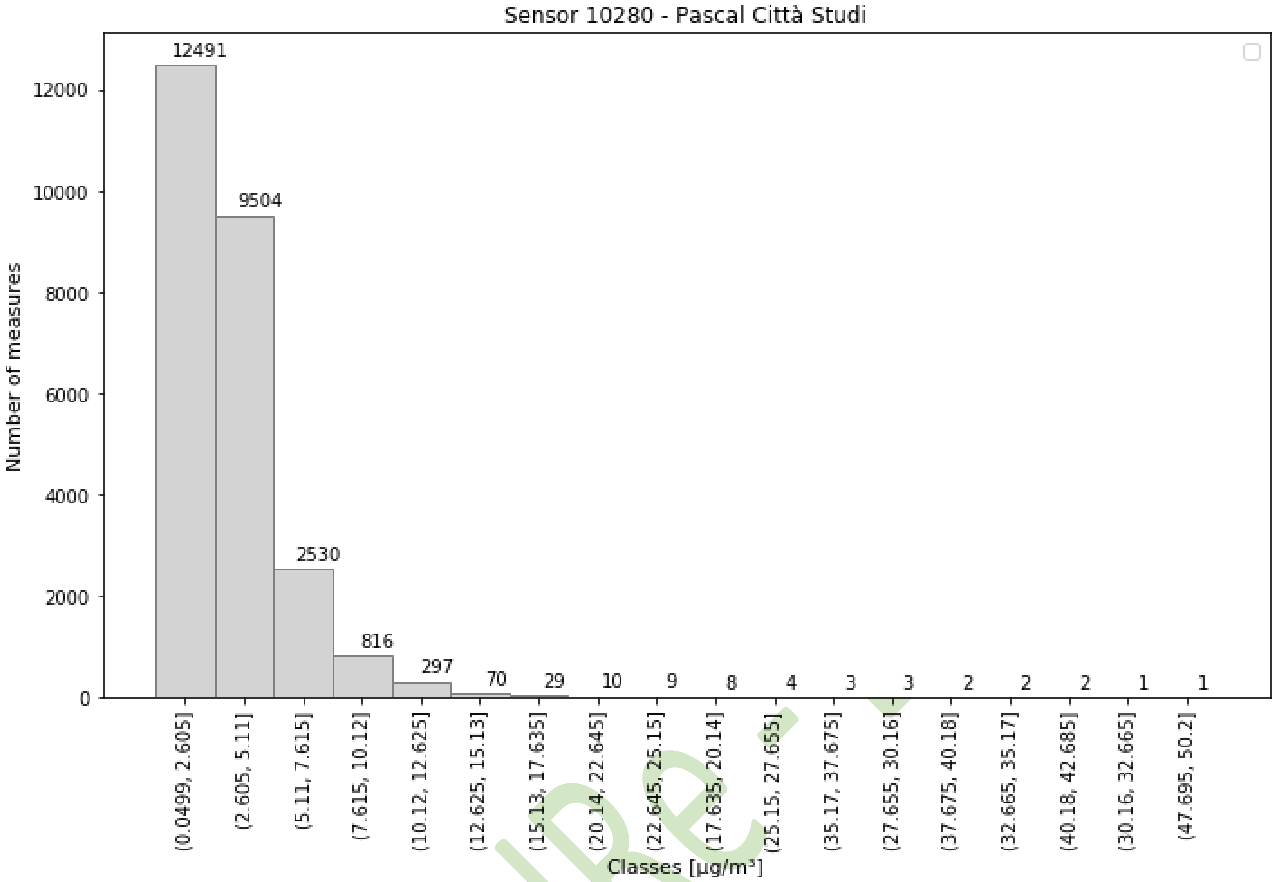


Figure 28: Number of SO2 measures for different SO2 values – Pascal Città Studi.

1.4 O3

As for the previous pollutants, also for the Ozone (O_3) sensors detecting valid measures are few. Out of the 6 sensors detecting O3 in Milan, data are available for only 2 of them: the ones installed in the via Verziere and Pascal Città Studi AQ stations.

Ozone is an oxidizer with many industrial applications. In nature, more than 90% of it is found in the stratosphere (10 to 50 km in height), where it operates as a protective barrier against UV sun radiation. In the troposphere (from the ground up to about 12 km) the ozone is formed as a result of chemical reactions between nitrogen oxides and volatile organic compounds, favoured by high temperatures and strong solar radiation. It is, therefore, a secondary pollutant whose precursors are generally produced by civil and industrial combustion and by processes that use or produce volatile chemical substances, such as solvents and fuels. Together with other compounds it constitutes the typical summer pollution called photochemical smog. (ARPA Lombardia). This is the reason why Figure 29, Figure 30 and Figure 31 show clearly a seasonal trend increasing during the hottest months. Among the considered pollutants this is the one showing a countertendency contributing to the decreasing of the AQ during the summer season. Fortunately, also in this case, the concentration registered by the 2 AQ stations has never exceeded the target threshold of 120μg/m^3

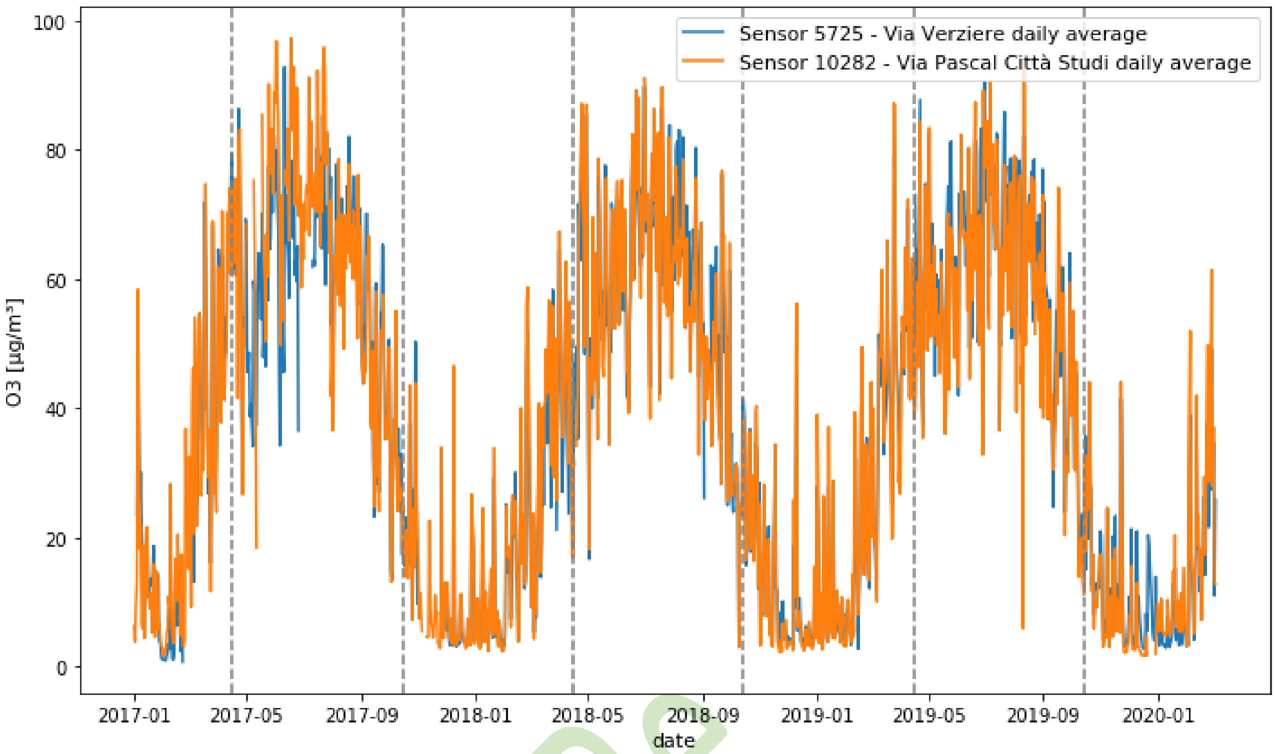


Figure 29: O3 daily average detected by working sensors

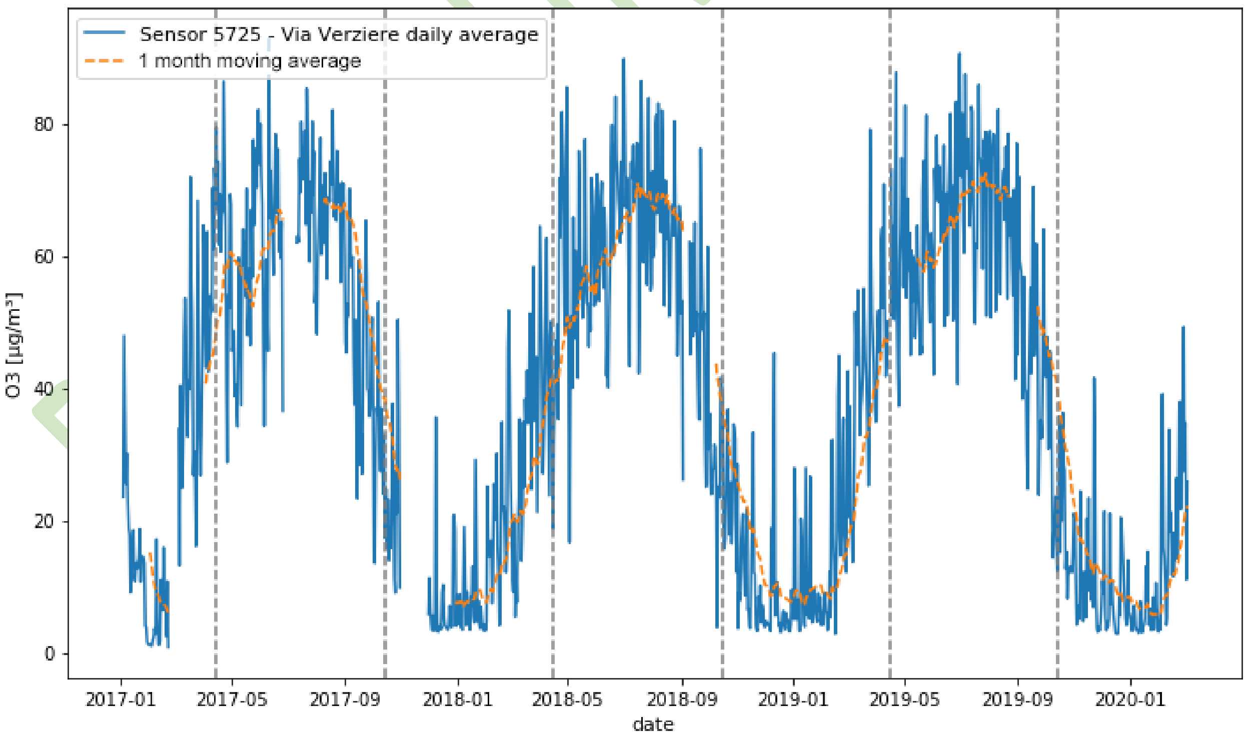


Figure 30: O3 detected by via Verziere AQ station.

