



# Dichotomous analysis of gaseous emissions as influenced by the impacts of COVID-19 in Brazil: São Paulo and Legal Amazon

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**Abstract** Atmospheric contaminants severely impact air quality in large global urban centers. The emergence of COVID-19 in China in December 2019 and its expansion around the world reduced human activities on account of the implementation of a social isolation policy. In Brazil, COVID-19 arrived in February 2020, and a policy of social isolation was adopted in March by state governments; this work aimed to evaluate pollutant gas emissions in Brazil in the face of the pandemic. In the city of São Paulo, the concentrations of nitrogen dioxide (NO<sub>2</sub>) and carbon monoxide (CO) were analyzed at three automatic monitoring stations of the Environmental Company of the State of São Paulo (CETESB). In this way, reductions in concentrations of these gases were observed after the decree of social isolation on March 24, due to a noticeable drop in vehicle traffic in the city. A reduction in concentrations of NO<sub>2</sub>, between 53.6 and 73%, and a decrease in concentrations of CO, from 50 to 66.7%, were obtained at the monitoring stations. Another impact caused by COVID-19 was the increase in deforestation and fires was identified in the Brazilian Legal Amazon after social isolation, due to the decrease in the inspection of environmental agencies. The fires produce thermal degradation of the biomass, generating pollutant gases and material particulate. These atmospheric

contaminants are extremely harmful to the health of Amazonian populations. Summed to the expansion of COVID-19 in this region, all these factors combined cause the public health system to collapse. CO<sub>2eq</sub> emissions increase estimates, according to the Greenhouse Gas Emissions Estimation System technical report, ranged from 10 to 20% in 2020, compared to those from 2018. If Brazil maintains deforestation at this pace, it will be difficult to meet the emission reduction targets agreed at COP21.

**Keywords** COVID-19 · Gas emissions · Social isolation · Environmental company

## Introduction

Air pollution severely impacts the global environment, resulting in acid rain, photochemical smog, ozone depletion, and climate change, in addition to damage to human society (Hong et al., 2019; Lelieveld et al., 2019; Peng et al., 2020; Seinfeld & Pandis, 2016; Takakura et al., 2019; Tong, 2019).

In late December 2019, cases of unknown pneumonia were reported in the city of Wuhan in China. In January 2020, the causative agent was identified as the SARS-CoV-2 virus (World Health Organization, 2020a), leading to the new disease named COVID-19. By March, the virus had spread globally, bringing world agents to declare this respiratory illness a pandemic (World Health Organization, 2020b). Within

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a few months, the virus had already spread to all continents and by September, it had totaled 900,000 deaths, hence impacting heavily on the global economy (Economic Outlook, 2020; World Bank, 2020). The necessary social isolation measures drastically reduced economic activities, leading to a decrease in the use of road transport and industrial activities, which led to a reduction in pollutant emissions and consequently improved air quality indexes in several countries (Chauhan & Singh, 2020b; Wang & Su, 2020; Shi & Brasseur, 2020; Bauwens et al., 2020; Xu et al., 2020; Tobías et al., 2020; Kerimray et al., 2020; Ogen, 2020; Chen et al., 2020; Liu et al., 2020, Singh & Chauhan, 2020).

Other authors have also been reporting the impacts of COVID-19 in relation to the reduction of local and global gaseous emissions. Le Quéré et al. (2020) pointed to a 17% drop in global CO<sub>2</sub> emissions daily in April 2020 when compared to 2019 average levels, slightly less than half, caused by changes in the use of surface transport. An estimate indicates that the fall will be of 4% to 7% in 2020, depending on the degree of social isolation adopted by countries. Xu et al. (2020) report that three cities, namely Wuhan, Jingmen, and Enshi in Central China, underwent a reduction in PM<sub>2.5</sub>, PM<sub>10</sub>, SO<sub>2</sub>, CO, and NO<sub>2</sub> emissions in February 2020. Therefore, the average index of air quality (AQI) for these cities in January, February, and March 2020 were 32.2%, 27.7%, and 14.9% below 2017–2019 levels, respectively. Muhammad et al. (2020) reported that NO<sub>2</sub> concentrations in the Wuhan region, China, fell by 30% in January and February 2020 compared to the same period in 2019; as for Italy and France, it lowered by 20% to 30% in March 2020 compared to March 2019. Chauhan & Singh (2020a) reported that several cities in India underwent a reduction in PM<sub>2.5</sub> due to lockdown.

The European Environment Agency (EEA) (2020) reported data on the reduction in concentrations of NO<sub>2</sub> emissions in European cities triggered by the lessening in road transport. In the city of Milan, the average NO<sub>2</sub> concentrations in the last 4 weeks were lower by 24% than in the first 4 weeks of this year. In Rome, the average concentrations of NO<sub>2</sub> in the last 4 weeks were 26–35% lower than in the same weeks of 2019. In Madrid, the average concentrations of NO<sub>2</sub> were reduced by 56% from 1 week to the other and, when compared with the same week in 2019, the decline reached 41%. In Lisbon, the average

NO<sub>2</sub> concentrations decreased by 40% from 1 week to another, and a 51% reduction when compared to the same week in 2019 (Muhammad et al., 2020).

