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Study of the Effects of the COVID-19 Pandemic on Air Quality: A Case Study in Cluj-Napoca, Romania

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Abstract: Many concerns are arising now regarding the effects of the pollution on inhabitants, especially in agglomerated areas. It is known that mobility is a major factor that generates threatening pollution that negatively affects the health and the comfort of residents. The present study focuses on this sensitive subject by observing the impact of reducing mobility on air quality. There are various studies on this topic, but this analysis addresses a gap in the literature, by covering a very active area, in terms of development and attractiveness for new inhabitants. The research study was carried on Cluj-Napoca city (Romania), by measuring the concentration of SO_2, NO_2, O_3, PM_{10}, $PM_{2.5}$ from five different air monitoring stations from Cluj County during 2019–2021. During the entire period, the concentrations of the measured pollutants regarding the air quality were far below the legally accepted limits, with some short time peaks generated by other human factors. Road vehicle traffic generates pollution, but they are not the only elements that have to be taken into consideration when the quality of life is regarded, so the lawmakers have a more complex task to comply when deliberating on this matter. It concludes that it is necessary to develop on the existing air quality measuring network stations, because it is necessary to increase the number and the quality of the measurements.

Keywords: automatic station type traffic; lockdown; pollution

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1. Introduction

The sanitary crises due to SAR-CoV-2 virus affected the whole world and forced the nations into partial or total lockdown, leading to decreases of unnecessary commercial activities, reducing the mobility of residents with restrictions on private and public transportation. The lockdown measures affected human activities in different ways: from food consumption [1–3] to tourism demands [4,5], and public transportation [6]. Moreover, the COVID-19 pandemic had a negative impact on both health systems and economies all over the world. However, previous studies revealed the fact that the pollution levels decreased leading to an increase in environmental health [7,8]. The decrease of the economic activities led to an increase in the air quality, due to the pollution reduction [9].

Air pollution has a high impact on human health, representing a risk factor for respiratory and cardiovascular issues [10]. Exposure to PM_{10} and $PM_{2.5}$ increases respiratory diseases [11,12], while sulphur dioxide (SO_2) and ozone (O_3) are associated with cardiovascular disease [13,14]. Additionally, nitrogen dioxide (NO_2) exposure increases the risk of incurring respiratory diseases [15]. The increase in air pollution is linked to economic development, urbanization, and transportation [16].

The tracked pollutants, SO_2, NO_2, O_3, PM_{10}, and $PM_{2.5}$ are substances that can generate serious health problems individually but especially when they act together. In the second case (photochemical smog that forms on sunny days in cities with congested traffic), a synergistic effect occurs, especially with NO_2 and SO_2, even when these two gases are below the maximum allowed limit by the rules in force. Photochemical smog can occur when solar radiation encounters pollutants, such as NO_2, volatile organic compounds, or aldehydes [17].

SO_2, like most other pollutants, comes from both natural and anthropogenic sources. Natural sources are volcanic eruptions, bacterial fermentation in wetlands, or oxidation of sulphur-containing gas resulting from biomass decomposition. Anthropogenic sources are represented by residential space heating systems using methane, from industry, and to a lesser extent, from compression ignition engines. Sulphur dioxide is a colourless gas with a suffocating and penetrating odour. It is transported over long distances because it easily attaches to dust particles. In the atmosphere, a reaction with water vapor leads to the formation of sulfuric acid, which gives rain an acidic character.

NO_2 is a highly toxic gas and appears as a brick-coloured gas. The main sources of nitrogen oxides are combustion from internal combustion engines, the energy sector, and from home heating systems [18,19].

From the category of volatile organic compounds, the most present elements are methane and benzene. Methane is the main gas used in most home heating systems and benzene comes from the fuel used, predominantly, in internal combustion engines that equip most cars.

From the category of aldehydes, the simplest and at the same time the only one in gaseous form, is formaldehyde obtained by oxidizing methane.

Ozone appears due to the rapid recombination of atomic oxygen with molecular oxygen. The presence of this gas, in the terrestrial atmosphere, at high altitudes, has beneficial effects by filtering ultraviolet radiation, but the presence of ozone at the level of human occupied areas is negative. Ozone can re-oxidize nitrogen monoxide, thus obtaining nitrogen dioxide and oxygen, but at the same time it destroys ozone.

Natural sources of particulate matter are volcanic eruptions or windblown dust. Anthropogenic sources of suspended particles, both those with a maximum diameter of 10 μm and those with a maximum diameter of 2.5 μm, are represented by combustion in home heating systems, combustion processes in motor vehicle thermal engines, in industry and from the energy sector. They can be present either in the form of primary particles, which are emitted as such into the atmosphere, or they can be secondary particles that are subsequently formed through the interaction of several pollutants [20].

Previous studies revealed that the lockdown measures led to a decrease in air pollution, improving the air quality parameters [21–23]. Evidence from prior research pointed out that the reduction of NO_2 levels [24,25], while Hashim et al. [26] revealed a reduction of 6% of NO_2 emission in Baghdad. Similar trends were recorded, even in the case of other air pollution: SO_2 levels decreased by 26% in the Yangtze River Delta Region [21], by 6.76% in 44 cities from the northern part of China [22], and by 49% in Morocco [27].

Studies conducted in different parts of the world reported higher levels of ozone (O_3) concentrations during the lockdown periods, compared with the ones recorded before the COVID-19 pandemic [23,28–30].

Contamination with particulate matter with a diameter less than 10 μg (PM_{10}) is mainly due to heating systems (over the cold season) and high traffic congestion and vehicle emissions [31]. Bao and Zhang [22] recorded a significant decrease of PM_{10} in China (13.66%), while Sicard et al. [14] reported a decrease of 8% in Europe and 42% in Wuhan, with regards to the PM_{10} levels. In India, Mahato et al. reported a reduction of PM_{10} of 60% during the lockdown period, while the NO_2 concentration levels decreased by 53%.

COVID-19 pandemic had an impact on diverse fields: communication mechanism [32], digitalization of tourism [33], emotional impact on breast cancer patients in active treatment [34], volunteering activities among medical students [35], economic impact of students' not being in the city [36], financial resilience of the hospitals [37], dental emergency services [38], and food consumption [39], to mention just a few. That is an additional argument for the importance of studying each of the three pillars of sustainability. However, there is no study dealing with the impact on air quality in the considered area, to appreciate the impact on the environmental issue.

Secondly, the impact on environment generated by COVID-19 is important for Romanian residents [40], together with the social and economic impacts. So, studies on air pollution were carried out in other regions in Romania, such as in the capital city of Bucharest [41], in major cities in Northeastern Romania: Bacau [42], in Southeastern Romania: Galati [43] and in Central Romania: Brasov [44], but not in the Cluj area. The studies observed that the pandemic crises had limited positive effects on reducing the pollution generated by traffic, and not so much from industries, and, also, it was pointed out that the bigger the city, the better the positive effect of pollution reduction. Studies confirm the opinion of other scholars [45,46] who investigated the literature review on the impact of COVID-19 on the air quality and expressed the necessity for additional studies in the other areas.

The main goal of the current research is to address to the above-mentioned existing gap in the scientific references, by investigating the impact of the COVID-19 lockdown measures taken in Cluj County on the concentration of the following pollutants: SO_2, NO_2, O_3, PM_{10}, $PM_{2.5}$. Data from five different air monitoring stations from Cluj County were collected to compare the pollution levels for the period 2019–2021.

2. Materials and Methods

The environmental protection agency in Cluj County has installed five automatic stations for measuring the air quality in Cluj County, four in Cluj Napoca city, the major city in the northwestern region of Romania and one situated in Dej, a smaller city situated 60 km from Cluj-Napoca (Figures 1 and 2) [47,48].

Figure 1. Location of Cluj-Napoca city and the location of the automatic stations in Cluj-Napoca.

Cluj-Napoca is a regional city, settled on the Transylvania plain, on the banks of the Someșul Mic River. Geographically, Cluj-Napoca is in the Someșul Mic corridor, at an altitude of 363 m and its coordinates are 46°46′0″ North, 23°35′0″ East. Cluj-Napoca city is bordered on the southern side by the hills that are part of the Someș plateau, with an elevation of around 700 m. To the south, the city is dominated by the hilly peaks of Feleacu (759 m) and to the west, Hoia Hill (highest 507 m). Cluj-Napoca city is the second largest city in Romania, has a surface of 180 km^2 and 324,000 inhabitants. The metropolitan area is about 1600 km^2 with approximately 500,000 inhabitants. The city has a rich cultural heritage, with many historical landmarks and monuments. Cluj-Napoca is also known for its vibrant student population, as it is home to several universities and colleges. The city has a diverse economy, with industries ranging from IT and software development to manufacturing and agriculture. Additionally, Cluj-Napoca is a popular tourist destination, known for its picturesque old town, cultural festivals, and lively nightlife.

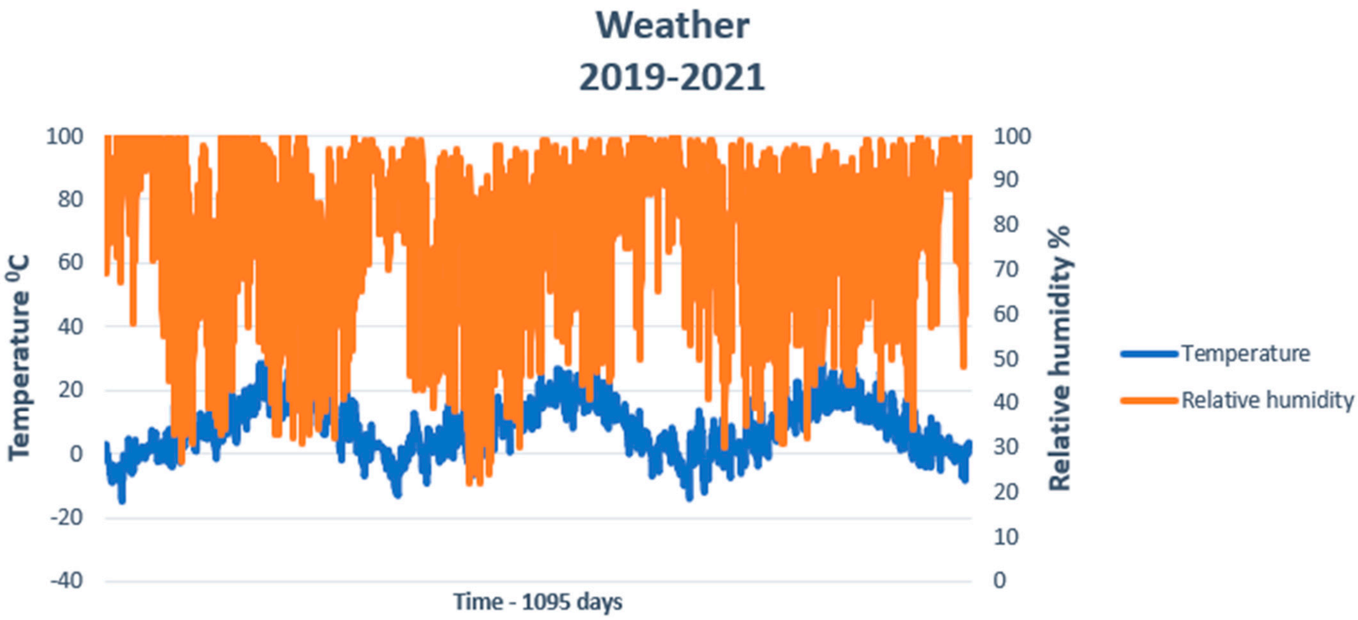

Figure 2. Temperature and relative humidity-daily average in Cluj-Napoca.

