The Impact of the Pandemic Due to Covid-19 On Mobility and Environment

Luis Elvas, Bruno Mataloto and Joao Ferreira

Abstract— According to Google News, the Covid-19 pandemic, affected around 530 million people, which is approximately 15% of the world's population. Given the rapid spread and mutability of the virus, it was found to have a major influence on mobility and the environment worldwide. Thus, it becomes relevant to evaluate the changes related to the displacements made by the Portuguese. Through this analysis, it will also be possible to ascertain the impact of the emissions of pollutant gases into the atmosphere, throughout the period affected by the effects of the pandemic.

Keywords— Covid-19, Machine Learning First Section.

I. INTRODUCTION

Given the measures to combat Covid-19 imposed by the Portuguese government, namely mandatory containment, it is expected that there will be a decrease in both the mobility in Lisbon is expected to decrease, as well as the emissions of NO2, one of the main main atmospheric pollutants.

In order to respond to the challenge and to obtain a more in-depth study, we will carry out a concentration forecast for the following year, more specifically between March 2022 and March 2023.

The choice of this theme for this study was based on the need to understand the impact of the pandemic beyond health. Given this, through the visualization of the data provided, it is hoped to obtain some information about the effect caused on the environment and on mobility.

Taking into account the objective of the challenge launched by the Lisbon City Hall, it was considered to adopt a methodology capable of structuring the whole process carried out throughout of this project. In this sense, the CRISP-DM methodology will be used since it allows the project's progression of the project in a phased manner. Thus, the following stages will be covered: Business Understanding, Data Understanding, Data Preparation, Modeling, and Evaluation.

In order to complement the study and add value to it, a dashboard will be a dashboard that will allow the visualization of the graphics performed, in a dynamic and updated.

Luis Elvas, Bruno Mataloto and Joao Ferreira, Instituto Universitário de Lisboa (ISCTE-IUL), ISTAR, 1649-026 Lisboa, Portugal

II. LITERATURE REVIEW

Air pollution is a problem that affects the environment (climate change, for example), human health (respiratory diseases, throat irritations, among others), and can decrease visibility or cause unpleasant odors [18].

Nitrogen dioxide (NO2) is a major air pollutant that results from burning fossil fuels at high temperatures, with automobile traffic being a major cause [14].

In addition to nitrogen dioxide, there are four other pollutants that have an influence on air quality, these being sulfur dioxide (SO2), ozone (O3), and PM10 or PM2.5 particles (particles of diameter 10 µm or less and 2.5 µm, respectively) [16].

Airborne particulate matter (PM) is not a single pollutant, but a mixture of many chemical species. Particulates vary widely in size, shape, and chemical composition. These are defined by their diameter for the purposes of air quality regulation. Those with a diameter of 10 µm or less (PM10) are inhalable to the lungs and can induce adverse health effects. Fine particles are defined as particles with a diameter of 2.5 µm or less (PM2.5) [4].

That said, it was found that the indicator used to assess air quality, is the annual average of NO2, a value that is obtained, based on the hourly concentrations measured at each station. Additionally, it was possible to understand that most of the future objectives in the field of air quality improvement, by the European Union, are the reduction of NO2 and PM10 levels [6].

According to information on the Lisbon City Council website, the effects of nitrogen dioxide (NO2) are one of the concerns in the environmental management of cities, namely in the city of Lisbon. In addition to this, the City Council states that over the past few years, the concentration of NO2 in the city of Lisbon has been decreasing (Information from November 2020). Although this decrease is positive, NO2 is still one of the most worrying pollutants for this municipality [2].

As of November 2021, the European Commission has taken Portugal to the Court of Justice of the European Union for poor air quality caused by high levels of nitrogen dioxide (NO2). According to a communiqué from the EU executive, Portugal has recorded continuous and persistent excess of the annual limit value of nitrogen dioxide in three air quality zones: Lisbon North, Porto Litoral and Entre Douro e Minho [10]. Nitrogen emissions are mostly produced by the transport sector (about 36%), followed by electricity generation (26.5%) [5].

https://doi.org/10.17758/EIRAI19.F0623133

This fact can also be corroborated by a news article written by Lusa, where it is stated that the pollution generated by traffic is the one that most damages the quality of the air. In addition, the same news report mentions that Portugal is one of the countries with violations to the standards declared by the European Union regarding air quality. Still, Portugal reports road traffic as the only reason for violation of the decreed standards [9].

