Assessing the environmental impact of car restrictions policies: Madrid Central case

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Abstract. With the increase of population living in urban areas, many transportation-related problems have grown very rapidly. Pollution causes many inhabitants health problems. A major concern for the International Community is pollution, which causes many inhabitants health problems. Accordingly, and under the risk of fines, countries are required to reduce noise and air pollutants. As a way to do so, road restrictions policies are applied in urban areas. Evaluating objectively the benefits of this type of measures is important to asses their real impact. In this work, we analyze the application of Madrid Central (MC), which is a set of road traffic limitation measures applied in the downtown of Madrid (Spain), by using smart city tools. According to our results, MC significantly reduces the nitrogen dioxide (NO_2) concentration in the air and the levels of noise in Madrid.

1 Introduction

According to the United Nations Populations Division, today, 55% of the world's population lives in urban areas. This proportion is expected to increase to 68% by 2050 [23]. This urban aglomerations are giving shape to new challenges from a social, economical, and environmental point of view, being mobility one of them. The fact is that mobility inside the city and inter-cities is a key aspect that determines the development of the urban areas.

The design of most of our cities prioritizes the use of motorized vehicles. This relegates the rest of uses and users with different negative impact over safety and health, as well as over well-being and development, especially for children and the elderly. For example, it has been demonstrated the causal link between the growth of car use and the reduction of children's access to public space in urban contexts, which critically affects their social and physical development [12]. Other authors demonstrate that eldery improve their independence and well-being in environments with safety walking access [13].

Another major concern derived of the rapid development of car oriented cities is the high generation of emisions (air pollutants and noise) and their impact on the inhabitants health [19]. Air pollution is the top health hazard in the European Union (EU) [8, 26] as it reduces life expectancy, loss of years of healthy life, and diminishes the quality of health. In the EU, it causes more than 400,000 premature deaths, being primarily associated with heart disease and strokes, followed by lung diseases and lung cancer. Noise pollution is also a major environmental health question; the European Environment Agency (EEA) estimates that environmental noise causes at least 16,600 cases of premature death in Europe each year [7]. Exposure to prolonged noise pollution can cause a range of health problems including annoyance, sleep disturbance, increasing hypertension, and cardiovascular diseases [2]. It can also have effects on children's cognition including communication difficulties, impaired attention, increased arousal, frustration, noise annoyance, and consequences of sleep disturbance on performance [10, 11].

As road traffic generates the referred problems (e.g., about 80% of the noise pollution is caused by cars [20]), reducing it seems to be an efficient strategy to improve urban livability and their inhabitants health. Accordingly, pedestrianization is a commonly implemented approach to this challenge. Pedestrianization can be defined as to convert a street into a car free space by excluding motor vehicles. It should be coupled with creation of effective public and non-motorized transportation facilities. Absolute pedestrianization is difficult to be implemented. Instead, authorities define road transportation limitation policies. For example,distribution and commercial vehicles may be allowed to enter in a pedestrianized area [16].

Many cities around the world started to shift toward non-car friendly access by implementing different plans and measures [16, 19]. However, changes on the spatial configuration of the city requires of a big investment that not all the council can afford. There are several studies that evaluate the impact of pedestrianization implementations [18, 19, 21, 24]. The findings of these studies highlight that this kind of measures have not only environmental health impacts. They positively affect tourism development, job creation, improving safety, enhancing the appearance of urban areas, etc. Fig. 1 shows the main benefits of pedestrianization in urban areas. Their conclusions are principally based on the use of surveys and urban simulation.

In this study, we analyze Madrid Central (MC) which has been implemented in Madrid (Spain), as a case study [1]. This low emissions zone (LEZ) gives continuity to dissuasive measures such as fine-tuning the circulation of certain license plates on alternate days or limitations of access to vehicles considered to be the most polluting, among others. But, does this measure have a positive impact over the reduction of pollution? How can we use smart city tools to take the best decision to evaluate benefits of this measure? The interest of this analysis is even bigger as there exists a controversial political use of this measure. Thanks to the virtues of smart city tools, we can analyze objectively the results of this kind of plans. Specifically, we take advantage of smart governance and transparency services to get data shared through open data platforms.

