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Atmospheric Emission Changes and Their Economic Impacts during the COVID-19 Pandemic Lockdown in Argentina

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Abstract: This work studied the emission changes and their economic effects during the Argentina's COVID-19 pandemic lockdown. We have analyzed the atmospheric emissions of the main greenhouse gases (GHG: CO_2, CH_4, and N_2O) and other pollutants (NOx, CO, NMVOC, SO_2, PM_{10}, $PM_{2.5}$, and BC) from various sectors such as private road transport, freight, public transport, agriculture machines, thermal power plants, residential, commercial, and governmental from January 2005 to April 2020. We focused on the months with the greatest restrictions of COVID-19 pandemic in Argentina (March and April 2020). The results show emissions reduction up to 37% for PM_{10}, $PM_{2.5}$, and BC, consistent with observed from satellite images and up to 160% for NOx, CO, NMVOC, and SOx. However, the residential sector has increased their emissions by 8% for the same period. As a consequence, 3337 Gg of CO_{2eq} of GHG emissions were reduced, corresponding to a 20% reduction compared to the same period in 2019. Besides, a 26% reduction in gross domestic product (GDP) was observed due to the COVID-19 pandemic. Our results show that each Tg of GHG reduction was associated to a 0.16% reduction of the GDP from the analyzed sectors. Thus, without a voluntary reduction in consumption associated to significant cultural and technological changes, reduction in GHG would still be associated with deepening inequalities and asymmetries between high and low consumption sectors (i.e., with better (lesser) education, health, and job opportunities), even within countries and cities.

Keywords: COVID-19; anthropogenic emission; atmospheric emissions; greenhouse gases; aerosols; air quality; economic impact; GDP; Argentina

1. Introduction

November 2019 was the date of the world's first case of coronavirus (COVID-19), patient zero being a person supposedly living in Wuhan, Hubei (China). In December 2019, China alerted the World Health Organization (WHO) of several cases of unusual pneumonia in Wuhan. On 9 January 2020, Coronavirus disease 2019 (COVID-19) was identified as an infectious disease caused by severe acute respiratory syndrome novel coronavirus 2 (SARS-CoV-2). It was then officially identified as the cause of the COVID-19 outbreak in Wuhan, China [1]. COVID-19 produces mild symptoms in most people (fever, cough, sore throat, and difficulty breathing) but can also lead to severe respiratory illness and death [2]. On 11 March 2020, WHO declared that the COVID-19 had been characterized as a pandemic [3]. In Argentina, the first case was confirmed on 3 March 2020 by the Ministry of Health [4], and the Argentine national government established a full lockdown on 20 March 2020 [5]. Additionally, many countries quickly closed their borders and established distance measures to prevent the spread of COVID-19. These measures limited most of the productive activities and generated a financial crisis. In fact, the International Monetary Fund has projected that during 2020 the world gross domestic product (GDP) will contract up to 4.9% due to the lockdown measures and their associated international financial crisis [6].

Several studies have shown that the reduction in anthropogenic activity has reduced the emission of atmospheric pollutants, and therefore, has improved air quality [2,7,8]. However, to the best of our knowledge, we did not find studies on the COVID-19 pandemic lockdown impact that relates to atmospheric emissions changes, air quality, and economic effects in Argentina. Hence, we hypothesize that the COVID-19 pandemic lockdown would generate a decrease in emissions, which in turn, would have a negative impact on the economy, but a positive impact on air quality. Thus, the main objective of this work is to analyze the changes in atmospheric emissions, their impact on air quality, and related effects on the economy during the COVID-19 pandemic lockdown in Argentina.

We estimate the atmospheric emissions of greenhouse gases (GHG), such as CO_2, CH_4, N_2O, and seven other pollutant compounds (NO_x, CO, NMVOC, SO_2, PM_{10}, $PM_{2.5}$, and BC) from various sectors, such as private road transport, freight, public transport, agriculture machines, thermal power plants, residential, commercial, and governmental, in particular during the most restrictive period of COVID-19 pandemic lockdown in Argentina (March to April 2020). The approach was based on the Intergovernmental Panel on Climate Change (IPCC) and the Program for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (EMEP) (2016) guidelines using emission factors and previous studies by the authors [9–13]. We analyze and compare the monthly emissions of 2020 with the same period in 2019, and during the last 16 years (January 2005 to April 2020). We study the improvement in air quality from satellite data (PM_{10} and $PM_{2.5}$). In addition, we perform the correlation between of GHG emission changes and GDP over the last 16 years (2005–2020) in Argentina. The results will serve to improve knowledge of pollutant emissions by sector, thus improving the air quality models applied during the COVID-19 pandemic lockdown, and implement measures to avoid their impacts in future financial crises. The rest of the article is ordered as follows. Section 2 overviews scientific literature on atmospheric emissions estimation and its relationship with financial crises. Additionally, it shows recent literature about the COVID-19 pandemic lockdown and its air quality effects. Section 3 describes the methodology applied to estimate emissions in Argentina; likewise, the improvement in air quality and economic impacts identified during Argentina's COVID-19 pandemic lockdown. Section 4 details the results and discusses them with updated literature, while Section 5 reports the conclusions and outlook.

2. Literature Review

2.1. Atmospheric Emissions and Financial Crisis

Since global change has become a world concern, many studies try to identify the main drivers to reduce emissions but uncoupling it from economic growth. Primary energy consumption and carbon emissions are strongly related to GDP per capita, population growth as well as technological indicators such as energy efficiencies (energy/GDP) or emissions intensities (GHG/energy consumption). The behavior of these key drivers at national or global scale helps us to understand trends and to identify emissions reductions opportunities [14–16]. Thus, recent and historic reduction in productive activities generated by financial crises, which produced air quality improvement [17–21] and GHG reductions, are helpful to calibrate the above-mentioned key drivers.

Another source of information is the elaboration of the emissions inventory, which relates activity (such as annual power plant energy generation) with GHG emissions and pollutants emitted to the atmosphere through well-known emissions factors [22]. These inventories are used for air quality estimation and public health evaluations at national, regional, or continental scale. In fact, the Program for Monitoring and Evaluation of the Long-Range Transmission of Air Pollutants in Europe (EMEP) has developed guidebooks that have two key functions: (1) to provide procedures that allow users to compile emissions inventories that meet the criteria quality of transparency, consistency, integrity, comparability, and precision; (2) provide estimation methods and suitable emission factors for inventory compilers (emission estimation) [23]. Most of South American inventories are derived from global datasets [24–26]. However, in Argentina, emission inventories have been developed at the national level with high spatial resolution (0.025° longitude × 0.025° latitude) [12], covering GHG emissions from the road transport sector [9], energy sector [11,27], ammonia emissions from the agriculture sector [28], and livestock production, agriculture, and biomass burning sectors [13,29]. Through these studies, it has been observed that atmospheric emissions are strongly related to the consumer economy.

2.2. COVID-19 Pandemic Lockdown vs. Improvement in Air Quality

Reductions in mobility and industrial activity impacted directly on energy consumption from power plants and transport, reducing their emissions to the atmosphere, not only in terms of GHG emissions (CO2, CH4, N2O), identified as the primary source of global warming [30], but reducing also air pollutants such as (CO, NO2, PM10, BC, volatile organic compounds, and others). This situation has also been observed during the COVID-19 pandemic lockdown around the world. In the city of Wuhan, China, known as the origin of the COVID-19 pandemic, the emission rate from mobile sources was observed and the contribution of local pollution in this city decreased during its lockdown [31]. Studies carried out throughout the 50 most polluted cities in the world analyzed the level of $PM_{2.5}$ during the COVID-19 pandemic lockdown. They found that the largest $PM_{2.5}$ reductions occurred in the capitals of America, Asia, and Africa [32]. Other studies showed that expected premature deaths due to improved air quality decreased by around 99,270 to 146,649 in 76 countries and regions as a result of the COVID-19 lockdown, compared to the same period in 2019 [33]. Moreover, Abu-Rayash [34] estimated that GHG emissions associated with the power sector decreased by 40 Gg in the province of Ontario, Canada, in April 2020 due to the COVID-19 pandemic lockdown. Furthermore, other studies conducted in Italy found, through carbon footprint assessment, a decrease between 5.6 and 10.6 Tg of GHG emissions under the COVID-19 pandemic lockdown [35]. Several studies presented improvements in air quality during the COVID-19 pandemic in the United States [7], Europe [36], Brazil [2,37], India [38], and China [39]. These studies also show that emission inventories are essential to understand the contribution of various human activities, to model and to predict the changing atmospheric composition, and design cost-effective mitigation measures [10].

3. Materials and Methods

3.1. Study Area and Data Source

This study focuses on the continental territory of the Argentine Republic, located in the extreme southern of South America, which covers 2,778,000 km^2 (Figure 1). Its political organization is organized in 23 provinces and the Autonomous City of Buenos Aires, as territorial divisions of the first order of the country. According to the World Bank in 2019, it was a medium-high income country with 44.9 million inhabitants, with a gross domestic product (GDP) of 450 billion dollars [40]. The data used in this investigation correspond to the official reports informed by statistical and census offices, Ministry of Energy, and other sources shown in the Table A1.

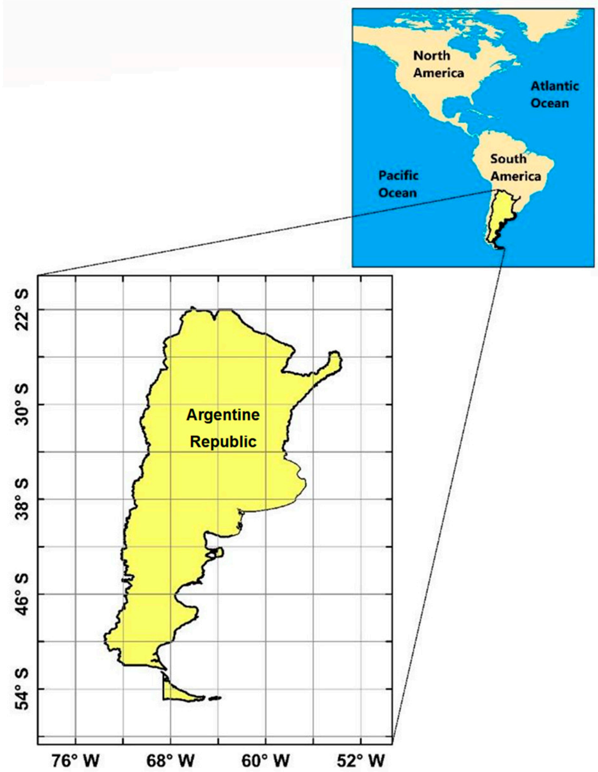

Figure 1. Location of Argentine Republic in the American continent and Western Hemisphere. Source: prepared by the authors.