Additionally, by analyzing information provided by the Lisbon Municipality, it was possible to understand that, on average, a driver in the city of Lisbon spends 32% of his time driving in traffic queues, which is equivalent to 42 minutes daily [3].

Considering the information present in the *Diário de Notícias*, a reduction in NO2 concentration was verified by comparing data from the city of Lisbon between February 20 and April 9, 2020. In Spain, it was observed that the containment did not significantly reduce air pollution. However, NO2 levels showed a considerable decrease which results in a positive impact in most cities [8].

Similarly, it was found that places such as China and India became *smog-free* due to containment. In perspective, in the city of Lisbon there was a decrease in the amount of NO2 during the containment period of 80% [17].

For the first time, the city of Lisbon was able to meet the annual limit value for nitrogen dioxide (NO2), the compound associated with traffic. According to a report by TomTom, it was found that traffic in Lisbon alone dropped by 30% in 2020, when compared to the previous year [11].

III. CRISP-DM Methodology

3.1. Business Understanding

In order to answer the problem proposed by the Lisbon Chamber, it was necessary to establish several more specific objectives, in order to evaluate the progress of the work developed. In this sense, the following objectives were established:

- Evaluate the evolution of the NO2 concentration.
- Analyze the traffic in the Lisbon area.
- Correlation between NO2 descent and traffic.
- Predict the NO2 concentration for 2023.

Under Challenge #49, the Municipality of Lisbon provided data on NO2 concentrations, collected in 6 sensors scattered throughout the city of Lisbon. Besides these, data were also provided regarding the traffic in the city, collected by Waze application, and meteorological data collected by IPMA. After the 1st feedback meeting, the City Council recommended the use of data present in the Lisboa Aberta website.

These contained information about the concentration of pollutants such as NO2 and traffic, captured by 80 sensors distributed throughout the city.

When analyzing the datasets related to the Waze and IPMA data, it was understood that there was a lack of information, so it was decided not to use them. In order to corroborate this decision, the procedures carried out before their exclusion (analysis and processing of the datasets) are attached.

3.2. Data Understanding

Dataset NO2

In order to study the effects of Covid-19 on mobility and the environment, the three datasets provided by the Municipality of Lisbon were analyzed. The first one for the year 2019, the second one for the year 2020, between January and September 30, and the last one for the period between October 1, 2020, and October 30, 2021, containing information about NO2 concentration.

The 2019 and 2020 datasets contain 8760 and 31279 rows, respectively, and feature 7 and 4 columns. The dataset from October 1, 2020 and October 30, 2021 has 39446 rows and 4 columns.

In a first phase, the relevant variables were selected, based on the defined objectives:

- (µg/m^3)\t: NO2 value registered in the following zones: Avenida da Liberdade, Beato, Entrecampos, Olivais, Restelo, Santa Cruz de Benfica.
- Date.

Open Lisbon Dataset

Considering the relevance of the information portrayed in the data contained in the Open Lisbon website, we proceeded to the analysis of its metadata. By doing so, it was possible to access data generated by 80 sensors distributed throughout the city of Lisbon. By grouping the information obtained from each of these it is possible to access data about several pollutants (NO2, Ozone, PM10, PM25, ...) and about traffic (traffic intensity).

Through the metadata it was also possible to understand that to access the data it would be necessary to extract them, sensor by sensor, in a selected time interval. In Table 1 you can see an example of the structure of each of the databases used, in this case referring to the concentration of NO2.

TABLE I
First 5 lines of the database about NO2 present in Lisboa Aberta website

	id	value	par	datetime	hour
0	QA0NO20001	59	QA0NO200	2022-02-08	9
1	QA0NO20001	71	QA0NO200	2022-02-08	8
2	QA0NO20001	65	QA0NO200	2022-02-08	7
3	QA0NO20001	57	QA0NO200	2022-02-08	6
4	QA0NO20001	50	QA0NO200	2022-02-08	5

3.3. Data Understanding

Dataset NO2

The data for 2020 and 2021 were structured differently, because instead of having a column for each location, there was only one column with all this information. Given this, we proceeded to transform them so that it was possible to compare them with the 2019 data. Subsequently, they were concatenated, giving rise to a database containing information on NO2 levels between 2019 and 2021.

Next, the missing values were treated, corresponding to 15.73% of the dataset (25929 NA's). Thus, each of the NA's was replaced by the average NO2 level of each station, for the respective date.