Cluj-Napoca has a temperate-continental climate, with four distinct seasons. The summers are generally warm, and the winters are cold, with occasional snowfall.

The urban area of the municipality presents a high degree of inhomogeneity which is generated by factors, such as the relief, number, size, and positioning of the buildings and the economic activities carried out, which can lead to the emergence of areas with different microclimates from one part of the municipality to another.

2.1. Temperature

The average annual temperature recorded at the weather station in Cluj-Napoca shows a value of 11.22 °C for the last decade, the trend saw an increase of 0.7 °C, compared to the previous decade, as presented in Table 1. The daily temperature average for the observed period is presented in Figure 2. The average temperature for the analysed period is 10.3 °C, which is about 8.2% lower than the decade average.

Table 1. Average temperature in Cluj-Napoca.

Nr.crt.	Year	Average Temperature [°C]	Min. [°C]	Max. [°C]
1	2010	+12.16	−18.42	+33.61
2	2011	+10.8	−21.52	+34.42
3	2012	+12.36	−22.91	+37.9
4	2013	+12.06	−16.4	+37.2
5	2014	+12.12	−9.07	+31.52
6	2015	+10.3	−17.7	+35.6
7	2016	+9.7	−14.7	+34.1
8	2017	+11.48	−13.24	+29.52
9	2018	+10.8	−16.7	+32.2
10	2019	+11.14	−15.0	+34.1
11	2020	+10.28	−14.3	+32.7
12	2021	+9.48	−13.8	+33.7

2.2. Precipitation

The average annual precipitation recorded in the last 10 years was 629 mm and the average monthly precipitation reaches its maximum in June (95 mm) and the minimum in March (22 mm).

2.3. Wind

The wind regime is a particularly important factor in terms of the presence and accumulation of air pollutants. The predominant direction of the winds is SW, W, NE, and W. The other directions have a reduced predominance, as presented in Figure 3. The calm period of air movements is high, on average 45%, the maximum reached in the cold period (December 61%) and the minimum in the warm period (June 31%).

Figure 3. Windrose Cluj-Napoca 2019–2021.

The main traffic corridor in the municipality is W-E, following the direction of crossing the city by the Someșul Mic River, and this arrangement helps air circulation in the W-E direction.

The highest average speeds are present in the NW direction. In general, the average air speeds have low values (<3 m/s), as presented in Table 2. Regardless of the season, average speeds show higher values in the NW direction (between 2.5 and 2.7 m/s). The biggest fluctuations regarding the directions are found in the spring and autumn and the smallest fluctuations are found in summer and winter.

Table 2. Average wind direction in Cluj-Napoca.

	2019	2020	2021
Wind direction		Average [m/s]	
N	1.27	2.27	2.15
NE	1.62	1.77	1.78
E	1.64	1.74	1.74
SE	2.14	1.85	1.9
S	1.71	1.84	1.63
SW	1.97	2	2.02
W	1.79	1.73	1.66
NW	2.68	2.53	2.62

The existence of a high proportion of atmospheric calm, especially in winter, contributes to maintaining the fog for a longer period and disfavours the dispersion of polluting emissions generated by traffic, industry, or by the household waste platform.

The air quality measuring station types are for traffic, urban, suburban, and industry, with one for each category. The traffic station is positioned approximately 25 m from a high-traffic intersection (roundabout) on the main street where traffic exceeds 10,000 vehicles/day. The suburban station, because of its positioning and very high traffic levels, can serve mainly as an automatic station for traffic.

S1—Cluj-Napoca, type: traffic, pollutants measured: SO_2, PM_{10}, and NO_2. The S1 station is located at the intersection of some main traffic arteries within the municipality, in an area where there are many apartment blocks. The station's positioning is in an area where air currents can move mainly in the NE-SW direction.

S2—Cluj-Napoca, type: urban, pollutants measured: SO_2, NO_2, PM_{10}, and $PM_{2.5}$. The S2 station is in the central part of the city where the traffic values are high and there are residential houses or offices for some institutions, but it is in a position where the air currents have less movement.

S3—Cluj-Napoca, type: suburban, pollutants measured: SO_2, NO_2, O_3, and $PM_{10.}$ The S3 station is in an area that has become heavily trafficked in recent years and there are also numerous blocks of flats. Its positioning near Someșul Mic River facilitates the movement of air currents and thus the dispersion of pollutants.

S4—Cluj-Napoca, type: industrial pollutants measured: SO_2, NO_2, and $PM_{10.}$ The S4 station is located on the edge of the industrial area, but there are also important roads in the vicinity and numerous apartment blocks. The position of the station is in an area that allows the permanent movement of air currents.

S5—Dej, type: urban, pollutants measured: SO_2, NO_2, O_3, and PM_{10}. The S5 station is in an area where there are mainly residential houses, but there is also an important road traffic artery nearby. The area benefits from the good movement of air currents.

The location of the automatic stations for measuring air quality is presented in Figure 1.

Air sampling, for the traffic station, is carried out at a height of 3 m, the positioning of the equipment is close to a six-lane traffic artery. Sampling is carried out automatically 24/24 h and calibration is performed daily.

The determination of the atmospheric pollutants is carried out in accordance with the European standards in force:

- Sulphur dioxide (SO_2)—by ultraviolet fluorescence provided in accordance with the SR EN 14212 standard;
- Nitrogen oxides (NO and NO_2)—by chemiluminescence, provided in accordance with the SR EN 14211 standard;
- PM_{10} and $PM_{2.5}$—gravimetric measurement for determining the mass fraction of PM_{10} or $PM_{2.5}$ particles in suspension provided in accordance with the SR EN 12341 standard;
- Ozone (O_3)—by ultraviolet photometry provided in accordance with the SR EN 14625 standard;
- TECORA sampler for the gravimetric determination of particulate matter in accordance with EN 12341.

2.4. Data Analysis

First, the daily average values of the concentration of the analysed pollutants were calculated for each of the five air monitoring stations. The boxplot method used to identify the outliers revealed 7 and 13 outliers from SO_2 dependent variables from station 1. The outliers did not have any significant impact on the results; thus, the final analysis was conducted using all of the data. A Shapiro–Wilk test revealed that the data were normally distributed ($p > 0.05$). Furthermore a one-way ANOVA was employed and Tukey's HSD was applied to test if there was any significant difference in the pollutants during the three analysed years. A correlation coefficient was employed to identify if there was any link between the pollutant levels and the meteorological conditions.

3. Results

3.1. Comparative Analysis of the Pollutants' Level between the Two Analysed Periods

In Romania, because of the COVID-19 pandemic, a sever lockdown was instated between 15 March 2020 and 15 May 2021, and included several other restrictions for population mobility, mainly during the night-time and weekends. For a better understanding of the following graphs, the lockdown occurred between days 75 and 135.

In the following graphs, the Vmax value refers to the maximum legal value, in force at the time of measuring.

The diurnal variation of the pollutants is monitored to understand how pollution levels change throughout the day. This information can be used to identify the sources of pollution and to develop strategies to reduce emissions. Additionally, understanding the diurnal variation can also help predict the potential health impacts of pollution and inform the public about when air quality is likely to be poor.

The obtained results will be compared to the European and Romanian maximum legal limits and to the World Health Organization's (WHO) recommended limits, established in 2021, so that we can have a more in-depth view of the situation.

The analysis of the sulphur dioxide concentration indicated that the recorded average values were from 6.13 μg/m^3 (station 4 during 2021) to 10.91 μg/m^3 (station 5 during 2021) (Table 3, Figure 4. The average concentration of SO_2 recorded in the first station, encountered an average decrease of 27.57% from 2019 to 2020, and of 16.51% from 2020 to 2021, which are both statistically significant ($p < 0.05$). The same trend was observed in station four as well with an average concentration of 7.19 μg/m^3 in 2019 to 6.84 μg/m^3 in 2020, while in 2021, the level of SO_2 was 6.13 μg/m^3. Station 5 recorded a statistically significant decrease of 26.19% in the levels of SO_2 from 2019 to 2020 ($p < 0.05$), while in 2021, the average level of SO_2, compared to 2020 were almost double. In the other two analysed stations, the concentration of SO_2 registered increases during the three analysed years. Even though in relative terms, changes may appear significant, changes in the values at some measuring stations are very small in absolute terms, relative to the legal maximum value. The SO_2 levels are well below Romanian and European limits (legal maximum daily average concentration is 125 μg/m^3 and legal maximum hourly average concentration is 350 μg/m^3) and well below the WHO's 2021 recommendations (40 μg/m^3), thus any small variation in concentration can be expressed as a significant amplitude, as shown in Figure 4. Figure 5 depicts the hourly evolution of SO_2 in the entire period. The diurnal evolution of the maximum values shows peaks in the early morning and in the afternoon and during the night-time in valleys. The lowest maximum recorded value was 20 μg/m^3 and the highest was 44 μg/m^3.

Table 3. Average concentration of SO_2 (μg/m^3).

Period	Station				
	S1	**S2**	**S3**	**S4**	**S5**
2019	10.70 ^{a}	6.46 ^{a}	6.08 ^{a}	7.19 ^{a}	7.71 ^{a}
2020	7.75 ^{b}	7.31 ^{b}	6.58 ^{b}	6.84 ^{a}	5.69 ^{b}
2021	6.47 ^{c}	10.33 ^{c}	6.67 ^{b}	6.13 ^{b}	11.92 ^{c}
ANOVA	$F(2, 1053) = 140.881$, $p < 0.001$	$F(2, 893) = 112.646$, $p < 0.001$	$F(2, 1083) = 12.176$, $p < 0.001$	$F(2, 1066) = 25.463$, $p < 0.001$	$F(2, 1022) = 797.075$, $p < 0.001$

Note: Means sharing a letter are not significantly different at 5% level.

