Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
The main objective of this study is to monitor the impact of the COVID-19 pandemic, which appeared in December 2019 and was declared by the World Health Organization as a global pandemic on March 11, 2020, on climate change and the environment through such measures as imposing a partial curfew and maintaining social distance measures, as well as the suspension of aviation and lowering the electricity consumption for the in-site work sectors in Egypt. These measures hindered the rates of people’s movements. These events have resulted in a decrease of Greenhouse Gas emissions and air pollutants, which have improved the environmental conditions and promoted the reduction of the causes of climate change in Egypt.

The study depends on analyzing Remote sensing products “Sentinel-5P images” to monitor the change in the air pollutants of the Greater Cairo Region (GCR) before, during, and after the outbreak of the COVID-19 pandemic. It also depends on using the methodology of the Carbon footprint, according to the Intergovernmental Panel for Climate Change (IPCC), for determining the size of the GHGs emissions avoided, as a result of the curfew in Egypt during the period from January to August 2020 compared to the same in 2019. The study deduces that the partial curfew and social distance measures related to the COVID-19 pandemic reduced GHGs emissions in Egypt by about 15% and about 17% for NO2 emissions in GCR, 15.6% for SO2, and about 7.7% for the CO emissions, compared to the same in 2019.

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1. Introduction

The world was exposed to a pandemic caused by the new Coronavirus that appeared in December 2019, called COVID-19. As a result, many countries adopted many measures to control the quick widespread of this virus by applying curfew, lockdown, and social distance measures, especially after the World Health Organization declared it as a global pandemic on March 11, 2020 (WHO, 2020a). These measures lowered the rate of people’s movements and the electricity consumption for the in-site work sectors, as well as suspended aviation.

According to the International Energy Agency, these global measures reduced the demand for energy by about 25% per week for the countries that declared a state of full lockdown and about 18% per week for the counties that declared a state of partial lockdown. At the global scale, the demand of energy was reduced by about 3.8% from January to March 2020. In addition, the global demand of Coal was reduced by about 8% compared to the same period in 2019. Oil was reduced by about 5%, gas by about 2%, and electricity by about 20%. Additionally, the global transportation sector has reduced its records by about 50% for road transportation and about 60% for aviation compared to the 2019 average (IEA, 2020). All these factors reduced the emission of air pollutants and Greenhouse Gas (GHG), as many studies expect that the global CO2 emissions will be reduced by about 17% at the end of 2020 compared to levels of the past 10 years (Friedlingstein et al., 2020; OECD, 2020; Le Quere et al., 2020). Many studies, however, confirmed that these reductions are a temporary event, and it will rise up again after the last drop (WMO, 2020).

In Egypt, partial lockdown and curfew measures were in effect on 25th March 2020, after the increase of the officially monitored cases of COVID-19. These measures include applying a curfew for 11 h from 19:00 to 06:00, which was later adjusted to be for 13 h from 17:00 to 06:00 on Vacations and official holidays. These
measures were canceled on the 24th of June 2020 followed by a gradual reopening of the facilities (EPCM, 2020). As a result, the consumption of energy was reduced, which reflected positively on the causes of climate change - GHG - and the environment in Egypt, especially air pollutants.

Furthermore, Egypt produced more than 190,000 GWh of electricity in 2019, and consumed about 80% of the production (MOEE, 2020). Egypt also consumed about 92.4 m tons of petroleum products including about 51.1 million-tons for natural gas in the fiscal year 2019/2020, with an annual increase of about 4% (MPMR, 2020). On the other hand, the energy sector contributed with the largest share of GHG emissions in Egypt by about 64.5% of the total GHG emissions in 2015 which was more than 325 million-ton CO2e, and the electric power sector contributed by about 43%, and Oil and Natural Gas contributed by about 34%, while transportation sector contributed by about 23% of the total energy sector, concerning the GHG emissions share in Egypt 2015 (BUR, 2018).

