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Analysis of the Main Anthropogenic Sources Contribution to Pollutant Emissions in Rome Italy, in Relation to the Pandemic Covid 19 Period

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Abstract –

Most cities worldwide suffer from serious air-quality problems, which have received increasing attention in the past decade. The most probable reason for the air-quality problems is the urban population growth, combined with a change in land use due to increasing urban areas. The emission of air pollutants is caused by different anthropogenic processes which can be categorized into the sources of urban traffic, industry, and domestic heating. Dispersion and dilution of air pollutants are strongly influenced by meteorological conditions, especially by wind direction, wind speed, turbulence, and atmospheric stability. New interdisciplinary research studies are needed to increase our understanding of the interactions among these aspects. The aim is to analyze the pollutant condition in Rome with qualitative and quantitative analysis, in order to understand which are the main pollutant sources and what is the correlation of habits of the population on air pollutant emissions.

During the pandemic period from march to may 2020 there was an hard lockdown with the stop of many human activities and we have studied the pollution situation in that period analyzing the effects of the stop of the vehicular traffic in comparison with the heating Plants in the city of Rome.

Index Terms : *air quality; pollutant emissions; statistic analysis; domestic heating; urban traffic; pandemic, Covid 19.*

INTRODUCTION

Outdoor air pollution has myriad sources, both natural and anthropogenic. It is a mixture of mixtures, and the mix of contaminants in outdoor air varies widely in space and time, reflecting variation in its sources, weather, atmospheric transformations and other factors. In any particular place, the pollution in outdoor air comes not only from local sources, but also from sources that affect air quality regionally and even globally [1]. The main reason for the air quality problems is urban population growth, because people are constantly moving from rural to urban areas [2]. The air pollutants results higher in urban area due to a combination of intense traffic and because of a combination of many elements such as other sources of air pollution (e.g., industrial activities, energy production plants and , domestic heating), [3]contributing to the emission of a variety of sub-stances. They are noticeable by the toxicological effects resulting from long-term exposure via inhalation [34].

The major pollutant produced are related to human activities, especially those produced by combustion and industrial processes. The International Agency for Research on Cancer (IARC) focused the attention on the human exposures to PM (Particulate Matter). The risk of being exposed to a mixture of pollutants depends on particulate matter smaller than 2.5 μm, which is a common useful indicator of the risk associated with exposure to a mixture of pollutants from various sources and in different environments, including ambient particulate matter pollution from transportation, wind-blown dust, burning of biomass, and industrial sources; second-hand smoke; burning of biomass and coal for household energy; and active smoking [4]. Therefore, the PM2.5 can be taken as indicator of population exposure to outdoor air pollution. Exposure to ambient fine particles (PM2.5) was recently estimated to have contributed 3.2 million premature deaths world-wide iIn 2010, 3.2 million of people died because of, due largely to cardiovascular disease, caused by the exposure to ambient fine particles (PM2.5) and 22300 deaths from people died because of lung cancer. More than half of the lung cancer deaths attributable to ambient PM2.5 were estimated to have been in China and other East Asian countries [4,5].China and East Asia show the largest number of people who lost their life [5,6].

With reference to NO2, SO2 and (PMs) there is general agreement in the scientific literature that they are the main agents responsible for the damage encountered on monuments and historical buildings in urban areas [7]. Atmospheric composition is of unquestionable importance in the study of the damage produced on building materials of artistic interest, since it directly influences the species characteristics and entity of the degradation mechanism occurring on the cultural heritage.

The urban areas modified the environmental features that contributed to the increase of pollutions. As a matter of fact, the large concentration of the built environment, road pavement and the high building materials capacitance changed the local micrometeorological conditions. Air temperature, humidity and wind velocity and direction are altered in the urban environment compared to rural areas. Furthermore, road traffic, domestic heating, industrial activities and lack buildings energy performance involves high dis-comfort for users [68-1820]. Besides the increase of pollutions, urbanization has led to an increase of the urban heat island intensity (spatially averaged surface or air-temperature difference between an urban and surrounding rural area(s) [1921]). Several studies are focused to reduce the urban heat island effect with different mitigation techniques [2022-2628].

The population exposure people exposed to air pollutants is even more evident considering the weak ventilation, due to because of the presence of high buildings with a consequent reduction of the dispersion of air masses. As a matter of fact, for this reason, the contaminants formed below the building height remain in the pedestrian level and in-crease the health damages especially during thermal inversion episodes. Several studies were conducted to analyze the correlation between the street canyon features and the pollution dispersion [2729]. If the ratio between the average height of the buildings (H) and the width of the canyon (W) is high enough to establish skimming flow conditions (at least higher than 0.65), the retention of pollutants within the urban canopy layer will be amplified [2830]. The major street canyons in the cities have high value of the ratio H/W with a consequent established helical vortex with an axis parallel to the canyon direction. In this case the transport of pollutants that go out of the canyon is limited reduced [2931].

The identification of analysis tools and methods, pollutant concentrations measurement, comparison with the threshold values prescribed by law, are the activities foreseen by the legislations in order to monitor the air quality and predict rehabilitation through the definition of plans of interventions.

As a first step, in order to plain a control strategy of the pollution concentration in medium and high scale cities, proper measurement and data processing are required to highlight the achievement of dangerous concentration levels of pollutants and formulate a prediction model.

Actually, the main active control strategy is based on the introduction of some limits of the urban traffic (e.g. number of the vehicles and vehicle categories that are authorized to transit). Other interventions include the increase of efficiency of the heating systems in buildings such as the replacement of traditional boilers with condensation ones integrated with more performing regulation systems based on energy load tracking.

In the present work, several kinds of pollutants concentration such as [CO], [SO2], [NOx], [NO], [NO2], [C6H6], [PM10], [PM2.5] and [O3] generated in Rome during 2019 have been analyzed applying different advanced post-processing technique. In particular, statistic and cross-statistic have been computed in time and Fourier domain. In particular, probability distribution, Kurtosis, Skewness, Poincaré sections and cross-correlation of the different pollutants were analyzed in order to assess the air pollution level in the city of

Rome and the correlation of anthropogenic sources with the pollutant emission to make a valid model.

In a second phase of this studio the results of pollutant emissions of the 2019 were compared with the data of 2020 where there was a long period of hard lockdown and many human activities as the vehicular traffic were stopped, and the most important source of the pollutant emissions was the heating systems of the buildings in the urban area of Rome.