Additionally, the date variable was transformed to the datetime type, and a new column was created where only the time is shown.

After the procedures performed previously, there were 115 nulls and 2 duplicate values, so it was necessary to remove them, in order not to negatively influence their analysis. Finally, there were no outliers.

After transformation and concatenation, the final dataset has 23437 rows and 8 columns.

Open Lisbon

In order to increase the robustness of the analysis, it was considered pertinent to use the data available in the Lisboa Aberta website. To do so, we proceeded to extract them, defining the indicator, parameter, sensor location and desired time interval. Thus, through the link below it is possible to see how these parameters are defined. 'https://opendatacml.qart.pt/measurements/QA0NO20001?startDate=201901010000&end Date=202202010000

Contrary to what was intended, it was only possible to access data from the time interval between 2021-06-01 and 2022-01-31.

Given this, the following parameters were used for all existing sensors:

- 0VTH - Hourly Traffic Volume.
- 0NO2 - NO2.
- 00O3 – Ozone.
- 00CO - Carbon Monoxide.
- PM10 - Particles with a diameter of less than 10 µm.
- PM2.5 - Particles with a diameter of less than 2.5 µm.

Then, we proceeded to the treatment of the datasets mentioned above, in order to ensure their uniformity. That said, the missing values (-99) and nulls were removed, so as not to influence future analyses. In addition, outliers were treated using the Tukey method, which is based on interquartile intervals [7].

3.4. Visualization

Analysis of Pollutants

Once the data analysis and treatment were finished, it became relevant to proceed to their visualization. In order to verify if NO2 is the most predominant pollutant in the city of Lisbon, we carried out 4 heatmaps for the following pollutants: NO2, Ozone, PM10 and PM2.5, Figure 1 to 4, respectively.

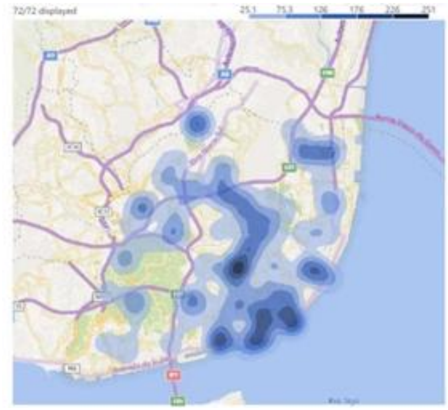

Fig. 1 Average NO2 Concentration in Lisbon

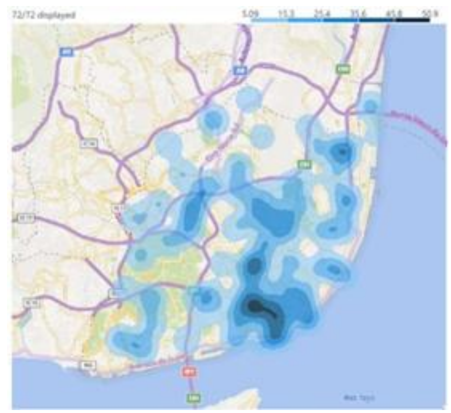

Fig. 2 Average Ozone Concentration in Lisbon

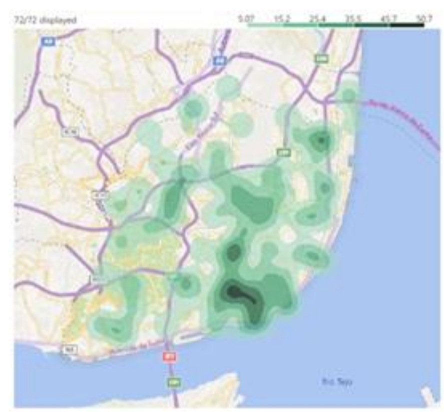

Fig. 3 Average PM10 Concentration in Lisbon

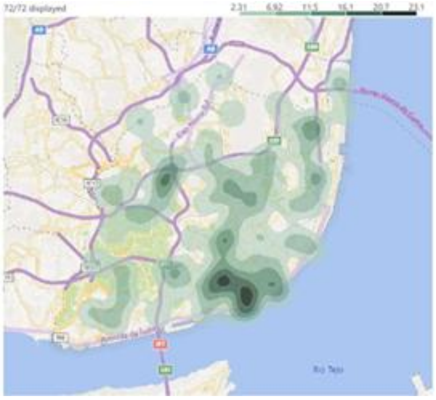

Fig. 4 Average PM2.5 Concentration in Lisbon

By analyzing the figures presented above, it is noticeable a greater density of the colors present in Figure 1, referring to the concentration of NO2. Thus, the results obtained coincide with the initial expectations, being for this reason the driving factor of this study.