For the NO_2 concentration, the highest value was found in station 1 in 2019 (61.64 ± 18.24 μg/m^3) while the lowest value was found in station 5 in 2021 (24.11 ± 9.23) (Table 4). It was noticed that the concentrations of NO_2 decreased in 2020, compared to 2019 in four of the five analysed stations. Station 5 (S5) recorded a slowly increase, but with no statistical significance ($p > 0.05$) (Table 4, Figure 6). The NO_2 concentrations registered by S1 encountered statistical significant differences among the three analysed years ($p < 0.05$). In 2020, S1 registered an average concentration of level NO_2 with 33.45% lower, compared with 2019, and with 39.65% in 2021, compared with 2019, while compared with 2020, in 2021 a decrease of 9.33% was recorded. The same trend was observed in the case of the S2, S3, and S4, however the differences recorded by S2 and S3 from 2020 to 2021 are not statistically significant ($p > 0.05$). Station 5 followed the general trend but with a slight increase in 2020. The changes in values are very small in absolute terms and relative to the legal maximum value. The Romanian and European maximum NO_2 hourly limit for human health protection is 200 μg/m^3 and the annual maximum legal limit is 40 μg/m^3 while the WHO's maximum recommendation is 10 μg/m^3 the annual limits and 25 μg/m^3 for the daily limits. Thus, the legal limits are met but the WHO's recommendations are exceeded, but in the second analysed period, the measured values are very close to the latest recommendations. There is a good correlation between NO_2 and the low wind speeds, atmospheric calm contributes to the low dispersion of NO_2 in the atmosphere. A seasonal, low-intensity trend can be observed in the graph, with higher values during the cold season and lower values during the summer. The high values of NO_2 are correlated to low temperatures and are mostly generated by the heating systems and by road vehicles. There was a slight decrease in NO_2 during the lockdown period, but the lower average temperatures limited the decrease of NO_2.

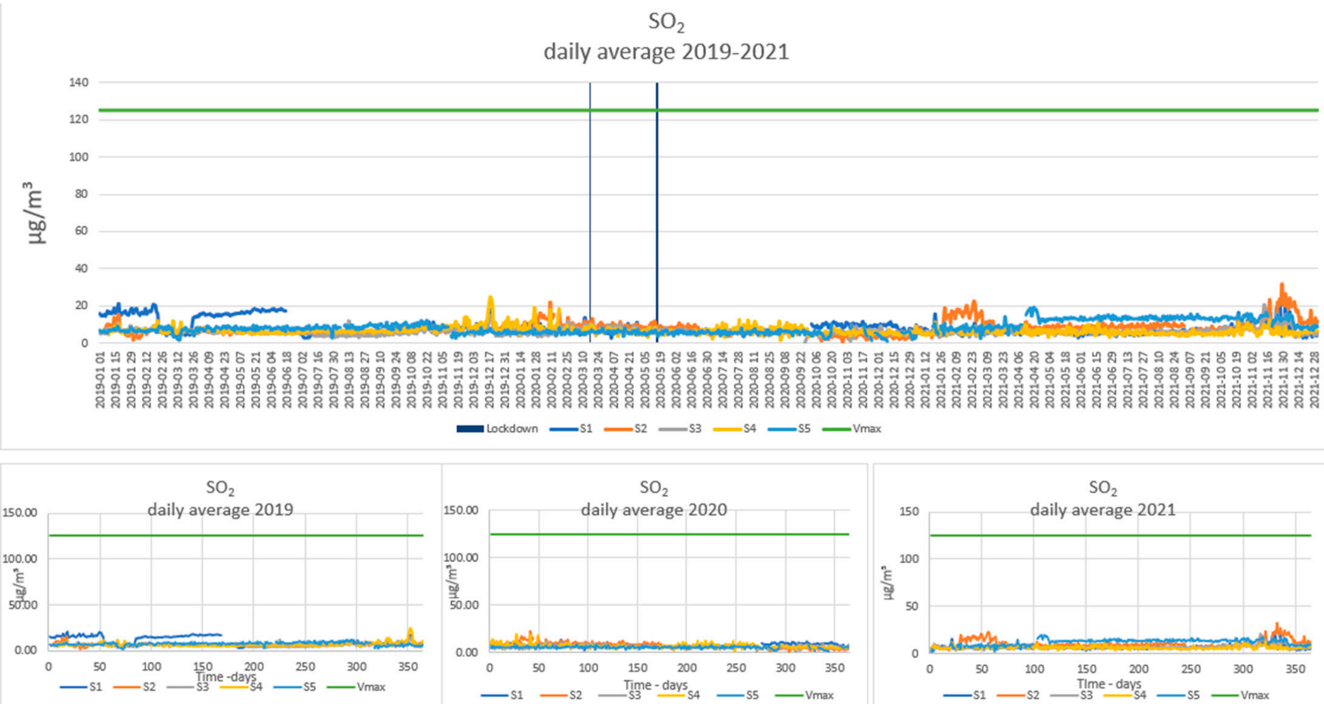

Figure 4. Evolution of SO_2 during the analysed periods. Vmax-legal maximum value.

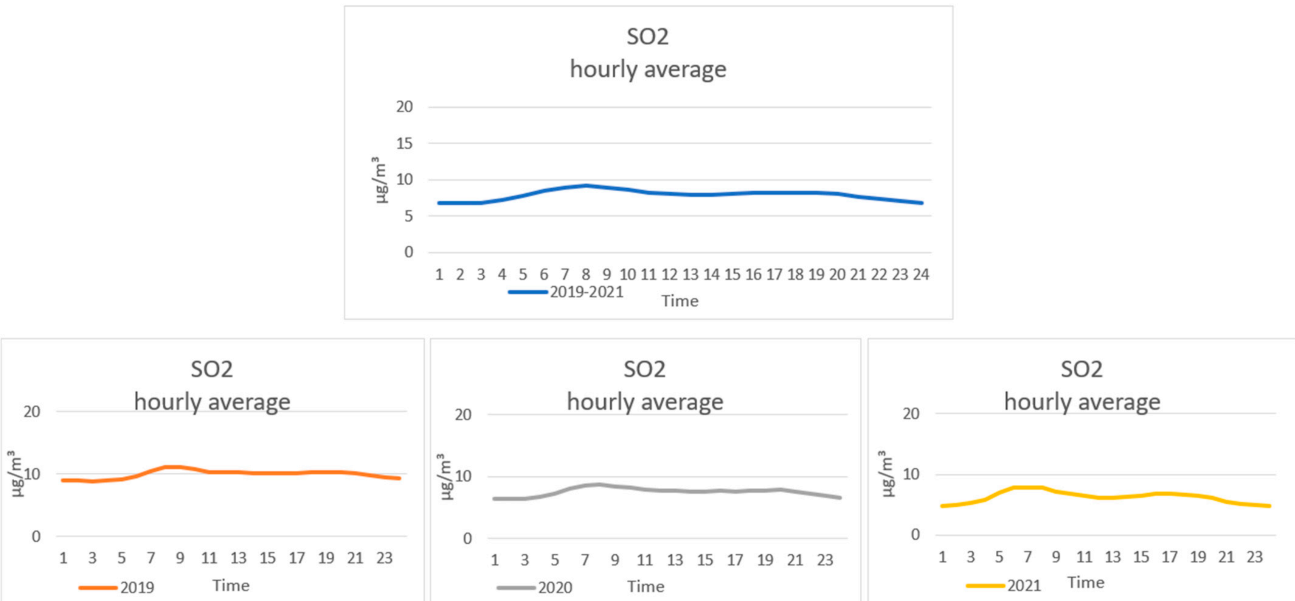

Figure 5. Hourly evolution of the average SO_2 during the analysed periods—S1 station.

Table 4. Average concentration of NO_2 ($\mu g/m^3$).

Period	Station				
	S1	**S2**	**S3**	**S4**	**S5**
2019	61.64 ± 18.24 [a]	35.49 ± 17.308 [b]	37.89 ± 14.20 [b]	49.71 ± 21.45 [a]	31.34 ± 11.15 [a]
2020	41.02 ± 20.47 [b]	28.33 ± 11.959 [a]	29.16 ± 12.08 [a]	39.07 ± 17.55 [b]	32.71 ± 11.72 [a]
2021	37.19 ± 11.53 [c]	28.69 ± 9.064 [a]	28.08 ± 11.21 [a]	30.66 ± 12.38 [c]	24.41 ± 9.23 [b]
ANOVA	$F(2, 966) = 80.582$, $p < 0.001$	$F(2, 580) = 17.359$, $p < 0.001$	$F(2, 943) = 56.115$, $p < 0.001$	$F(2, 861) = 78.629$, $p < 0.001$	$F(2. 988) = 59.360$, $p < 0.001$

Note: Means sharing a letter are not significantly different at 5% level.

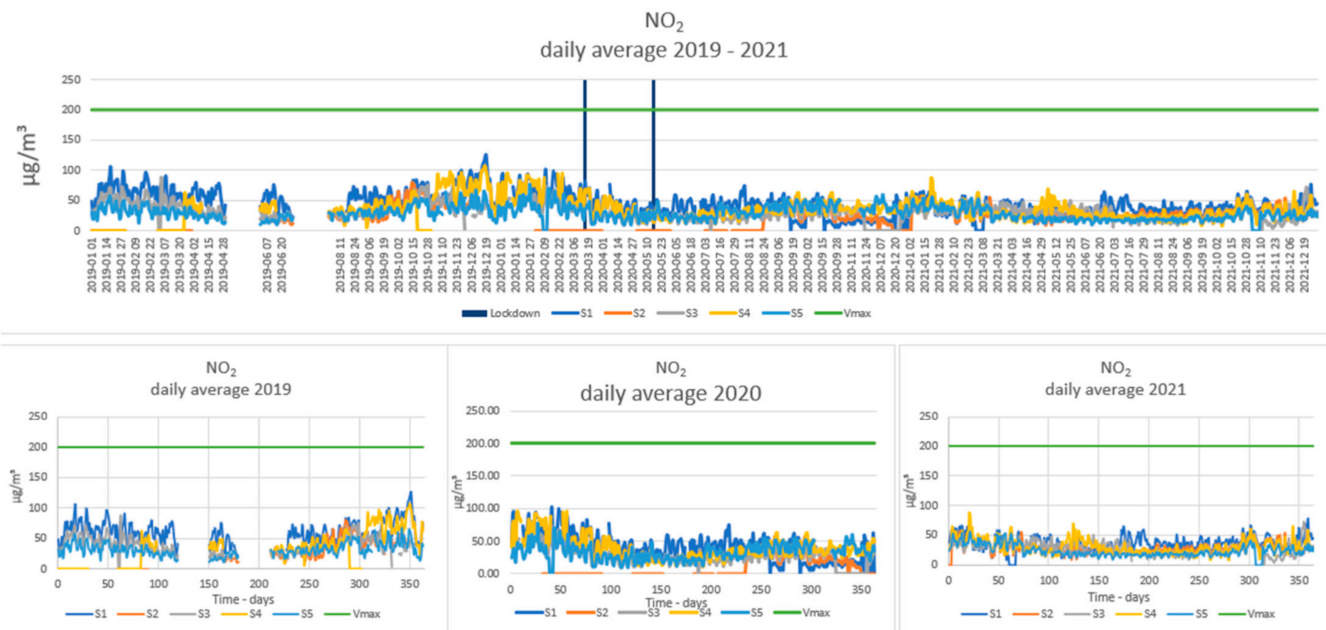

Figure 6. Evolution of NO_2 during the analysed periods. Vmax-legal maximum value.