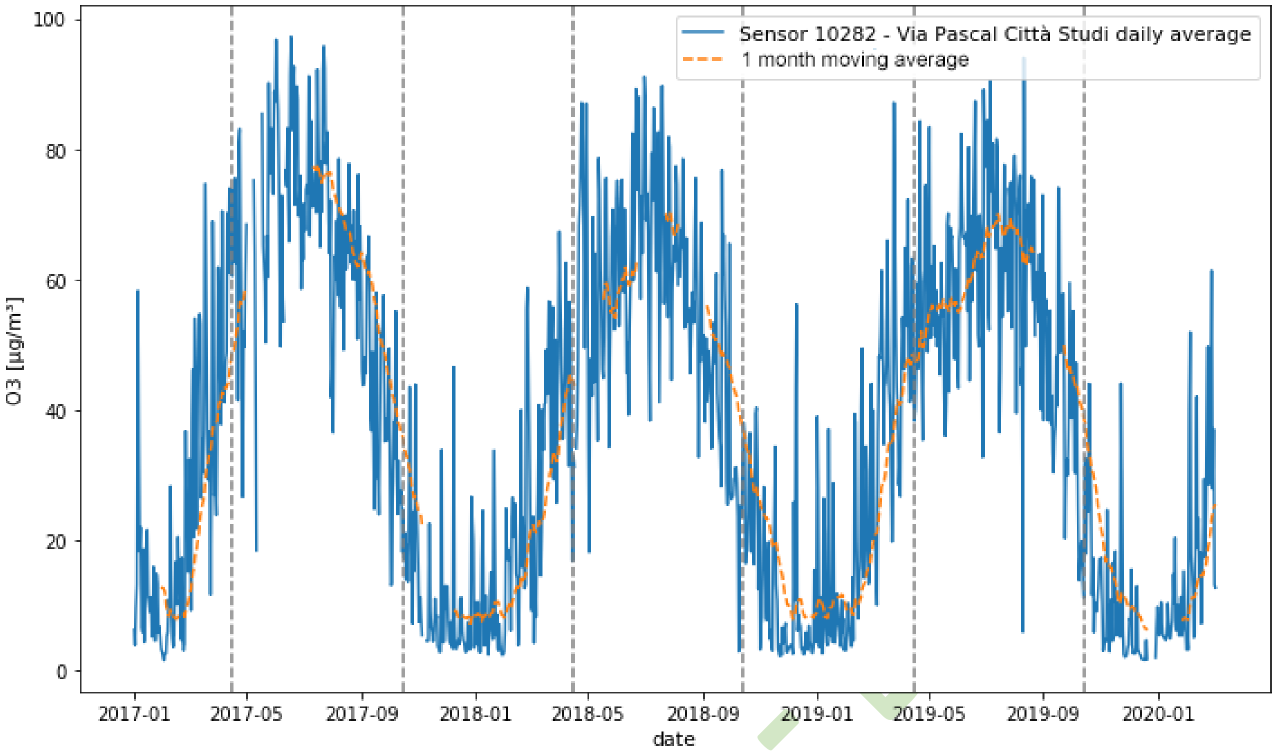


Figure 31: O3 detected by via Pascal Città Studi AQ station.

The analysis by classes (Figure 32 and Figure 33) confirms that in the most of the cases, the values detected are within the lowest class 10.53 for the via Verziere AQ station and below 10.08 for the Pascal Città Studi station. The remaining 9 classes for both the AQ stations show a quasi-flat distribution of values, showing a homogeneous distribution detections values over the whole range of values.

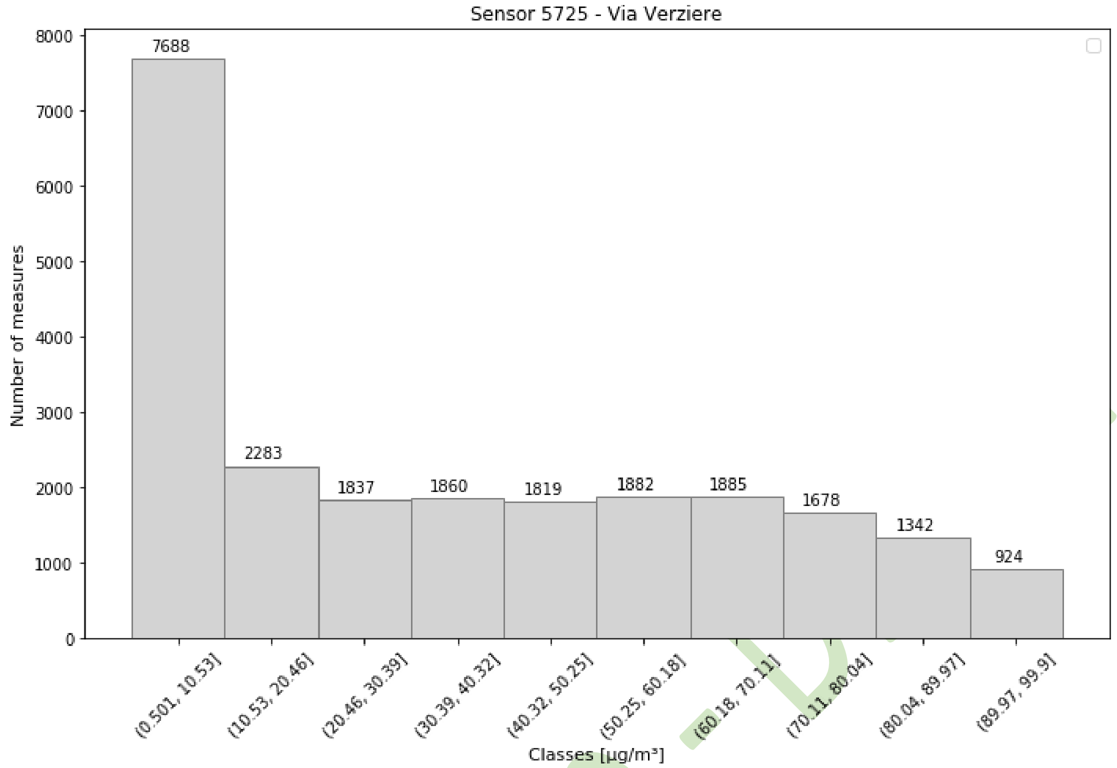


Figure 32: Number of O3 measures for different O3 values – via Verziere.

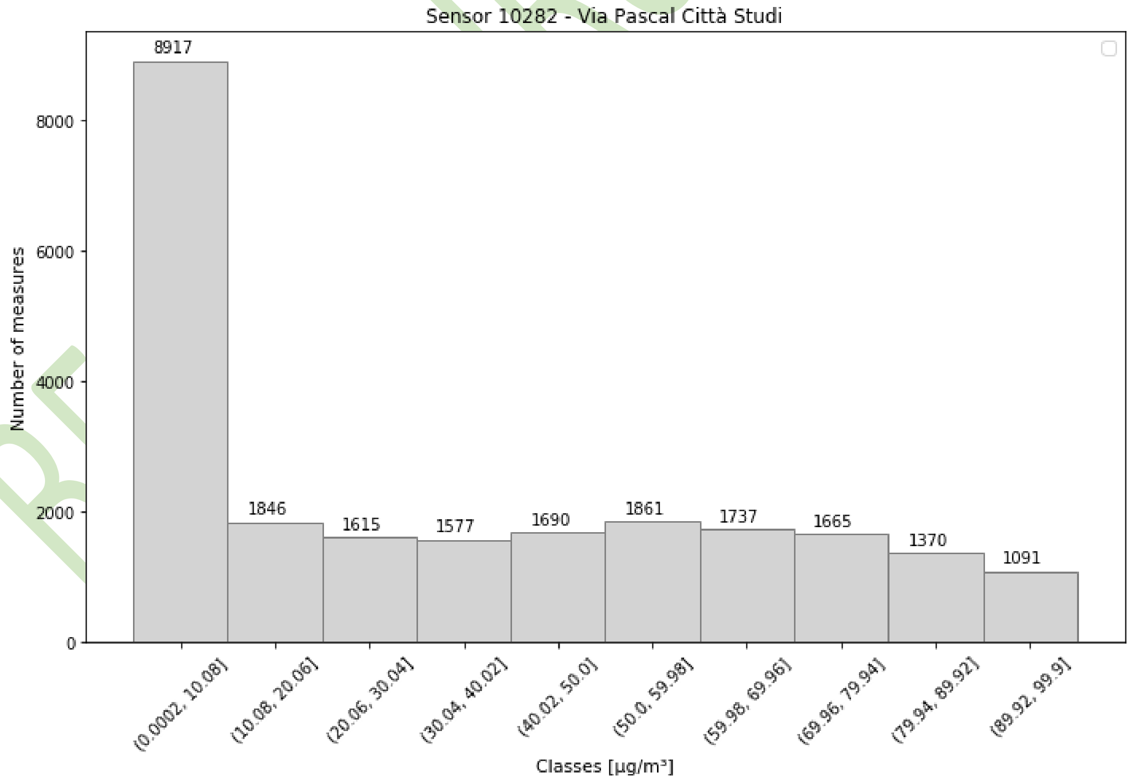


Figure 33: Number of O3 measures for different O3 values – via Pascal Città Studi.

1.5 NOx

The oxides of nitrogen (NOx) are determined by measuring the concentration of nitrogen monoxide (NO) and nitrogen dioxide (NO_2). The former, as is well known, is mainly produced by combustion engines in cars and trucks. NO_2, on the other hand, is produced by the oxidation of the monoxide with the oxygen in the atmosphere. It is therefore evident, and known in the literature, that NOx in cities like Milan is caused by traffic.

In Milano, ARPA owns 9 NOx sensors but only six of them have been collecting valid data since 2017. Moreover, as it can be seen in Figure 34, over the last two years there are many gaps in the NOx measures.

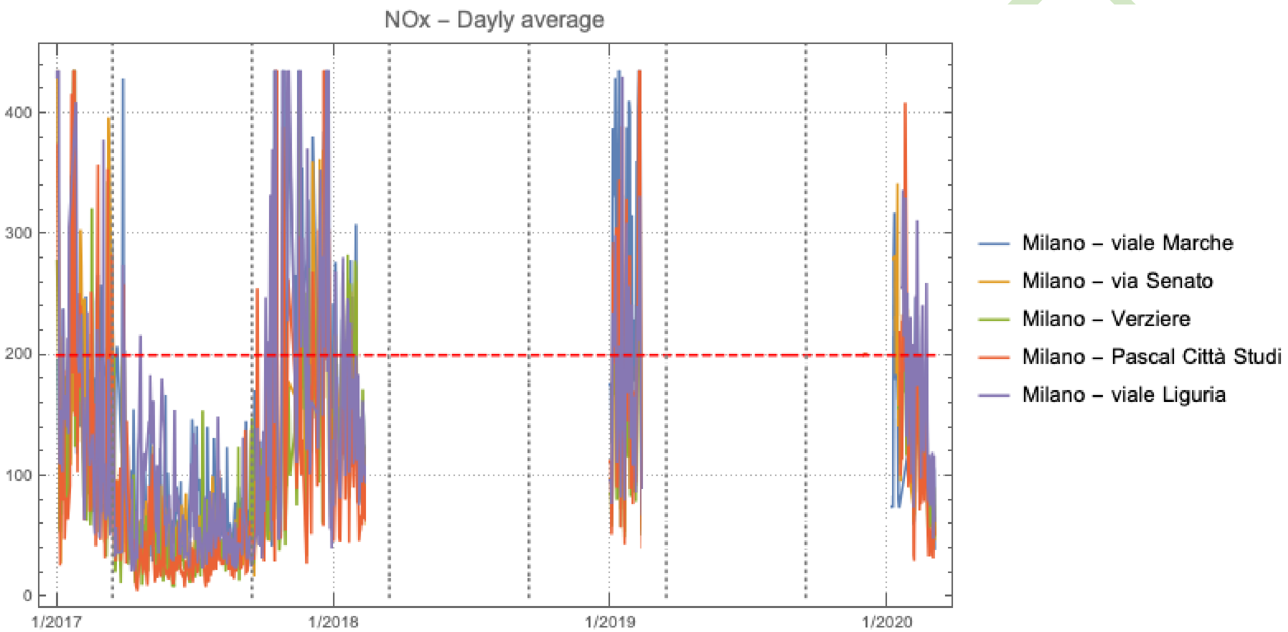


Figure 34: NOx daily average for the 5 AQ stations in Milano

In Figure 34, Figure 35, Figure 36, Figure 37, Figure 38 and Figure 39 the horizontal dashed red line is the threshold for the daily average on NOx (ARPA Lombardia) and the vertical dashed grey lines are the bounds of the heating period in Milano. Although there is a strong correlation between traffic and NOx concentration, it seems that during the heating period, i.e. in winter, there are higher peaks of NOx. Noteworthy, during the winter period cars are preferred as a transport system to other less polluting systems.