Given this, it was considered pertinent to analyze the evolution of the NO2 concentration throughout the day.

Fig. 5 NO2 Concentration over 24h

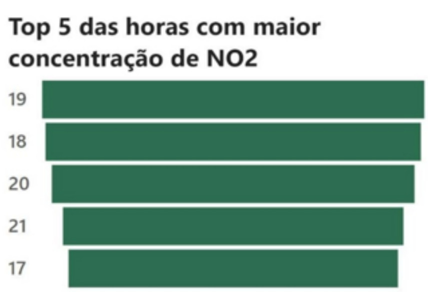

Fig. 6 Times when the NO2 Concentration is highest

As expected, the peaks of NO2 concentration coincide with peak hours (left side of Figure 5). Besides this, it was also considered relevant to analyze the hours whose NO2 emission registers more alarming values. Having said this, it was found that late afternoon/evenings present the highest concentrations of NO2. (right side of Figure 5).

NO2 Concentration in Lisbon

Having defined the NO2 concentration as the object of study, it became pertinent to visualize, through satellite images, its variation in the period between July 2021 and February 2022.

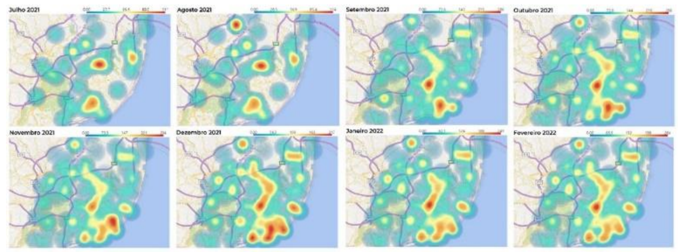

Fig. 7 Variation of NO2 concentration between July 2021 and February 2022, in Lisbon

Analyzing the above figure, it was found that until the end of the year 2021, the concentration of NO2 showed a significant increase, with the highest peak in the month of December (Figure 7). However, in the beginning of the year 2022, there was a sharp decrease in NO2 concentration, which may be explained by the high amount of Covid-19 positive cases in Portugal in those months (Figure 8) [12].

This relationship can be established due to the fact that positive cases require prophylactic isolation, which implies a decrease in mobility. Additionally, according to Público, 70% of confirmed cases in Portugal occur in the Lisbon and Tagus Valley Area, which makes the figure below even more impactful [13].

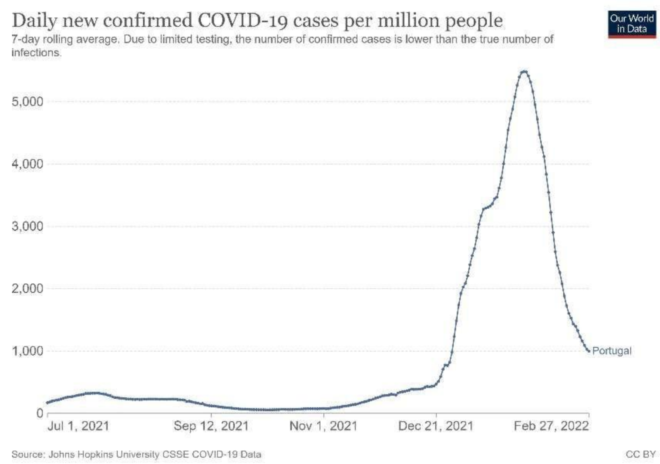

Fig. 8 Covid -19 Positive Cases between July 2021 and February 2022 in Portugal

Traffic in Lisbon city.

In order to analyze the traffic in the city of Lisbon, we visualized the variations of traffic concentration, for the period between August 2021 and February 2022 (Figure 9).

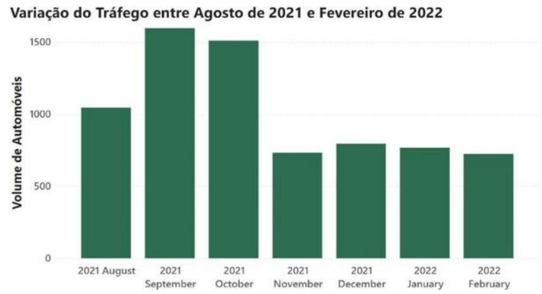

Fig. 9 Car Volume between August 2021 and February 2022, in Lisbon

However, when comparing the information in Figures 7 and 9, there is some inconsistency with respect to the months of November and December. This can be explained by the fact that there are only 5 sensors that record the volume of cars, compared to 80 sensors that record the concentration of NO2.