This study is the continuous of the research Assessment of the Air Pollution Level in the City of Rome that our research group has made using a lockdown for the pandemic covid as an opportunity to avoid the correlation between the two most important anthropogenic sources of pollution in the urban area the heating systems and the vehicular traffic.[46]

MATERIALS AND METHODS

2.1. Characteristics of the Study Area

Rome is the capital of Italy and one of the most overcrowded cities of Europe (3 mil-lion people for 12,850 km2). Considering the extra-urban areas, people are more than four million. It is a historical city that traces its origin to 753 a.C. and it was the capital of the biggest empire ever. That's why it is known as the eternal city and its cultural heritage finds no equals. Thanks to its position, Rome shows a Mediterranean climate: temperate winter and hot summer, with temperatures from 0 to 36. The greatest problem of this city is the lack of an adequate net of public transport, so people use cars [43]. Apart from traffic, there are a lot of other pollutant activities, such as domestic heating.

2.2. Monitoring Station Network

ARPA Lazio is the agency that monitors the air condition in the region of Lazio [44]. The monitoring network used in the present work consists of 39 monitoring stations of [CO], [SO2], [NOX], [NO], [NO2], [C6H6], [PM10], [PM2.5], and [O3] that are shown in Figure 1. The monitoring stations are located in strategic places. It collects data hour by hour in a place with a great concentration of pollution.

2.3. Pollutant Legislation

In the 1960s, the USA made the first laws to guarantee air quality. In Italy, it is regulated by DPR 203/88 [45], which states that it's possible to define as pollution each element able to:

- Alter the normal environmental condition and air quality;
- Generate a danger for human health;
- Compromise the environment;
- Alter the biological resources and public and private goods.

In this perspective, the 2008/50/CE directive of the European Parliament [46] finds its application in Italy through D.Lgs. 155\2010 [47], which defines the pollutant agents, the concentration limits into the air, the laws, and the measures able to reduce the pollutant concentrations. Benzene, carbon monoxide, nitrogen oxides, ozone, PM2.5, PM10, and sulfur dioxide are defined as pollutants. For each of them was defined a limit to reducing its effect. Table 3 reports the most relevant pollutants for this study.

2.4. Type of Pollutant

Carbon monoxide (CO) is a colorless, odorless gas emitted from combustion processes. Nationally and particularly in urban areas the, majority of CO emissions to ambient air come from mobile sources. CO can cause harmful health effects by reducing oxygen delivery to the body's organs (like heart and brain) and tissues. At extremely high levels, CO can cause death.

Nitrogen dioxide (NO2) is one of a group of highly reactive gasses known as "oxides of nitrogen," or "nitrogen oxides (NOX)." NO2 is used as the indicator for the larger group of nitrogen oxides. NO2 comes from emissions by cars, trucks and buses, power plants, and off-road equipment. In addition to contributing to the formation of ground-level ozone, and fine particle pollution, NO2 is linked with a number of adverse effects on the respiratory system.

Sulfur dioxide (SO_2) is one of a group of highly reactive gasses known as “oxides of sulfur.” The largest sources of SO_2 emissions are from fossil fuel combustion at power plants (73%) and other industrial facilities (20%). SO_2 is linked with a number of adverse effects on the respiratory system.

Particulate matter (PM) is a complex mixture of extremely small particles and liquid droplets. Particle pollution is made up of a number of components, including acids (such as nitrates and sulfates), organic chemicals, metals, and soil or dust particles. The size of particles is directly related to their potential for causing health problems. Once in-haled, these particles can affect the heart and lungs and cause serious health effects. There are two categories of PM:

- “Inhalable coarse particles,” such as those found near roadways and dusty industries, are larger than 2.5 micrometers and smaller than 10 micrometers in diameter.
- “Fine particles,” such as those found in smoke and haze, are 2.5 micrometers in diameter and smaller. These particles can be emitted from sources such as forest fires, or they can form when gases emitted from power plants, industries and automobiles react in the air.

With reference to NO_2, SO_2, and (PMs) there is general agreement in the scientific literature that they are the main agent responsible for the damage encountered on monuments and historical buildings in urban areas [34]. Atmospheric composition is of un-questionable importance in the study of the damage produced on building materials of artistic interest since it directly influences the species characteristics and entity of the degradation mechanism occurring on the cultural heritage.

Ozone (O_3) is not emitted directly into the air, but it is created by chemical reactions between oxides of nitrogen (NO_X) and volatile organic compounds (VOC) in the presence of sunlight. Emissions from industrial facilities and electric utilities, motor vehicle exhaust, gasoline vapors, and chemical solvents are some of the major sources of NO_x and VOC. Breathing ozone can trigger a variety of health problems, particularly for children, elderly people, and people of all ages who have lung diseases such as asthma. Ground-level ozone can also have harmful effects on sensitive vegetation and ecosystems.

Benzene (C_6H_6) is used as a constituent in motor fuel; as a solvent for fats, waxes, resins, oils, inks, paints, plastics, and rubber, in the extraction of oils from seeds and nuts, and in photogravure printing. It is also used as a chemical intermediate and in the manufacture of detergents, explosives, pharmaceuticals, and dyestuffs. It is found in the air from emissions from burning coal and oil, gasoline service stations, and motor vehicle exhaust. Acute (short-term) inhalation exposure of humans to benzene may cause drowsiness, dizziness, headaches, as well as eye, skin, and respiratory tract irritation, and, at high lev-els, unconsciousness. Chronic (long-term) inhalation exposure has caused several blood disorders, including reduced numbers of red blood cells and aplastic anemia, in occupational settings. Negative effects on reproduction have been reported for women exposed to high levels of inhalation, and adverse effects on the developing fetus have been observed in animal tests. Increased incidence of leukemia (cancer of the tissues that form white blood cells) has been observed in humans occupationally exposed to benzene.

2.5. Anthropogenic Sources

Today, air quality affects even small cities. To know the values of the emissions is fundamental to monitor air quality and consequently to find solutions to it.

Pollutant emissions can be divided into localized and spread. The first are the ones that can be studied singularly and can be localized. They show emissions higher than 90–100 tons per year that are referred to industries that use combustion processes. The second are the ones that can’t be classified as the first ones and they don’t go over the limits of the localized ones. They are referred to as urban traffic and building heating systems [44].