The main contributions of this work are: *i)* pointing out the potential of open data sources to evaluate the effect of car restrictions implemented in the cities; *ii)* analysing the environmental impact of the measures applied in MC; and *iii)* applying a multidisciplinary approach to assess mobility policies embedded in an

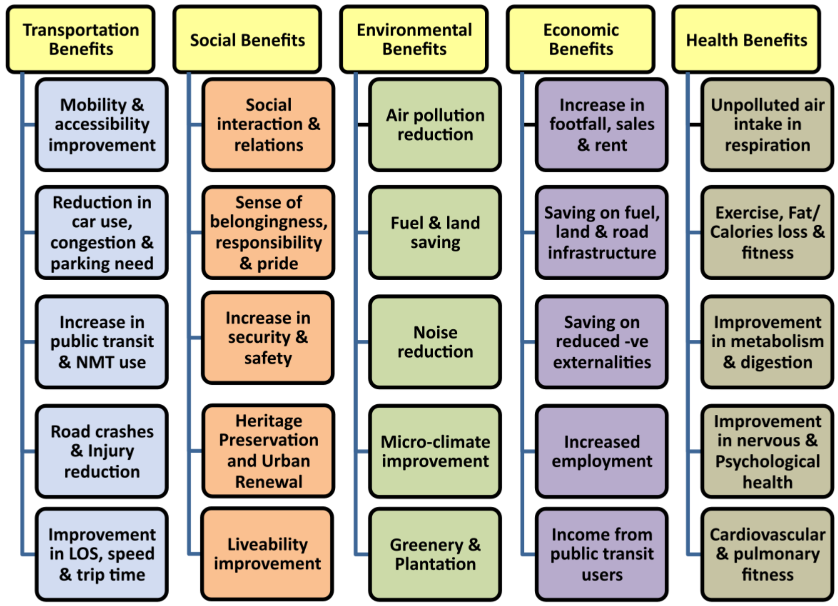


Fig. 1: Summary of pedestrianization benefits. Image created by Soni & Soni [19].

international framework of regulations and guidelines. Finally, nothing prevent us to apply the same approach to analyze other initiatives to deal with air quality, noise, and other challenges derived from urban growth.

The rest of the paper is orgaized as follows: first, we describe the goals, strategies and contextualization of MC, paying especial attention to the directives in which is embedded. Section 3 introduces the materials and methods used in this analysis. The evaluation of the air quality and noise based on the shared open data is shown in Section 4. Finally, Section 5 presents the conclusions and the main lines of future work.

2 Madrid Central: purpose, description and controversia

The concern over the air quality and noise across the EU leads to the adoption of different environmental and health directives. Those policies have the object to safeguard EU citizens from environment-related pressures and risks to health and wellbeing. Accordingly, emissions are monitored in every member state.

The European Commission adopted in 2013 a Clean Air Policy Package based on `Directive 2008/50/EC` [6] and `2004/107/EC` [5]. It points to the full compliance with the established air quality standards and set different objectives for 2020 and 2030. This EU air quality policy rests on three pillars: *i)* air quality standards; *ii)* national emission reduction targets established in the National Emissions Ceiling Directive; and *iii)* emissions standards for key sources of pollution, as the vehicles.

The EU directive about noise (`Directive 2002/49/EC`) [4] focuses on the determination of three main points: *i)* exposure to environmental noise; *ii)* ensuring that information on environmental noise and its effects is made available to the public; and *iii)* preventing and reducing environmental noise where necessary and preserving environmental noise quality where it is good. The directive of noise is not as exigent as the air quality one, leaving the limit or target values at the discretion of the States. However, it does clearly require the creation of noise maps and noise management plans for agglomerations with more than 100,000 inhabitants. In Spain, 63 municipalities have more than 100,000 inhabitants, being Madrid the biggest of them (3,266,126 people).

Regarding to the air quality and based on latest available data, the EU points that the transport sector is the largest contributor to nitrogen oxide emissions, and a significant contributor to particulate matter emissions. Several countries have exceeded repeteadly the PM_{10} and the NO_2, being Spain one of them. More specifically, the levels of pollution admitted by the EU were exceeded in the Spanish biggest cities (Barcelona, Madrid and Valencia). The main source of NO_2 is road traffic [14].

The EU demanded to Spain the reduction of these pollutants in the air, under the threat of taking the case before the European Court and the risk of important economic sanctions. This process is paralized in May of 2018 thanks to the adoption of certain measures to reduce pollutants, such as MC.

MC is a LEZ in Madrid, consisting in car access restrictions in a delimited area of the downtown (see Fig. 2). Those restrictions exclude residents of MC and authorized cars[3]. Otherwise, the access to this area requires vehicles to have an environmental sticker[4]. In other words, the measure seeks to eliminate transit traffic, which crosses but has no origin or destination in *Madrid Central*.