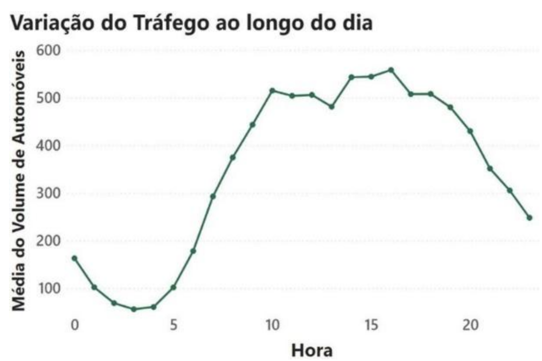

Fig. 10 Automobile Volume throughout the day in Lisbon

After analyzing the car traffic per month, it became pertinent to check the variations in car volume over the course of a day. As can be seen in Figure 10, the periods between 10 am and 7 pm do not present significant variations. However, the values shown do not correspond to those expected, since during peak hours there is no sharp peak (between 7am-9pm and between 5pm-7pm).

NO2 concentration in 6 zones of Lisbon city

In order to complement the data on NO2 concentration, with data prior to 2021, we used a dataset provided by the City Hall with these records, referring to 6 areas: Avenida da Liberdade, Beato, Entrecampos, Olivais, Restelo and Santa Cruz de Benfica. Given this, we proceeded to the analysis of the annual average of NO2 concentrations between 2019 and October 1, 2021.

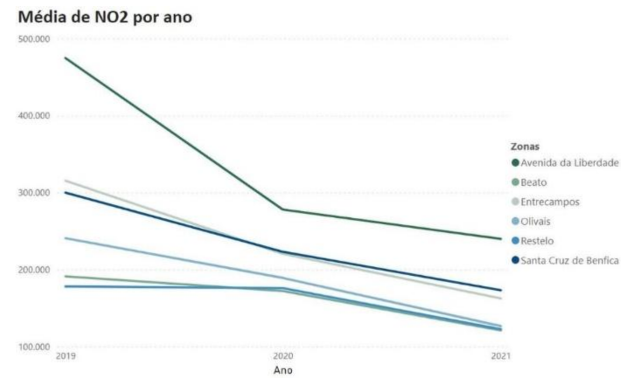

Fig. 11 Average NO2, between 2019 and 2021, in 6 zones of Lisbon

It is notable that Avenida da Liberdade presents the highest NO2 concentration compared to the other zones. These values can be explained by the high traffic characteristic of this avenue. However, it showed the sharpest decrease in the period between 2019 and 2020.

In the year 2021, the downward trend previously evidenced continued, but in a more subdued way. On the other hand, the Beato and Restelo areas are those that show a lower amount of pollution, i.e., lower NO2 concentration (Figure 11).

Over the years, there is a decreasing trend regarding the amount of NO2 in these areas. This can be justified by the measures to combat Covid-19, namely containment, which led to a decrease in mobility in the city of Lisbon.

According to Decree-Law 102/2010 there is a limit value for the average hourly concentration of NO2 which is 200 µg/ma. This value cannot be exceeded, in the same location, more than 18 times per calendar year. In addition, there is a maximum limit value of 40 µg/m^3 for the annual average concentration of NO2.

Taking into account the prominence presented by Avenida da Liberdade, in terms of concentration of NO2 it was considered necessary to verify that this zone met the pre- established requirements of the Decree Law presented above.

TABLE II

HIGHER NO2 CONCENTRATION, BETWEEN 2019 AND 2021, AT AVENIDA DA LIBERDADE

Momentos onde a concentração de NO2 excedeu o limite decretado por lei, na Avenida da Liberdade

Month	Concentração de NO2	Year	Day	Hour
February	200,40	2020	5	19
January	201,40	2019	8	17
October	202,20	2019	10	18
May	213,80	2019	31	23
July	223,10	2019	11	16
July	236,30	2019	11	17

By analyzing Table 2, it was found that during the analyzed time interval, Avenida da Liberdade exceeded the maximum limit of 200 µg/ma only 5 times. In this sense, although the established maximum value was exceeded, this fact did not occur more than 18 times in a calendar year, so no illegality occurred.