Cars are one of the main reasons for the increase in cities pollution. In recent years, the percentage of goods and people on the road increased compared to railway transportation. In Italy, in the 1980s there were about 20 million vehicles, in the 1990s there were about 33 million of them. This value became 39 million in 1998 [49]. Referring to the total amount of emission of road traffic, urban traffic represents 77% of the CO, 39% of CO_2, 27% of NO_X, and 29% of particulate matter [50].

Together with road traffic, building heating systems are an important factor for the air quality standard. They aren’t regulated yet, so they are difficult to monitor and im-prove.

The production of a pollutant that can be found in the air is caused both by natural processes, like volcanos activities and by human production. The natural processes are not taken into account in this study because they produce fewer effects than the anthropogenic ones, which include industrial processes, heating systems, energy generators, urban traffic, and even smoke. That’s why urban and industrial areas are more exposed than rural ones and show a higher level of risk. Anyway, the city of Rome is taken into account only the effects of urban traffic and heating systems.

2.5.1. Urban Traffic

Urban traffic is tough to be the main cause of pollution in the city of Rome because of the emission of incomplete combustion.

Most of the cars are petrol or diesel, and there is a very low increase in the use of electric or hybrid engines. In 2019, for 4,340,474 people, there were 2,665,174 cars, 521,070 motorcycles and 8589 buses [51]. Because of their incomplete combustion, diesel engines produce pollutants. The most relevant are sulfur dioxide (SO2), carbon monoxide (CO) nitrogen oxides (NOX), and particulate matter, which is the one to pay more attention to.

The benzene (C6H6) is used as a constituent in motor petrol and it causes the formation of toxic substances like carbon monoxide (CO), nitrogen oxides (NOX), and particulate matter.

2.5.2. Heating Systems

The aim of the heating system is to make people reach their wellness with an adequate temperature. In Rome, the most used systems are the independent and centralized ones. A heating generator, powered by liquid or gas fuel (methane or gasoline), makes these systems work.

Methane is the most used gas thanks to its widespread diffusion in Italy. It is called natural gas because it is a hydrocarbon already present in nature. It’s quite cheap and it produces pollutant as CO, NOX, PM10, and PM2.5.

Diesel boilers are safer than gas ones but they pollute more. In Italy, diesel isn’t as cheap as in the rest of Europe. They produce SOX and SO2.

Anyway, pollutants are produced because of the incomplete combustion that leads to the formation of CO and NOX.

Condensing boilers are able to save energy from steam water and heat from drain gas. Fumes are made cold as steam goes into liquid losing heat that goes in the water in the thermic system. The use of it reduces the emissions of CO, CO2 e NO, and particular matter up to 70%.

Different from urban traffic, heating systems are not regulated by any Italian or European law. The only rule is for the systems under 35 kW, which have to show less than 0.1% of CO in the drained gas. There are no limits for particular matter and NOX so producers are not so interested in environmental safeness.

2.6. Methodology

In this paper, the correlation of pollution concentration between different types of urban context was investigated to find a possible link between pollutant level and urban context during a normal year in comparison with 2020 year where for the pandemic covid 19 the people was in an hard lockdown from march to may and it was a stop of the hu-man activities and the vehicular traffic. These differences should bring to a different type of policy and environmental strategies in order to reduce the pollution concentration in each site. Furthermore, the quantification of the pollutant concentration impact from different types of anthropogenic sources can help to decide the priority of future policy strategies. To accomplish the objective of the present paper there is the need to analyze the spatial and temporal dependence of pollutant concentration in the different types of locations. Therefore, the quantification of the anthropogenic sources’ contribution can be investigated. The steps followed in the present paper are:

1. Temporally dependent on pollutant concentrations: The analysis investigates the trend of pollutant concentrations over years. The objective of this analysis is to find if there is the same behavior over time or not in depending also for the different seasons in comparison between a normal year and a pandemic year;
2. Anthropogenic sources' contribution to pollutant emissions: The analysis compares the mean pollutant concentration variation during the day for the different locations. the analysis is considered separately the contribution of the different type types of anthropogenic sources with the possibility to quantify their impact on pollutant con-centration, in comparison between a normal year and a pandemic year where many anthropogenic activities were stopped.

Furthermore, the nowadays policy strategy in Italy was analyzed in order to verify the validity of this technique from a pollutant level decrease point of view.

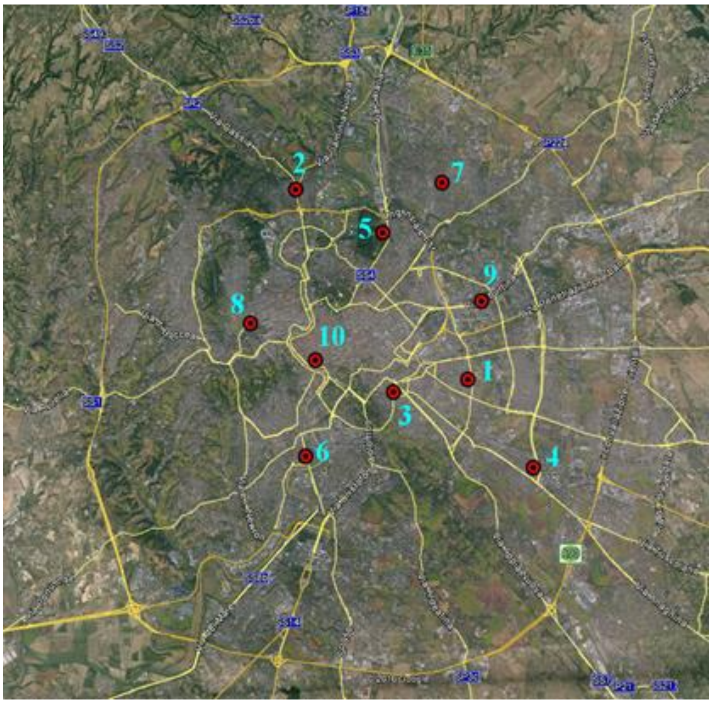


Figure 1. Google Earth map of Rome. Red circles are the monitoring stations taken into account.

RESULTS AND DISCUSSION

In the present study the data recorded in 2019 were considered. It is useful to consider the mean values of contaminants of each station in order to represent the average pollutant concentrations of Rome.