In Brazil, the first case of COVID-19 was diagnosed at the end of February 2020. The impacts on society and the Brazilian economy were devastating with almost 140,000 killed in September and a forecast of a gross domestic product (GDP) decrease of 9.1% in 2020 according to the International Monetary Fund (IMF) (International Monetary Fund, 2020). Brazil presented another relevant complicator, the federal government, instead of leading the fight against the global health crisis, adopted a policy of confrontation with state governors and minimized the risks related to the COVID-19 pandemic. This political stance hindered actions and exposed Brazilian society to an extremely serious and contagious disease.

The São Paulo state government decreed (São Paulo, 2020) social isolation on March 24. Its capital São Paulo is the largest city in Latin America, with a population of approximately 12 million inhabitants (Instituto Brasileiro de Geografia e Estatística, IBGE, 2020). Its fleet exceeds 8.6 million vehicles (Ministério da Infraestrutura, 2020), which generates intense atmospheric pollution. The social isolation decree considerably reduced road traffic and public and private transport on account of the pandemic-led trade shutdown. In general, this work aims to investigate the possible variation in the concentrations of carbon monoxide (CO) and nitrogen dioxide (NO<sub>2</sub>) gases in the city of São Paulo. The study was carried out in the period leading up to social isolation (from March 17 to 24) and in the period that followed (March 25 to April 17), in order to identify the influence of social isolation on these gasses' concentration values. The CO gas is an air pollutant from incomplete fuel combustion, especially those of fossil origin. As for the NO<sub>2</sub>, it is a pollutant and oxidant gas in the atmosphere, resulting from high combustion temperatures in fuel-powered engines, mainly diesel. The data referring to CO and NO<sub>2</sub> concentrations were obtained from three environmental monitoring stations of the Environmental Company of the State of São Paulo—CETESB (Environmental Agency of the State of São Paulo). The agency also has automatic meteorological stations to monitor parameters such as temperature, pressure, and relative humidity, which could influence the results.

A serious problem generated by COVID-19 was the increase in deforestation in the Amazon, aggravated by federal government's negative policies regarding environmental issues. Brazil holds great territorial extensions occupied by immense forests. In addition, it is one of the largest agricultural producers in the world, which generates huge agrarian conflicts between the economic interests of expanding agribusiness and the maintenance of environmental sustainability. At Conference of the Parties (COP21) in 2015, Brazil has pledged to reduce its carbon emissions by 37% by 2025, and by 43% by 2030, considering 2005 level rates (Conference of the Parties, 2015; Tollefson & Weiss, 2015), whose agreement was ratified in 2016 (Tollefson, 2016). In the document called Intended Nationally Determined Contribution (INDC, 2016), Brazil proposed to reduce its emissions from the forest sector and land use by strengthening compliance with the Brazilian Forest Code. The country has also compromised to bring illegal deforestation down to zero by 2030 in the Brazilian Amazon as well as restoring and reforesting 12 million hectares of forests by the same year.

The arrival of COVID-19 in Brazil reduced the consumption of beef, consequently increasing the presence of cattle on farms, hence rising methane ( $\text{CH}_4$ ) emissions. There was also a reduction in the government's Amazon deforestation monitoring, thereby incrementing  $\text{CO}_2$  emissions. The estimates are confirmed by deforestation alerts made via satellite by the DETER system (INPE, 2020). The data actually indicated that there was an increase in Amazon deforestation with the arrival of COVID-19, mainly from March on, while most countries in the world have shown a drop in  $\text{CO}_2$  concentrations in 2020 (Le Quéré et al., 2020).

Brazil is expected to be an exception with a 10% to 20% growth in its  $\text{CO}_{2\text{eq}}$  emissions in 2020, according to the Greenhouse Gas Emissions Estimation System report (SEEG, 2020b). Forest fires produce thermal degradation of biomass that releases various polluting gases such as  $\text{CH}_4$ ,  $\text{N}_2\text{O}$ ,  $\text{CO}$ ,  $\text{CO}_2$ , and nitrogen oxides ( $\text{NO}_x$ ) (Brando et al., 2020), in addition to particulate materials ( $\text{PM}_{2.5}$  and  $\text{PM}_{10}$ ), being very harmful to human health (Reddington et al., 2015; Smith et al., 2014; Tsai et al., 2019). The aim of this study was to evaluate the behavior of air pollutant concentrations in two very different Brazilian regions: the city of São Paulo and the Legal Amazon. Also, the analyses were conducted from the view point of

changes in the social mobility of populations, given the COVID-19 pandemic.

## Materials and methods

### Study area location (city of São Paulo)

São Paulo City is a state capital which carries the same name of its state and is located in the southeast region of Brazil (Fig. 1a). It is the largest Brazilian city, with an urbanization rate of 99.1% and a population of more than 12 million inhabitants (Instituto Brasileiro de Geografia e Estatística, 2019).