3.5. Modeling

Taking into account that Avenida da Liberdade shows the most alarming values regarding NO2 concentrations, it was considered relevant to predict the NO2 levels for the following year. For that, we used the data from Lisboa Aberta and the data provided by the City Hall, in order to add value to the prediction.

That said, we concatenated the data for sensor 76 (Avenida da Liberdade - Restauradores) from October 2, 2021, to February 29, 2022, and the Chamber data for Avenida da Liberdade from January 1, 2019 to October 1, 2021. The data from this sensor was filtered in order to be included after the end of the Chamber data.

Next, we used the package prophet, an open-source library used for univariate time series prediction, which was developed by Facebook. [15].

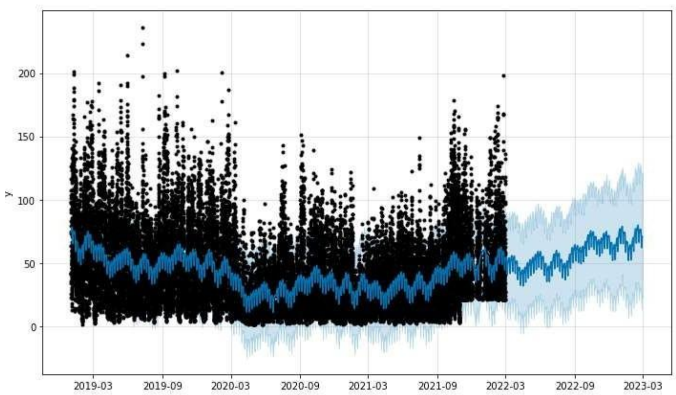

Fig. 12 Prediction of NO2 Concentration variation for the following year

Through Figure 12 referring to the forecast for the next year, it can be seen that the NO2 concentrations show an approximation to the pre-pandemic records. Given this, there is an increasing trend in the value of NO2 recorded daily.

Figure 13 contains information regarding the trend, weekly and yearly seasonality. By checking the trend, it is possible to identify a sharp decrease with the onset of the pandemic, and then an increasing trend after the return to normality (June 2021). Regardingthe weekly seasonality, it can be concluded that during the weekend there is a marked decrease in the NO2 concentration. In addition, there is also an annual seasonality in the months of May to September, as they reach values below normality.

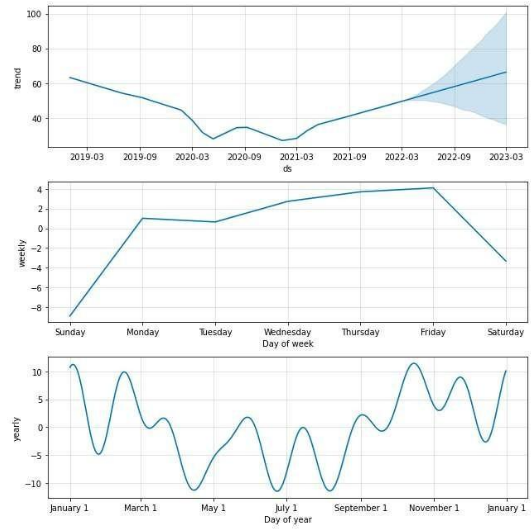

Fig. 13 Components of prediction model

In addition to the prophet [15], a prediction model was developed using the Random Forest algorithm for a time series [1]. In a first instance, the time series was transformed into a dataset for supervised learning. Then, the dataset was divided into a training set and a test set, followed by data adjustment. Finally, prediction and performance evaluation was performed.

3.6. Evaluation

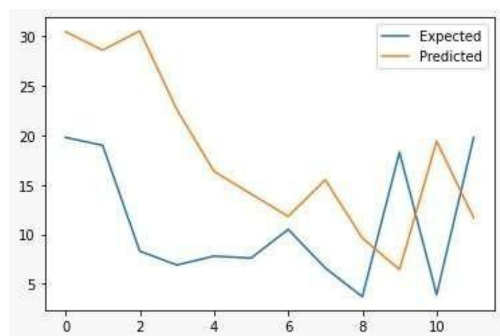

Fig. 14 *Random Forest* evaluation of the prediction model

Regarding the evaluation of the Random Forest model, the Mean Absolut Error (MAE) metric was used, which allows for the calculation of the mean absolute error between the observed values (Expected) and those predicted by the model (Predicted). Given this, a value of 10.475 was obtained, and since a univariate prediction was performed, the result obtained was in line with expectations.