A continuous decrease in values can be observed throughout the entire analyzed period. The reasons are represented by the renewal of the generation of vehicles on the road (the total number of vehicles increased by about 50,000 units with Euro 6 emission standards, and they replaced older vehicles that generally had Euro 3 or older emission standards) and public transportation was improved (many electric buses were introduced into service).

Figure 7 presents the hourly evolution of NO_2 in the entire period. The diurnal evolution of the maximum values shows peaks in the morning and afternoon and during the night-time in the valleys.

The concentration of O_3 was recorded in stations S3 and S5 (Table 5, Figure 8). The analysis of the O_3 concentration levels, revealed increases in station 3 from an average of 43.05 $\mu g/m^3$ recorded in 2019 to 58.06 $\mu g/m^3$ recorded in 2021. Contrary to the data recorded in station 3, in station 5, the registered levels of O_3 decreased by 23.18%, from 70.01 $\mu g/m^3$ in 2019 to 53.78 $\mu g/m^3$ in 2020, while in 2021 an increase of 11.73% was recorded, compared to 2020. The difference is statistically significant ($p < 0.05$). The maximum Romanian and European daily average legal limits for O_3 is 120 $\mu g/m^3$, while the WHO's 2021 maximum recommendation is 100. The measured concentrations are usually within all of the limits presented above, but there were a few occasions when they were exceeded because the local conditions were favourable for generation of O_3 and the dispersion was low due to low wind speeds. A strong seasonal trend can be observed in the graph, with higher values during the summer and lower values during the cold season.

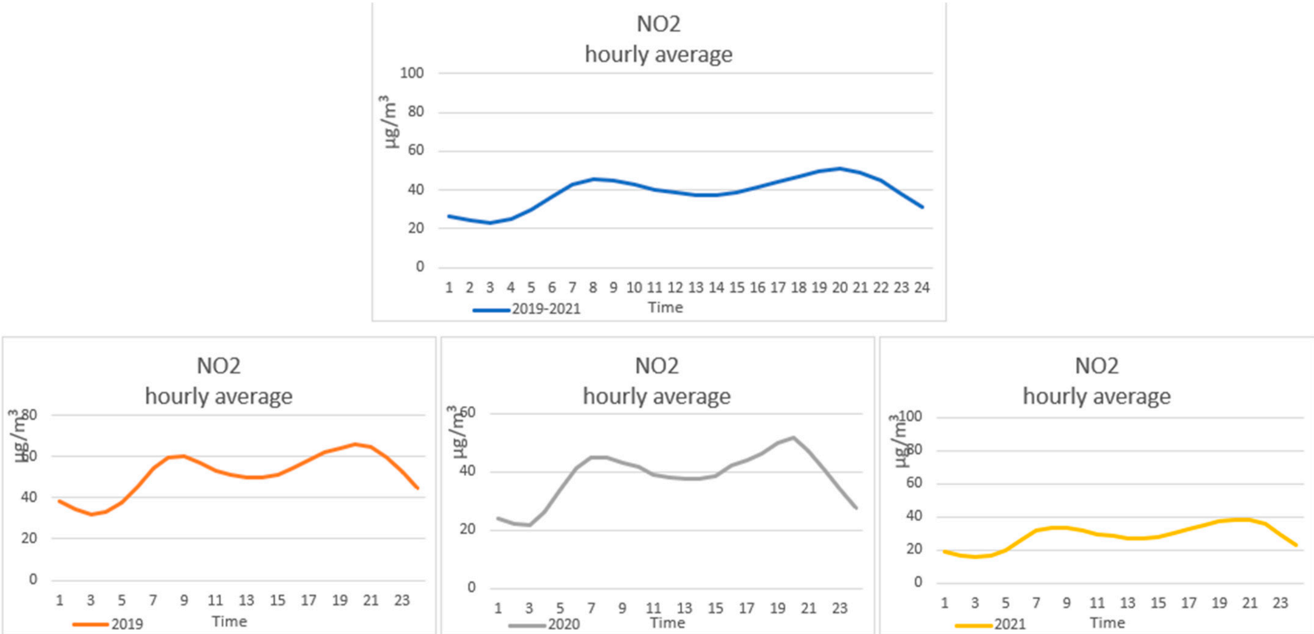

Figure 7. Hourly evolution of the average NO_2 during the analysed periods—S1 station.

Table 5. Average concentration of O_3 (μg/m^3).

Period	Station	
	S3	S5
2019	43.05 ± 26.86 ^{b}	70.01 ± 21.15 ^{a}
2020	54.73 ± 25.48 ^{a}	53.78 ± 23.93 ^{b}
2021	58.06 ± 29.47 ^{a}	60.08 ± 21.75 ^{c}
ANOVA	$F(2, 1064) = 29.684$, $p < 0.001$	$F(2, 990) = 43.689$, $p < 0.001$

Note: Means sharing a letter are not significantly different at 5% level.

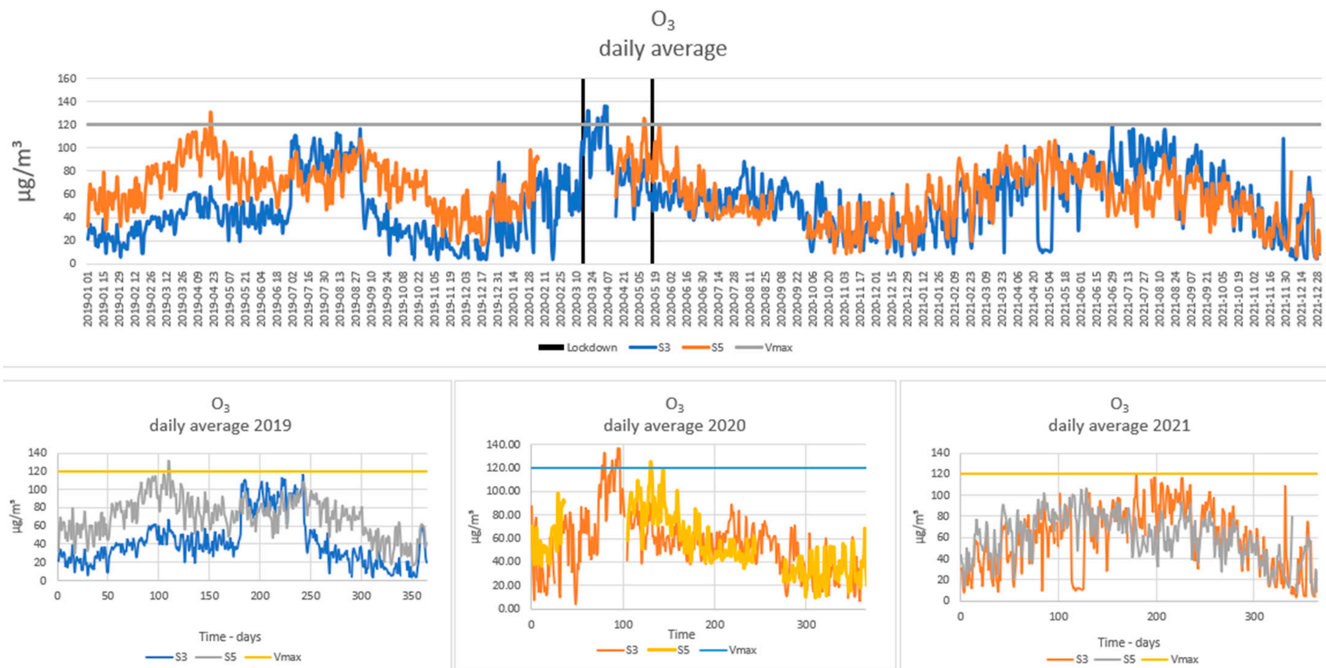

Figure 8. Evolution of O_3 during the analysed periods. Vmax—legal maximum value.

Figure 9 presents the hourly evolution of the O_3 levels for the entire period. The diurnal evolution of the maximum values shows peaks during the daytime and during the night-time in the valleys.

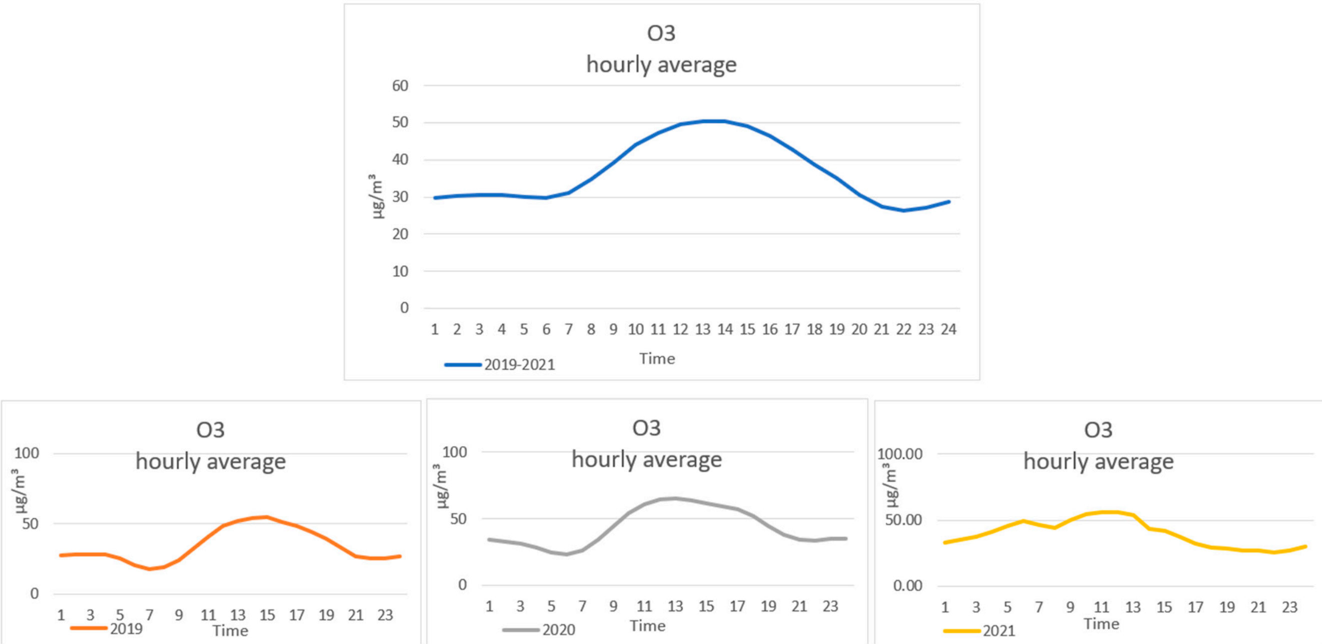

Figure 9. Hourly evolution of the average O_3 during the analysed periods—S1.