3.2. Emission Estimation

Emissions were calculated following the general equation proposed by the EMEP [22,41]:

$$E(p) = \sum (A(i,j) * ef(i,j,p)) \quad (1)$$

In Equation (1), E is the total emission (e.g., t/year), for a pollutant p; A is the activity of sector i, for technology j; and ef is the emission factor for that sector, technology, and pollutant. For example, the emissions (t/year) of CO (p) correspond to the monthly consumption of gasoline (j) of the private automotive sector (i). Particularly, the estimate was developed following the EMEP methodology [22], which was applied in articles previously published by the authors, i.e., private road transport, freight, public transport, and agriculture machines sectors [9]; thermal power plants, residential, commercial, and governmental sectors [11]. The governmental sector includes administrative public offices (at national, provincial, and municipal levels), schools, universities, hospitals, security, and armed forces. Commercial sector includes local shops, supermarkets, shopping centers, sports associations, and similar. User's classification was provided by the natural gas regulation agency [42]. Furthermore, we estimate the CO_{2eq} for the main GHGs. Therefore, we have considered the CO_{2eq} emissions with a 100-year horizon global warming potential (GWP100: CH_4 = 28, N_2O = 298) suggested by the IPCC in the 5th Assessment Report (AR5) [43]. The dataset that supports the calculations is provided in Appendix A. This includes the historical activity data (such as fuel consumption, number of vehicles, and population) and emission factors used for each sector (as shown in Table A1, Appendix A). We analyzed the monthly variations from January 2005 to April 2020. The reduction percentages were calculated based on the year 2019 and based on the history of the last 15 years (Table A2). Additionally, we analyzed the improvements in air quality through the use of remote sensing (Figures A1 and A2) and surface measurements by the air quality network of the city of Buenos Aires (Figure A3), both related to variations in the estimated emissions.

3.3. Economic Impact Analysis

Using quarterly GDP data reported by the Ministry of Economy of Argentina from January 2005 to June 2020 [44], we estimated the effect of changes in estimated GHG emissions on GDP using a multiple linear regression model. Then, we analyze the relationship between GDP reduction and GHG emissions during the COVID-19 lockdown, through the evaluation of the multiple regression model using the second quarter of 2020. Therefore, the cost of reducing GHG emissions in terms of the fraction of Argentina's GDP was estimated for the sectors analyzed.

4. Results and Discussion

4.1. COVID-19 Pandemic Lockdown in Argentina

Table 1 displays the different situations of "COVID-19 pandemic state of affairs" during the months of March and April 2020 in Argentina. Through these months, the most restrictive measures that affected the emissions reduction of anthropogenic atmospheric pollutants were implemented.

Table 1. Main related measures that have decreased the atmospheric emissions during COVID-19 pandemic lockdown in Argentina [5]. Source: compiled by the authors.

COVID-19 Pandemic State of Affairs	Start Date	Measure Established
The first case of COVID-19 is confirmed in Argentina	7 March 2020	The health ministry confirms the first case of COVID-19 in Argentina. Then, the inhabitants were encouraged to avoid social contact. In addition, the population was encouraged to make an immediate medical consultation due to the presence of fever and respiratory symptoms such as cough, sore throat, difficulty breathing, and having traveled in areas with circulation of the SARS-CoV-2 virus or having been in contact with any COVID-19 confirmed case.
Restrictions of mass gatherings and school closures	15 March 2020	The national government closed schools across the country. In additions, they closed maritime, land, and air borders for all non-resident foreigners. They stablished specific work licenses and hours of care for person all over 60, and all non-essential activities and crowding were cancelled.
Nationwide lockdown	20 March 2020	Nationwide lockdown until 31 March was established. Only essential activities were allowed (health care, food production and distribution, etc.)
Nationwide lockdown was extended with a few exceptions	13 April 2020	Each province and the Autonomous City of Buenos Aires, supervised by the national government, were empowered to get out of compulsory isolation, but establishing protocols that guarantee social distancing.
Nationwide lockdown was extended and relaxed some restrictions	27 April 2020	The quarantine was extended, only for cities with more than 500,000 inhabitants. The measure was also relaxed to allow recreational outings of one hour per day and within a radius of 500 m from their residences.

Measures implemented during the months of March and April indicate that the greatest restrictions that stopped almost all activities in Argentina were developed during the last weeks of March and first weeks of April. In fact, since 27 April 2020 (as shown in Table 1), several activities were reactivated, and lockdown measures were focused on the provinces and cities that reported most cases of COVID-19.

4.2. Monthly Variation of Emissions through COVID-19 Lockdown in Argentina

Figure 2 shows the monthly behaviors of the atmospheric emissions from January 2005 to April 2020. In general, the emissions inventories of all pollutants have increased due to the increase in economic activity. Only SO_2 generated mainly by thermal power plants fluctuates as thermal power plants consume coal and fuel oil during the winter and peak consumption hours. In fact, natural gas is primarily intended for residential use during the cold season. However, restrictions due to the COVID-19 pandemic (Table 1) caused reductions in the atmospheric emissions during the months of March and April 2020. All analyzed GHG and pollutants showed strong reductions (as shown in Figure 2) from February to April 2020: CO_2 (7691.5 Gg to 5803.4 Gg), CH_4 (1.718 Gg to 0.866 Gg), N_2O (0.428 Gg to 0.232 Gg), NO_x (46.286 Gg to 26.098 Gg), NMVOV (172.066 Gg to 63.052 Gg), CO (34.644 Gg to 12.846 Gg), SO_2 (2.041 Gg to 0.818 Gg), PM_{10} (0.794 Gg to 0.703 Gg), $PM_{2.5}$ (0.778 Gg to 0.697 Gg), and BC (0.266 Gg to 0.306 Gg).

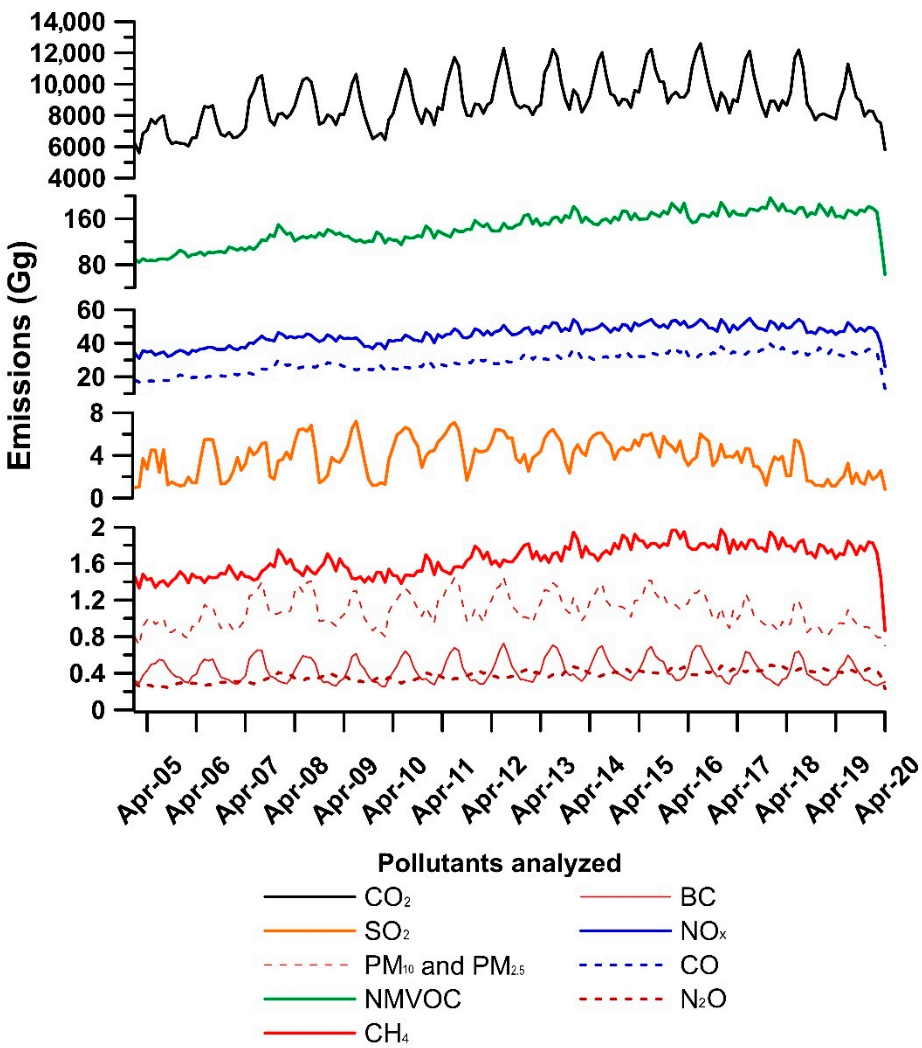

Figure 2. Total emissions (Gg) for all sectors and pollutants analyzed. It shows the monthly variations from January 2005 to April 2020. An abrupt decrease is observed in the last months analyzed (November 2019 to March 2020). Source: calculated by the authors.

Figures 3–9 display the monthly variations of March and April (2005–2020). Private road transport sector shows a slight increase from 2005 to 2019 (Figure 3) related to the increase in the number of vehicles (e.g., in January 2005, there were 7.8 million registered as Active Fleet, but 15.5 million in January 2020) [45]. Freight, public transport, and agriculture machines sectors (Figure 4) showed a slight decrease in emissions over the last 15 years. This is related to use of cleaner fuels such as biodiesel, biogas, and compressed natural gas [46]. Thermal power plants sector displays variations during all the considered years (Figure 5). These seasonal changes are mainly related to the type of fuel used (coal, natural gas, or fuel oil), natural gas during warm periods, and coal and/or heavy fuel oil in winter. Thermal power plants average generation is 60% thermal, followed by 30% hydroelectricity, and 10% others (nuclear, renewable). During summer and temperate climate, natural gas represents an average 95% of thermal generation, the remainder 5% includes fuel oil and coal, which is specially used at peak consumption hours. During winter months, natural gas is used as heating in homes. Therefore, thermal power plants use fuel oil and coal up to 35% as a replacement for natural gas (65%), increasing emissions of SO_2, and particulates. This fuel switching process produces SO_2 and BC emissions variability, which depends on daily temperatures, daily power demand, and natural gas availability (market prices) [42,46]. The residential sector showed a slight increase in April 2020 (Figure 6), while the commercial and government sectors showed a reduction in the months of March and April 2020 (see Figures 7 and 8) due to decreased activity. Total emissions showed (Figure 9) that the monthly emissions of April 2020 were the lowest value recorded in the last 16 years in Argentina (2005–2020): CO_2 (5803.4 Gg), CH_4 (0.866 Gg), N_2O (0.232 Gg), NOx (26.098 Gg), NMVOV (63.052 Gg), CO (12.846 Gg), SO_2 (0.818 Gg), PM_{10} (0.703 Gg), $PM_{2.5}$ (0.697 Gg), and BC (0.306 Gg).