Although the data aren't complete, some considerations on the NOx concentration can still be done. The correlation between NOx and traffic is proved by the fact that the sensor registering the highest values (Figure 40) is the one in viale Marche, one of the most congested areas in Milano.

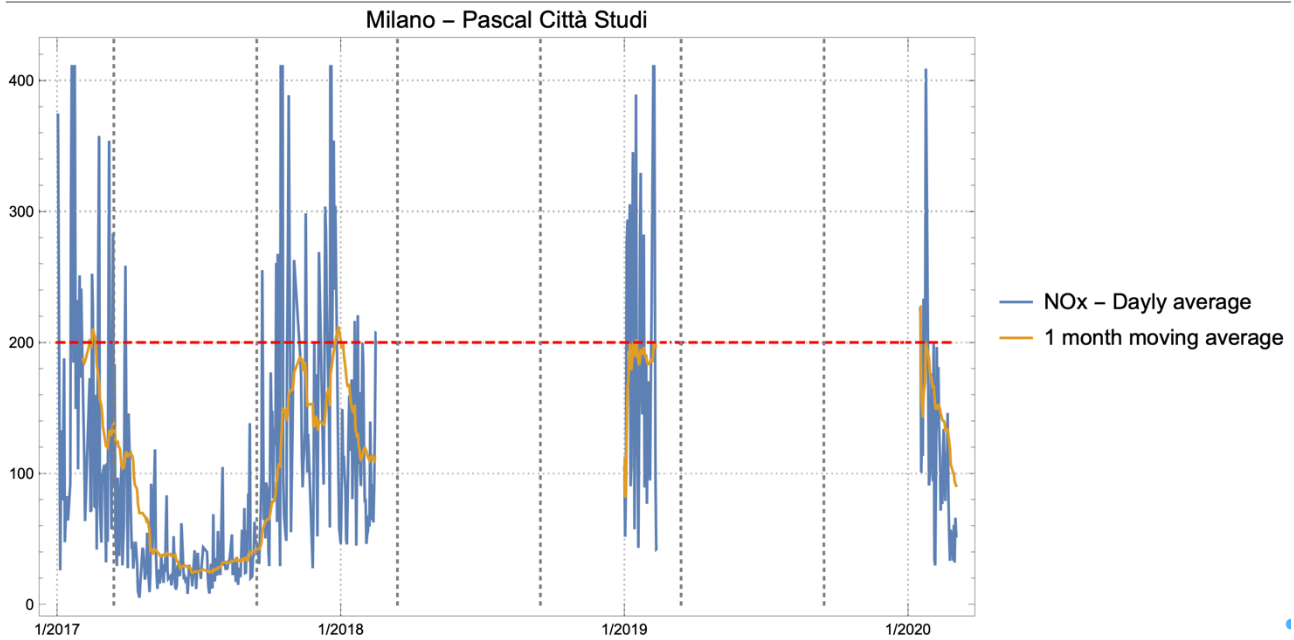


Figure 35: NOx daily (blue) and monthly (orange) average for the Pascal Città Studi AQ station.

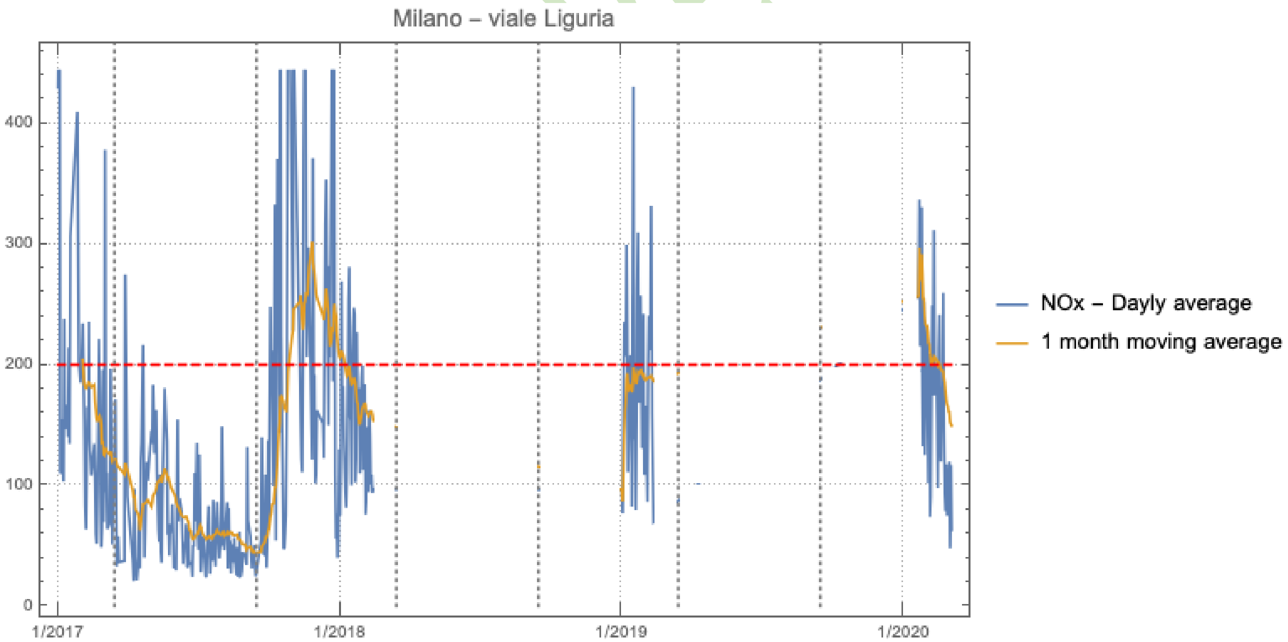


Figure 36: NOx daily (blue) and monthly (orange) average for the viale Liguria AQ station.

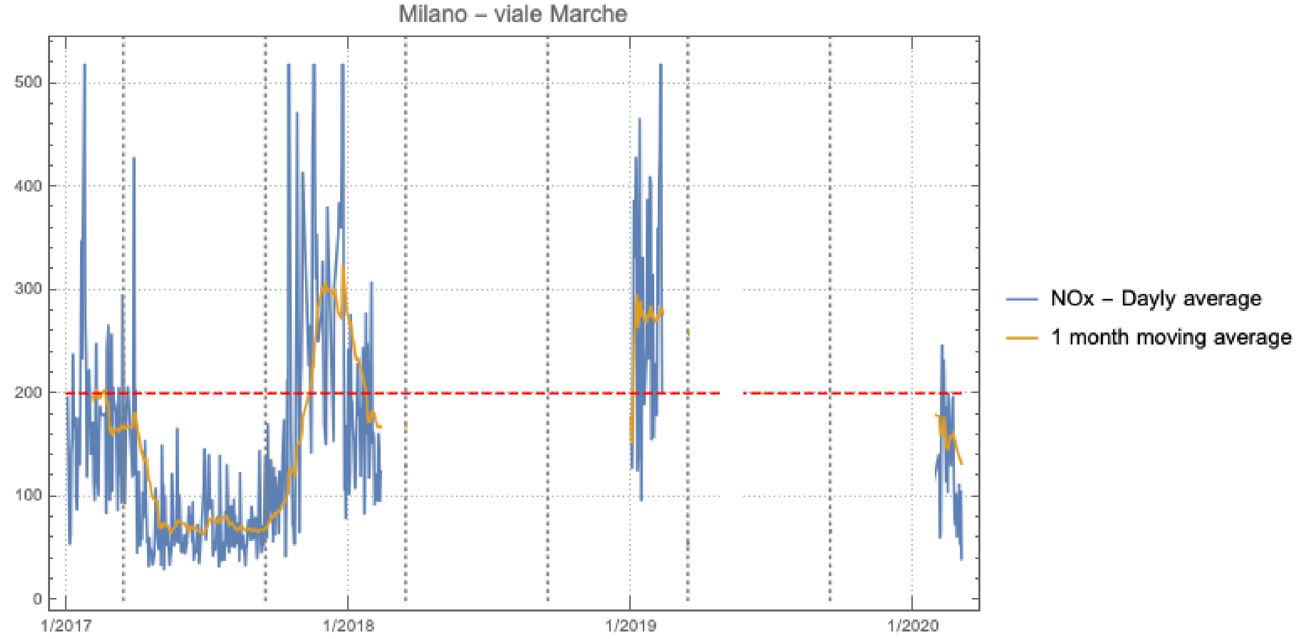


Figure 37: NOx daily (blue) and monthly (orange) average for the viale Marche AQ station.

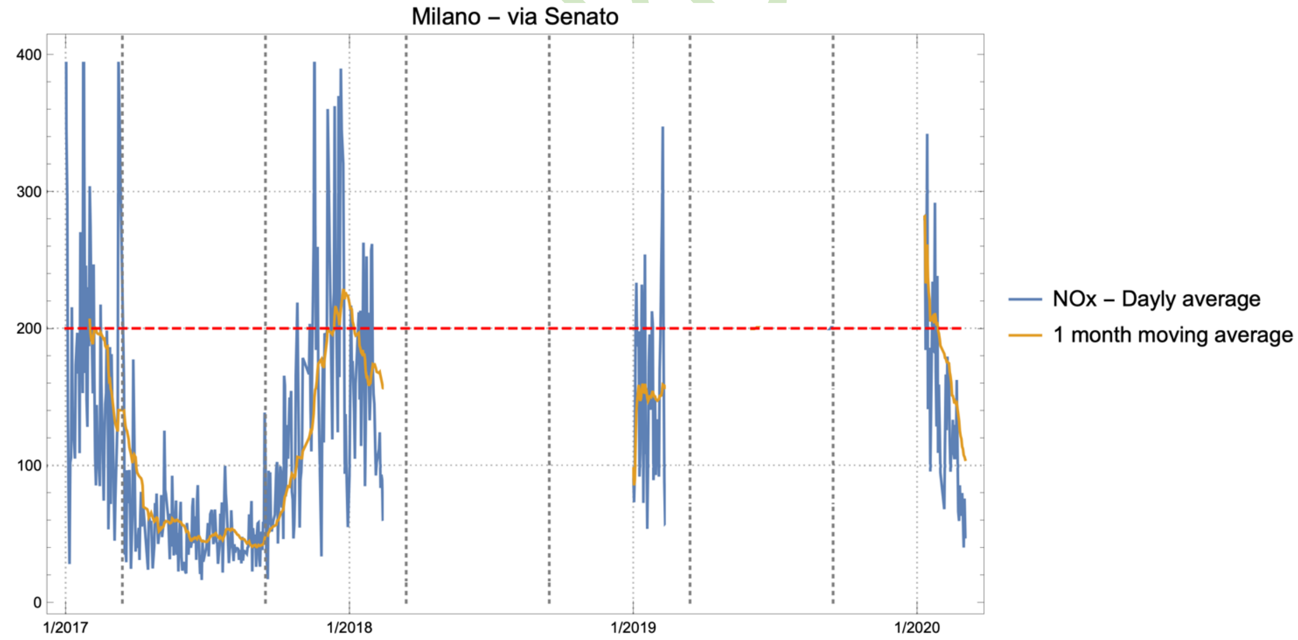


Figure 38: NOx daily (blue) and monthly (orange) average for the via Senato AQ station.