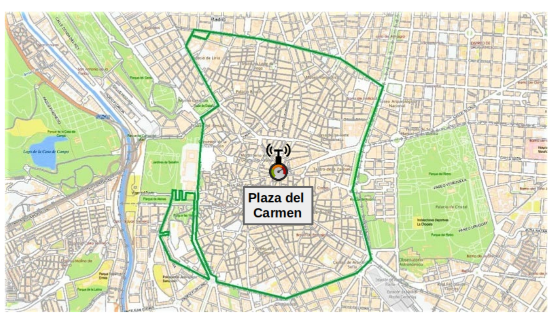


Fig. 2: MC area and the location of the sensor installed in Plaza del Carmen.

[3] People with reduced mobility; public transport; security and emergency services; car-sharing or moto-sharing; specific workers; distribution and commercial vehicles.
[4] There are no restrictions for vehicles labeled as 0 and ECO, but parking in the street for ECO vehicles is limited. B and C vehicles can only use car parks.

MC aims at improving air quality, but also responds to the idea of changing the uses of spaces in the city center, prioritizing the pedestrian one and reducing noise pollution. But as we said, its conformation mainly responds to ensure the objectives demanded by the EU. It should be pointed out that, thanks to this measure, Spain avoided to be brought to the European Court of Justice.

MC convers an area of 4,720,000 m^2, almost the entire *Centro* district, which is formed by the neighborhoods of *Palacio*, *Embajadores*, *Cortes*, *Justicia*, *Universidad*, and *Sol*. *Centro* district has 134,881 inhabitants, of which 12,377 are less than 17 years of age and 21,645 people are 65 years old or more. Those groups are more affected by noise and pollutants. Among other benefits referred to citizenship education, to stablish the perimeter of MC facilitates the understanding of zonal delimitation and aspires to introduce a behavioral change regarding the use of the car. MC is created by the *Ordenanza de Movilidad Sostenible* (October 5th, 2018) and the traffic restriction started on November 30, 2018. However, the fines for noncompliance did not started until March 16, 2019.

However, and despite of the fact that the European Union have told Spain to reduce their emissions under risk of fine, this restriction to the car use is suspended. After the elections (held on May, 26th 2019) the new goverment decided to apply a moratorium on fines from July 1st to September 30th 2019, approved under art. 247 of the *Ordenanza de Movilidad Sostenible*. This suspension leaded to the emergence of social movements claiming the paralization of this reversal based on the negative effects over health and environment, and a warning from the EU. After a contentious-administrative appeal filed by environmental groups, a judge has provisionally paralyzed this reversal of MC.

3 Materials and methods

In order to know more about the objective effects of MC, we analyze different indicators applicable to the dimensions of environmental pollution and noise. The source of data used in this study is provided by the Open Data Portal (ODP) offered by the Madrid City Council[5]. The data gathered by the sensor located in MC (*Plaza del Carmen*) is analyzed to evaluate the impact of the measures carried out (see Fig. 2). The temporal range of this study starts in December of 2016 and finishes in May of 2019, i.e., 30 months grouped in two periods: the 24 months previous to MC (named *Pre-MC*) and six months with the car restrictions (named *Post-MC*).

Following, we introduce the air pollutants evaluated, the outdoor noise metrics studied, and the methodology applied in the evaluation.

3.1 Air quality evaluation

The ODP provides the daily mean concentration of different air pollutants. The sensor located in MC evaluates six air pollutants: carbon monoxide (CO), SO_2, nitrogen monoxide (NO), NO_2, oxides of nitrogen (NOx), and O_3.

[5] Madrid Open Data Portal url: `https://datos.madrid.es/`

The pollutants with the strongest evidence for a public health concern, include particulate matter, SO_2, NO_2, and O_3 [26]. In fact, NO_2 itself caused 241,000 premature deaths among European citizens in 2015 and 2,515,000 of years of life lost [9]. Those pollutants (SO_2, NO_2, and O_3), are the ones we analyze, since those are the ones referred to in the guidelines published by the WHO [26] and in the regulations promoted by EU [8] (see Table 1). We have not data regarding particulate matter.

Table 1: WHO and EU maximum concentration of pollutants in the air.

pollutant	period	WHO guideliness	EU regulations
SO_2	24 hours	20 $\mu g/m^3$	125 $\mu g/m^3$
	1 hour	-	350 $\mu g/m^3$
	10 minutes	500 $\mu g/m^3$	-
NO_2	1 year	40 $\mu g/m^3$	40 $\mu g/m^3$
	1 hour	200 $\mu g/m^3$	200 $\mu g/m^3$
O_3	8 hours	100 $\mu g/m^3$	120 $\mu g/m^3$

3.2 Outdoor noise evaluation

As there is not a clear international regulation about the outdoor noise, we decided to evaluate this concern taking into account three variants of noise measurements: the equivalent sound pressure, the percentile noise, and the noise pollution (NPL) [17] levels.