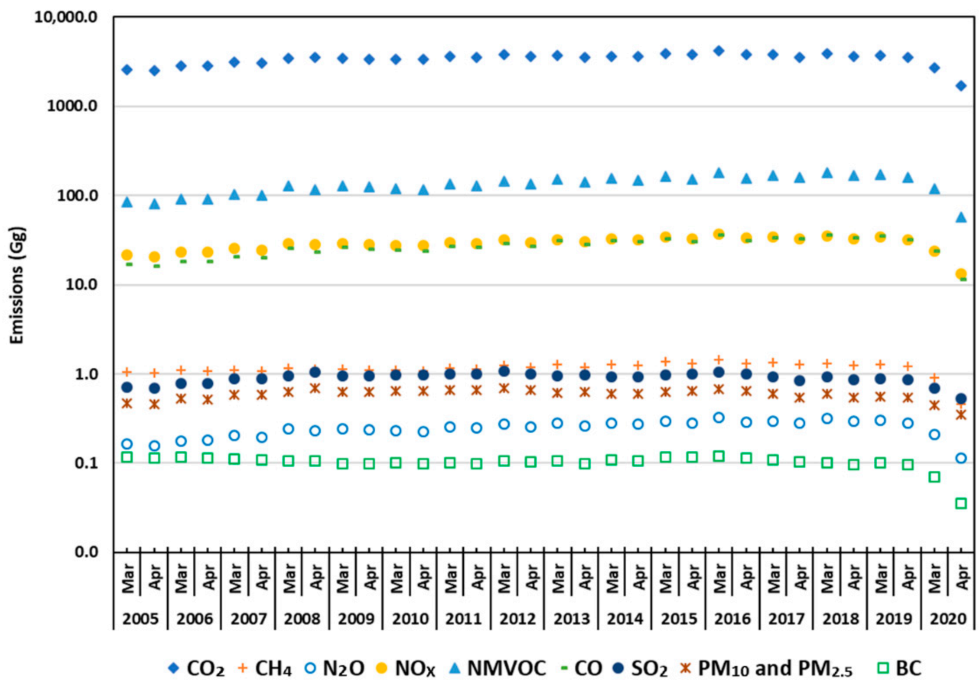

Figure 3. Estimated emissions (Gg) corresponding to the months of March and April from 2005 to 2020 for private road transport sector. Source: calculated by the authors.

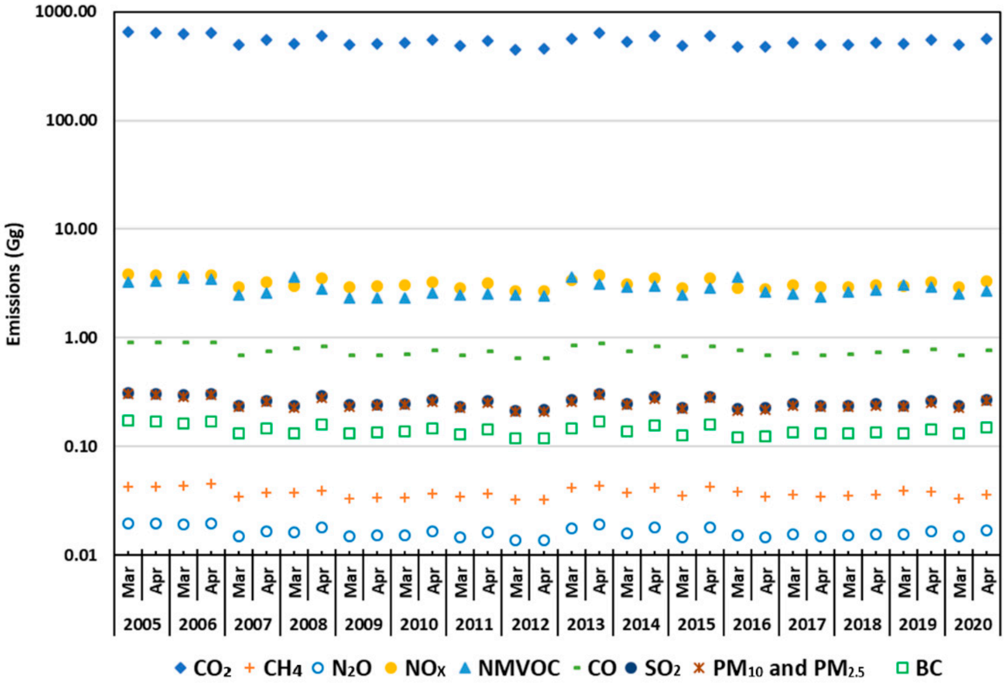

Figure 4. Estimated emissions (Gg) corresponding to the months of March and April from 2005 to 2020 for freight, public transport, and agriculture machines sectors. Source: calculated by the authors.

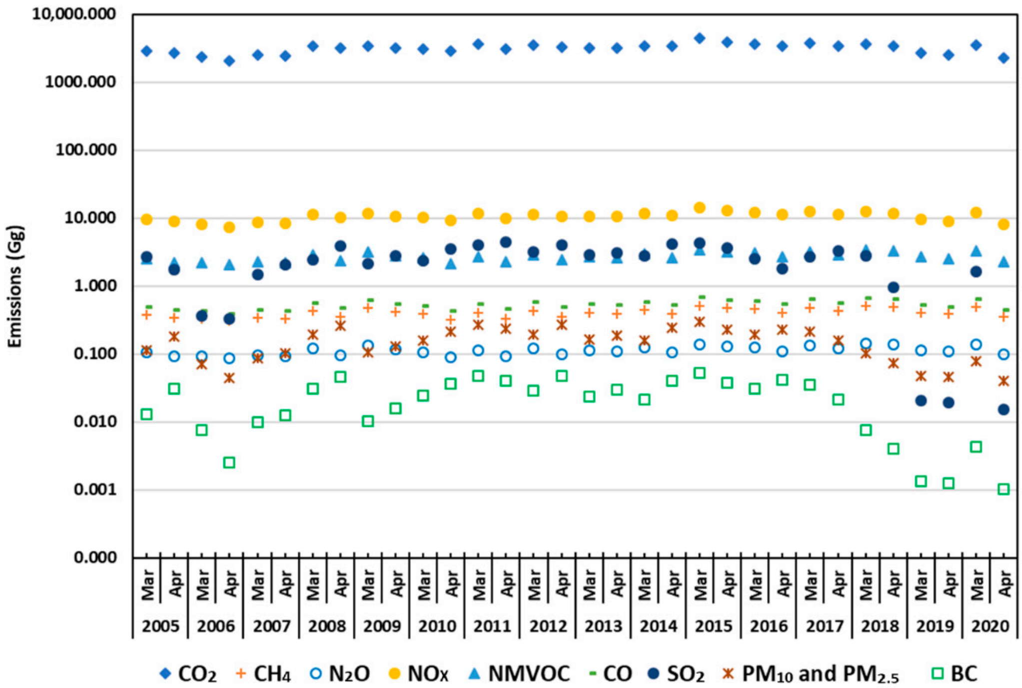

Figure 5. Estimated emissions (Gg) corresponding to the months of March and April from 2005 to 2020 for thermal power plants sector. BC and SO_2 emissions from power plants are highly variable, despite natural gas is the main used fuel, stationary high demand is covered by mineral carbon and fuel oil. Source: calculated by the authors.

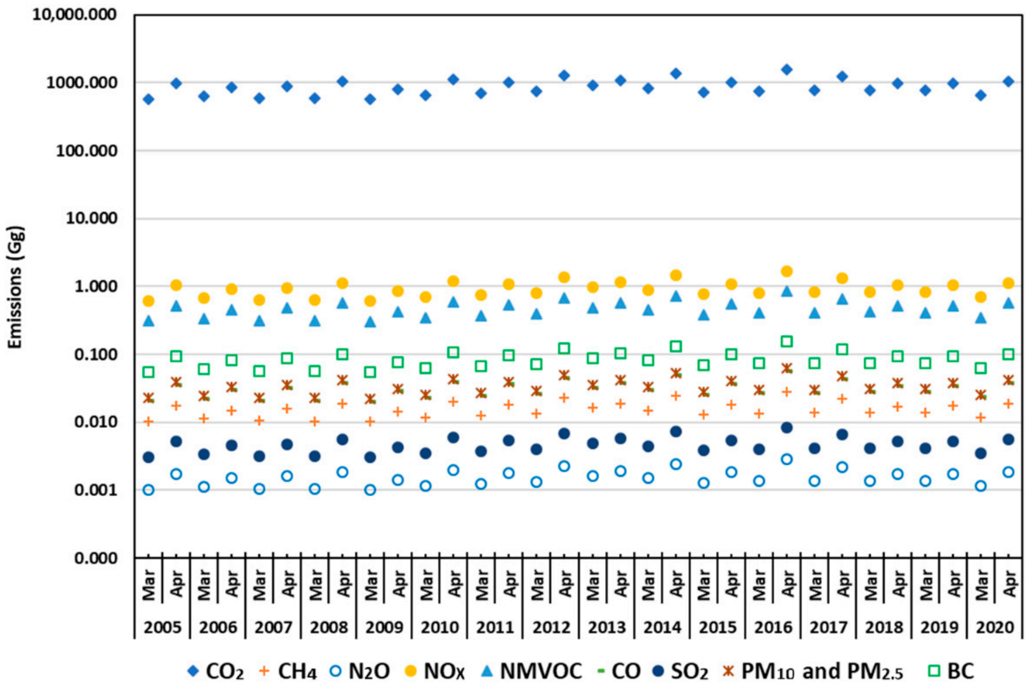

Figure 6. Estimated emissions (Gg) corresponding to the months of March and April from 2005 to 2020 for residential sector. Source: calculated by the authors.

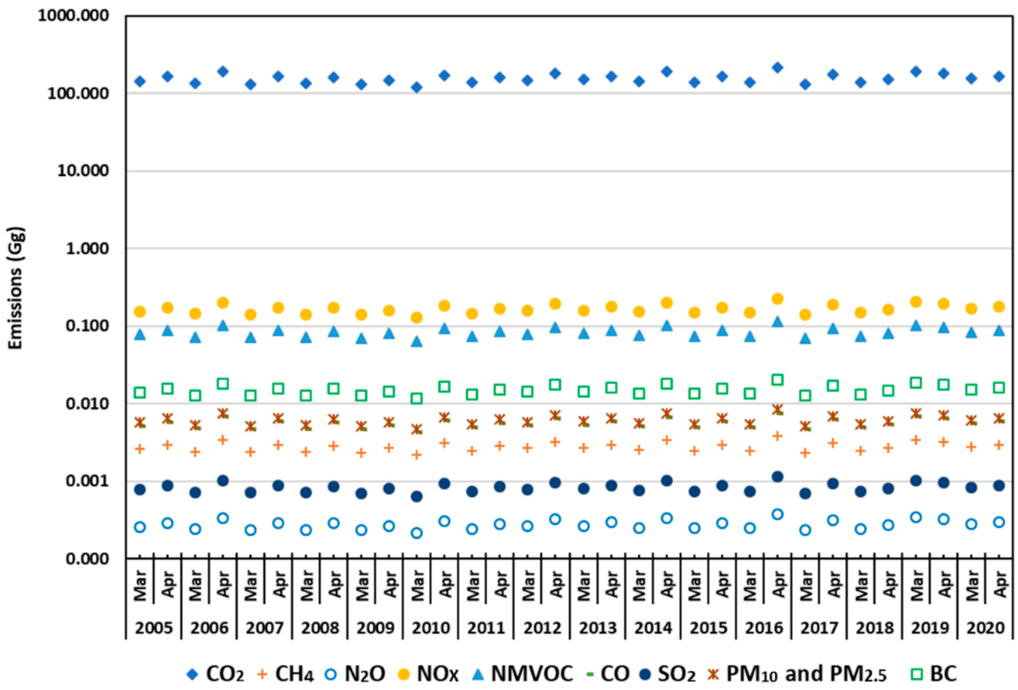

Figure 7. Estimated emissions (Gg) corresponding to the months of March and April from 2005 to 2020 for commercial sector. Source: calculated by the authors.