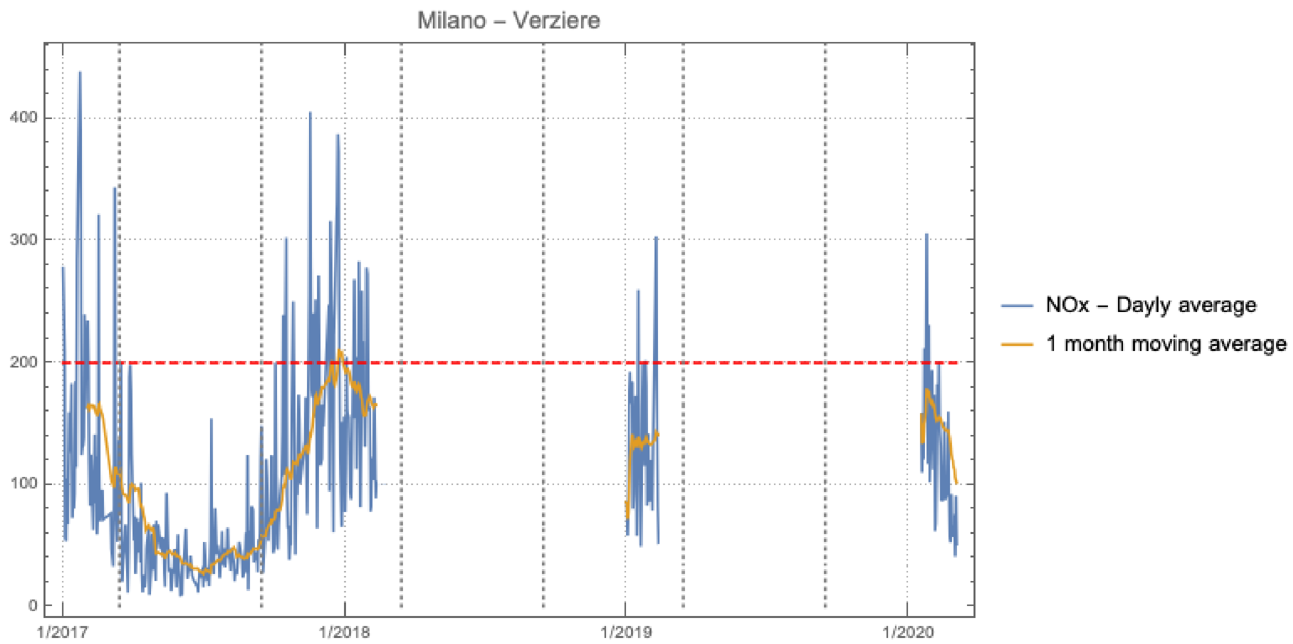
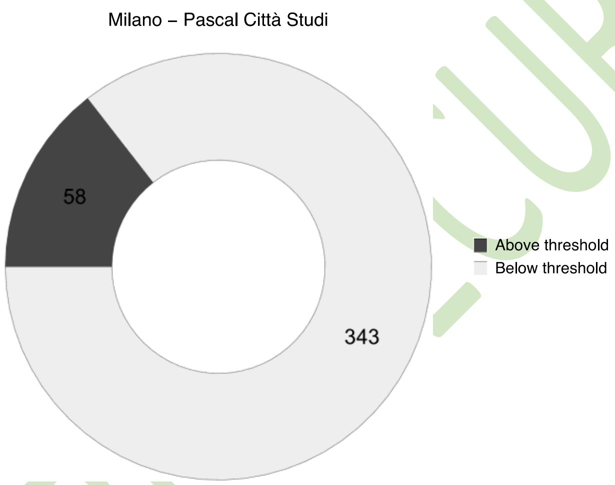
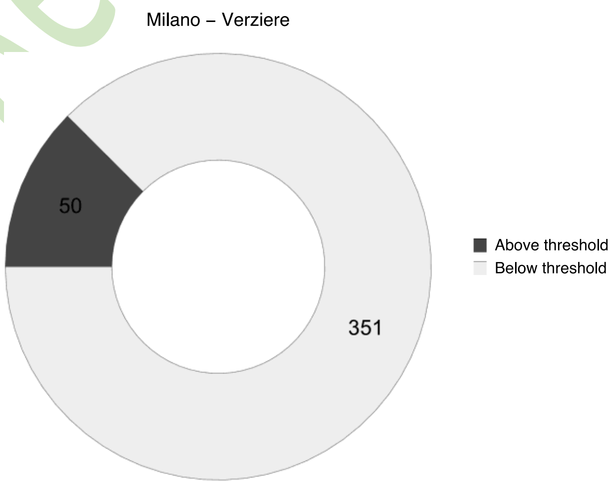


Figure 39: NOx daily (blue) and monthly (orange) average for the via Verziere AQ station.





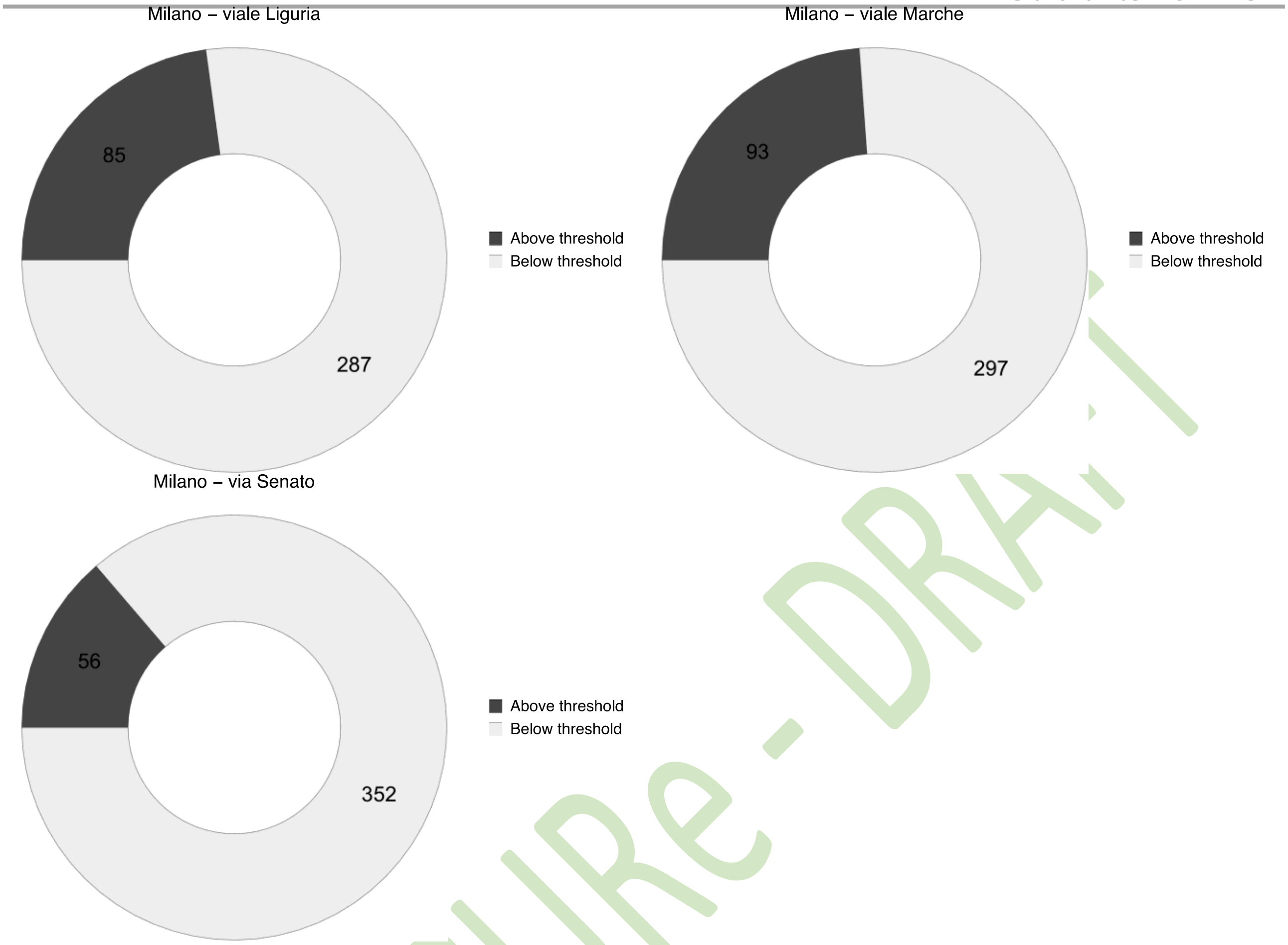


Figure 40: Number of days in which the NOx average is above the threshold stated in Law?????

This is also shown in Figure 41 where it can be seen that the sensor in viale Marche measures the maximum NOx concentration for 102 days, almost 160% more than the second most polluted sensor, the one in viale Liguria.

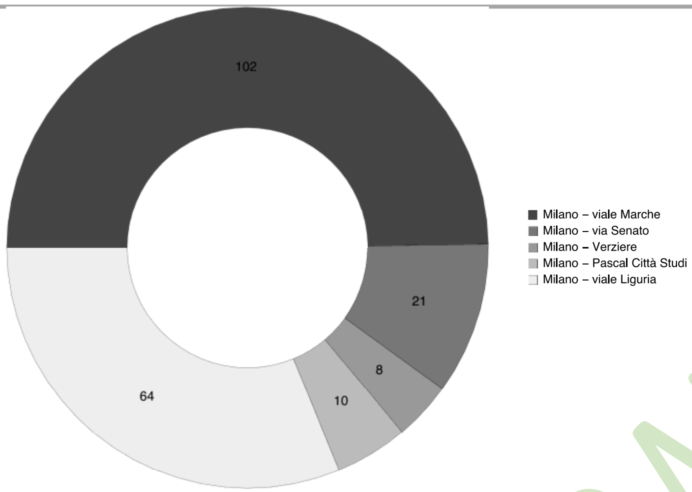


Figure 41: Number of times one sensor measures the maximum daily average value

Also for this pollutant the analyses by classes have been done. fortunately for all the 5 sensors analyses the values are often below the allowed threshold equal to 200µg/m^3. The distribution of the values in classes is reported in Figure 42, Figure 43, Figure 44 and Figure 45 and Figure 46. However, these analyses may be biased by the many missing in the historical series of the 5 AQ stations.