The equivalent sound pressure levels (L_{eq}) can be described as the average sound level over a selected period. We study the L_{eq24}, that corresponds to the L_{eq} measured during the whole day (24 hours). The L_{eq} measurements are also required for intermediate periods (normally three within a 24 hour period) to determine how noise varies with time and hence community activities. Here, we evaluate the L_{eqD}, L_{eqE}, and L_{eqN}, which represent the L_{eq} during the day (from 7:00h to 19:00h), the evening (from 19:00h to 23:00h), and the night (from 23:00h to 7:00h), respectively. According to the Comunity of Madrid regulations [3], L_{eqD} and L_{eqE} should be lower than 65 dB and L_{eqN} lower than 55 dB.

The percentile noise levels (L_x) are the levels exceeded for x percent of the time, where x is between 0.1% and 99.9%. We evaluate the L_{10}, L_{50}, and L_{90}. The L_{10} takes account of any annoying peaks of noise. The L_{90} is extensively used for rating the outdoor background noise.

The NPL estimates the dissatisfaction caused by road traffic noise comprising the continuous noise level (L_{eq}) and the annoyance caused by fluctuations in that level. It serves as an indicator of the physiological and psychological disturbance of the human system due to the noise pollution in the environment [17]. NPL is equal to L_{eq} plus 2.56 times the standard deviation of the noise distribution. However, it is approximated by $NPL \approx L_{eq} + (L_{10} - L_{90})$.

From the OPD, we get monthly mean values of each metric. This data reports the A-weighted sound level readings to replicate the response of the human ear to the annoyance caused by road traffic noise. Thus, all sound levels referred here are in terms of A-weighted decibel (dBA).

3.3 Methodology

In order to evaluate the impact of MC, we compare the data sensed during Pre-MC and during Post-MC. As MC measures started in December of 2018, this would be consider the first month of every row (number 1). Consequently, November becomes the last one of every year considered (number 12).

The impact on the studied indicators is calculated according to the *gap* for the months M that MC has been active (Eq. 1). The set M is defined as M={*December, January, February, March, April, May*}. The $x_m^{Post-MC}$ and $\overline{x_m^{Pre-MC}}$ represent the average value of the indicator x sensed during month $m \in M$. The gap returns the average percentage of decrease or increase for the indicator x.

$$gap = \frac{1}{|M|} \sum_{m \in M} \frac{x_m^{Post-MC} - \overline{x_m^{Pre-MC}}}{x_m^{Post-MC}} \; \% \tag{1}$$

We use pairwise statistical tests to compare between both periods with a statistical significance of 99% (i.e., p-value<0.01). When the samples data sets are normally distributed, we use the *Student's t-test*, otherwise, we apply the *Mann-Whitney* non-parametric one.

Giving this data in a specific temporal ordering, it is possible to raise questions about how the indicators are likely to behave in the future [25]. Polynomial regression, which have been successfully used in road traffic prediction [22], is applied here to predict the general future trend in pollution (air and noise) after the implementation of the road traffic restrictions in MC.

These last type of analyses, i.e., statistical tests and regressions, use the highest granularity of the data provided by the ODP: daily concentration of air pollutants and monthly levels of noise.

Finally, there are cases (data sensed) in which the concentration of the air pollutants exceed the maximum/threshold defined by WHO and/or EU (see Table 1). and the mean excess quantity. In this cases, we evaluate both dimensions in which this value is exceeded: the period of time and the mean excess quantity.

4 Results and discussion

This section evaluates the results of the actions taken in MC in terms of air quality and noise based on the data sensed.

4.1 Air quality

Table 2 reports the minimum (min), the maximum (max), the mean, the normalized standard deviation, and the gap for the concentration of the pollutants sensed in MC. As these measures are normally distributed, we apply the Student's t-test to asses the statistical significance of the difference between Pre-MC and Post-MC air quality. Fig. 3 shows the mean and the standard deviation of the concentration of the pollutants by months. Notice that for the Pre-MC months (in red), the results cover a wider amount of time, corresponding to two different years. Fig. 3 also shows the bloxplot of the concentration of the air pollutants for the months that coincide Pre-MC and Post-MC (i.e., from December to May).