This research data was made available by the air quality information system called QUALAR, from the Environmental Agency of the State of São Paulo—CETESB (Environmental Agency of the State of São Paulo, 2020). The system consists of a network of automatic monitoring stations (Fig. 1b) that continuously record pollutant concentrations in the atmosphere. The air quality standards in the State of São Paulo were established by State Decree No. 59113/2013. The data are processed based on the averages established by these legal standards and are made available hourly. Every day at 11 am, an Air Quality Bulletin is released, which presents a summary of the atmospheric pollution conditions of the last 24 h, the weather forecast (temperature, pressure, and relative humidity), and the pollutant dispersion conditions for the next 24 h.

In this work, the nitrogen dioxide and carbon monoxide concentrations obtained by chemiluminescence and non-dispersive infrared methods were evaluated, respectively. The information for the survey was collected based on data (daily averages of gas concentrations) from the monitoring stations Cerqueira César, Ibirapuera, and Congonhas, located in the metropolitan region of the city of São Paulo (Fig. 1c). By choosing the stations, we tried to identify from different places in the city the characteristics inherent to its urban mobility. What could be possibly related to the local socioeconomic activities of each region. For example, the choice of Congonhas station was due to the presence of a large airport that has intense aircraft traffic. Therefore, it produces a considerable increase in both the economic activities and in the traffic of cargo and passengers' vehicles (Silva & de Lollo, 2011), which leads to an increase in pollutant gas concentrations.



**Fig. 1** **a** Map indicating the State of São Paulo. **b** Location of CETESB air quality monitoring stations. **c** Stations analyzed: 1, Cerqueira César; 2, Ibirapuera; 3, Congonhas

The collection period preceded the beginning of social isolation (March 24, 2020), lasting between March 17 and 23, and later from March 25 and April 17. Social isolation indices are provided by the Information and Intelligent Monitoring System of the São Paulo State Government (SIMI-SP, 2020). It was implemented through an agreement with Brazilian mobile operators through a Big Data platform. The isolation index is based on the location of the operators' cell phone antennas (Radio Base Stations—RBSs), which “mark” a reference to the place where the cell phone has “slept” between 10:00 pm and 2:00 am. During the day, a cell phone that has moved away from this reference, what varies around 200 m in the city of São Paulo, is considered out of isolation. The index is updated daily, always showing the values for the previous day, maintaining the respect and privacy of each user (IPT, 2020).

#### Study area location (Legal Amazon)

The term “Legal Amazon” was only incorporated into Brazilian legislation recently, from Law No. 11.952, of June 25, 2009, and the Forest Code (Law No. 12.651, of May 25, 2012). The Legal Amazon is composed of 8 states and some municipalities in the state of Maranhão (Fig. 2). It is located in the north, midwest, and northeast regions of Brazil and has an area of approximately 5.2 million km<sup>2</sup>, which corresponds to 61% of the country territory (Instituto Brasileiro de Geografia e Estatística, 2014). It has an estimated population of 27 million inhabitants (Superintendência de Desenvolvimento da Amazônia, 2016). The major concerns in the Legal Amazon are the predatory exploitation of its forest resources,

illegal mining, agriculture (soy), and large-scale cattle bovine ranching, which increase deforestation and, consequently impacting severely on the region. Since 1988, there has been deforestation satellite monitoring.

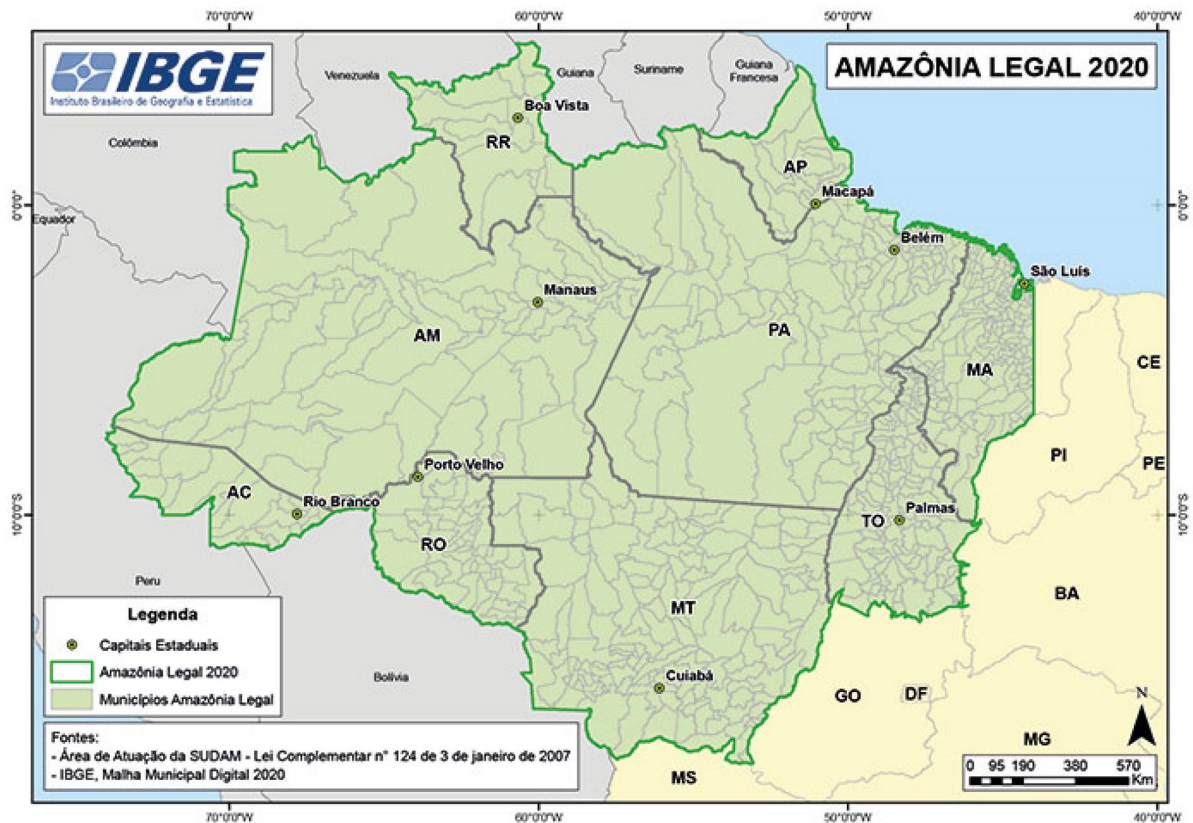
In 2004, the Real-Time Deforestation Detection System (DETER) project (INPE, 2020) was implemented, which maps and identifies clear-cut deforestation (complete removal of native forest) and changes in forest cover in real time (daily alerts of deforestation), facilitating the inspection and control of environmental agencies. A change in the deforestation pattern was recently detected, with a reduction in the dimensions per unit of the deforested areas, which required a new high-resolution monitoring standard. Then, in 2015, the DETER-B project (INPE, 2020) enabled almost real-time identification and mapping of deforestation and other changes in forest cover with a minimum area close to 1 ha. The images used are from the WFI sensors, CBERS-4 satellite (Sino-Brazilian Earth Resources Satellite), and AWIFS, from the IRS satellite (Indian Remote Sensing Satellite), with 64 m and 56 m of spatial resolution, respectively. The deforestation data used herein are available from the National Institute of Space Research.