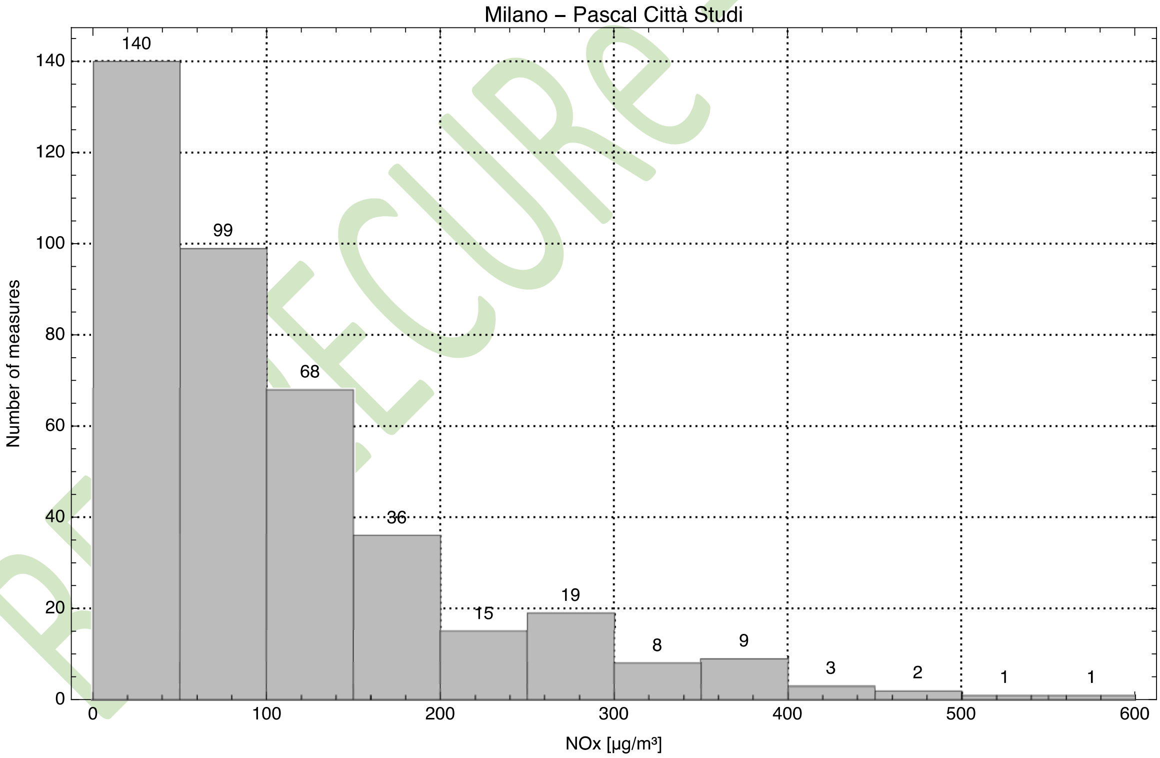


Figure 42: Analysis by classes of detected values. The sensor installed in Pascal Città Studi AQ station

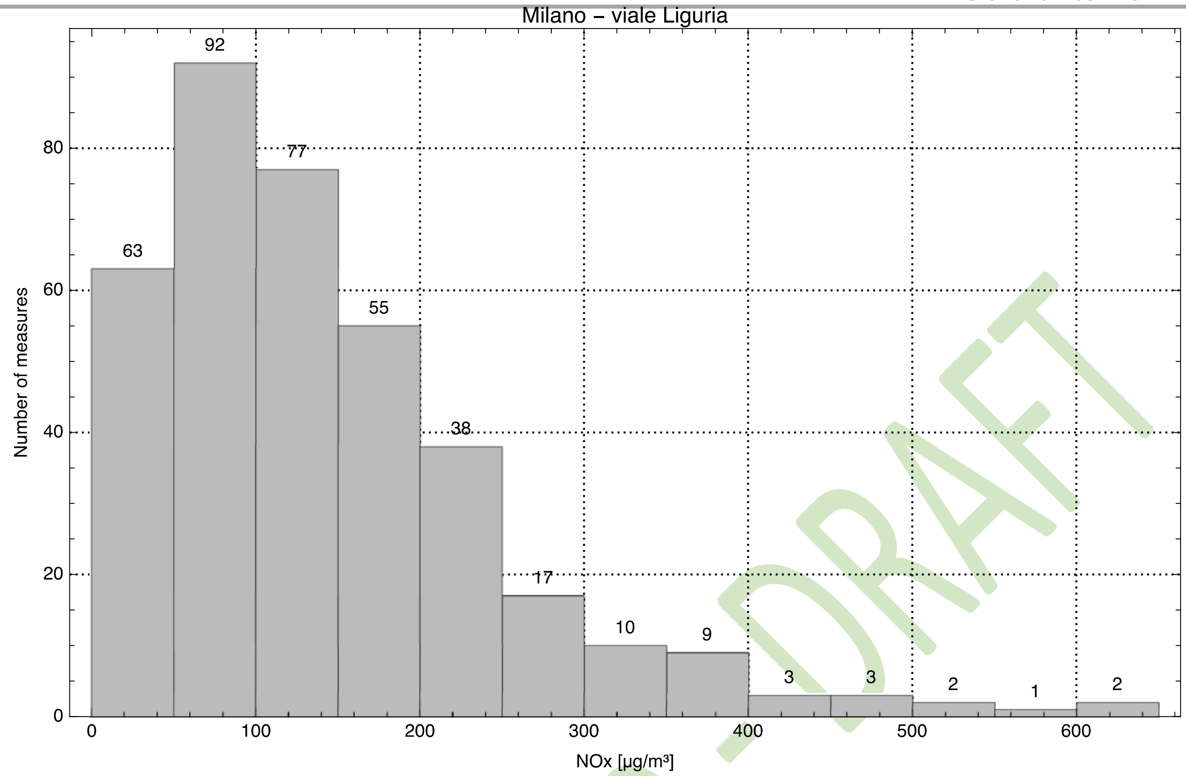


Figure 43: Analysis by classes of detected values. The sensor installed in viale Liguria AQ station.

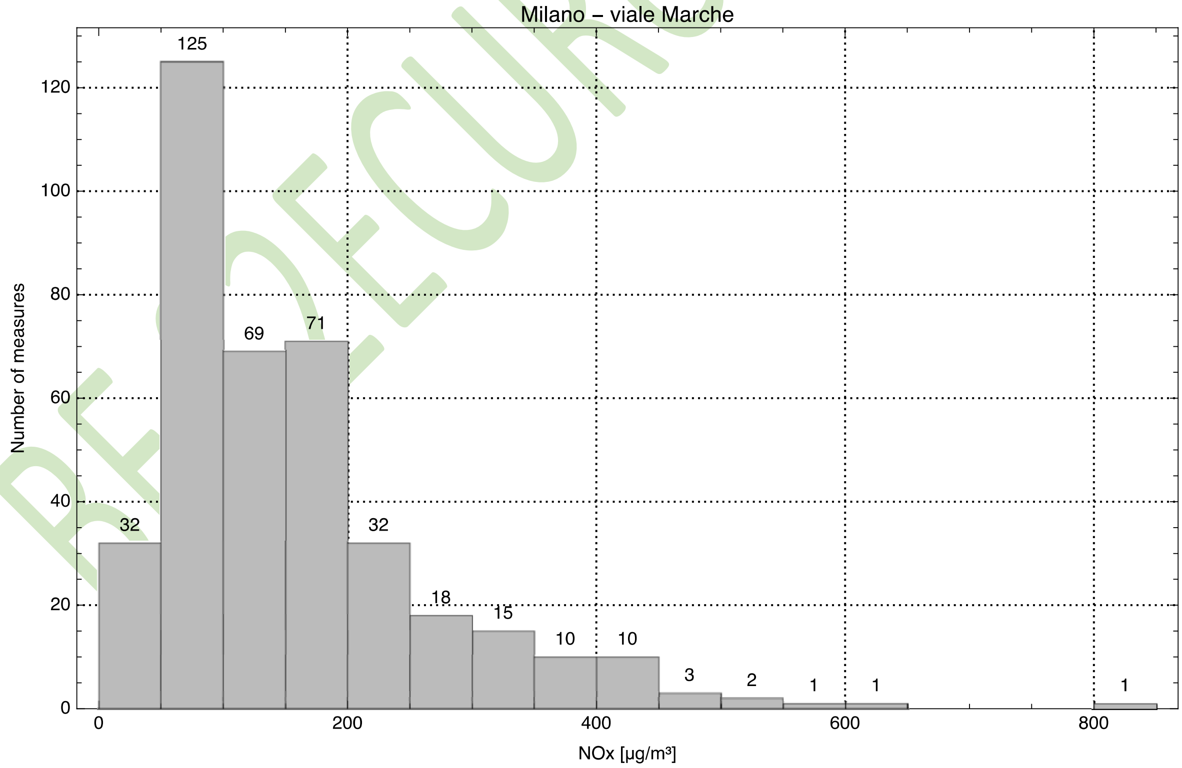


Figure 44: Analysis by classes of detected values. The sensor installed in viale Marche AQ station.

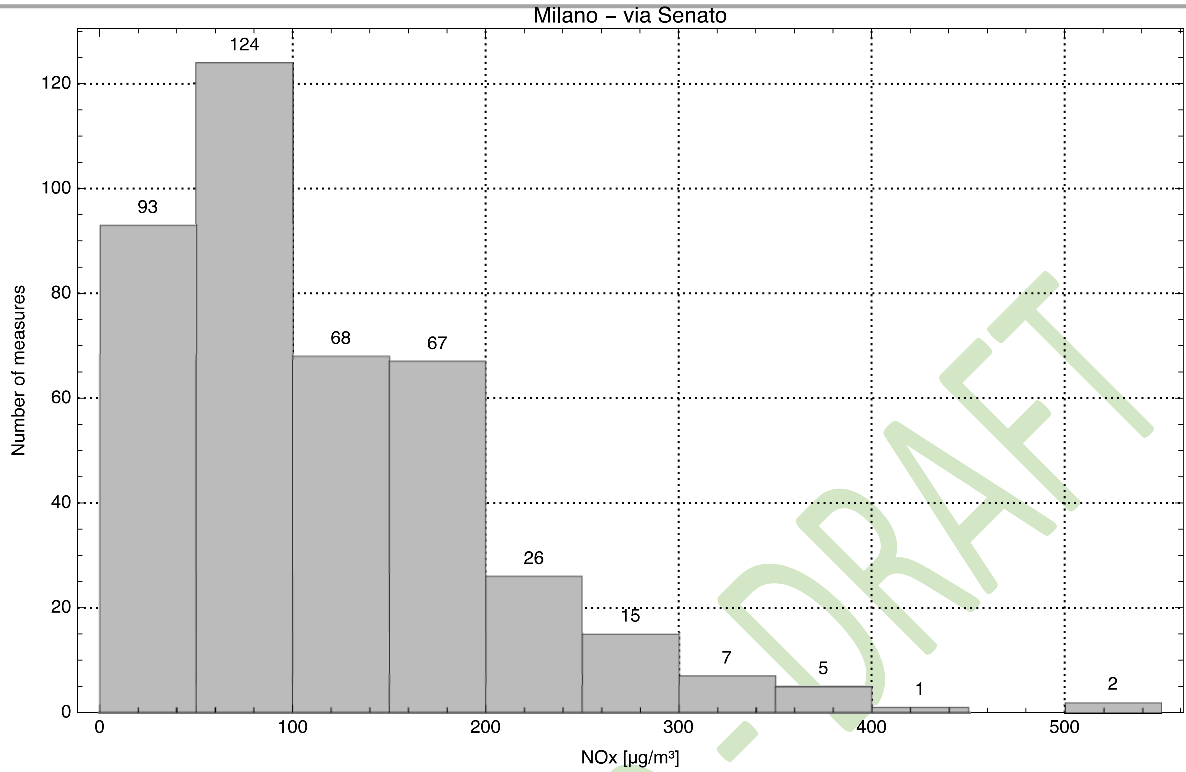


Figure 45: Analysis by classes of detected values. The sensor installed in via Senato AQ station.