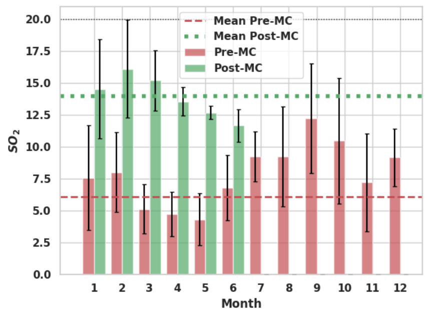
Table 2: Summary of the air pollutants sensed. The star($\star$) in the last column indicates there is statistical difference between periods analized (p-value<0.01).

metric	**Pre-MC**			**Post-MC**			**gap**
	min	**mean±stdev**	**max**	**min**	**mean±stdev**	**max**	
SO_2	1.00	7.82±50.37%	22.00	10.00	13.97±21.28%	24.00	$\star$56.14%
NO_2	15.00	46.92±31.27%	96.00	8.00	39.60±50.42%	96.00	$\star$-35.65%
O_3	1.00	39.31±52.32%	89.00	5.00	41.20±48.94%	84.00	22.67%

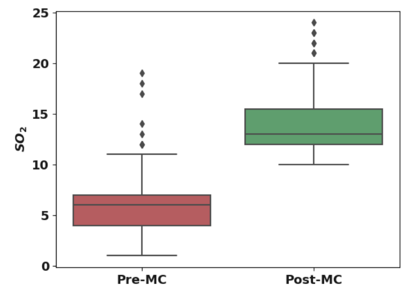
The concentration of SO_2 increases during Post-MC months in comparison to Pre-MC (gap=56.14%). Fig. 3.a1 shows the concentration of SO_2 for the time previous to MC (from June to November) is close to the Post-MC one. This may be explained by the influence of the meteorological conditions (i.e., wind direction and speed, atmospheric pressure, temperature, and relative humidity) possibly affecting the result in unexpected directions.

For both periods, the mean concentration does not exceed the threshold defined by WHO and EU (20 $\mu g/m^3$), however the maxima values do (see Table 2). In Pre-MC the threshold is exceeded during 0.43% of the time by 0.01 $\mu g/m^3$ and in Post-MC during 3.91% of time by 0.09. Thus, this excess is exceptional and negligible, so the EU has not found it problematic in Spain.

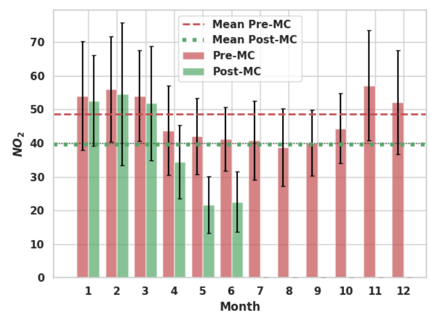
Focusing on NO_2, which is the pollutant that almost lead Spain to the European Court, its concentration is significantly reduced in more than one third (gap=-35.65% and Student's t-test p-value<0.01). The mean NO_2 concentration for Post-MC is 39.60$\mu g/m^3$, below the threshold established by WHO and EU (40 $\mu g/m^3$). As it can be seen in Fig. 3.b1, the concentration of NO_2 exceeds during several months the maximum one allowed by WHO and EU for both periods (Pre-MC and Post-MC) but with important diferences. During Pre-MC the threshold is exceeded during 64.01% of the time by 9.72 $\mu g/m^3$. During Post-MC the threshold is exceeded, but it does during less time and with a smaller value: 45.81% of the time by 8.26 $\mu g/m^3$. However, it is notizeable that there is a clear downward trend in the concentration of NO_2 after the application of road traffic limitation (see Fig. 3.b1). Taking into account independently each month, the maximum reduction of NO_2 occurs in April with a concentration of 22.54 $\mu g/m^3$ (gap=-93.93%).



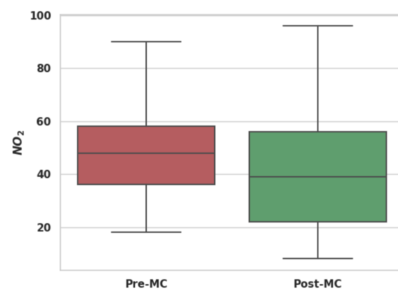
a1) SO_2 mean and standard deviation.