## Results and discussion

### Monitoring of the NO<sub>2</sub> and CO gases (São Paulo)

Figure 3 shows NO<sub>2</sub> concentrations (µg m<sup>-3</sup>) between days March 18 and April 17, 2020, at Cerqueira Cesar,





**Fig. 2** Map of the Legal Amazon (green color). Source: Instituto Brasileiro de Geografia e Estatística (IBGE), 2014

Ibirapuera, and Congonhas stations. The highest concentrations occurred between 18 and 19 March. On March 24, social isolation began and on March 29, the lowest concentrations of NO<sub>2</sub> were obtained. Figure 4 shows that the highest CO concentrations (ppm, part per million) also occurred between 18 and 19 March, whereas the lowest occurred on the following March 29.

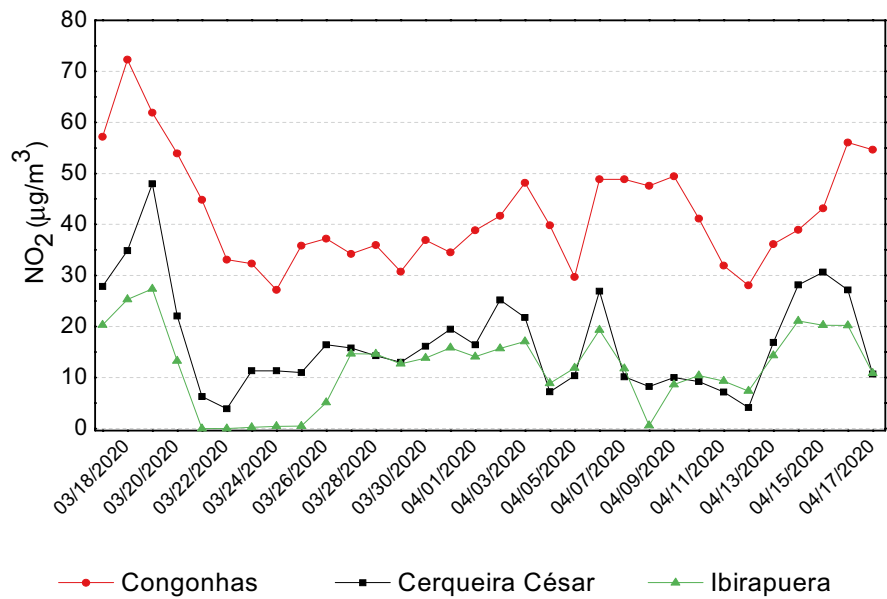
Table 1 shows the reduction variation (%) of NO<sub>2</sub> and CO gas concentrations in relation to the beginning of social isolation, which has a direct correlation between the factors. In order to better visualize the correlations between these factors, Fig. 5 shows the daily social isolation index of the State of São Paulo between the days March 5 and April 17, 2020, which is provided by the Intelligent Monitoring System of São Paulo (SIMI-SP, 2020).