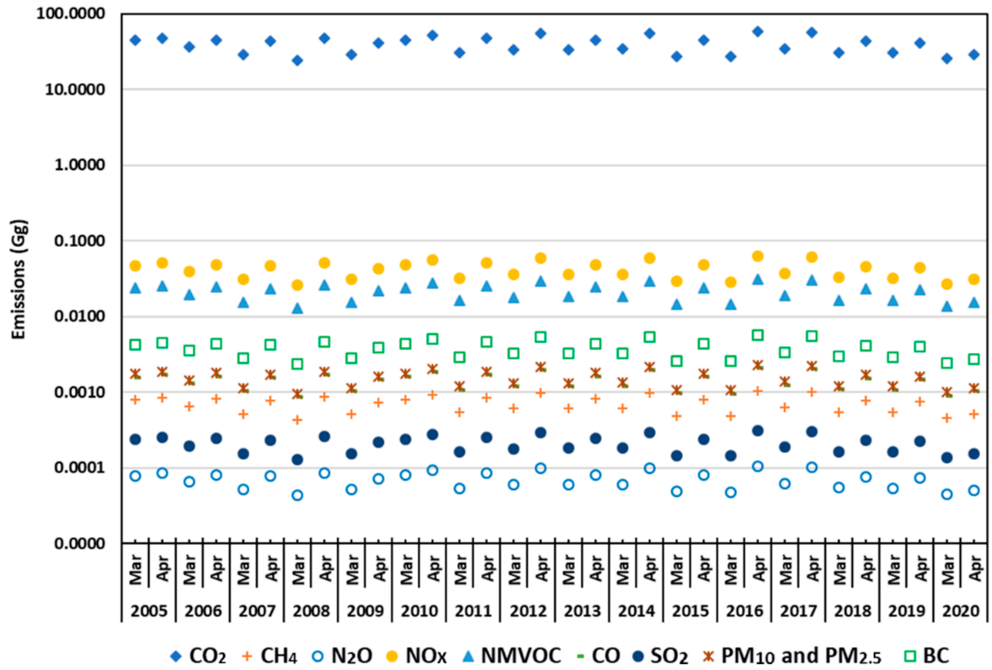

Figure 8. Estimated emissions (Gg) corresponding to the months of March and April from 2005 to 2020 for governmental sector. Source: calculated by the authors.

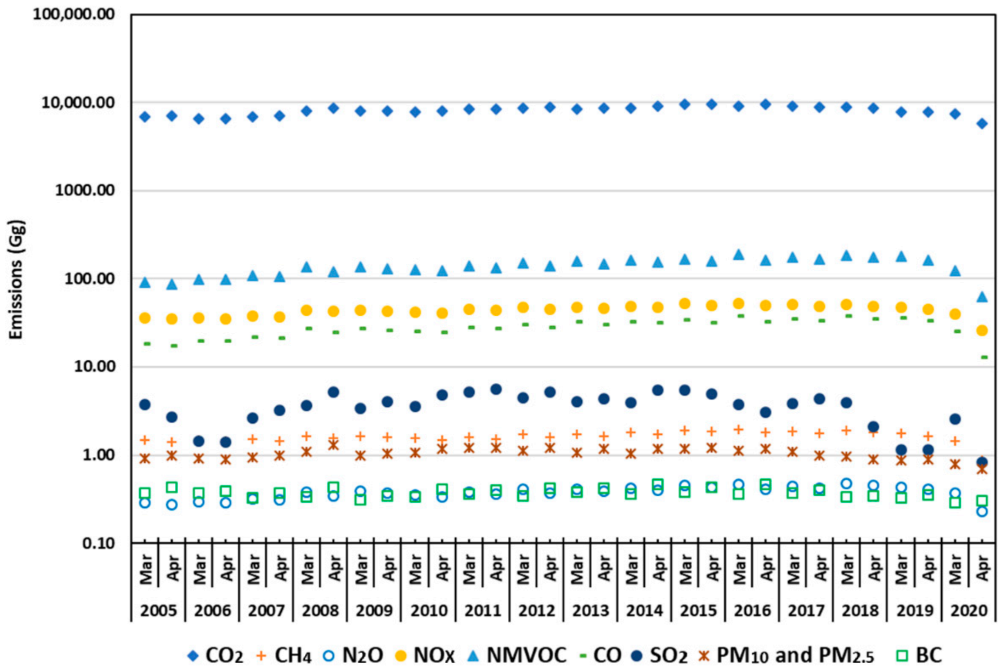

Figure 9. Estimated emissions (Gg) corresponding to the months of March and April from 2005 to 2020 for total emissions. This is the sum of the emissions of all the sectors analyzed. Source: calculated by the authors.

Changes observed for the months of March and April (2019 vs. 2020) indicated emissions decreases from almost all analyzed sectors. Freight, public transport, and agriculture machines sectors did not stop working during the COVID-19 pandemic lockdown in Argentina, as these activities were considered "essentials", and therefore, in April 2020, small increases were estimated for some pollutants: CO_2 (2%), N_2O (1%), NO_x (2%), SO_2 (3%), PM_{10} (3%), $PM_{2.5}$ (3%), and BC (3%), as shown in Figure 10, panel B. In addition, more people stayed in their homes since the start of the mandatory distancing measures (started on 20 March 2020), thus it seems that this produced an 8% increase in emissions from the residential sector in April 2020 (Figure 10, panel D).

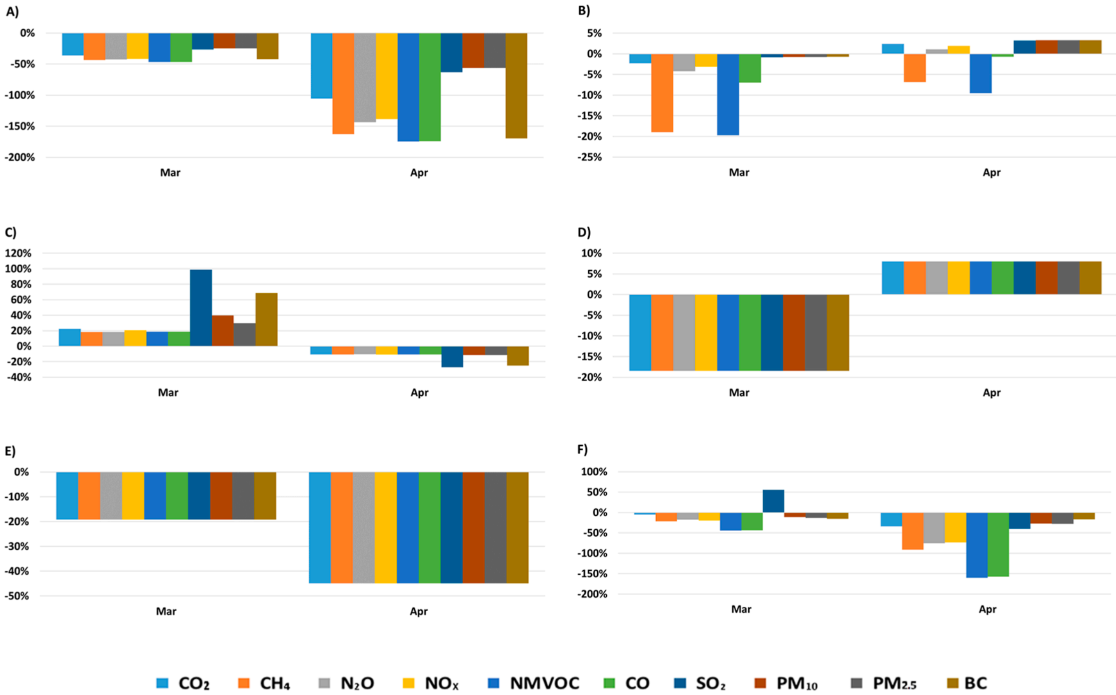

Figure 10. Percentage changes estimated by sector group for (**A**): private road transport, (**B**): freight, public transport, and agriculture machines, (**C**): thermal power plants, (**D**): residential, (**E**): commercial and governmental, and (**F**): total emissions, in March and April between 2020 and 2019 (value 2020–value 2019/value 2020). Source: calculated by the authors.

During 2020, the COVID-19 pandemic has generated lockdown measures that have negatively impacted the economy of many countries. This situation has reduced human activities and therefore their respective atmospheric emissions. Our results show reductions, which are consistent with previous studies. Zhu et al. [47] showed anthropogenic atmospheric emission reductions of 1.5–3.9% rate due to coal combustion reduction by the Asian financial crisis in 2002. Asefi-Najafabady et al. [19] performed a high-resolution global quantification of fossil fuel CO_2 emissions for the years 2006 and 2010. Their results showed decreases in CO_2 emissions in much of the northern eastern half of the United States and throughout northern Europe, India, and eastern China as a consequence of the global financial crisis. China, the largest CO_2 emitting country since 2006, has declined its emissions embodied in export from 2007 to 2012, mainly due to changes in the production structure and efficiency gains, even though developing countries turn into the main destination of China's export emissions. [48]. Trends of the EU's territorial and consumption-based CO_2 emissions from 1990 to 2016 showed that the global financial crisis in 2008 was a major turning point for the reduction in CO_2 emissions in Europe, further suggesting that the main factor driving territorial emissions of the EU before that financial crisis was a growth in GDP [17]. Additionally, a recent study looked at 419 financial crisis episodes in over 150 countries over the period 1970–2014. They exposed that CO_2, SO_2, and NO_x emissions decrease 1.4–6.2% shortly after the crisis, but their crisis effect disappears or reverses (1–2% increase) one or two years after the onset of the crisis [49].