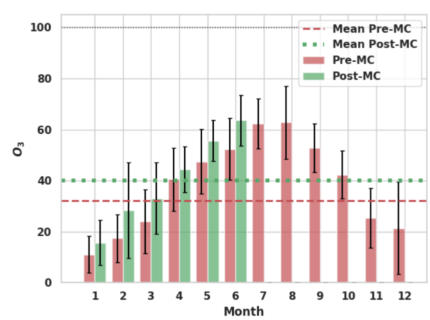
a2) SO_2 boxplot.



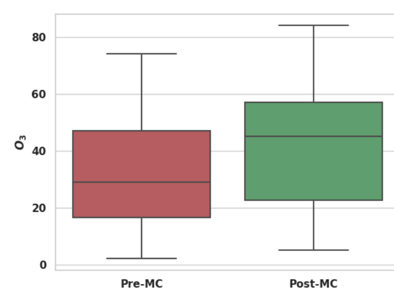
b1) NO_2 mean and standard deviation.



b2) NO_2 boxplot.



c1) O_3 mean and standard deviation.



c2) O_3 boxplot.

Fig. 3: Mean and standard deviation of the concentration of the air pollutants gropued by months (left side). The red dashed and greed doted lines show the mean value for the months from one to six for Pre-MC and Post-MC, respectivelly. Boxplot of the concentration of the pollutants (right side).

Fig. 4 illustrates the trend of NO_2 using the data grouped by weeks. According to the polynomial regression of grade 10 (black dashed line), NO_2 concentration increases during colder seasons and decreases in warmer ones. In turn, the linear regression (black line) shows a declined trend over time for this air pollutant. The behaviour of this variable (concentration of NO_2 in the air) under the application of MC measures point that the traffic restriction has a positive effect in the air quality. Therefore, MC is effective both for this environmental dimension and to avoid fines from the international community.

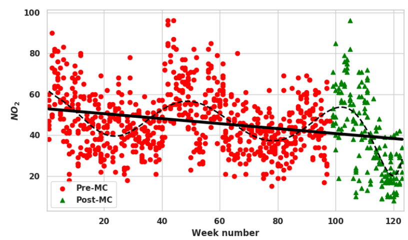


Fig. 4: NO_2 concentration linear regression. Red dots represent the Pre-MC data and the green triangles show Post-MC data grouped in weeks. The black line represents the general trend according to the linear regression.

The concentration of O_3 does not show a significant difference for both periods of time (see Fig. 3.c1 and c2). All the O_3 measures are bellow the maximun defined by WHO and EU (100 and 120 $\mu g/m^3$, respectively). The concentration of this pollutant shows an increase during Post-MC (gap=22.67%). This increment can be due by the oxidation of NO, i.e., the chemical reaction of O_3 and NO that forms NO_2 and O_2, which occurs in urban areas [15]. As the road traffic limitation reduces the concentration NO, the portion of O_3 that reacts with NO is lower. Therefore, the levels of O_3 do not decrease, and subsequenty, the concentration of NO_2 produced by the oxidation of NO is lower. In short, this upturn can be a chemical consequence of the reduction in the air of other components concentration.

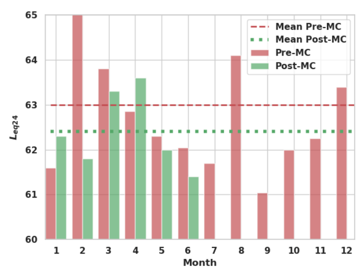
Finally, the evaluation of the SO_2, NO_2, and O_3 indicates that the final environmental balance may not always coincide with what was intuitively expected.

4.2 Noise polution

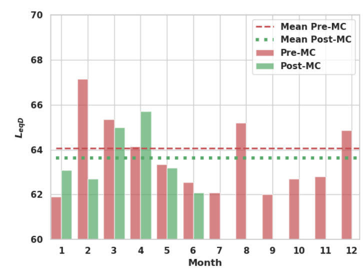
Table 3 reports the min, max, the mean, the normalized standard deviation, and the gap for the levels of noise in MC. As the levels of noise are not normally distributed and the size of the samples is low (>30), we apply the Mann-Whitney test to asses the statistical significance of the difference between Pre-MC and Post-MC noise pollution. Fig. 5 illustrates the mean of a representative set of different levels (L_{eq24}, L_{10}, L_{90}, and NPL) grouped by months. Fig. 6 shows the boxplots of the L_{eq24}, L_{10}, and L_{90} levels of noise.

Table 3: Summary of the sensed levels of noise. The star($\star$) in the last column indicates that there is statistical difference (p-value<0.01).