On April 5, social isolation reached 59%, the highest rate in that period. It is possible to note that this index was accompanied by a NO<sub>2</sub> and CO gas concentration

drop (Figs. 3 and 4) on the same day. From that day on, social isolation declined to 48% on April 9, causing concentrations to behave in the opposite direction, that is, to escalate. Social isolation increased to 58% on April 13 and dropped to 48% on April 17, for it is possible to notice from Figs. 3 and 4 that concentrations feature a tendency opposite to that of social isolation index figures (Fig. 5).

Table 1 shows the results of NO<sub>2</sub> and CO gas concentrations obtained for days March 19 and March 29, considering that isolation started on March 24. In view of the data, it is important to note that at the Congonhas station there was a significant plunge in the emission concentrations, depicting 57.4% for NO<sub>2</sub> and 66.7% for CO. At the Congonhas station, the highest concentrations of gases were identified when compared to other stations, due to the economic dynamism of this region. At the Ibirapuera station, the drop was of 53.6% for NO<sub>2</sub> and 60% for CO. In relation to the Cerqueira César station, NO<sub>2</sub> concentration rates fell 73% and CO ones

**Fig. 3** Daily average concentrations of nitrogen dioxide gas pollutants NO<sub>2</sub> (µg m<sup>-3</sup>) for 4 monitoring stations collected of the Air Quality Information System of CETESB's, between March 17 and April 17, 2020. Source: São Paulo State Environmental Agency (Environmental Agency of the State of São Paulo, 2020)

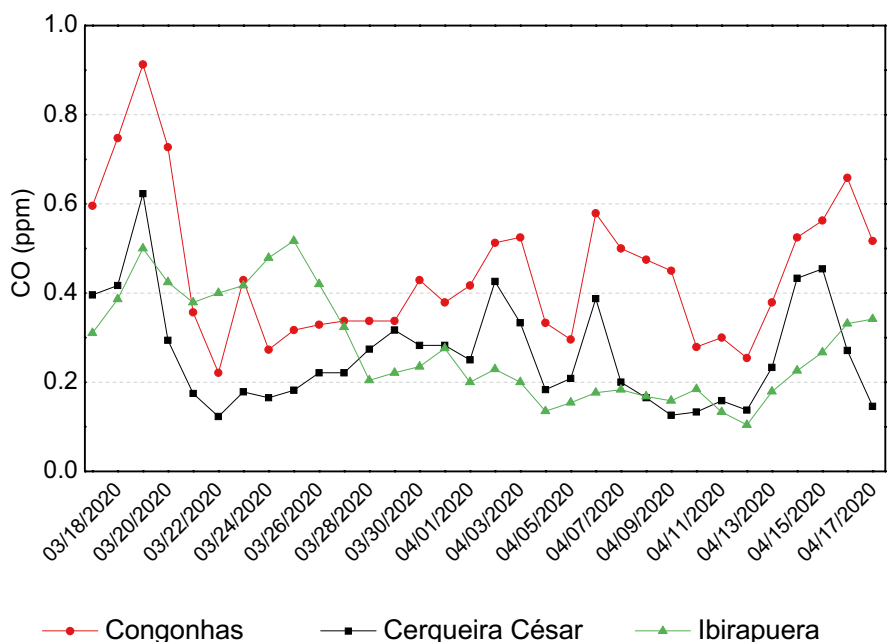


did so by 50%. These reductions clearly show the relationship between human activities and pollutant emissions, pointing to air quality improvement in the city of São Paulo.

The social isolation indices are shown in Fig. 5 and the data of the variations in the concentrations of CO and NO<sub>2</sub> gases are shown in Figs. 3 and 4, respectively. Using March 19 and 29 as a reference,

it was possible to make a direct comparison between the results in Table 1. The concentrations of these gases experienced drops on those days when social isolation rates were higher. According to the Intelligent Monitoring System of the State of São Paulo (SIMI-SP), the social isolation index was 42% on March 19 and 59% on March 29, directly influencing the behavior of gas concentrations. In São Paulo,

**Fig. 4** Daily average concentrations of carbon monoxide gas pollutants CO (ppm) for 4 monitoring stations collected of the Air Quality Information System of CETESB's, between March 17 and April 17, 2020. Source: São Paulo Catesb's State Environmental Agency (Environmental Agency of the State of São Paulo, 2020)



**Table 1** Mean concentration and relative change of NO<sub>2</sub> (µg/m<sup>3</sup>) and CO (ppm) stations in São Paulo. Emission concentrations refer to March 19 and 29, 2020

Type of station/air pollutant	19 day	29 day	Relative change (%)
Cerqueira César			
NO <sub>2</sub> (µg/m <sup>3</sup> )	48.0	13.0	73.0
CO (ppm)	0.6	0.3	50.0
Congonhas			
NO <sub>2</sub> (µg/m <sup>3</sup> )	72.3	30.8	57.4
CO (ppm)	0.9	0.3	66.7
Ibirapuera			
NO <sub>2</sub> (µg/m <sup>3</sup> )	27.4	12.7	53.6
CO (ppm)	0.5	0.2	60.0