Accordingly, the main objective of this paper is to study the impact of applying measures related to the COVID-19 pandemic on air pollutants and quality of GCR, as well as the impact of the pandemic on GHG emission and climate change in Egypt. Such is doable through the availability of energy consumption data at the national scale, using the Carbon footprint methodology and the integrated environmental dataset derived from Sentinel-5P images, and using GIS and Remote Sensing techniques to assess the positive impact of the COVID-19 pandemic.

2. Study area

Egypt has more than 101 million-pop in 2020 and includes 27 governorates. Cairo, the capital of Egypt, has the highest population by about 10 million-pop. (CAPMAS, 2020a). Both Cairo and Giza, as well as Al Qalyoubia, represent the Greater Cairo Region (GCR), which is one of the largest metropolitan regions in the world with an area covering more than 3200 km² and includes the largest industrial areas in Egypt, as shown in Fig. 1. GCR has more than 21 Ma as residents of the region, in addition to the millions who frequent the region on a weekday. This increases the population of the region in weekdays to be more than 25 Ma. As well as, GCR has high concentrations of PM10 that exceed six times of air quality index, and about 70% of the region has concentrations ranged between (200–250 ug/m³/year) (Moawad et al, 2017).

3. Data and methods

Data and methods used in this study could be summarized as what follows in Fig. 2, which includes data collection and tools used in the study.

3.1. Carbon footprint.

Carbon footprint can be defined as “a method of measuring the impact of activities of human, company, organization, city or country on climate change as a total GHG emission in the form of Car-
carbon dioxide equivalent (CO2e)\(^*\) (Madkour, 2019). GHG emission and Carbon footprint in the form of CO2e was calculated using methodologies and default emission factors which were suggested by the Intergovernmental Panel on Climate Change (IPCC, 2006). The Egyptian national emission factors for electricity grid for the period from January to August 2019 and 2020 were also provided in light of the data given by the Electricity Regulatory Agency (ERA, 2019; ERA, 2020). The study accounts for three main GHG including Carbon dioxide (CO\(_2\)), Methane (CH\(_4\)), and Nitrous oxide (N\(_2\)O). The main unit of measuring is metric tons (MT) of CO2e, based on the global warming potential (GWP) of each gas where CO2 has GWP 1, CH\(_4\) 21, and N\(_2\)O 298 over a 100-year interval (Global Warming Potentials, 2011).

**Table 1**
GHG emission factors used in the study.

| Activity of consumption | Emission factor | Unit          |
|-------------------------|-----------------|---------------|
| Electricity 2020        | 0.4557*         | Kg CO\(_2\)e/kwh |
| Electricity 2019        | 0.4921*         | Kg CO\(_2\)e/kwh |
| Oil & Petroleum products | 3165.36**       | Kg CO\(_2\)e/ton |
| Natural and liquid Gas  | 2542.04**       | Kg CO\(_2\)e/ton |
| Diesel                  | 3088.23**       | Kg CO\(_2\)e/ton |
| Aviation                | 0.18078**       | Kg CO\(_2\)e/passenger.km |
| Railway                 | 0.04115**       | Kg CO\(_2\)e/passenger |

\(^*\) ERA (2019); ERA (2020).
\(^**\) IPCC (2006), guidelines for National Greenhouse Gas Inventories.

**Table 2**
Sentinel-5P images used in the study and their characteristics.

| Source | Sentinel-5P |
|--------|-------------|
| Product | Nitrogen dioxide (NO\(_2\)) |
| Data type and Specific band | Level2_Offline_nitrogendioxide_tropospheric_column |
| Instrument/Channel | TROPOMI/UV–VIS |
| Spatial Resolution | 3.5 km \(\times\) 7 km for 2019 |
| Date of acquisition | 01.15&31-Mar-2019&2020/15&30-Apr-2019&2020/15&30-May-2019&2020/15&30-Jun-2019&2020/15&31-Jul-2019&2020 |
| Time of acquisition | 11:02 AM |