4.3. GHG Emission Reductions

Figures 11 and 12 display GHG emissions differences between 2019 and 2020. They indicate that 373.4 Gg and 1973.4 Gg of CO_2 were not emitted during the COVID-19 pandemic lockdown in March and April, respectively. Similarly, 8.62 Gg (March) and 22.03 Gg (April) less emissions of CO_{2eq}

than CH_4 and 9.52 Gg (March) and 52.05 Gg (April) than N_2O, as CO_{2eq} emissions were not emitted during the lockdown. This means a 28% and 91% GHG reductions (in March and April, respectively), as shown in Figure 12. Altogether, during the analyzed period in 2020, 3337 Gg of CO_{2eq} were not emitted, using a 100-year horizon global warming potential. This was equivalent to more than twice Malta's (annual) emissions (1538 Gg) or 4.2 months of Luxembourg's (annual) emissions (9605 Gg) of CO_{2eq}, both from 2017 [50].

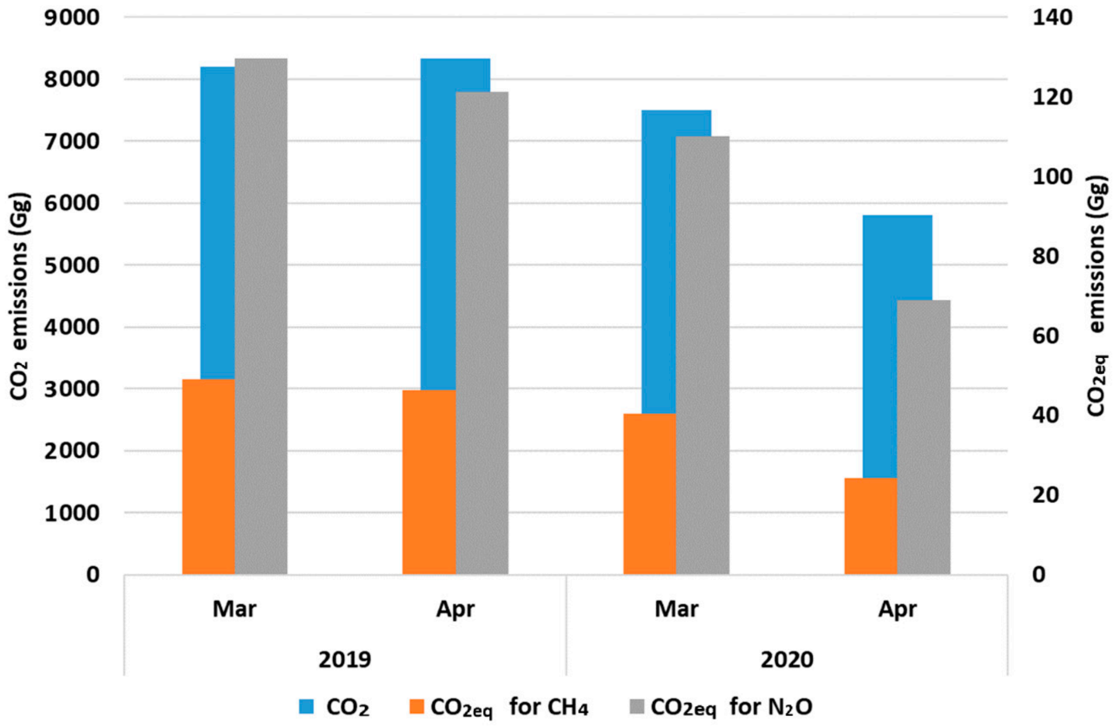

Figure 11. Total emissions for CO_2 and CO_{2eq} (CH_4 and N_2O), as main emitted GHG in 2019 and 2020 (March to April). Source: calculated by the authors.

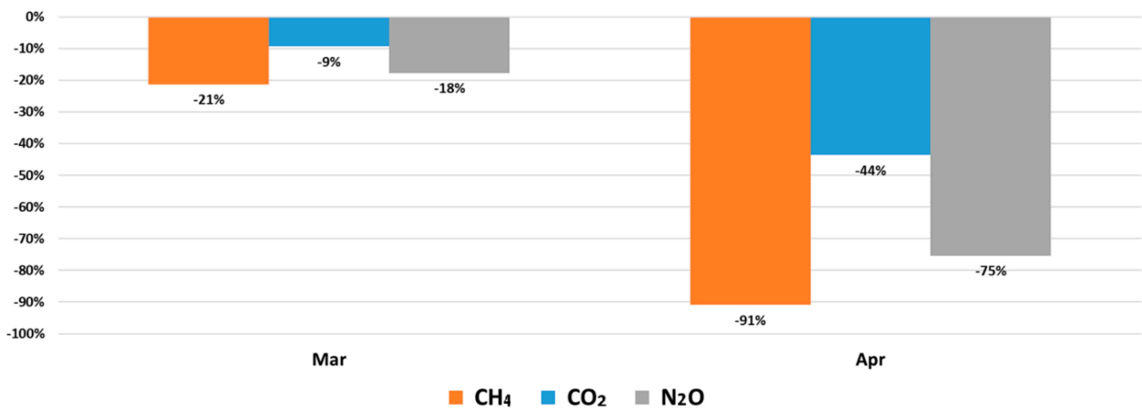

Figure 12. Percentage changes estimated for main greenhouse gases (CH_4, CO_2, and N_2O) in March and April between 2020 and 2019 [value 2020–value 2019/value 2020]. Source: calculated by the authors.

Overall, GHG emissions decrease at the same time as financial crises develop. Liu et al. [51] analyzed GHG data presented in April 2014 about land use, land use change and forestry, energy, industrial processes, solvents and other products, agriculture, and waste for 37 countries. Their results suggest that future emission reductions will derive mainly from mitigation actions aimed at fossil fuel consumption. Thus, reductions in human activities during financial crises are important drivers of GHG emission reductions. Other research analyzed the GHG emissions changes from road transport in Spain during the period from 1990 to 2010, showing that Spain's economic growth has been closely linked to the increase in GHG emissions, and only decreased during the economic crisis [52]. Moreover, changes in emission inventories for different production sectors (affected during financial crisis) has revealed some strategies to reduce future emissions [20,51–54]. Other studies have revealed that emissions only decreased during financial crises, even if they increased after those financial crises [18,21,49,55]. However, recent studies showed that an alternative to avoid repeating this situation, that is, increases in emissions after the financial crisis caused by the COVID-19 pandemic, would be to improve energy efficiency in economic recovery plans to respond to the COVID-19 of several countries, especially developed countries [56].

4.4. Economic Impact of Emissions Changes in Argentina

COVID-19 pandemic has generated a financial crisis in Argentina due to the closure established by the national and provincial governments to flatten the infection curve. These restrictions on the circulation of people have generated a reduction in economic activity. Therefore, we used a multiple linear regression technique to estimate the relative importance of population and GHG emissions in the GDP of Argentina. These parameters were first subtracted by their means and then normalized by their respective standard deviations of population, GHG and GDP, (denoted by σ_P, σ_G and σ_{PG}, respectively). A multiple linear regression analysis was conducted using these standardized parameters from January 2005 to April 2020; therefore, 62 data points were used for GDP, GHG, and population, respectively. Thus, the three-monthly average of the GDP, σ (one σ = 146.6 billion USD), can be expressed by:

$$\sigma = -0.8 \times 10^{-16} + 0.64P + 0.34G \quad (2)$$

where $\boldsymbol{P}$ and $\boldsymbol{G}$ represent normalized population and GHG, respectively. The multiple correlation coefficient (R^2) has a value of 0.63 with a mean absolute percentage error (MAPE) of 16%, which indicates that Equation (2) can describe the variation in GDP. Therefore, population and GHG changes can explain 63% of the GDP variation. Figure 13 shows the comparison between the observation and the regression prediction GDP, it displays a reasonable behavior of the multiple regression model used.

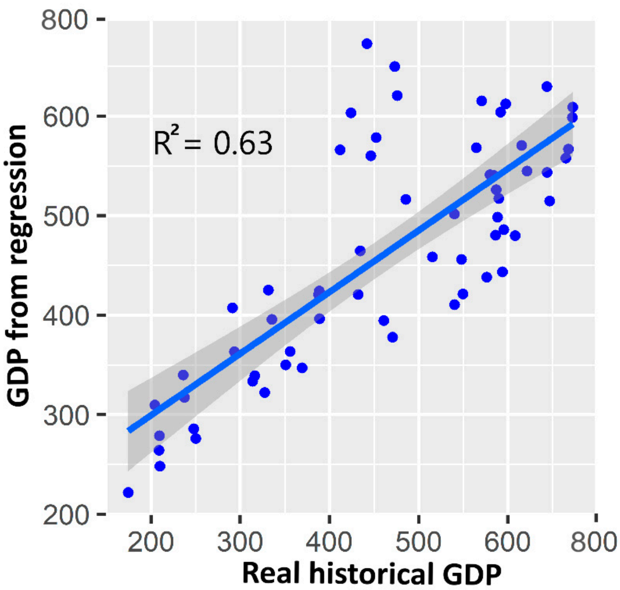

Figure 13. Comparison of the gross domestic product (GDP) predicted by the regression equation and real historical GDP (values expressed in billions of US dollars). Solid line displays the linear trend estimation, and its shaded area represent 95% confidence interval. Source: calculated by the authors.