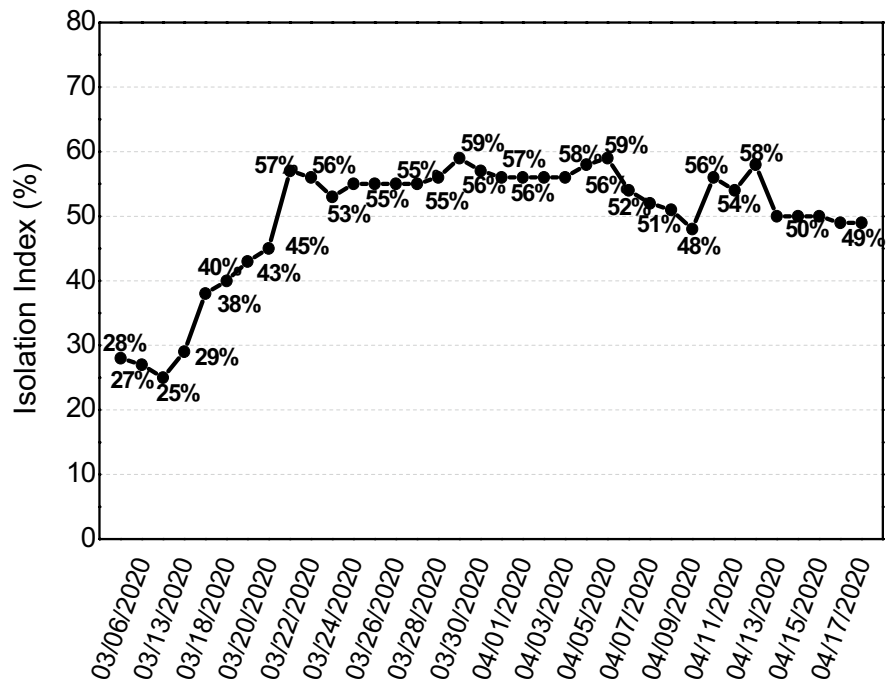
the isolation rate never exceeded 60%; the ideal rate for the government would be above 70%. Social isolation was not fully supported by the country’s population.

NO<sub>2</sub> is an extremely irritating gas for the pulmonary mucosa. When inhaled in high concentrations, even for a short period, it can cause respiratory symptoms such as coughing, wheezing, or difficulty

in breathing and aggravating existing respiratory diseases (Wang & Su, 2020). Prolonged exposure to NO<sub>2</sub> may also cause other serious health problems like hypertension and other cardiovascular diseases. Ogen (2020) reports that there was a 78% increase in COVID-19-related fatalities related to long-term exposure to this gas, in five regions located in Northern Italy and Central Spain. Higher NO<sub>2</sub> concentrations combined with the downward flow of air prevented the efficient dispersion of air pollution.

Having the NO<sub>2</sub> gas in high concentration rates led to the formation of acid rain; it generates aerosols when in contact with ammonia. In the presence of volatile organic compounds (VOCs) and solar radiation, it becomes a precursor of tropospheric ozone (O<sub>3</sub>) (Biswas et al., 2019; Liu et al., 2019, 2020; Atkinson, 2000). On another note, CO gas is highly harmful to human health, mainly regarding the cardiovascular system, and depending on the concentration levels and exposure duration, it becomes lethal (Kinoshita et al., 2020; Barn et al., 2018). CO is also considered to be an indirect greenhouse gas, as it is able to influence the atmospheric dynamics of methane (CH<sub>4</sub>) and tropospheric ozone (O<sub>3</sub>), which are important greenhouse gases (Bruhl & Crutzen, 1999;

**Fig. 5** Social isolation index daily of the state of São Paulo between the days March 5 and April 17, 2020. Source: Intelligent Monitoring System of São Paulo (SIMI-SP, 2020)



Gao et al., 2009). Therefore, these gases have a great capacity to pollute the atmosphere in large urban centers, causing serious public health problems.

The results shown in Table 1 indicated that there was a reduction in the concentrations of NO<sub>2</sub> and CO gases measured at the monitoring stations in the city of São Paulo after the decree of social isolation. These results are in accord with those obtained by Dantas et al. (2020) who report a reduction in the concentrations of these molecules at the monitoring stations in the city of Rio de Janeiro in Brazil after the social isolation decree. For NO<sub>2</sub>, the reduction was of 53.9% and 32.2% at the Irajá and Bangu stations, respectively, & the reduction in CO concentrations was 48.5% and 41.3% regarding Tijuca and Bangu stations, respectively.