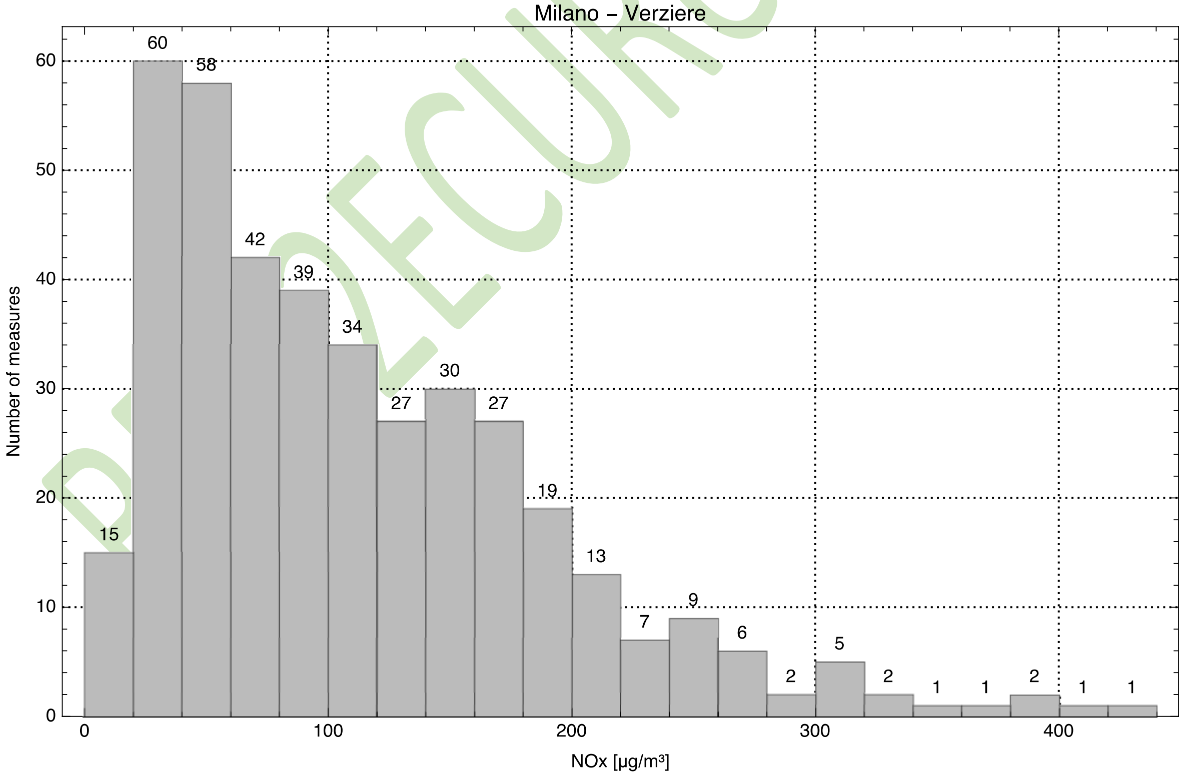


Figure 46: Analysis by classes of detected values. The sensor installed in via Verziere AQ station.

1.6 Black Carbon

Black carbon (BC) is defined as the set of carbon particles capable of absorbing light with a characteristic wavelength in the visible spectrum (380÷760 nm).

Current legislation does not provide for limits for these pollutants. The BC is a primary pollutant emitted during the incomplete combustion of fossil fuels and biomass and can be emitted from natural and anthropic sources as soot. In urban areas it can be taken as a tracer of emissions from internal combustion engines and the wide range of chemical species (and various toxicity) transported by it (ARPA Lombardia). The exposition to the BC in the short and long term is associated with a set of effects on the health and in particular on the respiratory and the cardiovascular system.

Data in this pollutant have been downloaded and analysed according to the steps described also for other types of pollutants and the results are summarised in the Figure 47, Figure 48, Figure 49, Figure 50 and Figure 51. As stated before a limit threshold for this pollutant has not been defined, therefore, there are presented the historical series and the analysis by a class of values.

For the analysed period, as for other pollutants, whose production is related to the employment of fossil fuels, the BC concentration increases during the cold months and remarkably decreases during summer.

Data on

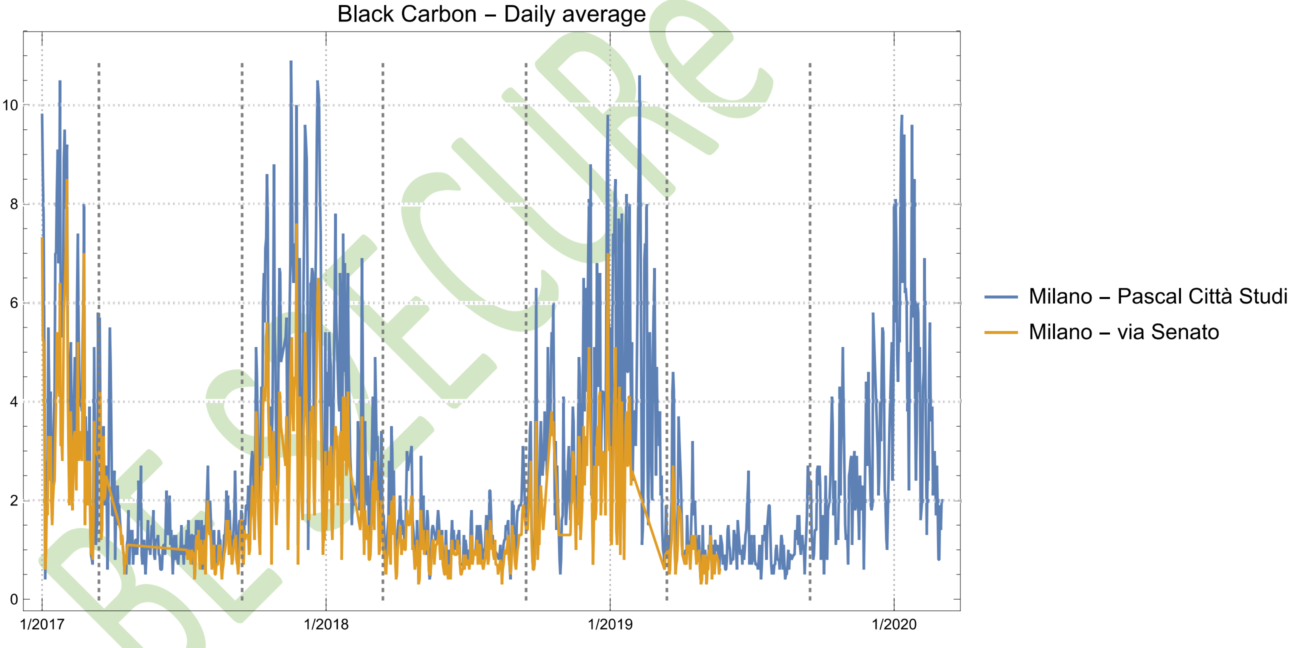


Figure 47: Black Carbon daily average

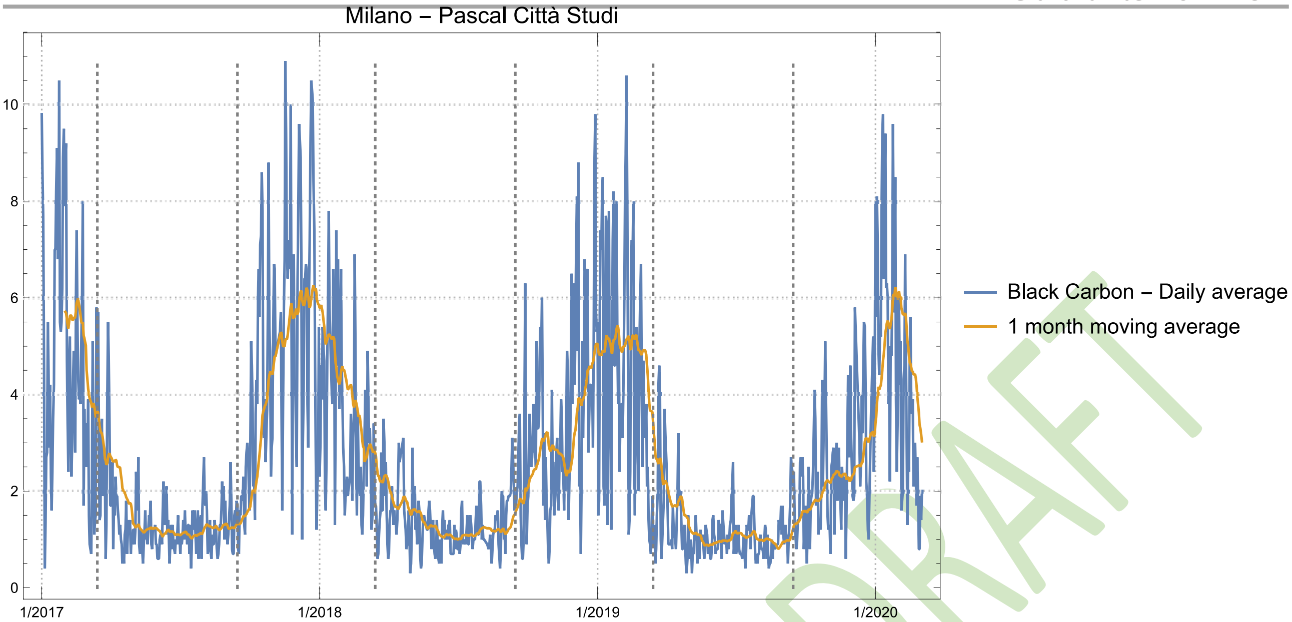


Figure 48: Black Carbon daily average and the monthly average for the Pascal Città Studi AQ station.