Using Equation (2), we can estimate the contributions of population and GHG to GDP changes during the period analyzed. Overall, population increased by 3.3 σ_P; meanwhile, GHG values increased by 5.6 σ_G. Thus, Equation (2) predicts that population and GHG increases contributed partially 52% and 48% to the increase in GDP between 2005 and 2020, respectively. This multiple regression model displays that an increase in GDP (growing productive activities) from the analyzed sectors would increase GHG emissions. For instance, if Argentina's GDP increases by 1%, then it would increase activity in the analyzed sectors, thus emitting 450 Gg CO_{2eq}. This also predicts that, during March–April 2020, 26% lower activity or GDP reduction have reduced GHG emissions from the studied sectors during COVID-19 pandemic. Argentina presents a particular situation, its GHG emissions are very dependent on energy consumption and livestock production [13,42,46]. GHG/Energy has been stable around (34 ± 4 g/MJ) in the seen period (2005–2020), energy/capita also has been increasing slowly with an average of 12,170 ± 1350 MJ/capita; producing and emissions/capita of 416 ± 82 kg/capita [11]. The lockdown situation has showed that a reduced economic activity (less GDP) has produced a decrease in GHG, mainly through reduced energy consumption (as shown in Figure 11). Furthermore, given the structural conditions of the countries' emissions, a reduction in GHG can be obtained by a reduction in energy consumption and reducing livestock production. However, both actions in the short term can be achieved by reducing the economic activity [57], which will have strong impact on many sectors, such as education, health, and so on. Improving energy efficiencies and emissions intensities are long-run solutions, which paradoxical requires high investments. Other low-cost solutions such as optimizing public transport (bus frequencies and runs), promoting bicycling, increasing home office, and others are permanently being proposed and implemented, with fair emissions reductions. However, reducing livestock production and agriculture will produce major emissions reduction in the very short run but will reduce Argentina's main income, reducing its GDP. From this perspective, our results also could indicate that reducing 1 Tg of GHG emissions (as CO_{2eq}) on the energy consumption sector would produce a 0.16% GDP contraction for the Argentine economy. Pandemics such as COVID-19 can cause serious damage to the regional economy in the short and long term [58–61]. Recent studies have analyzed the impact of COVID-19 on China's carbon emissions using national economic data, showing that GDP has potential merit in estimating changes in CO_2 emissions [62]. Huang et at. [63] studied the application of the Kyoto Protocol. They found that most of the signatory countries of this protocol failed to reduce GHG emissions, especially the industrialized countries, because they developed an economy based on the econometric method. In this sense, our results show that Argentina has developed an econometric model that explains the increase in GDP associated with the increase in GHG emissions from 2005 to 2020. Then, a reduction in GHG emissions would have a high negative impact on the Argentine economy under its the current production system. Therefore, it is necessary to break this relationship of simultaneous increase in GDP and GHG emissions. Thus, the post-COVID-19 investments needed to accelerate to more resilient, low-carbon, and circular economies should also be integrated into the stimulus packages for economic recovery promised by governments, as the shortcomings of the dominant linear economic model are now recognized and the gaps are known to be closed [64]. Although, the COVID-19 pandemic could trigger chain events leading to the downfall of the oil age in the early 2020s [64]. A new direction was proposed a few years ago, through the Paris Agreement, which commits all countries to address the change of global warming by establishing measures for the GHG emissions reduction [65]. However, other studies have highlighted the danger of depending on the benefits generated by the pandemic to achieve the Sustainable Development Goals established by the Paris Agreement [64]. Therefore, it is necessary to decouple economic growth from GHG emissions as seen in the World Bank data, showing that the world experienced economic growth without growth in carbon emissions in 2015 [66]. Our results indicate that Argentina's economy needs to make changes to match economic growth and reduction in GHG emissions, thus complying with the Paris Agreement.

4.5. Emissions Rate Variation and Air Quality Improvement on COVID-19 Pandemic Lockdown

Table 2 shows the studies reporting data on air quality improvement during the COVID-19 pandemic lockdown. Air quality improvements were observed with reductions of up to 73% and 75% for PM_{10} and $PM_{2.5}$ concentrations in Argentina, respectively (as shown in Figures A1 and A2). In addition, the largest NO_2 reductions (up to 64%) were observed in Southeast Asia. In fact, it was the most analyzed pollutant due to the availability and reliability of remote sensing data such as Sentinel-5P TROPOMI [67], by estimating proportionally other air pollutants. Other studies have shown improvements in air quality related to the COVID-19 pandemic in Argentina [68,69]. Moreover, because the sectors analyzed are related to urban activities in Argentina, the greatest reductions have been observed in large conglomerates such as the city of Buenos Aires. In effect, recent studies carried out by the Argentina National Space Activities Commission showed reductions in NO_2 concentrations in April 2020 in the largest urban conglomerates of Argentina [70,71]. These studies are consistent with our results, which showed NOx emission reductions of up to 73% in the same period (April 2020), for all the sectors analyzed (see Figure 10, panel F). Thus, most air quality reductions indices have been inferred from NO_2 tropospheric column available from this satellite data. Our results also show that emission reduction estimates are consistent with air quality measurements for the same period in Buenos Aires, its capital and largest city (Figure A3). Our results are consistent with previous studies that showed that some of the analyzed sectors, namely the thermal power plants, automobiles, taxis, trucks, buses, residential heating, and the commercial sector, represent more than 90% of the annual atmospheric emissions per CO and NOx in the city of Buenos Aires [72]. In addition, it can be seen that, in the months analyzed (March and April 2020), it corresponds to a transition from hot to cold season. These changes imply a reduction in wind speed [73,74] that leads to increases in the concentration, especially of NO_2 (see Figures A4 and A5). Even so, reductions in PM_{10} and NO_2 concentrations (Figure A3) could be observed during the pandemic lockdown.

Table 2. Comparison of air quality improvement due to the COVID-19 pandemic lockdown (% reduction identified). The middle hyphen (-) indicates the data were not reported. Source: compiled by the authors.

City/Country/Region	Pollutants							Reference
	NO_2	NO	CO	SO_2	PM_{10}	$PM_{2.5}$	BC	
China	20–30	-	-	-	-	-	-	[7]
Italy		-	-	-	-	-	-	
Spain		-	-	-	-	-	-	
France		-	-	-	-	-	-	
USA	30	-	-	-	-	-	-	
New Daly, India	53	-	30	-	60	39	-	[8]
Madrid, Spain	62	-	-	-	-	-	-	[75]
Barcelona, Spain	50	-	-	-	-	-	-	
Western Europe	30–50	-	-	-	5–15	5–15	-	[36]
Southeast Asia	63–64	-	25–31	9–20	26–1	23–32	-	[76]
São Paulo state, Brazil	54	77	65	-	-	-	-	[37]
City of Rio de Janeiro, Brazil	24–33	-	37–44	-	-	-	-	[2]
Almaty, Kazakhstan	35	-	49	-	-	6–34	-	[77]
Somerville, MA, USA	-	-	-	-	-	-	22–56	[78]
Argentina	-	-	-	-	38–73	41–75	-	This study (see Figures A1 and A2)
Buenos Aires City, Argentina	44	-	-	-	82	-	-	This study (see Figure A3)

4.6. Emissions Changes

It is interesting to note that under the COVID-19 pandemic situation many cities in the world experienced better air quality due to the cessation of many activities [7,8,37,68,77–80]. This article shows that the emissions reductions would be related to the improvement in air quality in Argentina (as shown in Table 2). Considering the GHG emissions monthly variations (January 2005 to April 2020) from different sectors, for instance the road transport sector, it shows a significant reduction in March and April 2020, reaching a reduction of 8.6% and 31% (7656 and 5897 Gg CO_{2eq}) compared to the same months in 2019 (8388 and 8502 Gg CO_{2eq}). In addition, 8.4% and 30.5% if we consider the average values of March and April for the 2005–2019 period (8374 and 8486 Gg CO_{2eq}), respectively, as shown in Table A1. These reductions can also be seen in the thermal power plants, commercial, and governmental sectors, while there is a slight increase in the residential sector, as was to be expected due to home quarantine (i.e., preventive and obligatory social isolation).

The analysis results on research hypotheses showed that there has been a reduction in atmospheric emissions for almost all the compounds analyzed, as much as compared to the same period in 2019, and also for the average (2005–2019). Only the emissions from the residential sector presenting a slight increase that we assume was due to the measures to stay at home. Furthermore, improvement in air quality was detected through satellite observations (PM_{10} and $PM_{2.5}$) and surface measurements by the air quality network of the city of Buenos Aires (PM_{10} and NO_2). These results were consistent with the estimated reductions in atmospheric emissions. The multiple regression model showed that more economic activities produce higher GDP and therefore higher GHG emissions. In fact, an evaluation of this model indicated that the contraction of GDP reduced GHG emissions from the sectors analyzed, during the pandemic restrictions.

The global spread of COVID-19 is showing that it is possible that climate change mitigation may also benefit from this situation related to pandemic lockdown [58]. For example, working from home and holding teleconferences reduce CO_2 emissions during COVID-19 restrictions [62]. However, this important reduction in GHG emissions and other pollutants induce us to reflect on the following points: (1) The emissions reduction occurred after a mandatory confinement due to the fear of a supposedly fatal contagion; (2) The confinement produced a reduction in consumption, commercial activity, industry, and transport. However, (3) this significant economic downturn produced losses of employment, reduced health, reduced education, and finally, reduced welfare and affected individual freedoms [81,82]. GDP reductions are associated with inequalities and asymmetries between high/low consumption sectors, with better/lesser education, health, job opportunities, and so on. These inequalities are not only evident between developed and less developed countries, but within the same countries and cities.

These unusual and extraordinary circumstances allow us to weigh the difficulties and costs, in terms of GDP contractions, of implementing GHG reduction plans aimed at achieving a reduction in global temperatures. Decoupling GHG and economic growth and decarbonizing the economy is still a hard challenge. At present, only a voluntary reduction in consumption associated with a major cultural and technological change would produce a reduction in GHG emissions.

5. Conclusions and Outlook

This study provides the first emission estimation data for various sectors during the COVID-19 pandemic lockdown in Argentina. The results showed emission reductions for March and April 2020, namely: GHG emissions (up to 90%), PM_{10}, $PM_{2.5}$, and BC emissions (up to 37%) and NOx, CO, NMVOC, and SOx emissions (up to 160%) compared to same months in 2019. Particularly, we found an increase in the residential sector emissions (8%). Meanwhile, Argentina's GDP contracted 26% during the COVID-19 pandemic. Our data also indicate that emission reductions were below average (2005–2019) for almost all estimated compounds during the most restricted months of pandemic lockdown analyzed. These findings demonstrate the reduction in the emission due the COVID-19 pandemic lockdown had improved air quality in Argentina. It also shows the positive correlation between GDP and GHG emissions. Therefore, decision makers could design strategies to decouple this positive relationship, taking advantage of the new challenges of the economic recovery during the post-pandemic. Moreover, this updated emissions estimation could be used not only as input data in air quality models but to understand the environmental and economic implications of GHG reductions strategies.

Our study showed a reasonable relationship between atmospheric emissions changes, improvement in air quality and its impact on the economy during the COVID-19 pandemic lockdown in Argentina. However, it has some limitations; due to the few months considered during the pandemic, more data are needed to achieve stronger relationships. In addition, another limitation was the inter-annual comparison of air quality during COVID-19 with previous years 2019 (e.g., Figures A1–A3), because it cannot exclude meteorological variations and influences of long-term trends on changes in air quality. For example, the exact contributions of the analyzed sectors to the reductions in air quality and its impact on GDP, require greater detail data collection from each emission source. Additionally, future work could better explain the changes in air quality by combining the improved atmospheric emissions estimated in this article using a chemical transport model [83,84]. In addition, analyzing the outcome of the coming months could give more indications how increasing/decreasing emissions impacts on air quality, as an expected recovery in GDP in the post-pandemic era may happen.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Data available for Argentina's monthly emissions estimated from January 2005 to April 2020. Source: calculated by the authors.