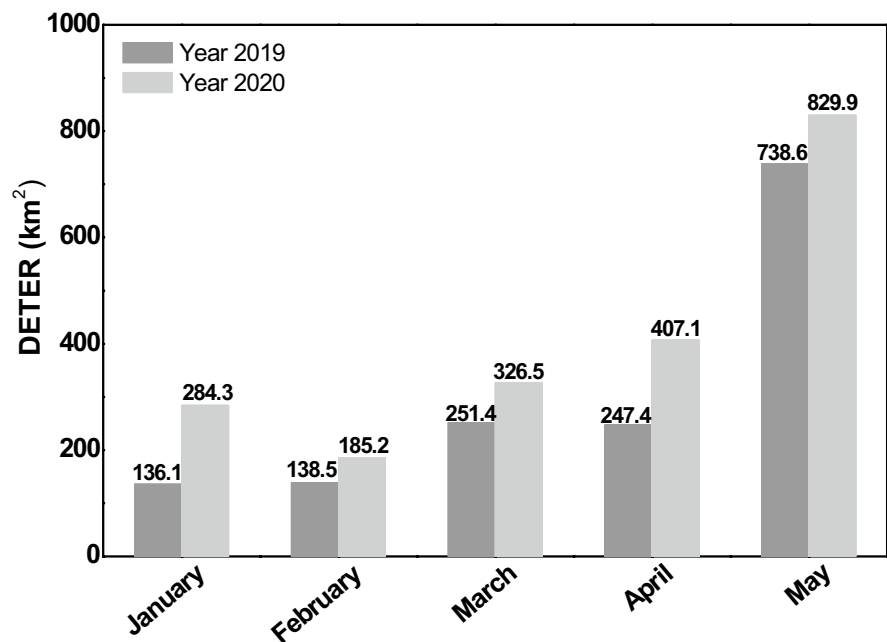
The results presented here (Table 1) are also in accord with those reported by Nakada and Urban (2020) who report a reduction in NO<sub>2</sub> and CO concentrations at the monitoring stations in the city of São Paulo (Marginal do Tiete, Pinheiros, and Centro da City). The reductions in the concentration rates were drastic: up to 54.3% for NO<sub>2</sub> and up to 64.8% for CO, and were observed in the urban area during partial block compared to the monthly average for the last 5 years. Its methodology is similar to the one presented in this work, whose data were obtained from different monitoring stations in the city of São Paulo.

The results obtained improve concentration statistics, as more stations were evaluated, enhancing the reliability of the results. Thus, there were reductions in the concentrations of NO<sub>2</sub> and CO during isolation in São Paulo. Both the work done in the city of Rio de Janeiro and the work done in the city of São Paulo point to the reduction of gas concentrations. The Brazilian transport sector mainly uses diesel, which is responsible for the emission of several pollutant gases, including CO and NO<sub>2</sub>. In addition, more than 60% of transport in Brazil is by road via a fleet of old trucks, but during social isolation, there was a considerable reduction in truck traffic in cities. For being the largest urban centers in Brazil, Rio de Janeiro and São Paulo are a good sampling of air pollution in the country.

#### Deforestation in the Legal Amazon: Gas emissions

Figure 6 shows the results of deforestation alerts (km<sup>2</sup>) in the Amazon, obtained by the DETER system (DETER, 2020), where the data for the months of January through May of both 2019 and 2020 were compared. The accumulated deforestation rate in Amazonia is calculated annually, using as a reference the deforestation that occurred between the month of August and the month of July of the next year, a period known as the “deforestation calendar.” The

**Fig. 6** DETER alerts, monthly, on the vegetation variation-capturing system, which releases suspected acts of deforestation in the Legal Amazon, from January to May of 2019 and 2020. Source: DETER, 2020





last available data refers to the period (August 2020 to July 2021), when an area of 10.476 km<sup>2</sup> of the Legal Amazon was deforested (IMAZON, 2021).

The accumulated deforestation rate within these months in 2020 is approximately 34.5% higher than that from the same period in 2019. It is also noted that from March 2020 there was a sharp growth in deforestation, already under the effect of COVID-19 in Brazil. Deforestation has grown in Brazil since the current government took office in 2019, and it is due to the reduction in enforcement, yet worsened since the pandemic started. DETER identified an 83.9% increase in forest deforestation alerts between January and November 2019 compared to the same period in 2018 (DETER, 2020).

Figure 6 also shows the remarkable growth of deforestation in 2020, mainly starting in March (325.6 km<sup>2</sup>) and arriving in May (829.9 km<sup>2</sup>), which represents an increase of over 150% in just 2 months. Certainly, social isolation contributed to the increase in the rate of deforestation, caused by the reduction in inspection. In fact, this process started in 2019, with the pose of the new government and its policies for dismantling the regulatory bodies (changes in environmental legislation). With the pandemic, this situation worsened drastically, and due to social isolation, there was a reduction in inspection capacity. Brazil is a giant country and the Brazilian Legal Amazon alone has more than 5 million km<sup>2</sup>, which naturally makes the inspection a difficult task to be done. A perverse combination of a negationist government and the arrival of a terrible pandemic has led to an alarming increase in deforestation in the Amazon rainforest.

The growth of deforestation and fires (Fig. 6) is extremely serious, since open fires produce large volumes of polluting gases (CH<sub>4</sub>, N<sub>2</sub>O, CO, CO<sub>2</sub>, and NO<sub>x</sub>) and particulate matter (PM) (Amaral et al., 2019; Brando et al., 2020; Reddington et al., 2019; Santos et al., 2018; Yang et al., 2019). The concern today is the overlap between these fires and the COVID-19 cases increase, as traditionally in times of fire season there is a greater demand for health treatment. All this may lead the public health system in the Amazonian states to collapse (Aragão, 2020; Morello et al., 2020), which is already burdened with cases of COVID-19, which increased from March onwards, and no decrease forecasted so far.