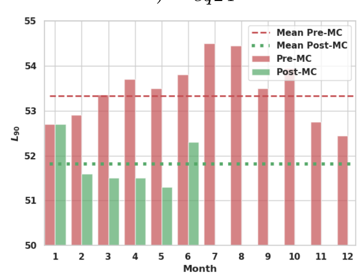
metric	**Pre-MC**			**Post-MC**			**gap**
	min	**mean±stdev**	**max**	**min**	**mean±stdev**	**max**	
L_{eqD}	61.30	63.68±3.56%	68.70	62.10	63.63±2.01%	65.70	-0.72%
L_{eqE}	60.40	61.96±1.24%	63.80	60.60	61.18±0.65%	61.80	$\star$-1.51%
L_{eqN}	59.00	60.57±1.32%	62.80	59.70	60.30±0.80%	61.00	-0.47%
L_{eq24}	60.50	62.70±2.66%	66.50	61.40	62.40±1.27%	63.60	-0.96%
L_{10}	63.10	64.53±1.60%	68.60	63.40	63.88±0.66%	64.50	$\star$-1.51%
L_{50}	57.60	58.66±0.77%	59.60	57.20	57.78±0.78%	58.60	$\star$-1.47%
L_{90}	52.40	53.46±1.46%	55.00	51.30	51.82±0.97%	52.70	$\star$-2.92%
NPL	70.70	73.77±3.40%	80.90	72.60	74.47±1.69%	76.50	-0.07%



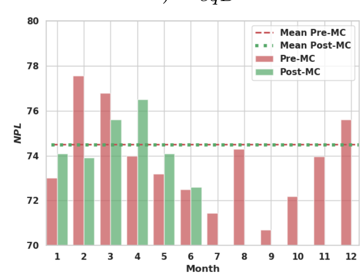
a) L_{eq24}



b) L_{eqD}



c) L_{90}

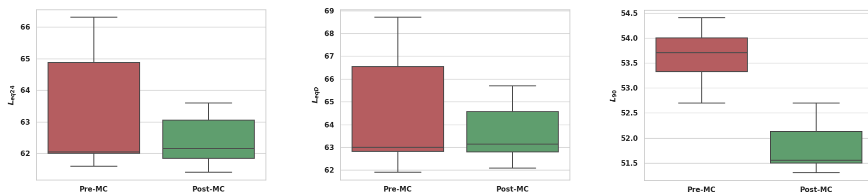


d) NPL

Fig. 5: Mean levels of noise analyzed here gropued by months. The red dashed and greed doted lines show the mean values for Pre-MC and Post-MC, respectivelly.

Regarding the equivalent sound pressure levels (L_{eqD}, L_{eqE}, L_{eqN}, and L_{eq24}), the highest difference between Pre-MC and Post-MC is given by the evening noise (L_{eqE}). This noise is reduced by 1.51% and it is statistically lower than evaluated one during Pre-MC (see Table 3). Among them, the L_{eqN} levels show the lowest decrease. This is mainly explained by the different car affluence during night time, as the nights experience the lightest road traffic flows.

As it can be seen in Fig 6.a, even if there is not a statistical difference regarding to the L_{eq24} level of noise between both periods, during Post-MC this level of noise is generally lower than during Pre-MC. This metric *averages* the whole noise evaluated during the 24 hours of the day. Therefore, in general the noise is lower during MC.



a) L_{eq24} b) L_{eqD} c) L_{90}

Fig. 6: Boxplots of the noise data metrics for both periods of time analized.

During Post-MC, the reduction of the day noise pollution allows the L_{eqD} be lower than 65 dB, which is the threshold proposed by Comunity of Madrid regulations (see Section 3.2). This value is exceeded just during some periods of March (month number 4 in Fig. 5b).

Focusing on the percentile noise levels (L_{10}, L_{50}, and L_{90}), Pre-MC and Post-MC differences are statistically significant. The highest improvement is shown by L_{90} (see Fig. 6.c), which represents the residual background levels of noise of the urban area analyzed (gap=-2.92%). As the continuous road traffic flow is one of the main sources of the backgroung noise, its reduction provoques a decrease on this type of noise. According to the Mann-Whitney test results, the significance reduction of L_{10} is lower than for the other two percentile levels (p-value<0.05). The L_{10} considers annoying peaks of noise. This type of maxima levels of noise are reduced by 1.51% with a mean value during Post-MC of 63.88 dBA.