Before calculating the mean values concentrations of Rome, Figure 2 and 3 show the mean, standard deviation, Kurtosis and Skewness values of each pollutant during the year 2019. These are analyzed in order to find the behavior of each pollutant in the different stations. In the case of [PM10], there is only one station that indicate a different Kurtosis value than the others. Despite this consideration, in all the concentrations the Kurtosis and Skewness values of the different stations are similar and it suggest that the mean of the network is possible.

From Figure 2 to Figure 7 is shown how the mean concentration of all stations work during the year in each hour. It can been seen that the major pollutant concentrations happen in the winter seasons from 8 to 13, and from 17 to 2, when there is a greater flow of cars in the city. The highest values are recorded from 19 to 23, when the heating systems are turned on. In the summer, the high values in these hours are due to the urban traffic.

It is worth to notice that the [CO], [NO], [NO2] and [C6H6] have similar trend during the year suggesting the presence of pollutant source simultaneously.

The [O3] is recorded to be higher in the summer and during the hottest hours, when the solar radiation is highest. As a matter of fact, the presence of solar radiation allows the reaction of nitrogen dioxide (NO2) in the formation of ozone (O3).

The [SO2] have values up to 8 µg/m3 compared with the limit of 125 µg/m3 reported in Table 1. That is foreseeable because the [SO2] is mainly caused by the combustion of fuel at power plants and other industrial facilities. As a matter of fact, in the center of Rome there isn't this kind of system.

The concentration of PM2.5 and PM10 has high values in the winter season and reach the maximum values in the last two months of 2019, with values close to 50 µg/m3 of PM2.5 and values close to 70 µg/m3 of PM10.

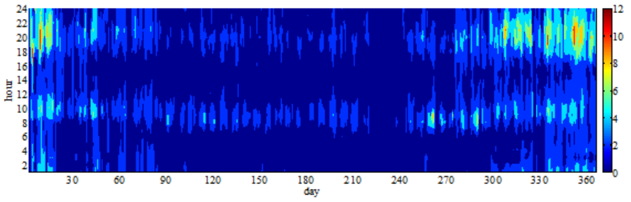


Figure 2. Hourly annual concentration variation of C6H6 during 2019 in µg/m3.

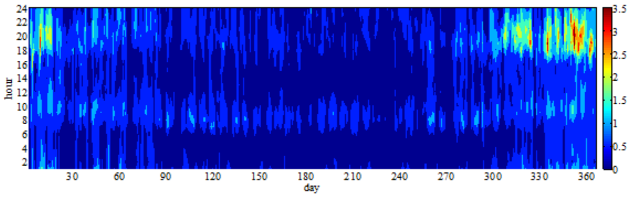


Figure 3. Hourly annual concentration variation of CO during 2019 in mg/m3

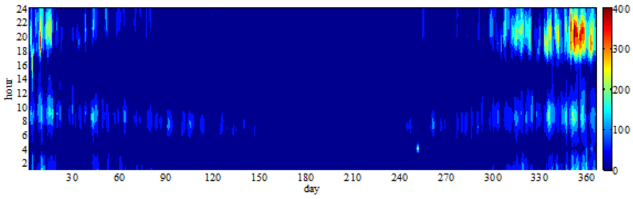


Figure 4. Hourly annual concentration variation of NO during 2019 in µg/m3.

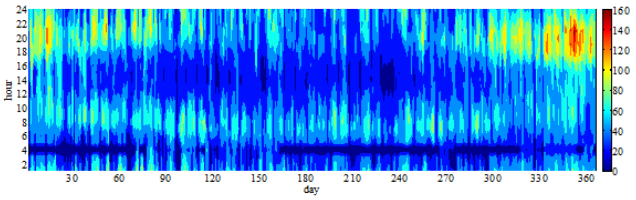


Figure 5. Hourly annual concentration variation of NO2 during 2019 in µg/m3.

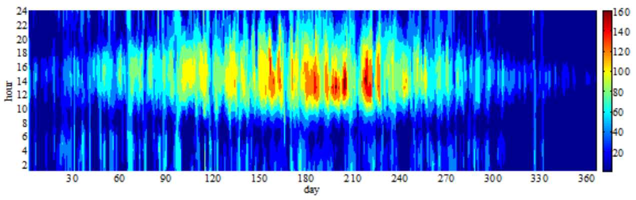


Figure 6. Hourly annual concentration variation of O3 during 2019 in µg/m3.

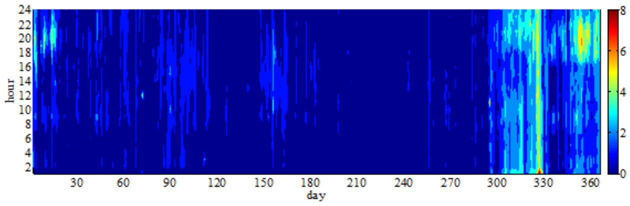


Figure 7. Hourly annual concentration variation of SO2 during 2019 in µg/m3.

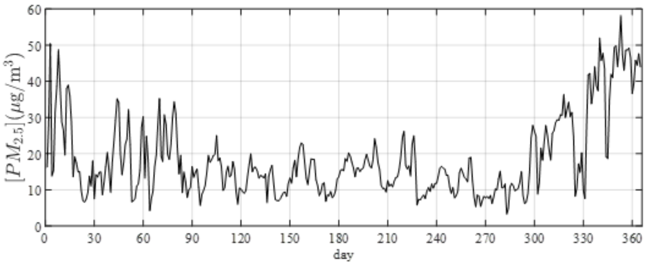


Figure 8. Hourly annual concentration variation of PM2.5 during 2019 in µg/m3.

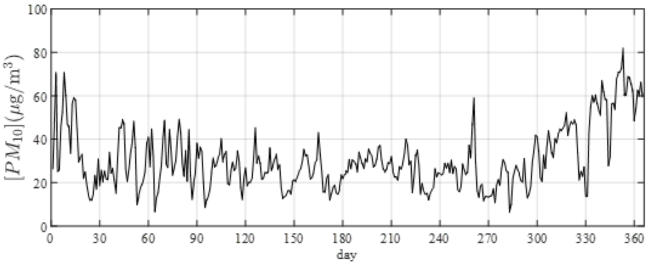


Figure 9. Hourly annual concentration variation of PM10 during 2019 in µg/m3.