The concentration of particulate matter (PM) represents one of the most common problems of air pollution. The data recorded at the level of the five analysed stations showed that the average level of PM_{10} recorded statistically significant decreased levels at the five stations from 2019 to 2020 ($p < 0.05$) (Table 6, Figure 10. The legal limits of particulate matter, PM_{10} are 50 $\mu g/m^3$ while the WHO's 2021 recommendations are 45 $\mu g/m^3$. Some of the reasons for the increased values for station 4 are the proximity to an important road, local industries, including the production of thermoelectric energy, domestic heating, as well as from accidental emissions from non-industrial sources, and spreading of anti-skid materials on the roads during cold periods. There is a good correlation between lower air temperatures and higher PM_{10} emissions because domestic heating is an important factor. Considering the continuous construction of new buildings and the change of function for other buildings near the air quality measuring stations, including numerous new apartment buildings and office buildings, this represents another reason for increase in PM_{10} emissions. These variations show the specificity of the area and a higher dependence on weather factors, the seasonal variation of PM_{10} emissions shows that their main source is represented by heating systems. A strong seasonal trend can be observed in the graph, with higher values during the winter and lower values during the warm season.

Table 6. Average concentration of PM_{10} ($\mu g/m^3$).

Period	Stations				
	S1	S2	S3	S4	S5
2019	32.14 ± 11.55^{a}	25.76 ± 11.01^{b}	26.61 ± 11.08^{b}	15.66 ± 10.94^{a}	24.92 ± 11.23^{b}
2020	22.24 ± 11.12^{b}	19.17 ± 10.22^{a}	20.78 ± 9.89^{a}	18.53 ± 11.30^{b}	19.78 ± 9.78^{a}
2021	24.41 ± 11.97^{c}	19.84 ± 11.61^{a}	20.77 ± 10.18^{a}	25.76 ± 15.09^{c}	21.46 ± 12.57^{a}
ANOVA	$F(2, 775) = 33.572$, $p < 0.001$	$F(2, 961) = 29.407$, $p < 0.001$	$F(2, 992) = 31.048$, $p < 0.001$	$F(2, 1027) = 59.170$, $p < 0.001$	$F(2, 967) = 115.953$, $p < 0.001$

Note: Means sharing a letter are not significantly different at 5% level.

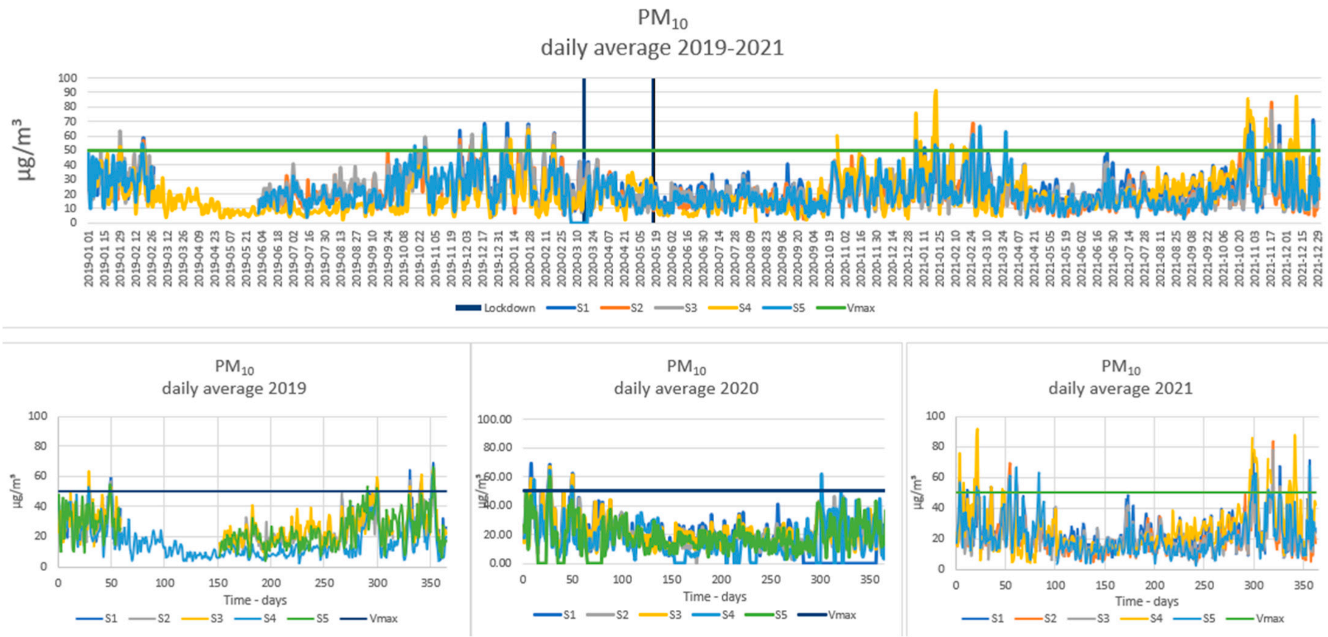

Figure 10. Evolution of PM_{10} during the analysed periods.

Data regarding the concentration of $PM_{2.5}$ that was used in this paper, originates from just one station (S2) since it was the only one providing measurements throughout the entire period (2019–2021). The results (Table 7, Figure 11) indicated a decrease by 18.84% during 2020, compared to 2019, and by 24.44% in 2021, compared to 2019. The differences are statistically significant ($p < 0.05$). The $PM_{2.5}$ legal limit is 25 μg/m^3 while the WHO's 2021 recommendation is 5 μg/m^3. Thus, the concentration is usually within the legal limits but is well outside of the WHO's recommendations. The evolution of the $PM_{2.5}$ concentration is in line with the general evolution of PM_{10}. A strong seasonal trend can be observed in the graph, with higher values during the winter and lower values during the warm season.

Table 7. Average concentration of $PM_{2.5}$ (μg/m^3).

Period	Station
	S2
2019	16.24 ± 7.59 ^{b}
2020	13.18 ± 7.75 ^{a}
2021	12.27 ± 7.6 ^{a}
ANOVA	$F(2,927) = 19.380$, $p < 0.001$

Note: Means sharing a letter are not significantly different at 5% level.

3.2. Influence of the Meteorological Conditions on the Pollutant Levels

A correlation coefficient was employed to see if there was any correlation between the pollutant levels and the meteorological conditions (temperature, humidity, and wind speed) (Table 8). The results indicated a significant moderate indirect relation between the levels of SO_2 registered at S2, S3, and S4 and temperature ($r(37) = -0.326$, $p < 0.05$; $r(37) = -0.371$, $p < 0.05$; $r(37) = -0.376$, $p < 0.05$). While in the case of S1, there was a significant moderate direct correlation between humidity and the levels of SO_2 ($r(37) = 0.329$, $p < 0.05$) and an indirect link between the level of SO_2 and wind speed ($r(37) = -0.340$, $p < 0.05$).

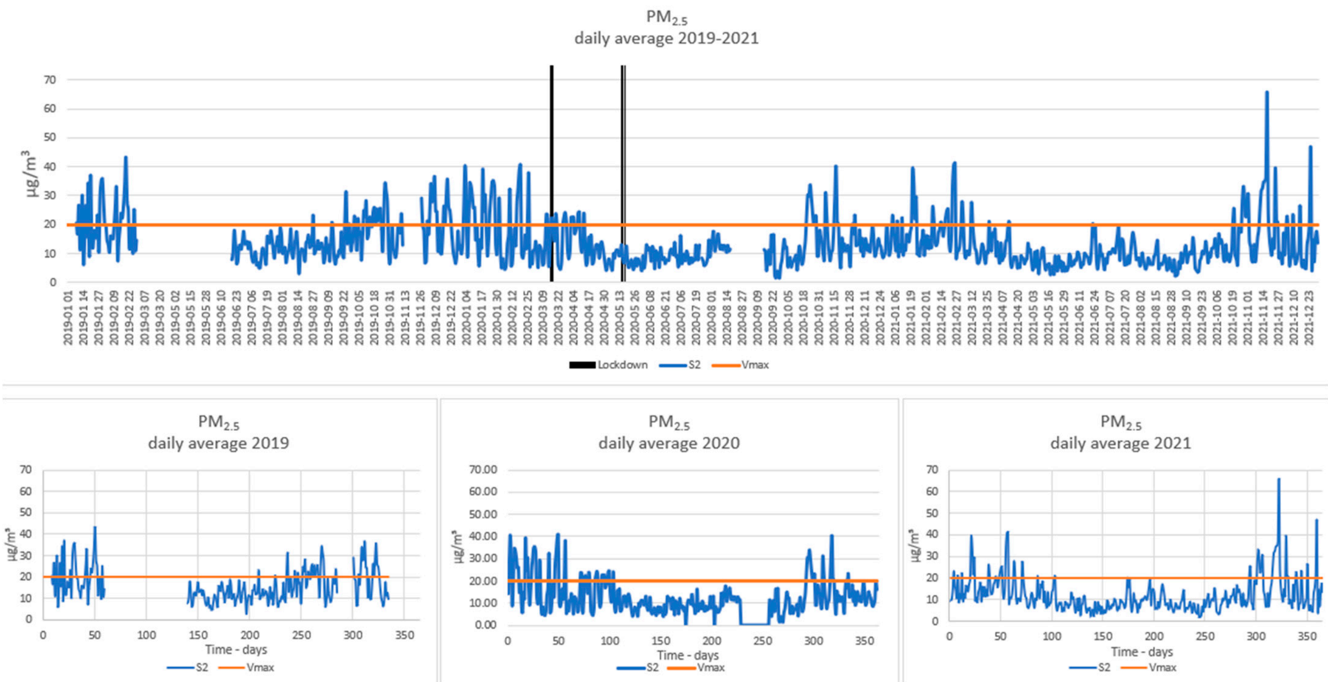

Figure 11. Evolution of $PM_{2.5}$ during the analysed periods. Vmax—legal maximum value.

Table 8. Correlation analysis.

Dependent Variable	Temperature Correlation Coefficient	*p*-Value	Humidity Correlation Coefficient	*p*-Value	Wind Speed Correlation Coefficient	*p*-Value
SO_2S1	−0.209	0.215	0.329	0.047 *	−0.340	0.046 *
SO_2S2	−0.326	0.049 *	0.215	0.201	0.047	0.784
SO_2S3	−0.371	0.024 *	0.048	0.779	0.048	0.784
SO_2S4	−0.376	0.022 *	0.085	0.615	−0.026	0.884
SO_2S5	0.181	0.283	−0.002	0.991	−0.175	0.314
NO_2S1	−0.277	0.097	0.079	0.644	0.007	0.970
NO_2S2	−0.185	0.281	0.361	0.030 *	−0.272	0.120
NO_2S3	−0.617	0.000 **	0.268	0.109	0.070	0.688
NO_2S4	−0.255	0.128	0.036	0.833	0.251	0.146
NO_2S5	−0.595	0.000 **	0.481	0.003 **	−0.076	0.664
O_3S2	0.660	0.000 **	−0.841	0.000 **	0.154	0.426
O_3S3	0.396	0.015 *	−0.662	0.000 **	0.231	0.181
O_3S5	0.157	0366	−0.565	0.000 **	0.334	0.057
PM_{10}S1	−0.386	0.024 *	0.284	0.103	0.156	0395
PM_{10}S2	−0.541	0.001 **	0.454	0.006 **	−0.268	0.132
PM_{10}S3	−0.617	0.000 **	0.375	0.029 *	−0.129	0.337
PM_{10}S4	−0.664	0.000 **	0.530	0.001 **	−0.152	0385
PM_{10}S5	−0.792	0.000 **	0.472	0.005 **	−0.012	0.947
$PM_{2.5}$S2	−0.583	0.000 **	0.416	0.010 *	−0.077	0.659

Note: * significant at the 0.05 level; ** significant at the 0.01 level.