IV. DASHBOARD

In a world characterized by constant emissions of harmful gases into the atmosphere, it is becoming increasingly important to monitor these values. Doing so will ensure a decrease in the consequences generated by these gases. All these factors create a strong impact on society in general and on the life of each one of us in particular.

In this way, a dashboard was developed, which can be updated when new data is inserted. This contains information on NO2, ozone, particles smaller than 10 micrometers and particles smaller than 2.5 micrometers. To visualize these, four heatmaps were made that allow filtering by year and month. In addition, it was considered relevant to show the evolution of NO2 concentration throughout the day, as well as the top 5 hours whose concentrations of this pollutant show more alarming values. In all these graphs it is possible to observe the adaptation of the same based on the selected filtering.

In the future, through this dashboard, the Municipality of Lisbon will be able to obtain this information, not only for the past but also for the present. For this, it will only have to resort to the following dashboard (Figure 15 and 16).

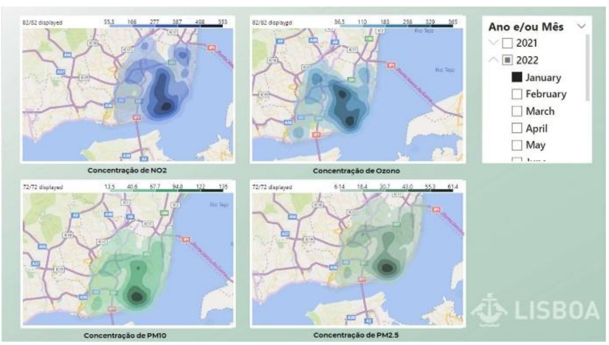

Fig. 15 *Dashboard* comparing the 4 types of polluting

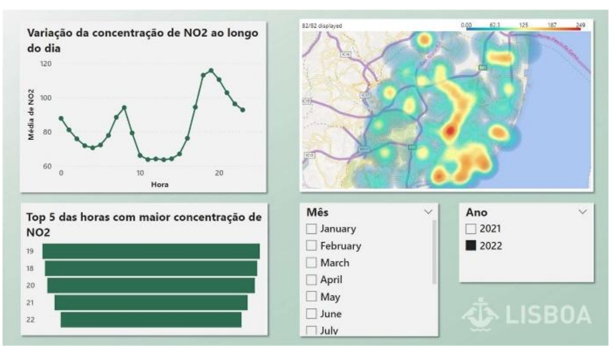

Fig. 16 NO2 Information *Dashboard*

V. Conclusion

Taking into account the challenge issued by the Lisbon City Hall, it became relevant to develop a study on the impact of the Covid-19 pandemic on the environment and pollution. Based on this, it was possible to investigate the changes in concentrations of pollutant gases and traffic variations. According to the data visualization, it was found that the traffic had changed as expected and that the concentrations of pollutant gases had decreased compared to the pre-pandemic period. Contrary to what was expected, it was verified that traffic does not present marked variations during working hours (9h - 18h), contrary to the expected peak hours. On the other hand, taking into account the heatmaps created, it was observed that given the mandatory containment, the concentration of NO2 suffered a sharp decrease. By analyzing the variation of the concentration of this pollutant gas throughout the day, it was found that the peaks coincide with peak hours. Finally, it was found that Avenida da Liberdade presents some records that exceed the limit values decreed by law. Still, as it does not exceed 18 times per calendar year, it does not break the law. Using the prophet package, a univariate time series forecast was made for the following year. Based on this, it was found that NO2 concentrations will approach pre-pandemic records. In addition to the prophet, a prediction model was developed using the Random Forest algorithm for the time series, in which the prediction and the evaluation of its performance were performed.

In order to add value to the study, a dashboard was developed that could be crucial for the decision-making process of the environmental engineers of the Municipality of Lisbon. Throughout the development of the project, several aspects emerged that could be improved for future analysis. In order to increase the robustness of the study, meteorological variables, such as wind direction and intensity, could be used to better understand the location of the pollutant gas emissions. Regarding data modeling, a multivariate prediction would be more feasible to obtain a more complex model. Regarding the use of traffic data, it is not possible to obtain a view of the city of Lisbon, due to the existence of only 5 sensors. Therefore, for a more realistic analysis, we would use a larger number of traffic sensors distributed throughout the Lisbon area, in order to cover as much of the existing mobility as possible.