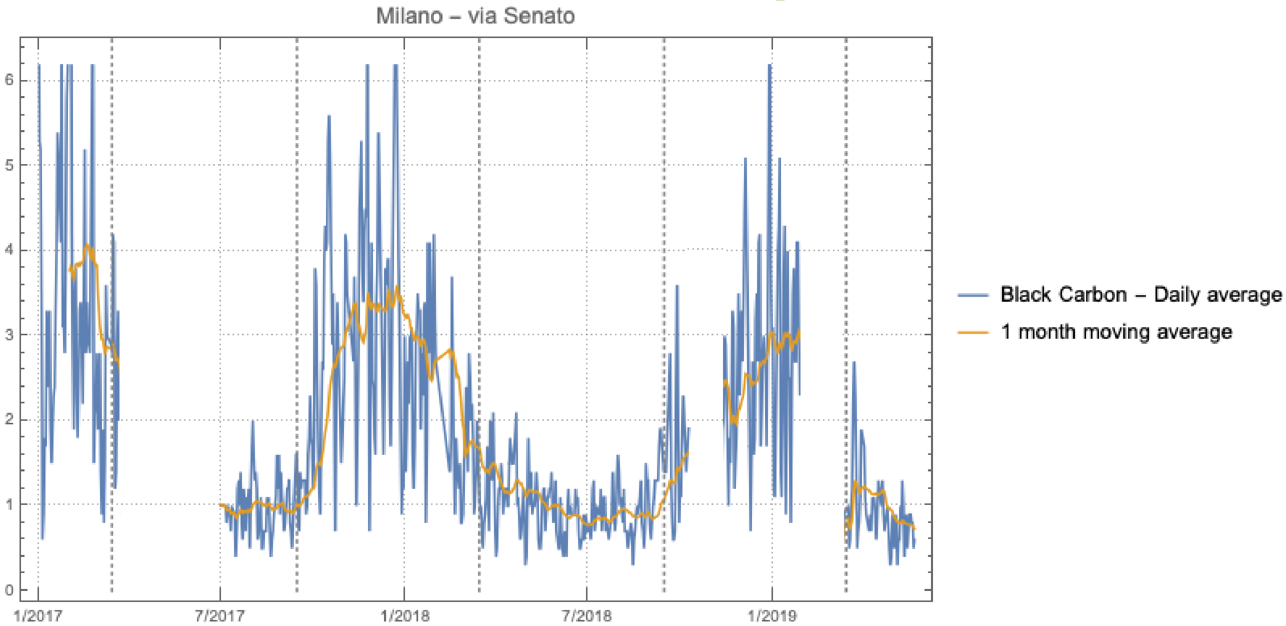


Figure 49: Black Carbon daily average and the monthly average for the via Senato AQ station.

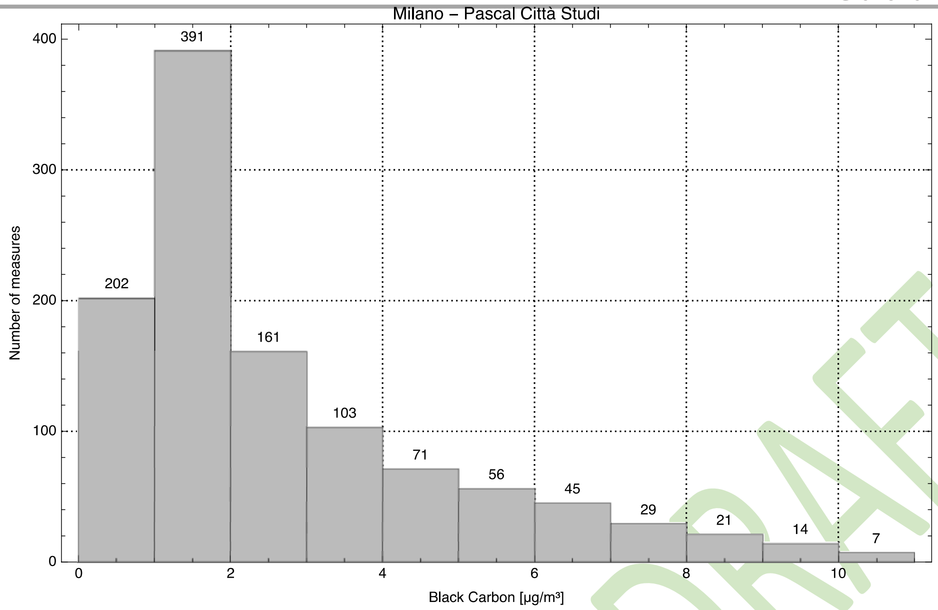


Figure 50: Black Carbon analysis by classes – Pascal Città Studi AQ station.

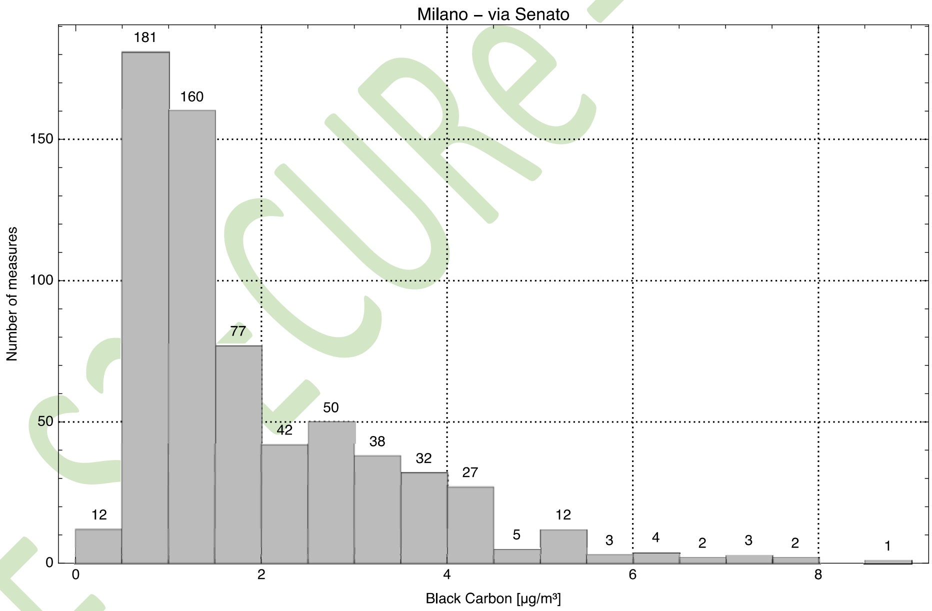


Figure 51: Black Carbon analysis by classes – via Senato AQ station.

3. The EPA Air Quality Index (AQI) in Città Studi

The last step concerns the calculation of the Air Quality Index (AQI), as defined by the US Environmental Protection Agency (EPA) (U.S. Environmental Protection Agency 2006). The AQI is a Key Performance Indicator, used for providing an overall assessment of the air quality in a specific region, based on the concentration of the main pollutants. The indicator allows to combine the concentration of the main pollutants comparable scale.

The analyses accomplished so far, provide key data and representation of the detected pollutants by sensors installed in the whole city of Milan since 2017. Therefore, for providing an insight on the case study area, located in the Città Studi neighbourhood, the AQI has been calculated for the Pascal Città Studi AQ central. This provides an insight on the closest AQ station available to the case study and informs on the trends of the pollutants in the Built Environment.

The AQI, in its basic formula, allows to compare the concentration of different pollutants present every day in the atmosphere (Eq. 1).

$$I_p = \frac{I_{Hi} - I_{Lo}}{BP_{Hi} - BP_{Lo}} ' (C_p - BP_{Lo}) + I_{Lo} \quad (1)$$

Where:

- I_p = the resulting AQI of the pollutant p;
- C_p = the rounded measured concentration of pollutant p;
- BP_{Hi} = the breakpoint that is greater than or equal to Cp (see
- Table 2);
- BP_{Lo} = the breakpoint that is less than or equal to C_p (see
- Table 2);
- I_{Hi} = the reference AQI value corresponding to BP_{Hi} (see
- Table 2);
- I_{Lo} = the reference AQI value corresponding to BP_{Lo}.

However, it shall be noted that given the lack of values collected for pollutant NOx, in particular when the amount of data points are compared amongst the analyzed pollutants, for this particular substance the AQI trend was not determined.

Table 2: Breakpoints for the AQI. Image taken from U.S. Environmental Protection Agency (2006).

This Breakpoint...						...equal this AQI		…and this category
O_3 (ppm) 8-hour	O_3 (ppm) 1-hour1	PM_{10} (µg/m^3)	$PM_{2.5}$ (µg/m^3)	CO (ppm)	SO_2 (ppm)	NO_2 (ppm)	AQI	
0.000 - 0.064	-	0 - 54	0.0 - 15.4	0.0 - 4.4	0.000 - 0.034	(2)	0 - 50	Good
0.065 - 0.084	-	55 - 154	15.5 -40.4	4.5 - 9.4	0.035 - 0.144	(2)	51 - 100	Moderate
0.085 - 0.104	0.125 - 0.164	155 - 254	40.5 - 65.4	9.5 - 12.4	0.145 - 0.224	(2)	101 - 150	Unhealthy for Sensitive Groups
0.105 - 0.124	0.165 - 0.204	255 - 354	65.5 - 150.4	12.5 - 15.4	0.225 - 0.304	(2)	151 - 200	Unhealthy
0.125 - 0.374 (0.155 - 0.404)[4]	0.205 - 0.404	355 - 424	150.5 - 250.4	15.5 - 30.4	0.305 - 0.604	0.65 - 1.24	201 - 300	Very unhealthy
(3)	0.405 - 0.504	425 - 504	250.5 - 350.4	30.5 - 40.4	0.605 - 0.804	1.25 - 1.64	301 - 400	Hazardous
(3)	0.505 - 0.604	505 - 604	350.5 - 500.4	40.5 - 50.4	0.805 - 1.004	1.65 - 2.04	401 - 500	Hazardous

[1] Areas are required to report the AQI based on 8-hour ozone values. However, there are areas where an AQI based on 1-hour ozone values would be more protective. In these cases the index for both the 8-hour and the 1-hour ozone values may be calculated and the maximum AQI reported.

[2] NO2 has no short-term NAAQS and can generate an AQI only above a value of 200.

[3] 8-hour O3 values do not define higher AQI values ($ 301). AQI values of 301 or higher are calculated with 1- hour O3 concentrations.

[4] The numbers in parentheses are associated with 1-hour values to be used in this overlapping category only.

In the case that there are more pollutants for the same day on which implement the AQI calculation, this overall AQI corresponds to the highest value of the individual pollutant's AQI.

The effects of the pollutants on human health are collected in Table 3. A higher level of detail can be found in the report *Guidelines for the Reporting of Daily Air Quality – the Air Quality Index (AQI)* (U.S. Environmental Protection Agency 2006).

Table 3: Pollutant Specific Sensitive Groups. The table is taken from the U.S. Environmental Protection Agency (2006).

When this pollutant has an index above 100	Report these Sensitive Groups
Ozone (O_3)	People with lung disease, children, older adults, and people who are active outdoors are the groups most at risk
PM2.5	People with heart or lung disease, older adults, and children are the groups most at risk
PM10	People with heart or lung disease, older adults, and children and the groups most at risk
CO	People with heart disease are the group most at risk
SO_2	People with asthma are the group most at risk

The results of the AQI calculation for pollutants measured by the Pascal Città Studi AQ central are represented in Figure 53 and Figure 54. AQI for the pollutants PM 10, PM 2.5, O_3 and SO_2 have been calculated for each day in the considered period 01 January 2017 – end February 2020. The overall AQI shows a seasonal trend, in accordance with the historical series of the pollutants, already described in the previous paragraphs. Coloured horizontal lines represent different thresholds of the AQI, according to its value, as represented in Figure 52.