Observance of air quality standards represents a great challenge in cities, especially in the ones in which traffic and other additional sources are combined with bad weather conditions. With reference to this issue, the results herein provided shown that the major pollutant concentrations are observed in the winter seasons during the intense traffic flow and the threshold values are often exceeded. Furthermore, according to the coefficient of variation values, Rome has a strongly unsteady behaviour in terms of a family of pol-lutant concentration which fluctuate significantly.

[C6H6] are strongly related to the concentration of pollutants species such as [CO], [NO] and [NO2], as confirmed by the cross-correlation analysis. This correlation is due to the fact that nitrogen oxide prompts and carbon oxides are combustion products and that their fluctuations are caused by the oscillations of the city traffic flux. [O3] is weakly related to the production of benzene and it is also in phase opposition with it. For this reason, the Poincaré section of [C6H6] upon [NO] and [C6H6] upon [O3] was investigated. It is worth to notice that there is a strong linear dependence between [C6H6] and [NO] and a more com-plex interdependence of [O3] and [C6H6]. Qualitatively is provided that, to a reduction of [C6H6] under a certain threshold level which corresponds to an increase of [O3]. Such be-haviour could be attributed to exogenous state variable.

Chemical data collected by the network of microclimatic monitoring stations of ARPA Lazio

The hourly data of the concentrations of atmospheric contaminants for 2019 and 2020 relating to the "green belt" of Rome, taken from the ARPA Lazio network, as men-tioned above, were analyzed.

Each pollutant is recorded hour by hour by all or some ARPA control units. Never-theless, since the control units themselves are equipped with electronic instruments, it is possible that during the recording of the data there are interruptions due to breakdowns or maintenance. In addition, some anomalous values have been identified for one or more consecutive hours, probably due to interference or temporarily elevated local concentra-tions. Therefore, these series of values have been cleaned of these outliers and interpola-tions have been performed to make up for the gaps.

The data series, both for 2019 and for 2020, relate to the period from January 1st to September 30th and each data represents an hourly average concentration value of a given pollutant among all those recorded at the same time by all control units, a large amount of data is therefore available, i.e. 24 hourly data for 273 days (274 days for 2020, which is a leap).

By interpolating these data on an hourly basis, for the entire duration of the observa-tion period, the trend of this pollutant can be observed and the differences between the different years can be noted.

Annual trends on an hourly basis

The first representation of the data is therefore the annual trend of the concentrations of contaminants on an hourly basis. In 2019, a trend typical of all years is observed for almost all pollutants, with a decrease in concentration over the period; in 2020, on the other hand, for most of the contaminants, a more abrupt decrease is observed at the begin-ning of March (around 1700) due to the lockdown.

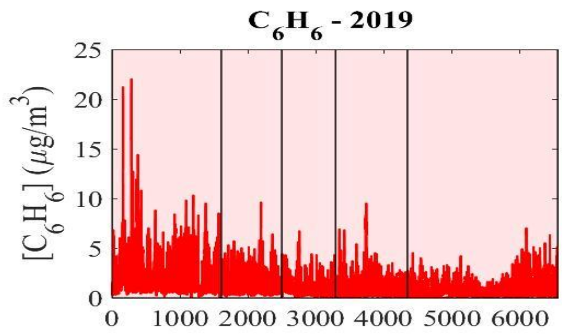
From these comparisons, the effect of the decrease in traffic can be observed, taking into account, however, that in the same period there may have been a more intense use of private heating. Through the analysis of these data it is observed that generally the first period of 2020 was on average more "polluted" than the same in 2019.

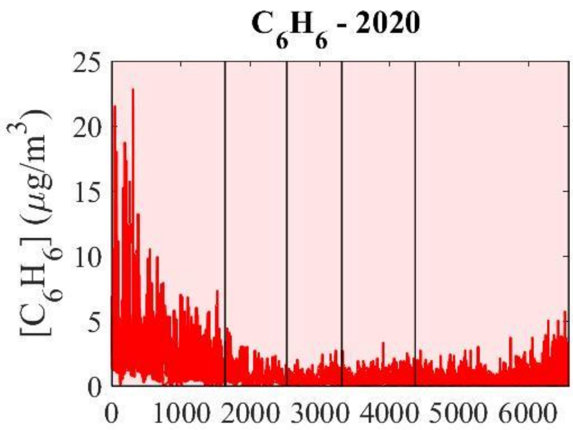
In the periods following the lockdown (from mid-May onwards, therefore approxi-mately from now 3300) the reduction in the movement of remote workers and students continues, given that many offices have opted for smartworking and universities have remained mostly closed. This can be compared with the lowest average concentration in 2020.

Furthermore, observing the final part of the graphs (summer months up to 30 Sep-tember), in which all the lockdown restrictions were eased, lower concentrations were recorded in 2020, probably due to both the time needed for the contaminant to return to the characteristic values of minimum concentration (observable in any case in the last part, ie September).

In making these comparisons, it is assumed that 2019 was a year that saw a fairly normal trend in concentrations (13).

The aforementioned trends follow for the various contaminants

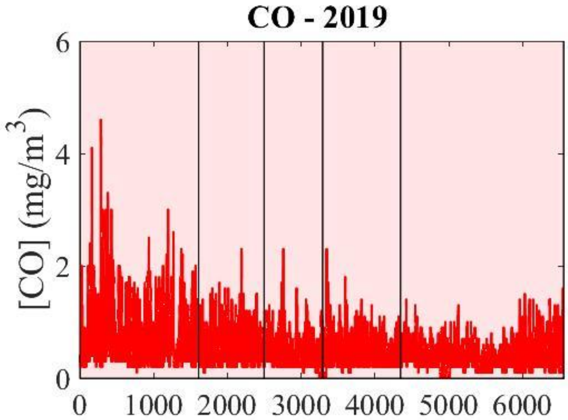


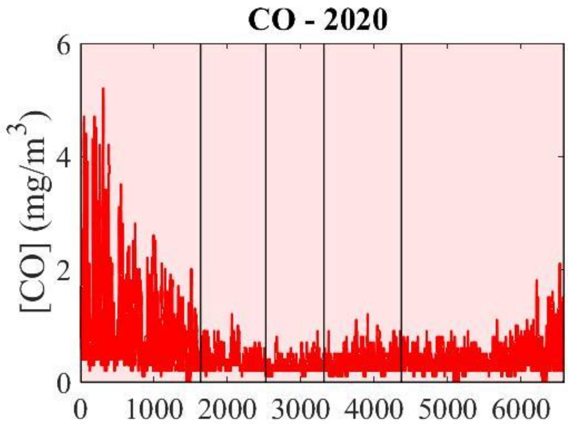


Benzene

A decreasing trend is observed for benzene in the year for both years. In 2020, a slightly higher concentration is observed in the first period compared to the previous year, while from the second onwards, during the lockdown period, there is an average lowering of the concentration probably due to the decrease in vehicular traffic. After the lockdown, when traffic restrictions have no longer been applied, there is a slight increase which however remains at lower values than in 2019.