\(^*\) Sources: (NO2: Eskes et al., 2018 & SO2: Romahn et al., 2020 & CO: Apituley et al., 2018).
Table 3
Total GHG emissions (million-ton CO2e) from all energy sectors in Egypt for the period from January to August 2020 compared to 2019.

| Month    | Petroleum Products Consumption (million-ton CO2e) | Natural Gas Consumption (million-ton CO2e) | Butane Consumption (million-ton CO2e) | Diesel Consumption (million-ton CO2e) | Electricity consumption (million-ton CO2e) | Air flights passengers (million-ton CO2e) | Railway pax (million-ton CO2e) | Total Emissions (million-ton CO2e) |
|----------|--------------------------------------------------|------------------------------------------|--------------------------------------|--------------------------------------|----------------------------------------|------------------------------------------|---------------------------------|----------------------------------|
| January  | 8.4 7.7                                         | 9.5 9.7                                  | 0.9                                  | 3.4 3.3                              | 5.9 5.4                                | 1.8 2.2                                  | 0.0009 0.0012                  | 30.0 29.2                       |
| February | 7.5 7.1                                         | 8.4 8.8                                  | 0.8                                  | 3.5 3.2                              | 5.6 5.3                                | 0.0 0.0                                  | 0.0009 0.0011                  | 25.8 25.2                       |
| March    | 8.6 7.6                                         | 9.6 9.0                                  | 0.9                                  | 3.8 3.1                              | 5.8 5.2                                | 0.0 0.0                                  | 0.0009 0.0008                  | 28.7 25.7                       |
| April    | 8.1 6.8                                         | 9.2 8.5                                  | 0.8                                  | 3.7 2.9                              | 5.6 4.8                                | 2.0 0.0201                               | 0.0010 0.0004                  | 29.6 23.9                       |
| May      | 8.2 6.5                                         | 10.1 9.3                                | 0.9                                  | 3.7 2.7                              | 5.7 4.8                                | 1.6 0.0669                               | 0.0010 0.0004                  | 30.5 24.5                       |
| June     | 7.5 6.0                                         | 9.7 9.7                                  | 0.8                                  | 3.2 3.2                              | 6.3 5.4                                | 1.7 0.2007                               | 0.0010 0.0005                  | 29.6 25.1                       |
| July     | 7.9 6.5                                         | 10.5 10.5                                | 0.7                                  | 3.2 3.4                              | 6.5 5.7                                | 1.9 0.3344                               | 0.0010 0.0007                  | 30.7 27.5                       |
| August   | 8.2 6.5                                         | 10.7 10.7                                | 0.7                                  | 3.2 3.0                              | 6.7 6.2                                | 2.1 0.4682                               | 0.0011 0.0008                  | 31.7 27.9                       |
| Total period | 64.9 55.2                                      | 77.8 67.1                                | 6.5                                  | 27.8 24.9                            | 48.6 43.1                              | 11.0 3.3                                | 0.0078 0.0058                  | 236.6 209.0                     |
| Total for lockdown period | 40.8 33.6                                      | 49.2 46.9                                | 4.0                                  | 17.6 15.5                            | 30.5 26.3                              | 7.2 0.6221                               | 0.0049 0.0027                  | 149.2 126.7                     |

Fig. 3. Monthly change in the total GHG emissions (million-ton CO2e) from all energy consumption sectors in Egypt for the period from January to August 2020 compared to 2019.