The correlation analysis between the NO_2 levels and the meteorological conditions revealed a significantly strong indirect link between the temperature and NO_2 for S3 and S5 (r(37) = −0.617, $p < 0.01$; r(37) = −0.595, $p < 0.01$). Between humidity and the levels of NO_2, the results indicated a significant moderate correlation at S1 and S5 (r(37) = 0.361, $p < 0.05$; r(37) = 0.481, $p < 0.05$). There was no significant correlation between the NO_2 levels and the wind speed during the analysed period.

Furthermore the results of the correlation analysis between the O_3 levels and temperature indicated significantly strong direct link at S2 (r(37) = 0.660, $p < 0.01$) and a significantly moderate correlation link in the case of S3 (r(37) = 0.396, $p < 0.05$). A significantly strong indirect correlation was recorded between the O_3 and the humidity levels in all three analysed stations (r(37) = −0.841, $p < 0.01$; r(37) = −0.662, $p < 0.001$; r(37) = −0.565, $p < 0.01$). There was no significant correlation between the levels of O_3 and the wind speed.

The correlation analysis between the temperature and PM_{10} suggested a significant moderate indirect link in case of S1 and a strong indirect link in the other four analysed stations (r(37) = −0.386, $p < 0.05$; r(37) = −0.541, $p < 0.01$; r(37) = −0.617, $p < 0.01$: r(37) = −0.664,

$p < 0.01$; r(37) = −0.792, $p < 0.01$). There was a significantly moderate direct correlation between the levels of PM_{10} and humidity in the case of S2 (r(37) = 0.454, $p < 0.01$), S3 (r(37) = 0.375, $p < 0.05$), S4 (r(37) = 0.530, $p < 0.01$), and S5 (r(37)50.472, $p < 0.05$). There was no significant correlation between the wind speed and the levels of PM_{10}.

There was a significant indirect correlation between the levels of $PM_{2.5}$ and temperature (r(37) = −0.583, $p < 0.01$) and a significant direct correlation between the levels of $PM_{2.5}$ and the humidity (r(37) = 0.416, $p < 0.05$).

3.3. Evolution of Energy Consumption

To have a better understanding of the situation regarding air pollution, in addition to the meteorological conditions, a number of registered road vehicles and measured levels of air pollutants, energy consumption was observed (Table 9, Figure 12), using the official data gathered from the National Statistics Institute [49].

Table 9. Energy consumption.

Field	Unit	Year		
		2019	2020	2021
Electric energy (total)	MWh * 10	792,025.1	770,139.9	801,174.4
Thermal energy	Gcal	468,011	440,012	466,997
Unleaded gasoline	tons	227,063	222,857	244,955
Diesel (total)	tons	1,200,769	1,126,885	1,262,895
Petroleum bitumen	tons	119,995	116,326	103,397
Mineral oils	tons	3816	4959	4116
Thick greases	tons	10	14	12
LPG	tons	39,546	34,761	40,815
Natural gases (total)	thousands cubic meters	665,678	516,472	651,481
Energy from unconventional sources (total)	tons of oil equivalent	396,000	680,000	690,000

* The National Institute of Statistics, Cluj-Napoca.

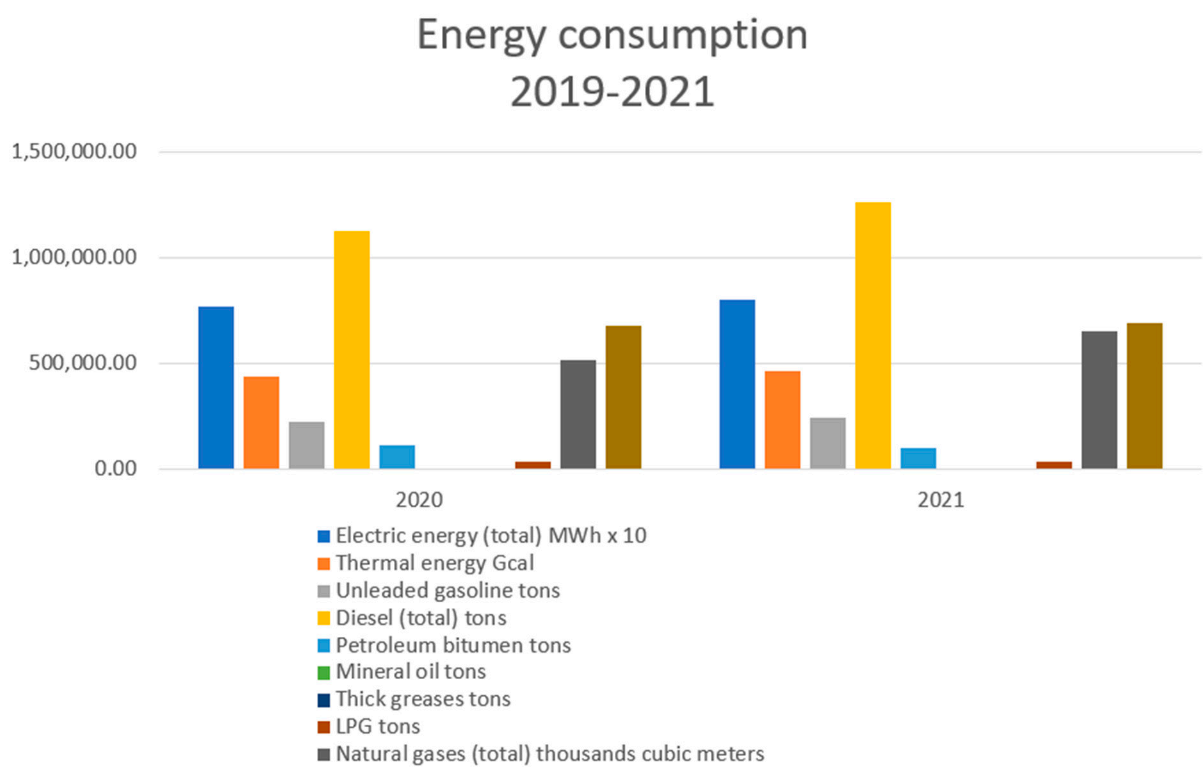

Figure 12. Energy consumption (The National Institute of Statistics, Cluj-Napoca).

The primary energy sources comprise the production of primary energy carriers (net coal, crude oil, usable natural gas, firewood, hydroelectric energy, nuclear–electric energy and energy from non-conventional sources); the import of primary and transformed energy; the stocks on January 1st of the primary energy carriers at the producing, consuming and distribution units. It is followed by categories of origin: from own production/import, in physical units, thousands of tons of oil equivalent. The transformation into conventional units is based on the energy characteristics of the primary energy carriers, and for imported electricity, it is based on the real energy potential of electricity (0.800 kg oil equivalent/kWh or 3600 kJ/kWh).

The values are not exhaustive, they refer to a group of consumers, they are the same for the entire observed period, so the values used are relevant to determine the general trend of energy consumption, which was, in general, lower in 2020 than it was in 2019, but in 2021, the initial values were exceeded, thus the information about energy has the role of informing about the general trend.

4. Discussion

The municipality of Cluj-Napoca presents various sources of pollution for the atmosphere, that is generated by anthropic activity related to a regional centre of the size of this municipality. The industrial sources of pollution are represented by the production of thermal or electrical energy and various industrial processes. The urban sources of pollution are the heating installations of buildings (both public and residential), food preparation processes (both domestic and from public food), the traffic category (road, railway, and air), municipal waste storage, the activity of constructions (which in recent years is one of the highest in the country), building and rehabilitating transport infrastructure, etc.

The main problems of Cluj-Napoca municipality, in terms of car traffic, are the insufficient bypasses (and incomplete) and the high traffic values. Thus, in Cluj-Napoca, a total of 164,891 vehicles are recorded entering and leaving the city each day. The western entrance to Cluj-Napoca (by Florești) is the busiest in the country with an average of 58,660 vehicles/day. Although in the last decade, some bypasses were completed, the city is still transited by a significant number of vehicles [50].

The total number of road vehicles registered in Cluj County has increased from 321,930 [51] on 31.12.2018 to 378,087 on 31.12.2021 [52]. The east-west transportation corridor is the most used in the city and it is at its upper limit in terms of traffic capacity during peak hours in the morning, at peak, the maximum projected values are exceeded by up to 300%. The new vehicles have much lower emission levels and by replacing the old vehicles, it contributes to the lowering of emissions. Furthermore, the new buses and trams have a greater efficiency and they also replace very old and polluting vehicles.

The total urban fund of pollutant emissions represents the sum of the emission values from the regional fund to which are added sources from the urban environment, such as those from transport (road, railway, and air), energy production (including heating systems in homes and public buildings), industry, agriculture, and household waste. The regional fund represents, on average, 10.1 $\mu g/m^3$ NO_2 and 19.5 $\mu g/m^3$ in the case of PM_{10}.

Average estimates regarding NOx emissions in Cluj-Napoca show that transport is the most important source, with a share of 81% of the total (road transport with heavy vehicles represents the most important component, 51%, followed by cars with about 17% and the vans with 6.5%). The average estimates regarding PM_{10} emissions show that, in this case, transport is the main source, in the case of Cluj-Napoca municipality, with 45% of total emissions, followed by road paving with 31% and the heating of homes with 11% [53].

It should be mentioned that between 15.03.2020 and 15.05.2022, a state of emergency was established in Romania, which meant substantial limitations on people's mobility and at the same time work from home was encouraged.

From the primary energy consumption point of view, it can be observed that, in general, the 2020 values recorded a decrease, compared to the values recorded in 2019, but most of the time, the values recorded in 2021 exceeded even the initial values from 2019.

Considering the subsidies offered by the government for the production of green electric energy, we can observe an important increase in energy from unconventional sources (mainly photovoltaic). The conventional fuels for road vehicles (gasoline, diesel, and LPG) show lower values in 2020, compared to 2019, but in 2021 they are higher than they used to be in 2019, before the COVID−19 pandemic.

The NO_2 levels show a smaller peak in the evenings in 2020, compared to 2019, and a more compact curve during the daytime. The measurement conducted in 2021 showed smaller values due to the smaller number of measurements and the data gap was not compensated. Even so, the average measured levels are higher than the WHO's recommendation.

The levels of SO_2 are well below the recommended limits but we can observe a decrease in 2020, compared to 2019, but the year 2021 showed higher levels than in 2019.