Note: benzene is detected by three out of ten control units, two of which are located in very busy areas and one in a green space.

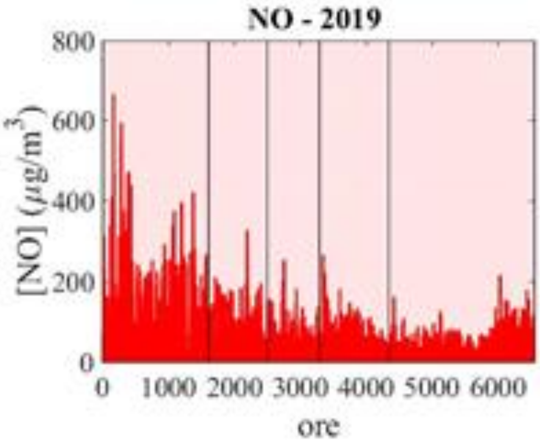


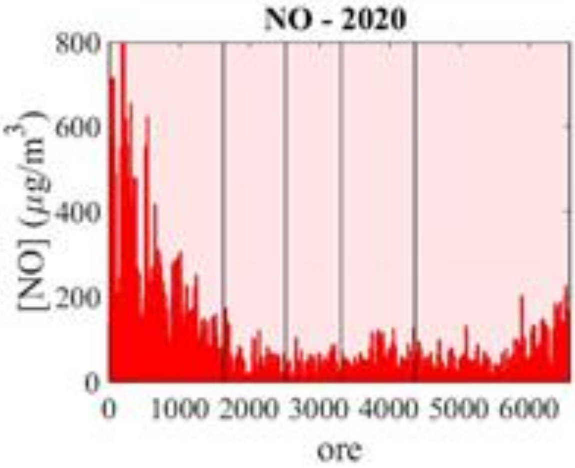


Carbon monoxide

The trend of carbon monoxide is similar to that recorded for benzene, but lower con-centrations can be observed compared to 2019 in the period of the lockdown (approxi-mately between 1700 and 3300) greater than those of benzene. Similarly to benzene, at the end of the lockdown, an increase in concentration can be observed on average, remaining however at levels lower than the characteristic ones, both due to the actual non-achievement of the 2019 traffic percentages and the time necessary for the contami-nant to return to the usual levels. of concentration.

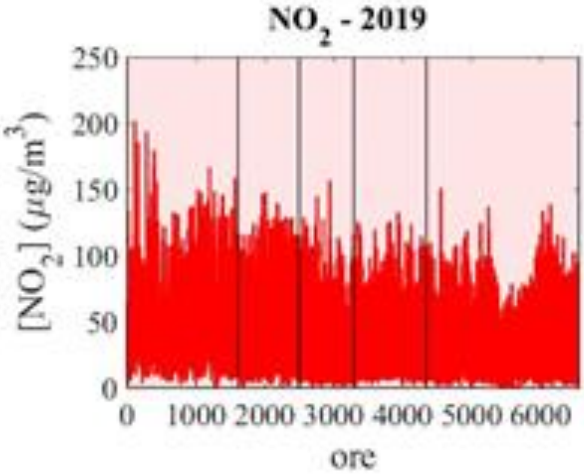
Note: carbon monoxide is detected by only two out of ten control units, one of which is located in an urban area and one in a green space. One of these is the Fermi control unit, which also detects benzene, which is located in an area close to a very busy intersection of Viale Marconi.

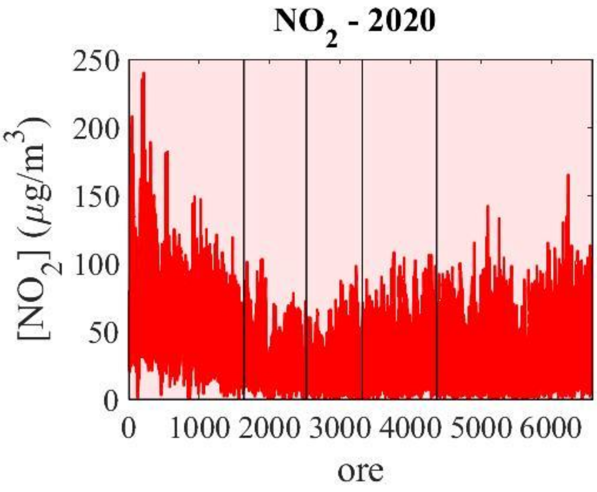




Nitrogen monoxide

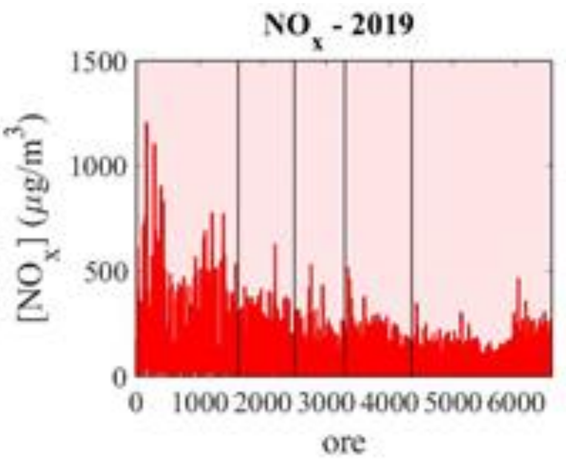
As in the other two pollutants observed, much higher values are recorded for nitrogen monoxide in the first period of 2020 than they are in 2019. From the lockdown onwards, a significant decrease in the concentration of the pollutant is seen and this can determine a good sensitivity of the pollutant. 'pollutant to vehicular traffic, likewise the strong recovery in the fourth and fifth period.