Table 4
Total GHG emissions (million-ton CO2e) from electricity in Egypt by sectors for the period from January to July 2020 compared to 2019.

| Month/Sector | Industry | Agriculture, Irrigation and Drainage | Public Utilities and Governmental Agencies | House usages | CommercialUsages | Other Agencies |
|--------------|----------|--------------------------------------|-------------------------------------------|--------------|-----------------|---------------|
| January      | 2019     | 1.8                                  | 0.2                                       | 0.8          | 2.4             | 0.3           | 0.4           |
|              | 2020     | 1.8                                  | 0.2                                       | 0.7          | 2.4             | 0.3           | 0.5           |
| February     | 2019     | 1.7                                  | 0.2                                       | 0.7          | 2.2             | 0.3           | 0.4           |
|              | 2020     | 1.8                                  | 0.2                                       | 0.6          | 2.3             | 0.2           | 0.4           |
| March        | 2019     | 1.8                                  | 0.2                                       | 0.8          | 2.2             | 0.3           | 0.4           |
|              | 2020     | 1.7                                  | 0.3                                       | 0.6          | 2.3             | 0.2           | 0.4           |
| April        | 2019     | 1.8                                  | 0.3                                       | 0.8          | 2.2             | 0.2           | 0.4           |
|              | 2020     | 1.6                                  | 0.2                                       | 0.7          | 2.1             | 0.2           | 0.4           |
| May          | 2019     | 1.8                                  | 0.4                                       | 0.9          | 2.3             | 0.2           | 0.4           |
|              | 2020     | 1.6                                  | 0.3                                       | 0.7          | 2.3             | 0.2           | 0.4           |
| June         | 2019     | 1.8                                  | 0.3                                       | 0.9          | 2.5             | 0.3           | 0.5           |
|              | 2020     | 1.6                                  | 0.3                                       | 0.8          | 2.4             | 0.2           | 0.4           |
| July         | 2019     | 1.8                                  | 0.4                                       | 0.9          | 2.6             | 0.3           | 0.6           |
|              | 2020     | 1.6                                  | 0.4                                       | 0.8          | 2.7             | 0.2           | 0.5           |
| Average of the total period | 2019     | 1.8                                  | 0.3                                       | 0.8          | 2.3             | 0.3           | 0.5           |
|              | 2020     | 1.7                                  | 0.3                                       | 0.7          | 2.4             | 0.2           | 0.4           |
| Average of the lockdown period | 2019     | 1.8                                  | 0.3                                       | 0.8          | 2.4             | 0.3           | 0.5           |
|              | 2020     | 1.6                                  | 0.3                                       | 0.7          | 2.4             | 0.2           | 0.4           |
Table 5
Air pollutants emissions (μmol/m²) in GCR.

| Item   | year | 1Mar | 15Mar | 31Mar | 15Apr | 30Apr | 15May | 31May | 15Jun | 30Jun | 15Jul | 31Jul | Average |
|--------|------|------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|---------|
| NO₂    | 2019 | 238  | 135.7 | 413.9 | 428  | 385   | 421   | 184   | 246   | 198   | 473   | 184   | 300.6  |
|        | 2020 | 325  | 246   | 306   | 354   | 349   | 145   | 146   | 142   | 163   | 315   | 254   | 249.5  |
| SO₂    | 2019 | 1136 | 2044  | 2037  | 1164  | 1638  | 1808.2| 1952  | 2035  | 1683  | 1386  | 1088  | 1633.7 |
|        | 2020 | 1011 | 1517  | 1320  | 1134  | 1230  | 1612  | 1741  | 1809  | 1004  | 1374  | 1126  | 1352.5 |
| CO     | 2019 | 36,773| 38,454| 35,910| 49,150| 46,778| 39,890| 36,342| 38,733| 37,517| 55,355| 48,328| 42111.8|
|        | 2020 | 42,428| 40,478| 31,627| 46,374| 41,839| 37,284| 32,820| 35,292| 37,542| 43,191| 38,856| 38884.6|

* source: (calculated from Sentinel-5P images, see Sect. 3.2 and Table 2).
The study calculating the carbon footprint of Egypt during the pandemic depends on three steps of the calculation. The first includes collecting data that are involved in the calculation process. This includes (Electricity, Petroleum products, Natural Gas, Butane (Liquefied Petroleum Gas LPG), and Diesel consumption, transportation movements data for aviation, and railway passengers) for the period from January to August 2020 and 2019, to determine the impact of the COVID-19 pandemic compared to the same period in the last year 2019. The second involves applying the emission factors obtained from the National grid and IPCC in different units of GHG. The final one involves converting all units to CO2e and calculating the total carbon footprint of the period of applying the COVID-19 pandemic measures compared to the same period of the last year 2019. Table 1 illustrate the emission factors used in this study.