Item	Description
Specific subject area	Estimation of atmospheric emissions from private road transport, freight, public transport, agriculture machines, thermal power plants, residential, commercial, and governmental sectors.
Type of data	Tables and figures
How data were acquired	Data collection of the monthly amount and type of production for each sector, and estimation through different methods. In addition, specific emission factors were applied for each sector for the calculation of the different polluting species [9,12,13,27,29].
Data format	Raw and processed
Parameters for data collection	The data were estimated for the activity level recorded from January 2005 to April 2020 for each sector and polluting species (CO_2, CH_4, N_2O, NO_x, CO, NMVOC, SO_2, PM_{10}, $PM_{2.5}$, and BC).
Data source location	Country: ArgentinaLatitude and longitude: 22° to 56°S latitude and from 52° to 75°W longitude
Data accessibility	With the article and a public repository: • Repository name: Mendeley Data • Data identification number: 10.17632/ppk4dn9dn2.1 • Direct URL to data: http://dx.doi.org/10.17632/ppk4dn9dn2.1

Table A2. Estimated percentage changes for March and April between 2020 and average 2005–2019 [value 2020–average 2005–2019/value 2020], for sectors: private road transport, freight, public transport, agriculture machines, thermal power plants, residential, commercial, governmental, and total emissions, respectively. Source: calculated by the authors.

Sectors	Month	CO_2	CH_4	N_2O	NO_x	CO	NMVOC	SO_2	PM_{10}	$PM_{2.5}$	BC
Private road transport	March	–28%	–34%	–21%	–25%	–18%	–18%	–32%	–34%	–34%	–51%
	April	–94%	–145%	–107%	–111%	–122%	–121%	–70%	–67%	–67%	–182%
Freight, public transport, and agriculture machines	March	–5%	–12%	–6%	–5%	–13%	–7%	–4%	–4%	–4%	–4%
	April	0%	–7%	0%	0%	–4%	–1%	1%	1%	1%	1%
Thermal power plants	March	5%	14%	14%	7%	14%	12%	–45%	–93%	–94%	–406%
	April	–32%	–9%	–8%	–23%	–10%	–12%	–16097%	–304%	–250%	–2413%
Residential sector	March	–7%	–7%	–7%	–7%	–7%	–7%	–7%	–7%	–7%	–7%
	April	–2%	–2%	–2%	–2%	–2%	–2%	–2%	–2%	–2%	–2%
Commercial sector	March	9%	9%	9%	9%	9%	9%	9%	9%	9%	9%
	April	–4%	–4%	–4%	–4%	–4%	–4%	–4%	–4%	–4%	-4%
Governmental sector	March	–26%	–26%	–26%	–26%	–26%	–26%	–26%	–26%	–26%	–26%
	April	–65%	–65%	–65%	–65%	–65%	–65%	–65%	–65%	–65%	–65%
Total emissions	March	–20%	–17%	–7%	–13%	–17%	–17%	–38%	–30%	–28%	–22%
	April	–46.9%	–80.9%	–56.1%	–64.2%	–111.3%	–109.2%	–346.5%	–50.9%	–46.2%	–30.3%

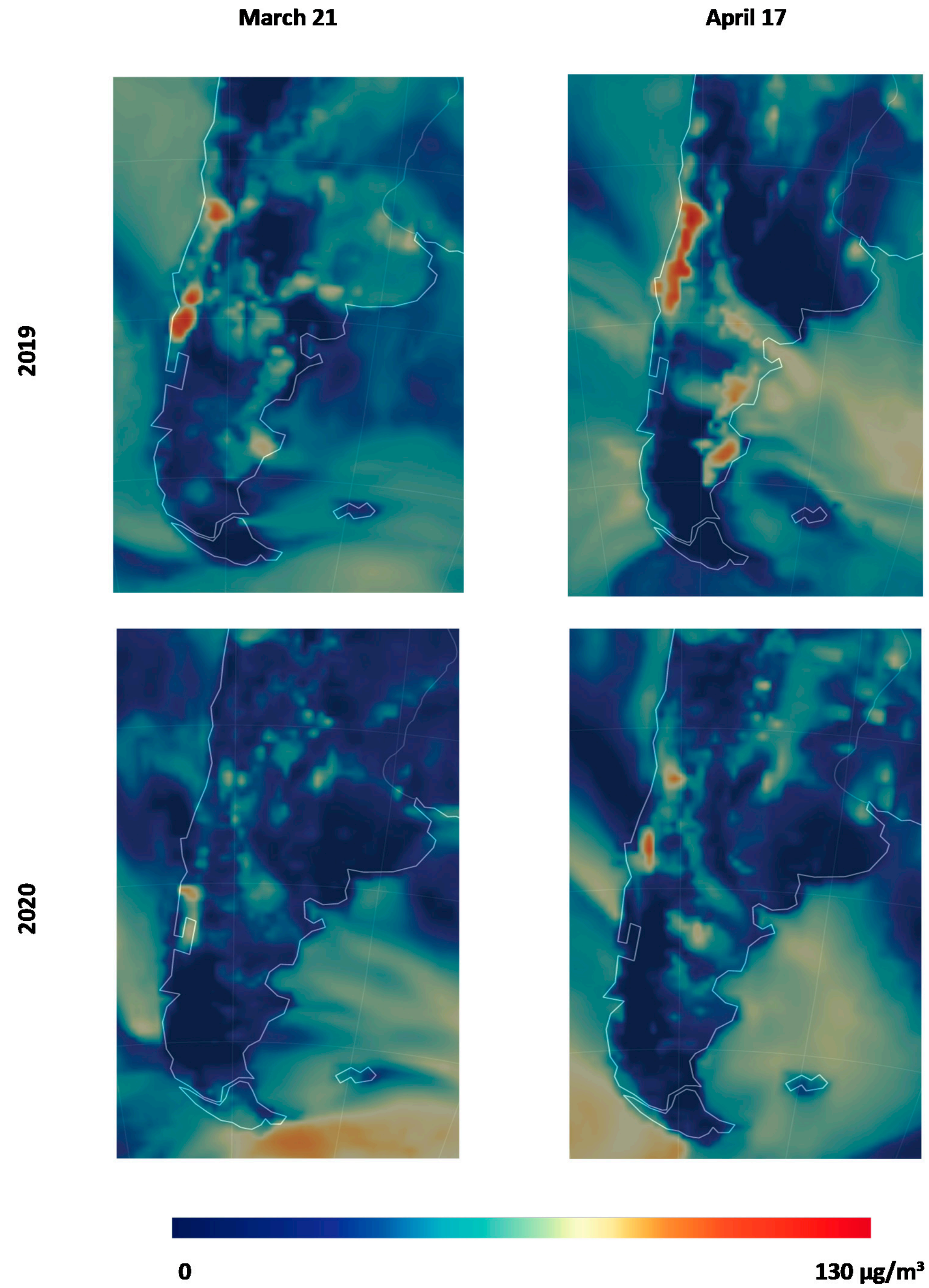

Figure A1. Satellite images obtained on 21 March and 17 April (2019 and 2020), showing PM_{10} levels mainly in Argentina. Source: Earth (CAMS/Copernicus/European Commission + ECMWF) [85]. The 2020 data compared to the previous year 2019 display reductions of up to 73% and 38% for March and April, respectively.

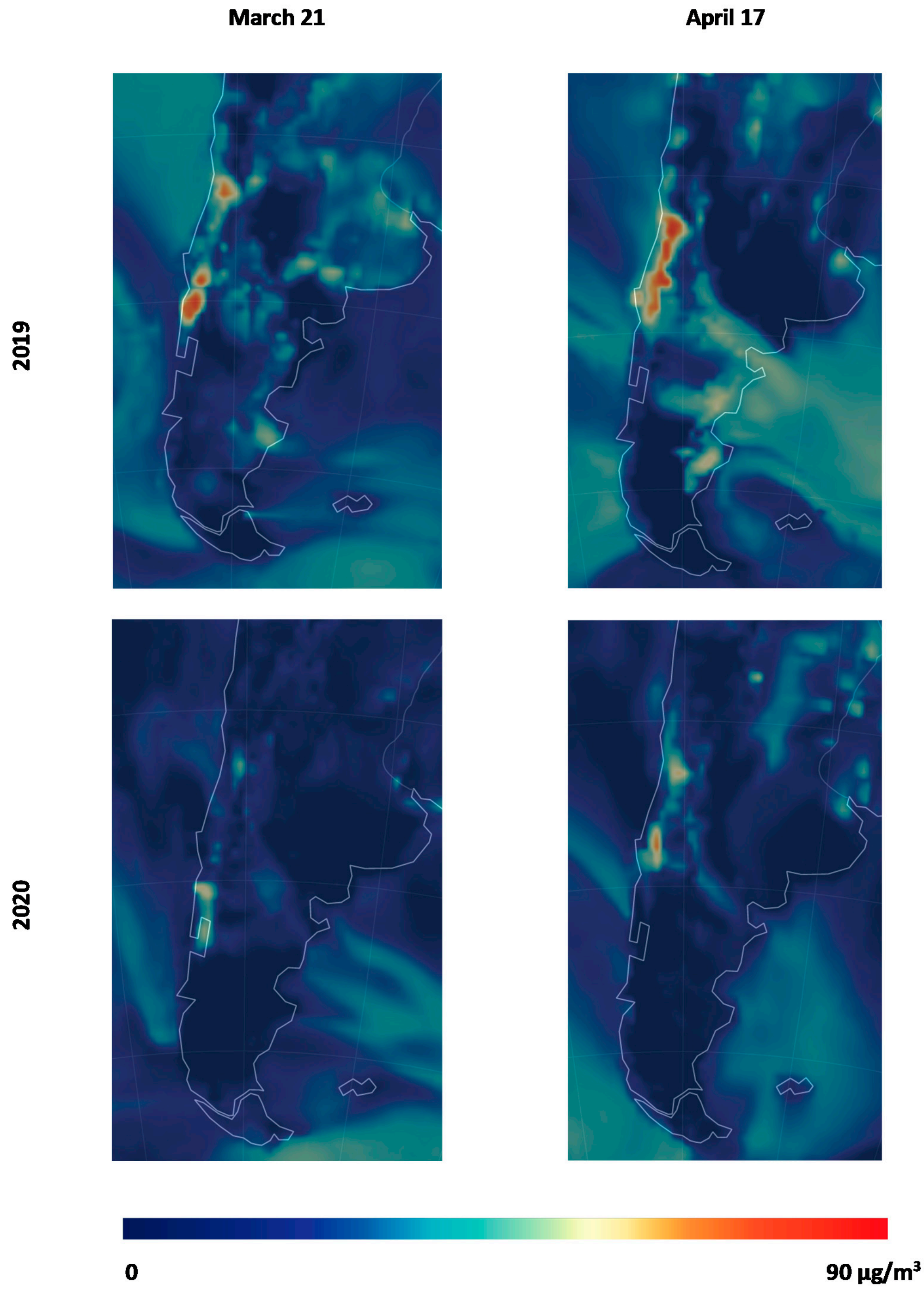

Figure A2. Satellite images obtained on 21 March and 17 April (2019 and 2020), showing $PM_{2.5}$ levels mainly in Argentina. Source: Earth (CAMS/Copernicus/European Commission + ECMWF) [85]. The 2020 data compared to the previous year 2019 display reductions of up to 75% and 41% for March and April, respectively.