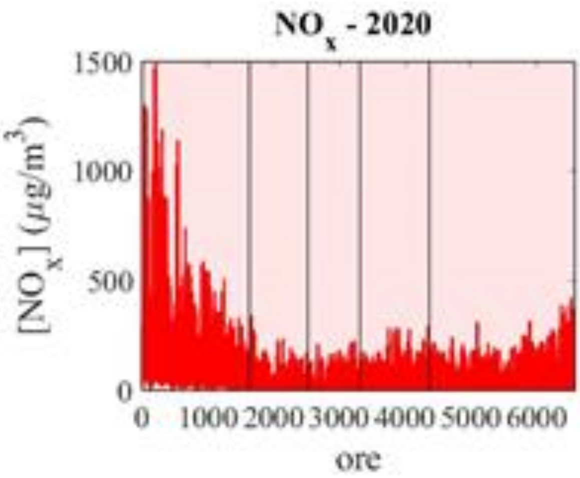




Nitrogen dioxide

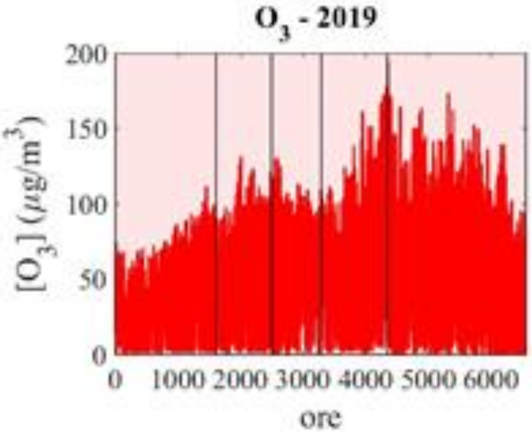
Unlike what has been seen for nitrogen monoxide, for the dioxide there is not a con-siderable lowering of the contaminant during the lockdown, but a good approach to av-erage values during the summer. This could mean that nitrogen dioxide comes from both vehicle traffic and heating.

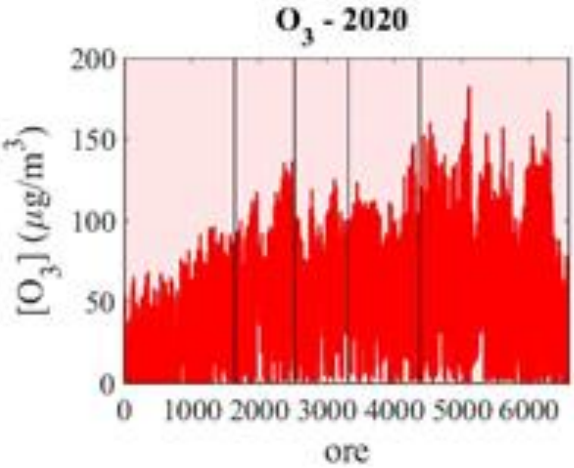




Nitrogen oxides

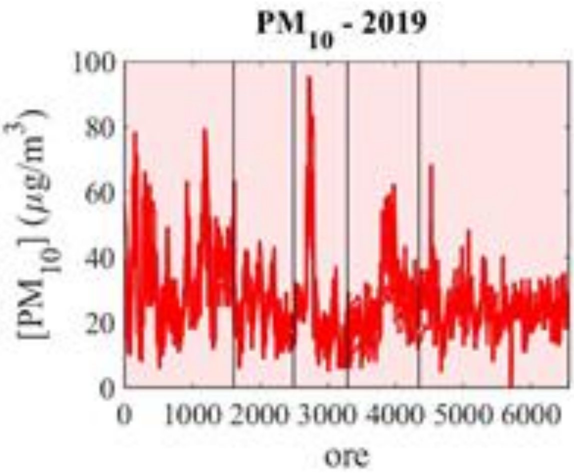
The trend of the other nitrogen oxides follows a middle ground between monoxide and dioxide, confirming the claims made for the two previous species.

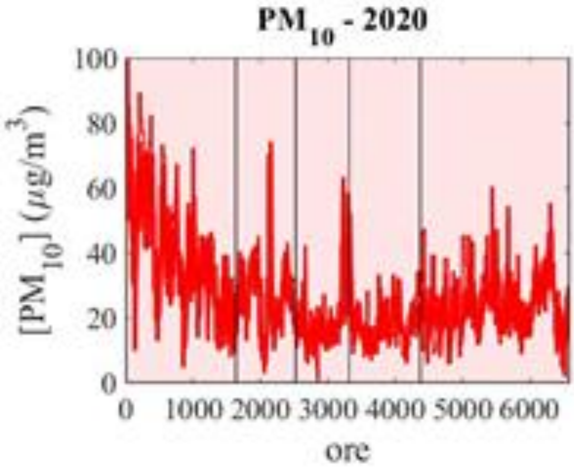




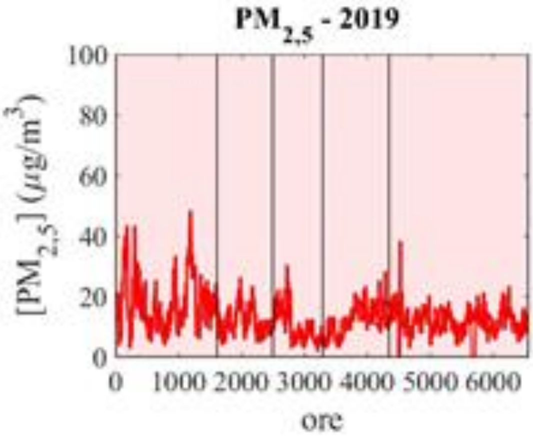
Ozone

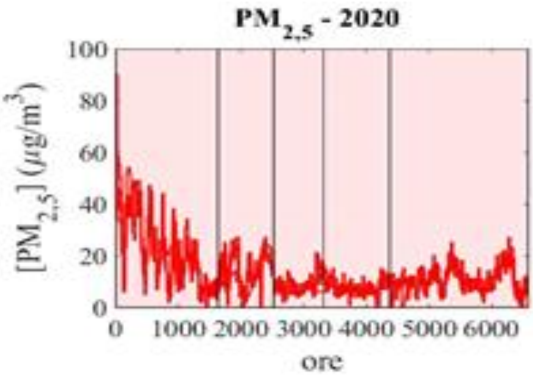
The trend in ozone concentration is somewhat different from that of other species. Its concentration depends on solar radiation, therefore increases in concentration are ob-served throughout the year. The effect of the reduction in vehicular traffic is not observed, since in the two years the average values of the periods are very similar to each other.