3.2. Remote sensing techniques (Sentinel-5P images).

The study relied on Remote sensing techniques to monitor air pollutants concentrations during the pandemic period and the previous period, it is the best tool and methodology for time tracking and change detection in the phenomena’ behavior at this time. The study used the products of Sentinel-5 Precursor (5P) is a European Space Agency (ESA) satellite launched to monitor air pollutants using sensors referred to as TROPOMI (Tropospheric Monitoring Instrument), with a spatial resolution of 5.5x5.5 km per pixel for images acquired after 9th August 2019. Before this date, the spatial resolution was 7x7km (ESA, 2019). The study depends on Sentinel-5P level 2 (L2) data for total vertical column and tropospheric column values for NO2 Nitrogen dioxide, SO2 sulfur dioxide, and CO carbon monoxide products. The data are downloaded from (Sentinel-5P Pre-Operations Data Hub, https://s5phub.copernicus.eu/dhus#//home), for monitoring air pollutants before and after the pandemic in GCR. Table 2 illustrate Sentinel-5P images used in the study and their characteristics.

Sentinel-5P NO2 and CO images were analyzed and manipulated using SNAP (Sentinel Application Platform) as a common Sentinel toolbox used for earth observation processing and analysis for sentinel products (ESA, 2020). In addition to using machine learning techniques for analyzing SO2 images using Google Earth Engine (GEE) programming script as illustrated in appendix, where GEE is “a planetary-scale platform for earth science data and analysis” (GEE, 2020).

4. Results

4.1. Impact of the pandemic on climate change

The study depends on the carbon footprint methodology to assess the impact of the COVID-19 pandemic on climate change in the form of GHG emissions using the data about activities of consumptions, and emission factors, as shown in Table 1 (see Sect. 3.1).

Table 3 and Fig. 3 clearly show that the total GHG emissions were about 209 million-ton CO2e for the period from January to August 2020 with a reduction rate of about 11.7% for the same period in 2019, in which the total emissions were about 236.6 million-ton CO2e. In addition, the rate of the percentage change of GHG emissions for the period of the pandemic was about 15% for the period from March to June 2020 compared to the same period in 2019. Additionally, the period from May to April 2020 recorded the lowest emissions of GHG by about 19.65% and 19.32% compared to the same months in 2019, respectively. These reductions in GHG emissions are related to the reduction in movement in the same period of the 20th of April to the 31st of May 2020 (see Sect. 5).

Accordingly, the aviation sector has the largest reduction in GHG emissions by about 91.3% for the curfew period compared to the same period in 2019, and about 70.1% for the period of the study from January to August 2020 compared to the same in 2019. In addition, the petroleum products sector emissions have reduced by about 17.6% for the period of curfew and about 14.9% for the period of the study compared to the same in 2019. Diesel consumption emissions have also been reduced by about 12.3% for the lockdown period, while natural gas and Butane LPG show the lowest reduction in emission by about 4.7%, and 3.4% respectively. The natural gas sector has reduced its emissions by about 2.3 million-ton CO2e, which is higher than the diesel sector for the period of lockdown.

Moreover, the reduction in emissions of the railway sector between the curfew period compared to the same in 2019 was about 44.7% and about 25.9% from January to August 2020 compared to the same in 2019. These changes reflect the reduction of demands for this type of transportation in Egypt, even though
Fig. 7. Spatial distribution of tropospheric NO2 emissions in GCR (μmol/m²) for the period from the 15th of March to the 15th of July 2020 compared to the same period in 2019. * source: (Sentinel-5P/NO2 tropospheric column images, see Sect. 3.2 and Table 2).
the contribution of this sector in GHG emission in Egypt was fewer, which was 7800 ton-CO2e in 2019 compared to 5800 ton-CO2e in the curfew period 2020.