VI. References

[1] Brownlee, J. (2020). *Random Forest for Time Series Forecasting*. Available at at https://machinelearningmastery.com/random-forest-for-time-series-forecasting/

[2] Lisbon City Hall. (2020). *Campaign for Measuring Nitrogen Dioxide in Lisbon*. Available at https://www.lisboa.pt/atualidade/noticias/detalhe/campanha-de-medicao-de-dioxido-de-azoto-em-lisboa

[3] Lisbon City Hall. (s.d.). *25 Tips on air quality*. Available at https://cidadania.lisboa.pt/fileadmin/atualidade/publicacoes_periodicas/ambiente/25_dicas_qualidade_ do_ar.pdf

[4] California Air Resources Board (n.d.). *Inhalable Particulate Matter and Health (PM2.5 and PM10)*. Available at https://ww2.arb.ca.gov/resources/inhalable-particulate-matter-and-health

[5] Dias, A., Fernandes, M., & Sousa, A. (2004). *Environmental impacts and emissions trading*. AssociaçãoPortuguesa da Indústria de Cerâmica.

[6] European Environment Agency (2022). *Emissions from road traffic and domestic heating behind breaches of EU air quality standards across Europe*. Available at https://www.eea.europa.eu/highlights/emissions-from- road-traffic-and

[7] Horsch, A. (2020). *Detecting And Treating Outliers In Python - Part 1*. Available at https://towardsdatascience.com/detecting-and-treating-outliers-in-python-part-1-4ece5098b755

[8] Lusa. (2020). *Air quality in several Portuguese cities increased in confinement due to traffic reduction*. Available at https://www.dn.pt/vida-e-futuro/qualidade-do-ar-em-varias-cidades-portuguesas- aumentou-no-confinamento-devido-a-reducao-do-tra-trafego-13019528.html

[9] Lusa. (2021). *Traffic pollution is the most damaging to air quality in the EU, Portugal takes red card*. Available at https://sicnoticias.pt/mundo/poluicao-do-transito-e-a-que-mais-prejudica-qualidade- do-ar-na-ue-portugal-leva-cartao-vermelho/

[10] Lusa. (2022). *Brussels takes Portugal to court over poor air quality*. Available at https://www.rtp.pt/noticias/mundo/bruxelas-leva-portugal-a-tribunal-por-causa-de-ma-qualidade-do- ar_n1362696

[11] Light, P. (2021). *From New York to Liberty Avenue, what confinement does to air quality*. Available at https://www.dn.pt/edicao-do-dia/09-fev-

2021/de-nova-iorque-a-avenida-da-liberdade-o-que-o- confinement- does-a-air-quality--13330485.html#media-1

[12] Our World in Data. (2022). *Covid-19Data Explorer*. Available at https://ourworldindata.org/explorers/coronavirus-data-explorer?time=2021-07-01..2022-02-27&facet=none&Metric=Confirmed+cases&Interval=7-day+rolling+average&Relative+to+Population=true&Color+by+test+positivity=false&country=~PRT

[13] Pereira, A. (2021). *What's in it for Lisbon? Five hypotheses for the covid-19 numbers.* Available at https://www.publico.pt/2021/06/17/sociedade/noticia/lisboa-cinco-hipoteses-numeros-covid19-1966885

[14] State of the Environment Portal (2021). *Air Pollution from Carbon Dioxide*. Available at https://rea.apambiente.pt/content/polui%C3%A7%C3%A3o-atmosf%C3%A9rica-por-di%C3%B3xido-de-azoto

[15] Prophet. (2022). *Quick Start*.

[16] *https://facebook.github.io/prophet/docs/quick_start.html#python-api*

[17] Air Quality. (2019). *Qualar Index*. Available at https://qualar.apambiente.pt/node/metodo-calculo- indices.

[18] Saints, F. (2022). *O impact environmental of the pandemic Covid-19.*Available a t h t t p s : / / g a l p . c o m / p t / p t / e m p r e s a s / b l o g / b l o g – p o s t / R e c u r s o s - n a t u r a i s - e - q u a l i d a d e - d o - a r - i m p a c t o - d a – C o v i d - 19

[19] Vaz, S. (2016). *Environment in Portugal*. Francisco Manuel dos Santos Foundation