Particulate matter

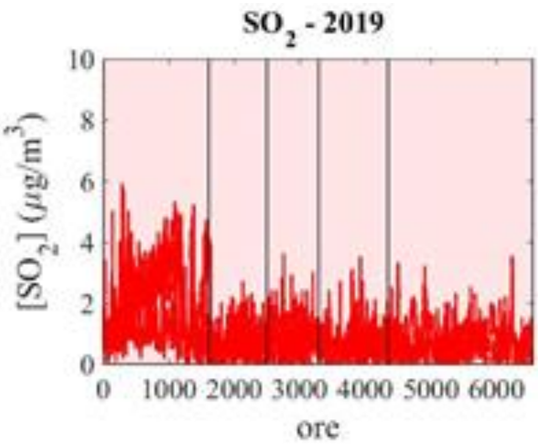


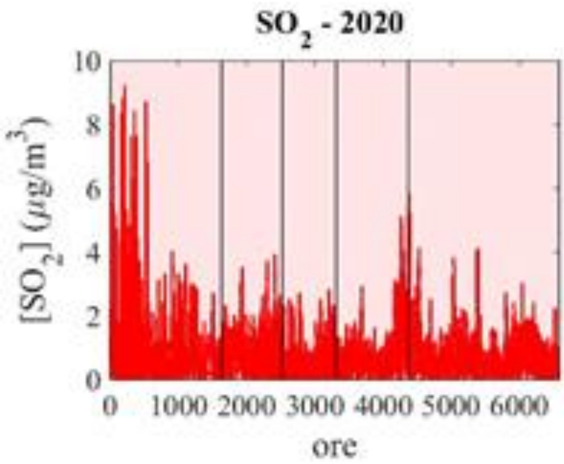


Particulate matter

The trend of the particulate matter (PM10 and PM2.5) does not provide particular information in this analysis. It does not seem to be affected by the decrease in traffic, even exceeding the average values of 2019, and remains practically constant throughout the year. The high values of the first period of 2020 may have the same significance as those seen for the other pollutants.

Observing the graphs, however, it can be noted above all how the particulate matter during the first period, in both years, still has higher values than the spring and summer ones. This may represent an origin of a fair part of the particulate matter from heating.





Sulfur dioxide

Sulfur dioxide is a chemical species that has no particular relevance in the urban context, since it has a predominantly industrial origin: in fact the recorded values are very low and in any case do not show a decrease linked to traffic during the lockdown. Instead, it is probable that these data testify to the achievement of a threshold value below which it is not possible to go.

Note: sulfur dioxide is detected by two out of ten control units, therefore the values obtained could give a rough estimate.

CONCLUSIONS

In the light of the results obtained, answers can be given to the starting questions.

First of all, having processed the data relating to 2019 and 2020 in different ways,

it has been verified that there is no direct correlation between climate data and traffic data, but a more or less rainy or windy period provides a set of lower or higher concentration.

Furthermore, given the lack of correlation between average traffic values and data on pollutants, it can be said that the concentrations recorded in periods without heating are not attributable to traffic alone, there could be other sources to take into consideration.

An interesting fact that emerged from this analysis, relating to the lockdown period of 2020, is that relating to the timing that the various species take to appreciate a lowering of their concentration, as well as an increase. Furthermore, it was possible to observe, for some species, such as particulate matter and sulfur dioxide, probable values beyond which it was not possible to go down. It is more difficult to give an estimate of the time required for lowering, since on average, for the contaminants this time (of the order of one month, in the case of long residence times), coincided with the last period of ignition of the warm ups.

This could be the demonstration that only a very extended period of traffic limitation can be useful in lowering concentrations in the city, given the times in which concentrations undergo significant decreases, and not a one-day period, such as blockades of the city. traffic and other measures imposed by the European Community, except for the absorption of peaks. Only some species, such as nitrogen oxides, need very short times to reduce the concentration, but the same times are those necessary for an increase up to usual values.

It is not able to intervene ex post in any way as this study demonstrates, it will be essential to continue the policy, which in the context of the ecological transition, is leading to the massive use of clean energy gradually abandoning fuels such as gas, diesel and petrol to improve the problem. pollution in urban areas.

The main objective for the reduction of air pollutant is to reach, thanks to the implementation of suitable mobility policies, an urban sustainable development, i.e. to improve traffic mobility conditions, to increase road safety and to decrease traffic caused by pollution and to re-qualify urban spaces. It includes rationalizing public space, safeguarding citizens' health and life quality, and preserving historical and architectural heritage.

In order to reduce the pollution in Italian cities and in particular in Rome, measures are needed to decrease the level of the various substances dispersed into the air. One of the main actions that can be performed is the reduction or elimination of the use of the most polluting cars, i.e. cars Euro 0, 1 and 2. As a matter of fact, Roma Capitale has imposed the circulation reduction of these cars permanently from December 15, 2015 [37].

Regarding the reduction of the pollutants due to buildings heating systems, it is necessary to replace traditional boilers with more efficient systems, such as condensing boilers. As a matter of fact, the condensing boilers allow to reduce the utilization of combustion and a consequence decrease of emission.

However, the boilers are only one element of the heating systems. Its efficiency depends on other elements such as distribution, emission and regulation. Using condensing boilers coupled with other high heating systems elements, can improve the total efficiency and reduce the environmental emission.

The Poincaré sections in Figure 15 gives a significant contribution to the modeling purpose: such as dynamical model (ODE) or regression approach (LUR) [see among many 38,39].

More specifically, the experimental analysis show a correlation between [C6H6] over [NO] and [C6H6] over [O3]. This aspects are well known for small scale zero-dimensional reactor, but for very large scale problems as the city domain is not commonly investigated. So a reduction of a three dimensional large scale process to zero-dimensional phenomenon as in homogeneous volume can be consider the first step for a mathematical model development by means of an ODE system as follows:

$$\dot{x}=f[x(t)] \qquad \text{where } x(t)=\{[NO],[O_3],[C_6H_6],\dots\} \tag{3}$$

This aspect is the fundamental task to predict the time evolution of the pollutant species generated within an urban domain.

Furthermore as result, can be clearly concluded that Rome has a strongly unsteady behaviour in terms of pollutant concentration. All-time series are positive skewed, indicating that some short time rare events, of pollutant concentration, have an order of magnitude bigger than the expected values. Such as intermittent behaviour, to the best of our knowledge, is not investigated in the literature available and must be taken into account for modelling purpose.

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