The Electricity sector shows major changes in GHG emissions by about 4.2 million-ton CO2e with a change rate of 13.8% compared to the same in 2019 and about 11.4% for the period for the study compared to the same in 2019, due to the change in consumption through the period of curfew by about one million MWh per month (see Sect. 5). At the sectoral level of the electricity consumption (Table 4 and Fig. 4), commercial usage shows a major reduction in the consumption by about 17.8% for the curfew period and about 17.5% for the period of the study compared to the same in 2019, even though the industry sector shows the highest reduction in GHG emissions by about 10.9% as for the curfew period and about 7% as for the period of the study compared to the same in 2019. In addition, house consumption was the only sector that show a positive change by about 0.4% for the curfew period and about 1.2% for the total period of the study. Generally, house usage contributed by about 42% of the total GHG emissions from the electricity sector at the curfew period compared to 39% for the same in 2019, as seen in Fig. 5.

4.2. Impact of the pandemic on air pollutants

The study depends on Remote sensing techniques to monitoring air pollutants in GCR using Sentinel-5P images for air pollutant gases, such as nitrogen dioxide NO2, sulfur dioxide SO2, and carbon monoxide CO, in order to assess the impact of the pandemic on reducing the rates of emission (see Sect. 3.2).

4.2.1. Nitrogen dioxide (NO2)

Table 5 and Fig. 6 shows the time series of Nitrogen dioxide tropospheric column values for the pandemic period from the 1st of March to the 31st of July 2020 compared to the same in 2019. In this period, the NO2 emissions decreased by about 17% compared to the same in 2019. They show their lowest values from the 15th of March to the 30th of April 2020 by about 35.2% and 20.6%, respectively. This coincided with the end of Ramadan and vacation days, which are characterized by low movement rates as illustrated from Google and Apple mobility data. In addition, there is a relative rise in the NO2 emissions during the period from the 31st of March to the 30th of April 2020 due to the normal daily activities that take place during the daytime (see Sect. 5).

4.2.2. Sulfur dioxide (SO2)

Table 5 and Fig. 8 illustrate that SO2 emissions decreased by about 15.6% for the pandemic period compared to the same in 2019, and the lowest values of emissions were at the period from the 31st of March to the 15th of April 2020 by about 35.2% and 35.7% respectively. This is due to the major reduction in electricity generation in Egypt (see Sect. 5), where the correlation value between the two time-series is 0.45.

Figure 9 shows the spatial change in the distribution of SO2 emissions in GCR for the pandemic period compared to the same in 2019. Accordingly, the major change of SO2 emissions related to the locations of power plants (PP) for generating electricity in GCR which was about 93% for North Cairo PP, 61% for Shoubra El-Kheima PP, 43% for South Cairo PP, 52% for Tebbin PP, and 73% for West Cairo PP, in addition to –67% for coke production areas in Tookh, Qaha, and Benha at the northern of the GCR. This change also includes the sites which have construction works at the east of Cairo and the Capital by about –41%. However, many of these sites normally have an increase in the annual rate of SO2 emissions of about 0.65%, and 23% for New Cairo, 6.5% for the downtown, 3.2% for Benha, and about 5.4% for Tebbin, as an average of the annual change rate for SO2 emissions for the period 1999 – 2014 for these areas (Madkour, 2018).
Fig. 9. Spatial distribution of SO2 vertical column emissions in GCR (µmol/m²) for the period from the 15th of March to the 15th of July 2020 compared to the same period in 2019. *source: (Sentinel-5P/SO2 vertical column images, see Sect. 3.2 and Table 2).
4.2.3. Carbon monoxide (CO).