Considering the precursors of tropospheric O_3 (volatile organic compounds VOCs—the main source in the city is traffic fuel combustion and evaporation—and through photochemical reactions with NO_x and radicals, in the presence of solar radiation), the generated amounts can vary widely, thus observing the annual maximum values during the summer days during the daytime.

The pollutant emissions followed the evolution of traffic levels, in general, and showed higher values during the rush hours.

Not all pollutants were determined hourly, because particulate matter (PM_{10} and $PM_{2.5}$) was determined by using the standardized method (gravimetric).

As could be observed, in general, the evolution of the monitored pollutants decreased in the period after the emergence of the COVID-19 pandemic.

Table 10 and Figure 13 present the comparison between the legal limit, the WHO's recommendations, and the average values measured in Cluj County.

Table 10. Pollutant limits comparison during the analysed period (μg/m^3).

Second Period	**Parameter (μg/m^3)**				
	SO_2	**NO_2**	**O_3**	**PM_{10}**	**$PM_{2.5}$**
Average Cluj—all stations	7.74	37.75	41.07	20.83	11.97
Legal limit	125	200	120	50	25
WHO recommendations	40	25	100	45	5

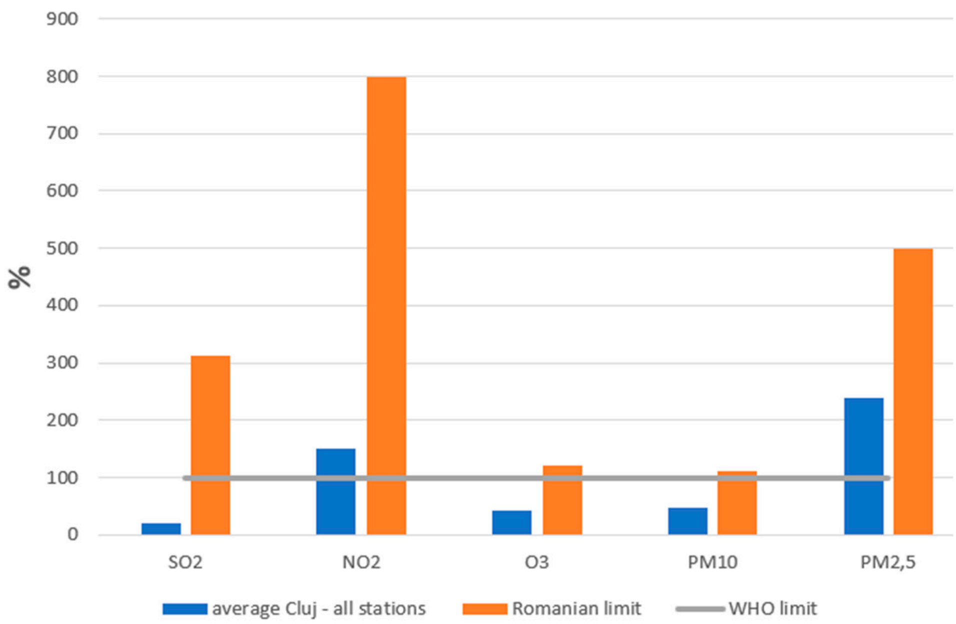

Figure 13. Legal limit, WHO recommendations and the average values measured during the analysed periods (%).

The values of the legal limits in force are mostly respected, but there are numerous exceedances, if we refer to the values recommended by the WHO, according to the 2021 update. Thus, such a situation can represent an opportunity, in terms of amending the legislation in force, in the sense of aligning with the values recommended by the WHO for better protection of people's health and better air quality, in general.

It is recommended to develop the existing network of stations for determining the air quality, both inside the municipalities and in the intensively populated areas or possibly those affected by the activities of the industries.

5. Conclusions

Assuring the life quality on urban agglomeration is a continuous responsibility of the local, regional, and national authorities. That involves not only updating the regulations, but, also, the constant measurement of the level of pollutants and comparing the results with the maximum limits imposed by laws and regulations. In the cities, as Cluj-Napoca is, residents are confronted with an accelerated industrial and building development, and it is a major task to keep pollution under control. A significant share of the pollution is generated by urban traffic, which increases once the industry amplifies. Consequently, an unanticipated lockdown is, nevertheless, expected to generate an increase in air quality.

The research aimed to fill an existing gap in the literature, as in Cluj-Napoca, there were significant studies conducted regarding the impact of COVID-19, in some of the most critical social and economic areas: health, consumer perception, behaviour change, online study, but there is a lack of study of the impact on the environmental issues. Diverse studies on the effects of the pandemic crisis on air quality were conducted in different major cities in Romania (Bucharest, Brasov, Galati, Bacau), but not in Cluj-Napoca, while the necessity of exploring the impact on new areas was highly recommended. So, this study is contributing to enrich the knowledge on how the restrictive measures generated by COVID-19 are influencing the air quality in urban agglomerations, offering new perspective about how the traffic decrease is influencing the quality of life.

For example, limiting population mobility during the COVID-19 pandemic has led to a decrease in some pollutants at some measurement stations and lower average temperatures in 2020 and then in 2021, coupled with the fact that people spent more time at home, it generated a higher consumption of electricity and heat.

On that matter, the study focused using the measurements of concentrations of SO_2, NO_2, O_3, PM_{10}, $PM_{2.5}$ in five different air monitoring stations from Cluj County between 1 January 2019 and 31 December 2021. The study confirmed that reducing the mobility of industrial and individual cars during the pandemic period, generated an improvement in the air quality, keeping the pollutants at a very low level, and by that, improved the quality of life in the city. Of course, the quality of life is a much more complex issue measuring not only the amount of pollution, but also measuring other elements, such as health in general, the ability to participate in life events and other activities that bring joy.

That is one of the major limits of the study when addressing quality of life as a goal. Another major limit is, since the number of stations for measuring air quality is relatively limited, they are not able to deeply cover the particularities of the studied area.

Based on the results, it would be appreciated that the network of stations for measuring air quality were to be developed in number (to ensure a much better coverage of areas with specific microclimates) and in the quality (higher frequency of data acquisition) of the measurements. There is, also, plenty of room for further work to be carried out by scholars to measure the impact of the recovering economy in the Cluj area, and, at the same time, the impact of improving the air quality with the increased number of hybrid and electric cars.

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References

1. Zwanka, R.J.; Buff, C. COVID-19 generation: A conceptual framework of the consumer behavioral shifts to be caused by the COVID-19 pandemic. *J. Int. Consum. Mark.* **2021**, *33*, 58–67. [CrossRef]
2. Ivkovic, N. Beyond the pandemic—A new era of consumer behavior. In *Economic and Social Development: Book of Proceedings*; Varazdin Development and Entrepreneurship Agency: Varazdin, Croatia, 2021; pp. 6–17.
3. Muresan, I.C.; Harun, R.; Brata, A.M.; Brata, V.D.; Chiciudean, D.I.; Tirpe, O.P.; Porutiu, A.; Dumitras, D.E. Factors Affecting Food Consumers' Behavior during COVID-19 in Romania. *Foods* **2022**, *11*, 2275. [CrossRef] [PubMed]
4. Polyzos, S.; Samitas, A.; Spyridou, A.E. Tourism demand and the COVID-19 pandemic: An LSTM approach. *Tour. Recreat. Res.* **2021**, *46*, 175–187. [CrossRef]
5. Priya, S.S.; Cuce, E.; Sudhakar, K. A perspective of COVID 19 impact on global economy, energy and environment. *Int. J. Sustain. Eng.* **2021**, *14*, 1290–1305. [CrossRef]
6. Gkiotsalitis, K.; Cats, O. Public transport planning adaption under the COVID-19 pandemic crisis: Literature review of research needs and directions. *Transp. Rev.* **2021**, *41*, 374–392. [CrossRef]
7. Sarmadi, M.; Rahimi, S.; Rezaei, M.; Sanaei, D.; Dianatinasab, M. Air quality index variation before and after the onset of COVID-19 pandemic: A comprehensive study on 87 capital, industrial and polluted cities of the world. *Environ. Sci. Eur.* **2021**, *33*, 134. [CrossRef]
8. Venter, Z.S.; Aunan, K.; Chowdhury, S.; Lelieveld, J. Air pollution declines during COVID-19 lockdowns mitigate the global health burden. *Environ. Res.* **2021**, *192*, 110403. [CrossRef]
9. Wang, Q.; Su, M. Drivers of decoupling economic growth from carbon emission—An empirical analysis of 192 countries using decoupling model and decomposition method. *Environ. Impact Assess. Rev.* **2020**, *81*, 106356. [CrossRef]
10. Burnett, R.; Chen, H.; Szyszkowicz, M.; Fann, N.; Hubbell, B.; Pope, C.A.; Apte, J.S.; Brauer, M.; Cohen, A.; Weichenthal, S.; et al. Global estimates of mortality associated with long-term exposure to outdoor fine particulate matter. *Proc. Natl. Acad. Sci. USA* **2018**, *115*, 9592–9597. [CrossRef]
11. Huang, R.; Ning, H.; He, T.; Bian, G.; Hu, J.; Xu, G. Impact of PM_{10} and meteorological factors on the incidence of hand, foot, and mouth disease in female children in Ningbo, China: A spatiotemporal and time-series study. *Environ. Sci. Pollut. Res.* **2019**, *26*, 17974–17985. [CrossRef]
12. Alotaibi, R.; Bechle, M.; Marshall, J.D.; Ramani, T.; Zietsman, J.; Nieuwenhuijsen, M.J.; Khreis, H. Traffic related air pollution and the burden of childhood asthma in the contiguous United States in 2000 and 2010. *Environ. Int.* **2019**, *127*, 858–867. [CrossRef] [PubMed]
13. Amsalu, E.; Guo, Y.; Li, H.; Wang, T.; Liu, Y.; Wang, A.; Liu, X.; Tao, L.; Luo, Y.; Zhang, F.; et al. Short-term effect of ambient sulfur dioxide (SO_2) on cause-specific cardiovascular hospital admission in Beijing, China: A time series study. *Atmos. Environ.* **2019**, *208*, 74–81. [CrossRef]
14. Sicard, P.; Khaniabadi, Y.O.; Perez, S.; Gualtieri, M.; De Marco, A. Effect of O_3, PM_{10} and $PM_{2.5}$ on cardiovascular and respiratory diseases in cities of France, Iran and Italy. *Environ. Sci. Pollut. Res.* **2019**, *26*, 32645–32665. [CrossRef] [PubMed]
15. Copat, C.; Cristaldi, A.; Fiore, M.; Grasso, A.; Zuccarello, P.; Signorelli, S.S.; Oliveri Conti, G.; Ferrante, M. The role of air pollution (PM and NO_2) in COVID-19 spread and lethality: A systematic review. *Environ. Res.* **2019**, *191*, 110129. [CrossRef]
16. Kaplan, G.; Avdan, Z.Y.; Avdan, U. Spaceborne Nitrogen Dioxide Observations from the Sentinel-5P TROPOMI over Turkey. *Proceedings* **2019**, *18*, 4. [CrossRef]
17. Rahman, A.; Luo, C.; Khan, M.H.R.; Ke, J.; Thilakanayaka, V.; Kumar, S. Influence of atmospheric $PM_{2.5}$, PM_{10}, O_3, CO, NO_2, SO_2, and meteorological factors on the concentration of airborne pollen in Guangzhou, China. *Atmos. Environ.* **2019**, *212*, 290–304. [CrossRef]
18. Garbatov, Y.; Georgiev, P.; Fuchedzhieva, I. Extreme Value Analysis of 18 Air Pollution in the Winter Seaport of Varna. *Atmosphere* **2022**, *13*, 1921. [CrossRef]
19. Chereches, I.A.; Borzan, A.I.; Baldean, D.L. Contribution of developing advanced engineering methods in interdisciplinary studying the piston rings from 1.6 spark ignited Ford engine at Technical University of Cluj-Napoca. *IOP Conf. Ser. Mater. Sci. Eng.* **2017**, *252*, 012072. [CrossRef]
20. Diapouli, E.; Fetfatzis, P.; Panteliadis, P.; Spitieri, C.; Gini, M.I.; Papagiannis, S.; Vasilatou, V.; Eleftheriadis, K. $PM_{2.5}$ Source Apportionment and Implications for Particle Hygroscopicity at an Urban Background Site in Athens, Greece. *Atmosphere* **2022**, *13*, 1685. [CrossRef]
21. Li, L.; Li, Q.; Huang, L.; Wang, Q.; Zhu, A.; Xu, J.; Liu, Z.; Li, H.; Shi, L.; Li, R.; et al. Air quality changes during the COVID-19 lockdown over the Yangtze River Delta Region: An insight into the impact of human activity pattern changes on air pollution variation. *Sci. Total Environ.* **2020**, *732*, 139282. [CrossRef]