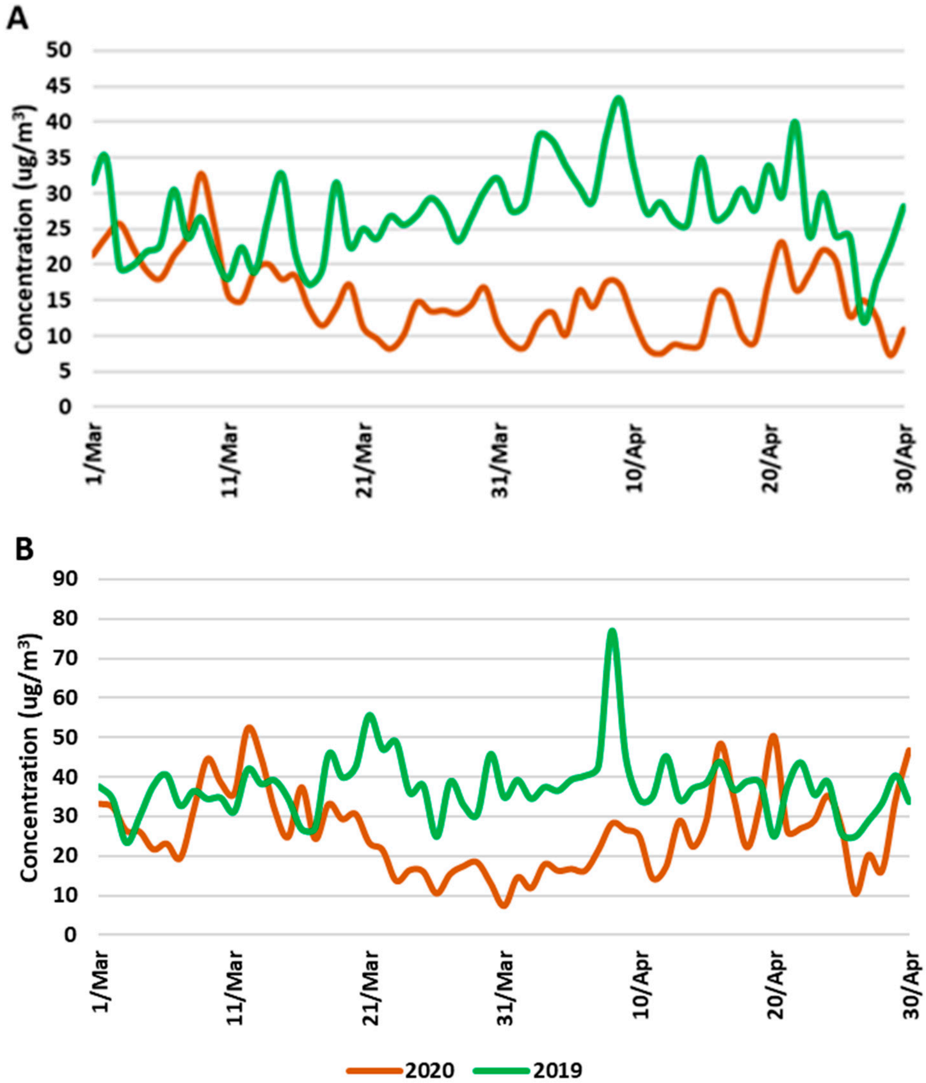

Figure A3. Daily mean values measured from the Buenos Aires city air quality network for PM_{10} (**A**) and NO_2 (**B**) [86]. The 2020 data compared to the previous year 2019 shows an average reduction of 44.3% and 82.9% for NO_2 and PM_{10}, respectively.

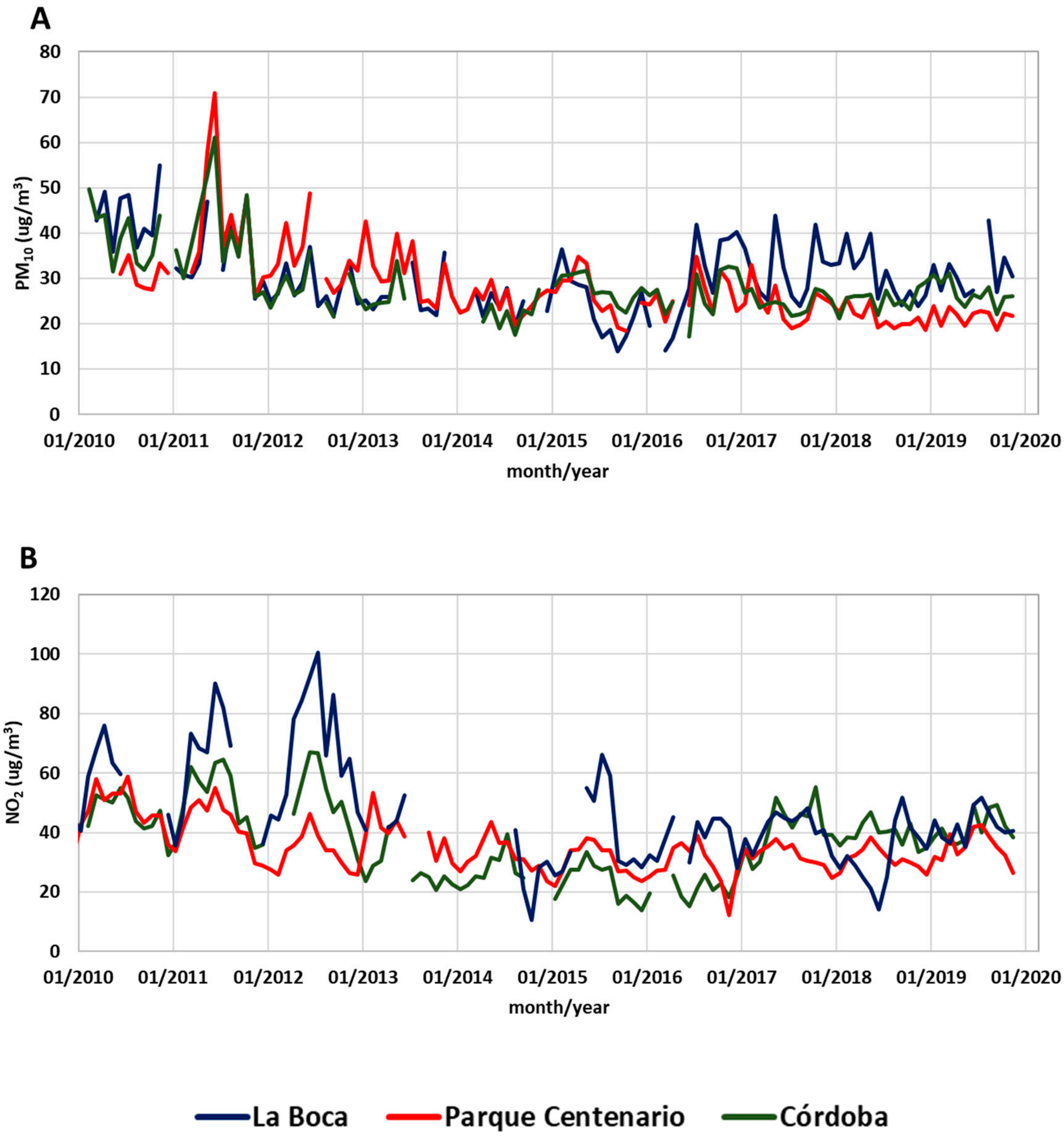

Figure A4. Monthly variation for PM_{10} (**A**) and NO_2 (**B**) concentrations from 2010 to 2019. Measured from the Buenos Aires city air quality network [86]. Each line represents the behavior for the stations presented in Figure 1. Data not shown indicate that it was not measured at least 75% of the time.

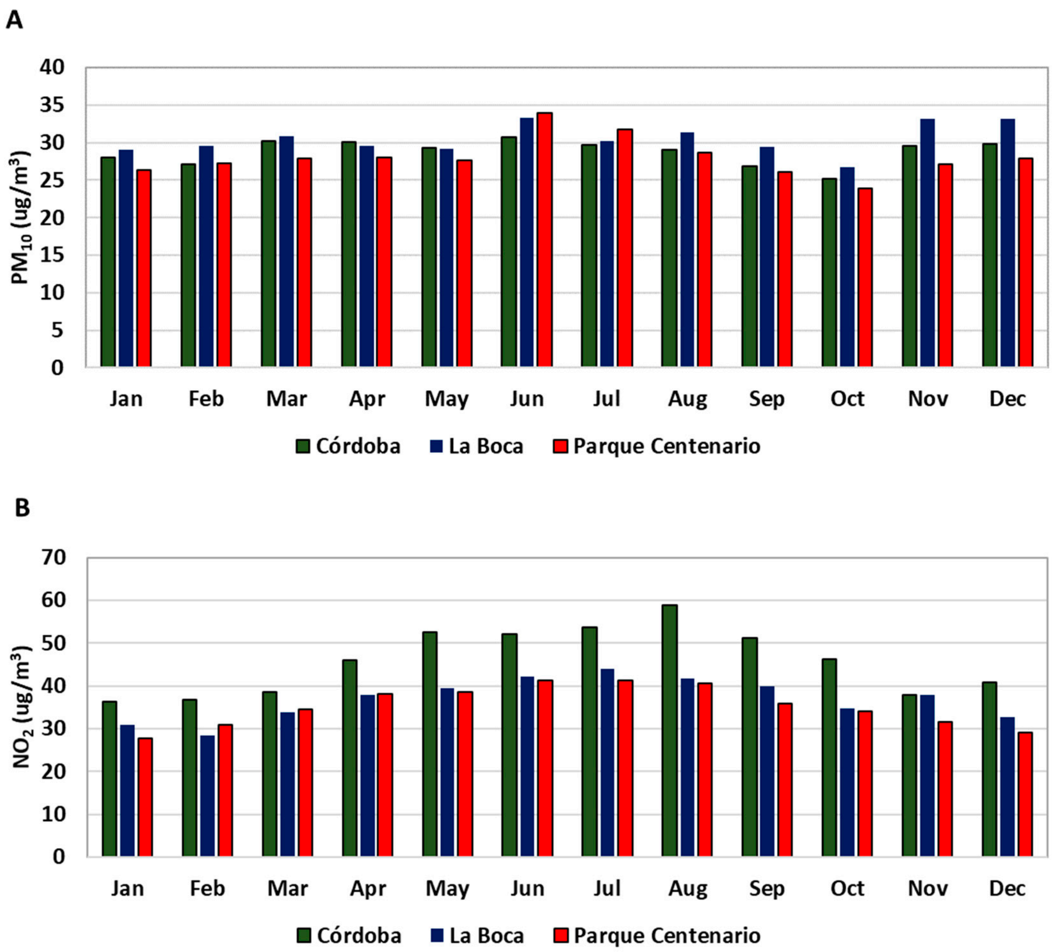

Figure A5. Monthly concentrations for PM_{10} (**A**) and NO_2 (**B**). Average values (2010 to 2019) measured from the Buenos Aires city air quality network [86]. Each line represents the behavior for the stations presented in Figure 1.

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