Table 5 and Fig. 10 show that the CO emissions decreased by about 7.7% for the pandemic period compared to the same in 2019. The major reduction period was from the 15th to the 31st of July 2020 by about 21.9% and 19.6% respectively.

Furthermore, the spatial change in the distribution of CO emissions in GCR shows in Fig. 11 for the pandemic period compared to the same in 2019. Accordingly, the major spatial change was in the downtown of the GCR in relation to the heavy traffic movement by about 34.7%, and 27.3% for industrial areas in the south of the region (Helwan, Tebbin), 23% for the sixth of October in the west, 22.6% for Shoubra El-Kheima in the north of the region, and 23.5% for Badrasheen in the southwest of the region. Many of these sites normally show an increase in the annual rate of CO emissions of about 13.4% for the downtown, 13.8% for Shoubra El-Kheima, and about 9.5% for GCR, as an average of the annual change rate for CO emissions for the period 1999 – 2014 for these areas (Madkour, 2018).

5. Discussion

Since the date Egypt announced the first confirmed case of COVID-19 on the 14th of Feb 2020, the curve of positive cases daily increased and recorded 442 cases on the 25th of March, as illustrated in Fig. 12. At the time, the Egyptian government took many measures to maintain social distance and to control the increase of the infected. Besides, Google and Apple mobility data show a decrease in the daily movement of people in Egypt by about 20 to 65% for the period from 15th February to 31st August 2020 with an average of 31.4% from the base day. The median value of the movement rate from 3rd January to 6th February 2020, as obtained from Google community reports, and a decrease in the movement by about 20 to 80% with an average of 32.3%, as obtained from Apple mobility trends reports for the same period as illustrated in Figs. 13 and 14 (Google mobility data, 2020; Apple mobility data, 2020). Such data reflect the size or the number of requests for directions in Google and Apple maps for both Android and iOS users during the curfew days. In addition, in the GCR the movement decreased to 42% as an average, and the movement to workplaces decreased by about 32.7 from the baseline after the lockdown and curfew (Google mobility data, 2020).

Moreover, this reduction in the movement rates in Egypt and GCR is reflected in the reduction of the consumption for all types of energy. Electricity consumption is reduced by about 4.35% in the period from January to August 2020 and the same in 2019. Diesel consumption by about 10.24%. Petroleum products consumption by about 14.9%. Natural gas consumption by about 2.16. Butane or LPG consumption by about 2.9%. This is accompanied by the reduction in the demand of different transportation modes by about 70.1% for air flights passengers, and about 26% for railways passengers.

On the other hand, the transportation sector contributes about 79% of Nitrogen oxide NO2 in the atmosphere. Fossil fuel combustion and biomass burning contribute by about 9%. Industries by 8%, and Energy Generation by 4% (World Bank, 2013). Accordingly, the World Health Organization recorded Cairo as the eighth in the World and first in Africa in NO2 concentrations with an average of 65 μg/m3 (WHO, 2016). As well, the incomplete combustion of fossil fuels, heavy traffic areas, biomass burning, wood and gas stoves boilers, and furnaces are the main sources of Carbon monoxide (CO) in the atmosphere (EPA, 2020). As a result of the curfew and all applied measures, all these sectors which are the major air pollutants sources were affected during the study period compared to the previous period.

Accordingly, that explains the decrease in GHG emissions and air pollutants which were affected by the decreases in movement rates and energy consumption at the same time of applying these measures. In addition, by analyzing the time series, the difference in the trend of consumption and emissions data was observed, where the electricity consumption increased in February 2020.
more than 2019 by about 0.3 million-MWh, while GHG emissions decreased by about 0.3 million-ton CO\textsubscript{2}e. In August 2020, the consumption rose to levels of 2019, while GHG emission decreased by about 0.4 million-ton CO\textsubscript{2}e, as illustrated in Figs. 15 and 16. These changes are related to the change in the electricity generation mix which differed from 2019 to 2020 where the usage of heavy oil decreased from 10.3% to 2.25% in the generation and the usage of natural gas increased from 77.4% to 83.51%. In addition, the reli-