The work by an important Amazon researcher, Philip M. Fearnside (Fearnside, 2002), presented the

net emissions of greenhouse gases from deforestation in the Legal Amazon. In 1990, for an initial fire where the estimated deforestation rate was  $13.8 \times 10^3$  km<sup>2</sup> year<sup>-1</sup>, the emissions were of the order of  $270 \times 10^6$  t,  $0.87 \times 10^6$  t,  $20.90 \times 10^6$  t,  $0.05 \times 10^6$  t,  $0.66 \times 10^6$ , and  $0.55 \times 10^6$  t for CO<sub>2</sub>, CH<sub>4</sub>, CO, N<sub>2</sub>O, NO<sub>x</sub> (NO+NO<sub>2</sub>), and non-methane hydrocarbons (NMHC), respectively. By using the values of the deforestation rate adopted by Fearnside, it was possible to estimate the emissions corresponding to the deforestation carried out in the very first months of 2020.

The reduction in air quality is notable in several regions of the Legal Amazon and has been worsening due to the increase in deforestation (Melo et al., 2020; Silva et al., 2020). Some studies on the influence of air pollutants on transmission and worsening of viral respiratory infections have been presented, such as the review by researchers Domingo and Rovira (2020) who report results indicating that chronic exposure to air pollutants delays and complicates the recovery of patients with COVID-19. The number of studies on this subject is still limited. Therefore, research needs to be carried out urgently given the seriousness of the matter.

Conticini et al. (2020) investigated the relationship between the lethality of the coronavirus (SARS-CoV-2) and air pollution in Northern Italy, one of the most polluted regions in Europe. Prolonged exposure to polluted air leads to a chronic inflammatory stimulus, even in young and healthy individuals, hence posing pollution as an additional cofactor of the high level of lethality recorded in this area. The confirmation of these studies worldwide leads to an extreme concern as wood fires increase in Brazilian north and midwest regions, where the COVID-19 pandemic is currently expanding.

Deforestation and fires reduce carbon stocks, increase greenhouse gas emissions, reduce biodiversity in the Amazon region, and alter climate patterns (reducing rainfall) that lead to major droughts (De Faria et al., 2017; Favero et al., 2020; Flores et al., 2017; Silva Junior et al., 2018). Excessive deforestation can lead to dangerous breaking points, generating warmer and more prolonged droughts and, in addition, native plant species would have greater regenerating difficulty. Studies indicate that if the forest cover is reduced by 20% to 25%, its ability to sequester carbon would collapse (Amigo, 2020; Lovejoy & Nobre, 2019), thereby drastically reducing

biodiversity, the evapotranspiration process, the cloud covers, and the circulation of ocean currents. Changes in the hydrological cycle would affect the economy and society of South America, mainly in Brazil.

In December 2015, Brazil participated in Conference of the Parties (COP21) held in Paris, where it pledged to reduce its carbon emissions by 2030 by 43%. The increase in deforestation that has worsened since 2020 (Fig. 6) is completely at odds with the promises made at COP21. Le Quéré et al. (2020) report that the drop in global CO<sub>2</sub> emissions, for 2020, would be of 4% to 7%, depending on the duration of the pandemic. In Brazil, the most carbon-intensive sectors are changes in land use, which account for a 44% of total emissions, followed by the agricultural sector which is responsible for 25%. Thus, the deforestation rises and the reduction in beef consumption (economic downturn) expanded methane emissions since COVID-19 arrived, leading, thus, to the scenario of growth in carbon emissions for 2020, according to the SEEG (2020b) technical report, which points to emission increase of 10% to 20% in relation to 2018, against world expectations.

In the agricultural sector (SEEG, 2020a), there was a 20% reduction in cattle slaughter in April compared to previous March 2020 and a 30% decrease in its average over the last 10 years. This is equivalent to approximately 500,000 oxen that remained in the pastures in a month. As a consequence, March alone depicted an increase of approximately 1 MtCO<sub>2eq</sub> in the annual GHG emissions of this sector. According to the SEEG report (2020a), within a conservative scenario regarding the average deforestation in the Amazon, in the next 3 months, the country shall increase its gross emissions by approximately 226 MtCO<sub>2eq</sub>, compared to 2018, in the land use change sector, which is equivalent to an increase of 29%. Brazil is in the opposite direction to what it agreed at COP21.

## Conclusions

The COVID-19 impact in Brazil proved to be extremely serious from both economic and social points of view. Deaths reached almost 140,000 at the end of September, with prospects of a 9.1% GDP drop (IMF, 2020). From the environmental point of view, with regard to atmospheric pollution, there was a reduction in the

concentrations of NO<sub>2</sub> and CO gases in São Paulo, the largest Brazilian urban center. However, the parallel deforestation increases in the Legal Amazon led various gas pollutants and particulate concentrations to grow, which are extremely harmful to human health, impacting on the public health services in states where COVID-19 is expanding. The increase in GHG emissions from forest fires makes it difficult to comply with Brazilian environmental policies to mitigate climate change. The environmental impacts produced by COVID-19 in Brazil originated from complex interactions between economic, political, and public health aspects, such as the reduction of emissions in São Paulo and the increase in emissions from burnings in the Amazon, an issue difficult to resolve.

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