0-50 Good	51-100 Moderate	101-150 Unhealthy, Sensitive groups	151-200 Unhealthy	201-300 Very unhealthy

Figure 52: AQI thresholds according to the U.S. Environmental Protection Agency (2006).

The charts represented in Figure 53 demonstrate that the most critical pollutant is the PM2.5. AQI of this pollutant is almost always above the Good air quality threshold. And it is the pollutant that for most of the times has been considered in the algorithm as the highest value among the calculated AQI calculated for the 4 pollutants.

Further analysis concerns the counting of the values obtained for each class as represented in Figure 54. This analysis shows that for most of the times, the AQI value or the Pascal Città Studi central are below the Moderate threshold, in none of the cases the values exceed the very unhealthy threshold.

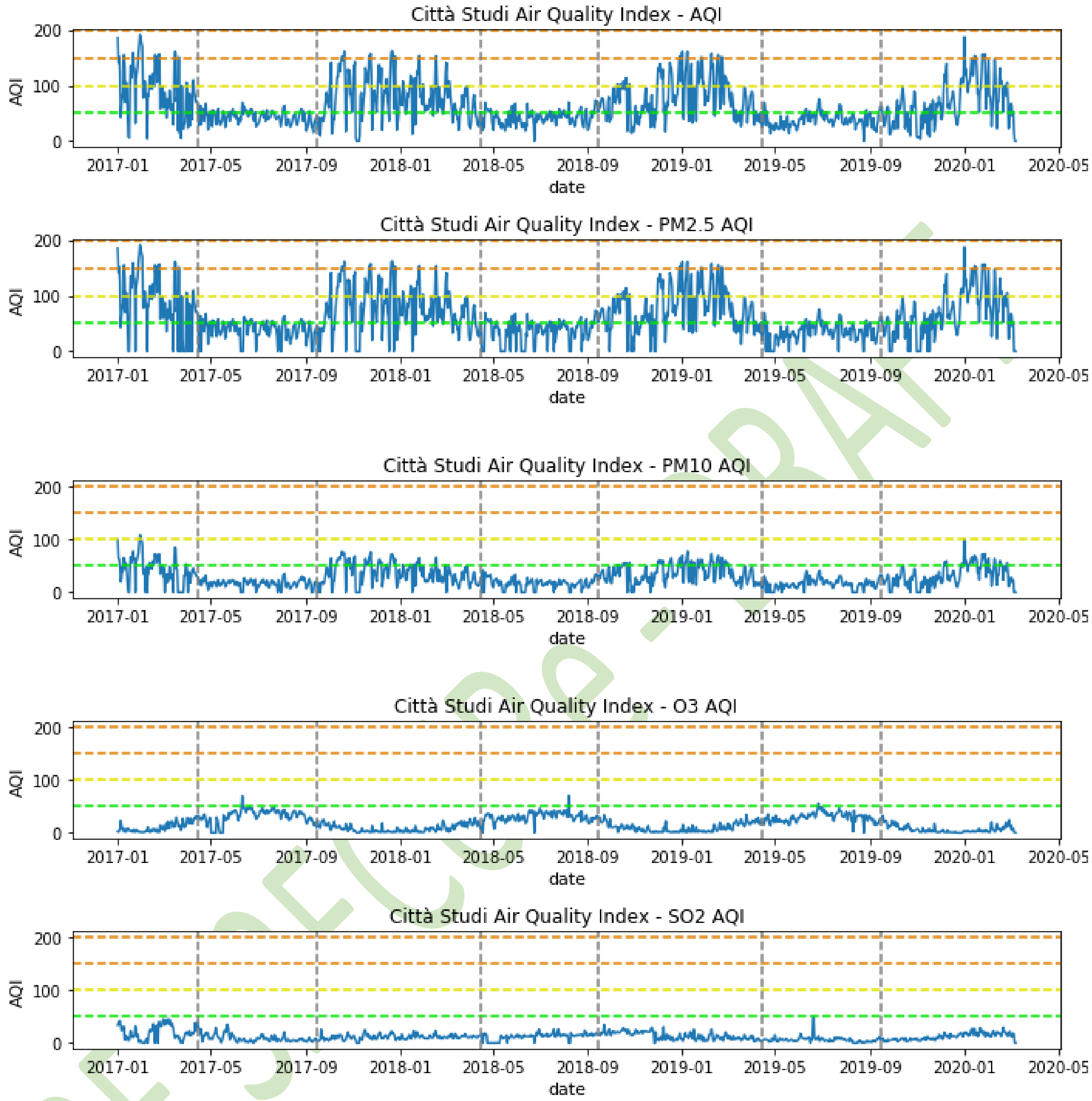


Figure 53: Air Quality Index calculated for available pollutants detected by the Città Studi AQ central

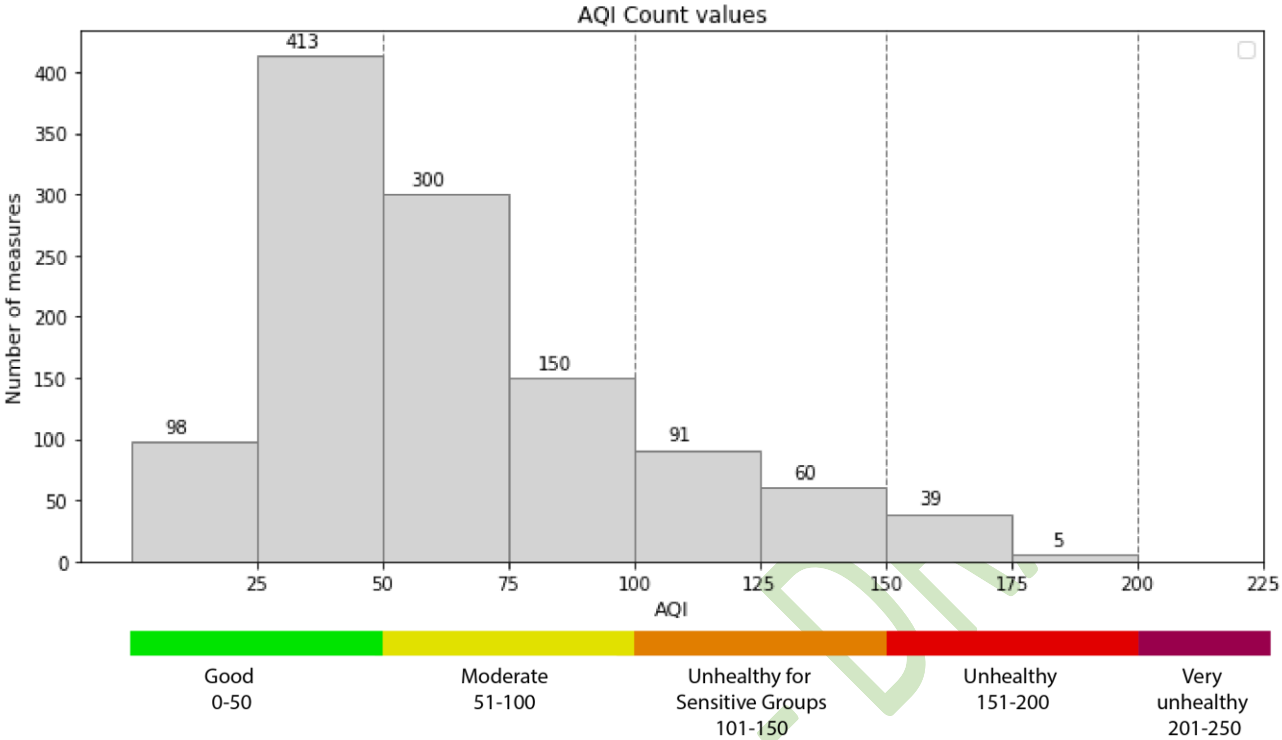


Figure 54: count of the values calculated for each class.

4. Conclusions

Through the analyses in this report we studied the trends of the major pollutants in the city of Milan through their historical series; classification and the comparison of their concentrations over the time. Moreover, whenever the concentration of the pollutants exceeded the allowed thresholds, further analyses have been accomplished in order to investigate the individual detections accomplished for each sensor installed in the ARPA AQ stations. This allows to identify also the most polluted areas in the city according to the location of the AQ stations.

Unfortunately, despite the AQ stations are equipped with a reasonable number of sensors measuring different pollutants, not always the data are available or enough good for performing the needed analyses. This is due to the fact that some sensors are not working (or they registered wrong data) in the period considered: January 2017 – February 2020.

In order to narrow down the scale of the analyses, in the last section of this report the EPA AQI has been calculated. This index allows to compare major pollutants on a daily basis, in order to calculate a synthetic KPI describing the air quality, in relation to the hazard that it may cause to disadvantaged groups. This further calculation allowed to identify the most critical pollution for the Pascal Città Studi AQ central: the PM2.5 concentration. This pollutant corresponds almost always to the highest value of the AQI calculated on data of all available pollutants. However, the PM2.5 AQI often remains within the Goo - Moderate AQI threshed.

These analyses provide the basis for further studies on the concentration of the pollutants at different heights, which is going to be performed with a real-time AQ data sensor as next step of the research.

5. References

ARPA Lombardia Dati e Indicatori. https://www.arpalombardia.it/Pages/Ricerca-Dati-ed-Indicatori.aspx#

ARPA Lombardia Monossido di carbonio - Aria / Qualità dell'Aria | ARPA Lombardia. https://www.arpalombardia.it/Pages/Aria/Inquinanti/Monossido-di-carbonio.aspx?firstlevel=Inquinanti. Accessed 13 Mar 2020b

ARPA Lombardia Biossido di Zolfo - Aria / Qualità dell'Aria | ARPA Lombardia. https://www.arpalombardia.it/Pages/Aria/Inquinanti/Biossido-di-Zolfo.aspx?firstlevel=Inquinanti. Accessed 16 Mar 2020c

ARPA Lombardia Carbonio elementare,Organico e Black Carbon - Aria / Qualità dell'Aria | ARPA Lombardia. https://www.arpalombardia.it/Pages/Aria/Inquinanti/Carbonio.aspx?firstlevel=Inquinanti. Accessed 17 Mar 2020d

European Committee for Standarization (2014) EN 12341: 2014 Ambient air - Standard gravimetric measurement method for the determination of the PM10 or PM2,5 mass concentration of suspended particulate matter. 53

European Environment Agency (2019) Air quality in Europe — 2019 report. EEA Report No 10/2019

Paolini R, Zani A, MeshkinKiya M, et al (2016) The hygrothermal performance of residential buildings at urban and rural sites: sensible and latent energy loads and indoor environmental conditions. Energy Build. https://doi.org/http://dx.doi.org/10.1016/j.enbuild.2016.11.018

U.S. Environmental Protection Agency (2006) Guidelines for the Reporting of Daily Air Quality – the Air Quality Index (AQI)

World Health Organization (2019) Global Ambient air pollution

(2013) Decreto del Presidente della Repubblica 16 aprile 2013, n. 74 Regolamento recante definizione dei criteri generali in materia di esercizio, conduzione, controllo, manutenzione e ispezione degli impianti termici per la climatizzazione invernale ed estiva degli edifici e per la preparazione dell'acqua calda per usi igienici sanitari, a norma dell'articolo 4, comma 1, lettere a) e c), del d.lgs. 19 agosto 2005, n. 192