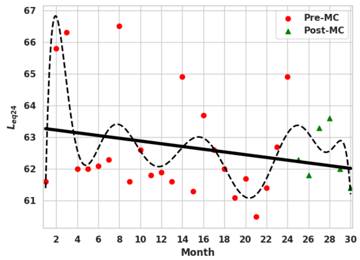
There is not a significant reduction of NPL (see Table 3). This is principally because this metric depends on L_{eq24} and the difference between L_{10} and L_{90}. On the one hand, there is not a significant difference in the L_{eq24}. On the other hand, both percentile noise levels are reduced during Post-MC. However, the reduction of L_{90} is grater, and therefore, the difference between them L_{10} and L_{90} increases. For example, if we substract the mean values of L_{10} and L_{90} we get that for Pre-MC 64.53-53.46=11.07 dBA and for Post-MC 63.88-51.82=12.06 dBA.

Fig. 7 illustrates the trend of some representative levels of sound (L_{eq24}, L_{eqD}, L_{90}, and NPL). According to the polynomial regression of grade 10 (black dashed line), there is a reduction of the equivalent levels of noise during the months between 19 and 22. In turn, according to the linear regression (black line), the noise in MC is being reducing over the time with MC actions.

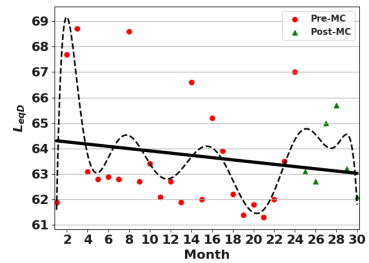
Finally, it is clear that the limitation of road traffic flows reduces all the different noise pollution metrics in MC, according to the sensed data.

4.3 Global discussion

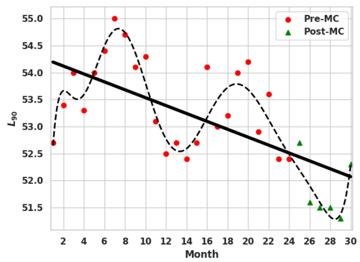
According to the analysis carried out, MC has reduced concrete pollutants in the air and in the sensed levels of noise. Specifically, regarding the air quality, the lowering of NO_2 is a very positive result. As we stated in Section 2, this is the component of pollution which affects health the most, increassing bronchitis,



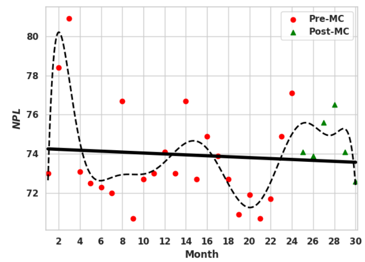
a) L_{eq24}



b) L_{eqD}



c) L_{90}



d) NPL

Fig. 7: Noise sensed linear regression. Red dots represents the data sensed during Pre-MC and green triangles the ones sensed during Post-MC grouped in months. The black line represents the general trend according to the lineare regression.

asthma and lung problems especially among the children and the older people. Besides, this is the component which lowering was specifically required to Spain by the EU. Accordingly, the reduction of this pollutant is extremely positive, not just having a positive effect for health but fulfilling so the international directions and so, avoiding the risk of fine.

Secondly, as the road traffic is the predominant source of noise pollution in urban areas, it was expected a reduction on all the levels of noise. This was proved to be true. However, and this is relevant, the levels of noise during the night are still higher than the threshold proposed by the Comunity of Madrid [3]. This should be a question to consider in the development of future actions.

5 Conclussions and future work

The quickness of the urbanization process brings new pollution problems, among others. This requires quick responses to create sustainable societies from an environmental, economical, and social points of view, as well to create inclusive spaces. A reliable diagnosis is key to address such challenges. Smart city initiatives, along with open data solutions and smart technologies have proved to be invaluable tools of analysis, helping decision making and leading to the best outcome for the city.

In this work, we evaluate data from ODP to evaluate the real impact of MC in terms of environmental benefits and acomplishment of international directives. Despite of the lifespan of MC, the measures proved to be effective addressing emission problems (reducing NO_2 and noise). These results may be used as a point to oppose the decission of removing MC by the new government.

The lack of use of open data standards in OPD and the poor documentation found hardeness the analysis capacity for this type of studies. For example, we have found data with different granularity for the same indicators (i.e., noise).

The future research lines are: *i)* analysing the impact of MC not just in the downtown but in the whole city of Madrid *ii)* new multivariable analysis taking into account new data (e.g., metheorological conditions); *iii)* evaluating MC (or MC-like) measures considering new dimenssions (such as, morbidity, economical impact, use of spaces, mobility behavoural changes); and *iv)* studying effects on espcific population groups (e.g., children and the elderly).

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