22. Bao, R.; Zhang, A. Does lockdown reduce air pollution? Evidence from 44 cities in northern China. *Sci. Total Environ.* **2020**, *731*, 139052. [CrossRef] [PubMed]
23. Briz-Redón, A.; Belenguer-Sapiña, C.; Serrano-Aroca, A. Changes in air pollution during COVID-19 lockdown in Spain: A multi-city study. *J. Environ. Sci.* **2021**, *101*, 16–26. [CrossRef] [PubMed]
24. Berman, J.D.; Ebisu, K. Changes in U.S. air pollution during the COVID-19 pandemic. *Sci. Total Environ.* **2020**, *739*, 139864. [CrossRef] [PubMed]
25. Marlier, M.E.; Xing, J.; Zhu, Y.; Wang, S. Impacts of COVID-19 response actions on air quality in China. *Environ. Res. Commun.* **2020**, *2*, 075003. [CrossRef]
26. Hashim, B.M.; Al-Naseri, S.K.; Al-Maliki, A.; Al-Ansari, N. Impact of COVID-19 lockdown on NO_2, O_3, $PM_{2.5}$ and PM_{10} concentrations and assessing air quality changes in Baghdad, Iraq. *Sci. Total Environ.* **2021**, *754*, 141978. [CrossRef]
27. Otmani, A.; Benchrif, A.; Tahri, M.; Bounakhla, M.; El Bouch, M.; Krombi, M.H. Impact of COVID-19 lockdown on PM_{10}, SO_2, and NO_2, concentrations in Sale City (Morocco). *Sci. Total Environ.* **2020**, *735*, 139541. [CrossRef]
28. Lovrić, M.; Pavlović, K.; Vuković, M.; Grange, S.K.; Haberl, M.; Kern, R. Understanding the true effects of the COVID-19 lockdown on air pollution by means of machine learning. *Environ. Pollut.* **2021**, *274*, 115900. [CrossRef]
29. Mahato, S.; Pal, S.; Ghosh, K.G. Effect of lockdown amid COVID-19 pandemic on air quality of the megacity Delhi, India. *Sci. Total Environ.* **2020**, *730*, 139086. [CrossRef] [PubMed]
30. Zabrano-Monserrate, M.A.; Ruano, M.A. Has air quality improved in Ecuador during the COVID-19 pandemic? A parametric analysis. *Air Qual. Atmos. Health* **2020**, *13*, 929–938. [CrossRef]
31. Wilczyńska-Michalik, W.; Gasek, R.; Michalik, M.; Dańko, J.; Plaskota, T. Mineralogy, chemical composition and leachability of ash from biomass combustion and biomass–coal co-combustion. *Mineralogia* **2018**, *49*, 67–97. [CrossRef]
32. Țînțaș, C.D.; Brînzac, M.G.; Coman, M.; Samoilă, M.; Duran, B.O. Evaluation of the Interaction and Communication Mechanisms Between the Health Authorities and the Public in the Context of the COVID-19 Pandemic, 2022. UNICEF. Available online: https://www.unicef.org/romania/reports/evaluation-communication-mechanisms-context-covid-19-pandemic (accessed on 5 January 2023).
33. Popescu, D.; Coros, M.M.; Pop, I.; Bolog, C. The Green Deal—Dynamizer of Digitalization in Tourism: The Case of Cluj-Napoca Smart City. *Amfiteatrul Econ. J.* **2022**, *24*, 110–127. [CrossRef]
34. Nicolescu, S.; Baban, A. Pandemic and resilience: A qualitative analysis of the emotional impact of the COVID-19 pandemic on breast cancer patients in active treatment. *Cogn. Brain Behavior. Interdiscip. J.* **2021**, *25*, 243–259. [CrossRef]
35. Pop, A.I.; Mirel, S.; Florea, M.; Lotrean, L.M. The Impact of the COVID-19 Pandemic on Research and Volunteering Activities among Medical Students: A Cross-Sectional Study among Romanian and International Students from One Medical Faculty from Romania. *Int. J. Environ. Res. Public Health* **2022**, *19*, 7477. [CrossRef]
36. Chirica, A.; Lazar, D.T. Cluj-Napoca Without Students: An Estimation of the Gap in the City's Economy. *Transylv. Rev. Adm. Sci.* **2021**, *62E*, 44–59. [CrossRef]
37. György, A.; Simionescu, I. The Impact of COVID-19 on the Romanian Hospitals' Expenses. A Case Study Toward the Financial Resilience after the Pandemic. *Transylv. Rev. Adm. Sci.* **2021**, *17*, 22–36. [CrossRef]
38. Petrescu, N.B.; Aghiorghiesei, O.; Mesaros, A.S.; Lucaciu, O.P.; Dinu, C.M.; Campian, R.S.; Negucioiu, M. Impact of COVID-19 on Dental Emergency Services in Cluj-Napoca Metropolitan Area: A Cross-Sectional Study. *Int. J. Environ. Res. Public Health* **2020**, *17*, 7716. [CrossRef]
39. Muresan, I.C.; Harun, R.; Arion, F.H.; Brata, A.M.; Chereches, I.A.; Chiciudean, G.O.; Dumitras, D.E.; Oroian, C.F.; Tirpe, O.P. Consumers' Attitude towards Sustainable Food Consumption during the COVID-19 Pandemic in Romania. *Agriculture* **2021**, *11*, 1050. [CrossRef]
40. Matei, E.; Ilovan, O.R.; Sandu, C.D.; Dumitrache, L.; Istrate, M.; Jucu, I.S. Athanasios Alexandru Gavrilidis, Early COVID-19 Pandemic Impacts on Society and Environment in Romania. Perception Among Population with Higher Education. *Environ. Eng. Manag. J.* **2021**, *20*, 319–330. [CrossRef]
41. Zoran, M.; Savastru, R.; Savastru, D.; Tautan, M. Cumulative effects of air pollution and climate drivers on COVID-19 multiwaves in Bucharest, Romania. *Process Saf. Environ. Prot.* **2022**, *166*, 368–383. [CrossRef]
42. Oana, I.; Grzegorz, P.; Mirela, P.-L.; Claudia, T.; Emilian, M.; Piotr, G. Indicators of Impact Selected Municipal Units on the Air Quality—Case Study from Poland and Romania. *Processes* **2022**, *10*, 2485. [CrossRef]
43. Roșu, A.; Constantin, D.-E.; Voiculescu, M.; Arseni, M.; Roșu, B.; Merlaud, A.; Van Roozendael, M.; Georgescu, P.L. Assessment of NO_2 Pollution Level during the COVID-19 Lockdown in a Romanian City. *Int. J. Environ. Res. Public Health* **2021**, *18*, 544. [CrossRef]
44. Maftei, C.; Muntean, R.; Poinareanu, I. The Impact of Air Pollution on Pulmonary Diseases: A Case Study from Brasov County, Romania. *Atmosphere* **2022**, *13*, 902. [CrossRef]
45. Silva, A.C.T.; Branco, P.T.B.S.; Sousa, S.I.V. Impact of COVID-19 Pandemic on Air Quality: A Systematic Review. *Int. J. Environ. Res. Public Health* **2022**, *19*, 1950. [CrossRef]
46. Sokhi, R.S.; Singh, V.; Querol, X.; Finardi, S.; Targino, A.C.; Andrade, M.D.F.; Pavlovic, R.; Garland, R.M.; Massagué, J.; Kong, S.; et al. A global observational analysis to understand changes in air quality during exceptionally low anthropogenic emission conditions. *Environ. Int.* **2021**, *157*, 106818. [CrossRef]

47. Ministerul Mediului, Agentia Nationala Pentru Protectia Mediului. Available online: http://apmcj.anpm.ro/ (accessed on 22 November 2022).
48. Chereches, I.A.; Petean, I.; Paltinean, G.A.; Mocanu, A.; Muresan, L.; Arghir, G.; Tomoiaga-Cotisel, M. Airborne Particles pollution in Dej City. *Stud. UBB Chem.* **2018**, *63*, 159–166. [CrossRef]
49. Institutul National de Statistica. Available online: https://insse.ro/cms/ (accessed on 2 January 2023).
50. The Cluj Napoca metropolitan bypass in the context of the Sustainable Urban Mobility Plan. Cluj Napoca, 31 March 2016. Available online: https://www.nord-vest.ro/wp-content/uploads/2016/11/3.-PMUD-Cluj-TRAM.pdf (accessed on 2 January 2023).
51. Directia general Permise de Conducere si Inmatriculari. Parc Auto la 31.12.2018. Available online: https://www.drpciv.ro/news-details/statistica/5c791f30ea80e4044f372a40 (accessed on 2 January 2023).
52. Directia general Permise de Conducere si Inmatriculari. Parc Auto la 31.12.2021. Available online: https://www.drpciv.ro/news-details/statistica/61f25599a9a3d0045ab62179 (accessed on 2 January 2023).
53. Primăria Municipiului Cluj-Napoca. *Planul Integrat de Calitate a Aerului Pentru Aglomerarea Urbană Cluj-Napoca*. 2020. Available online: https://files.primariaclujnapoca.ro/2022/02/03/PMUD_Cluj-Napoca.pdf (accessed on 2 January 2023).