Fig. 11. Spatial distribution of CO total column emissions in GCR (\textmu{mol}/m\textsuperscript{2}) for the period from the 15th of March to the 15th of July 2020 compared to the same period in 2019. * source: (Sentinel-5P/CO total column images, see Sect. 3.2 and Table 2).
ance on renewable energy also increased from 12.3% to 14.3%. These variables are reflected in the emission factor for the electricity consumption, which decreased from 0.49217 in 2019 to 0.45577 kg-CO2e/KWh in 2020 (ERA, 2019; ERA, 2020).

6. Conclusion

The main objective of this study is to monitor and observe the impact of the maintained COVID-19 pandemic measures to control the fast and wide spread of the pandemic on the GHG – as one of the main causes of climate change – and the environment in Egypt, especially the Greater Cairo Region (GCR). The study is based on the integration of different datasets e.g. Sentinel-5P images, GIS techniques, and Carbon footprint methodology. The study concludes that all measures to control the COVID-19 pandemic have reduced GHG emissions in Egypt by about 15% compared to the same in 2019. This reduction has temporary few effects on the concentrations of GHG in the atmosphere due to the length of life of these gases. There is also a temporary improvement in air quality in GCR by about 17% for NO2 emissions, 15.6% for SO2, and about 7.7% for CO emissions. According to World Health Organization, all short-term environmental enhancements are the result of the change in many unacceptable human conducts and economic costs (WHO, 2020b).

The study deduces the important role of Remote sensing techniques especially, Sentinel-5P images in monitoring and analyzing air pollutants with high spatial resolution products compared to other images from other satellite platforms e.g. MODIS, OMI, and AIRS which provide the same products in a different spatial resolution lower than Sentinel-5P. These products enable the current study to reach a deep spatial analysis and more detailed results of air pollution in GCR. This also includes the role of Big
Fig. 14. Apple mobility data of the change percentage of the movement, whether driving or walking, in Egypt from the 15th of February to the 31st of August 2020. * source: (Apple mobility data, 2020).

Fig. 15. Monthly change in the electricity consumption (million-MWh) in Egypt for the period from January to August 2020 compared to 2019. * (). Source: CAPMAS, 2020b

Fig. 16. Monthly change in the total GHG emissions from electricity (million-ton CO2e) in Egypt for the period from January to August 2020 compared to 2019.
Data science in monitoring and analyzing the behavior of people during the pandemic for developing plans to control the pandemic spread all over the world, as seen from Google and Apple mobility data.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

The author acknowledges the free-accessed data used in this paper from Sentinel-5P Pre-Operations Data Hub, CAPMAS, ERA, Google, Apple, and IPCC. SO2 analyses produced with Google Earth Engine.

Appendix

Google Earth Engine Script for extracting and analyzing Sentinel-5P/L2_SO2 images

```javascript
var collection = ee.ImageCollection('COPERNICUS/S5P/NRT/L3_SO2')
  .select('SO2_column_number_density');

var collection = ee.ImageCollection('COPERNICUS/S5P/NRT/L3_SO2')
  .select('SO2_column_number_density');

var band_viz = {
  min: 0.0003,
  mean: 0.0009,
  max: 0.0010,
  palette: ['#ffffff', '#ccf666', '#green', '#yellow', '#red']
};

var band_viz = {
  min: 0.0003,
  mean: 0.0009,
  max: 0.0010,
  palette: ['#ffffff', '#ccf666', '#green', '#yellow', '#red']
};

Map.addLayer(collection, band_viz, 'SSP SO2');

Export.imageToDrive(
  image: collection.select('SO2_column_number_density').mean(),
  description: 'SO2-15-3-2019',
  scale: 50,
  region: geometry,
  fileFormat: 'GeoTIFF',
  fileNamePrefix: 'SO2-15-3-2019',
  maxPixels: 50000000
);
```

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