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Spatio-temporal Analysis of Pollutant Gases using Sentinel-5P TROPOMI Data on the Google Earth Engine during the COVID-19 Pandemic in the Marmara Region, Türkiye

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Abstract: In this study, the changes in nitrogen dioxide (NO_2), carbon monoxide (CO) and sulfur dioxide (SO_2) pollutant gases were examined between June 2019 and June 2021 during the COVID-19 pandemic period. For this purpose, monthly and annual averages of Sentinel-5P TROPOspheric Monitoring Instrument (TROPOMI) values were calculated on the Google Earth Engine (GEE) platform. According to the results obtained using the GEE platform, the average column density values of NO_2, CO, and SO_2 in the Marmara Region between the selected dates were calculated as 8.40E-05 mol/m^2, 3.23E-02 mol/m^2, and 3.75E-04 mol/m^2, respectively. During the lockdown, these values decreased to 7.84E-05 mol/m^2, 3.05E-02 mol/m^2 and 2.75E-04 mol/m^2 respectively. According to TROPOMI data, these three gas column density values showed a decreasing trend during the COVID-19 pandemic lockdown period. However, in a 25-month examination in general, these three gas values showed an increasing trend due to population growth, industrialization, and increasing traffic density.
Key words: Sentinel-5P, TROPOMI, NO_2, CO, SO_2, Google Earth Engine, COVID-19

Analiza prostorno-vremenske raspodjele onečišćujućih plinova korištenjem podataka Sentinel-5P TROPOMI na Google Earth Engine platformi tijekom COVID-19 pandemije u Mramornoj regiji u Turskoj

Sažetak: U ovoj studiji su analizirane promjene u koncentraciji zagađujućih plinova dušikovog dioksida (NO_2), ugljen monoksida (CO) i sumpor dioksida (SO_2) između lipnja 2019. i lipnja 2021. godine, u vrijeme pandemije COVID-19. U tu svrhu, mjesečni i godišnji prosjeci vrijednosti Sentinel-5P TROPOspheric Monitoring Instrument (TROPOMI) su izračunati na Google Earth Engine (GEE) platformi. Prema rezultatima dobivenim korištenjem GEE platforme, prosječne vrijednosti gustoće stupaca NO_2, CO i SO_2 u Mramornoj regiji između odabranih datuma iznosile su 8,40E-05 mol/m^2, 3,23E-02 mol/m^2, odnosno 3,75E-04 mol/m^2. Tijekom lockdowna, ove vrijednosti su se smanjile na 7,84E-05 mol/m^2, 3,05E-02 mol/m^2, odnosno 2,75E-04 mol/m^2. Prema TROPOMI podacima, ove tri vrijednosti gustoće plina su pokazale trend smanjenja tijekom lockdowna uslijed COVID-19 pandemije. Međutim, tijekom 25-mjesečnog ispitivanja općenito, ove tri vrijednosti emisije plinova pokazale su trend rasta zbog rasta stanovništva, industrijalizacije i povećanja gustoće prometa.
Ključne riječi: Sentinel-5P, TROPOMI, NO_2, CO, SO_2, Google Earth Engine, COVID-19

1. INTRODUCTION

It is crucial to take measures to reduce air pollution to protect public health and the environment. It is also important to monitor air quality to identify areas with high pollution levels and take necessary actions to reduce exposure. Advances in Remote Sensing (RS) technology have made it easier and more affordable to monitor air quality, and this information can be used to make decisions about land-use planning and other policies. Overall, it is essential to raise awareness about the dangers of air pollution and take action at all levels, from individual to government, to reduce emissions and improve air quality for the health and well-being of both current and future generations.

The concentration of dangerous gases in the atmosphere is rapidly increasing worldwide because of industrialization, urbanization, the increase in the number of motor vehicles accompanying urban development, automation, deforestation, and fossil fuel consumption (Singh et al. 2023). This increase in air pollution causes more than one million deaths worldwide every year due to the damage it causes to the lungs and respiratory system, especially in crowded cities (Shah et al. 2013; Fu et al. 2020). According to data from the World Health Organization (WHO, 2016), air pollution is responsible for one in every nine deaths. The most common pollutants include nitrogen dioxide (NO_2), sulfur dioxide (SO_2), carbon monoxide (CO), ground-level ozone (O_3), and particulate matter ($PM_{2.5}$ and PM_{10}). All these pollutants, especially in vulnerable populations with lung disease or asthma, are associated with the development and/or exacerbation of respiratory diseases that reduce lung function (Halonen et al. 2009). CO can cause mild cardiovascular and neurobehavioral effects, even at low concentrations (Raub et al. 2000).

The sources of air pollutants can be divided into two categories: artificial and natural. Natural sources include fires, volcanic eruptions, and pollen, while artificial sources of air pollutants include NO_2, CO, SO_2, particulate matter, and industrial fuel use (Sakti et al. 2023). Air quality can be measured through ground-based stations or through Earth observation satellites. In recent years, remote sensing (RS) techniques have become widely used for tracking air pollutant gases on a global scale (Yilmaz et al. 2023). The Sentinel-5P (Precursor) satellite technology is the latest technology launched by the European Space Agency (ESA) in 2017 to observe air quality and air pollutants such as O_3, methane (CH_4), formaldehyde (HCHO), CO, NO_2, and SO_2 (Nugroho 2023). One of the recent RS technologies, the Google Earth Engine (GEE) platform contains various satellite images such as Landsat, Sentinel, and MODIS that can be used for many research purposes (Ateş 2022; Ateş et al. 2022; Matci et al. 2022; Yılmaz et al. 2022). GEE, one of the new technologies in recent years, also allows for complex analyses such as image processing, classification, change detection and time series analysis including extraction of image statistics to be easily performed, saving time and speed (Acar et al. 2021; Sannigrahi et al. 2021; Yilmaz et al. 2023).

The COVID-19 pandemic, which rapidly spread its impact worldwide in 2019, has brought with it various scientific studies. The effects of the comprehensive lockdown implemented during the lockdown process on air pollution have been the focus of scientists. Ghasempour et al. (2021) investigated the spatio-temporal change of NO_2 and SO_2 from Sentinel-5P TROPOspheric Monitoring Instrument (TROPOMI) and aerosol optical depth (AOD) derived from MODIS in Türkiye during the COVID-19 period between January 2019 and September 2020. According to the results, NO_2 gas reaches minimum values in spring, then starts to rise in summer months and reaches maximum values in winter months. Unlike NO_2, SO_2 remained at minimum values throughout the spring and summer seasons. Ogen (2020) examined the relationship between long-term exposure to NO_2 and the COVID-19 death rate. The study found that 78% of the 4443 COVID-19 deaths occurred in five regions located in northern Italy and central Spain, which also had the highest NO_2 concentrations and poor airflow for efficient dispersion. Zhang et al. (2021) investigated the effects of the COVID-19 outbreak on global air quality by examining global NO_2 dynamics obtained from satellite observations between January 1 and April 30, 2020, in their study. An unsupervised machine learning algorithm called Apriori was used to investigate this relationship. In their study, they found that there was a decrease in NO_2 values in countries where lockdown was applied. Metya et al. (2020) used CO and NO_2 derived from The Atmospheric Infrared Sounder (ARIS) and SO2 derived from Ozone Monitoring Instrument (OMI) in India and China in January-April 2020. The results showed that tropospheric NO_2 levels decreased by an average of 17% over India and 25% over China. In addition, a decrease of about 17% was observed in boundary layer SO_2 over the Eastern sector of India and a decrease of 6.5% was determined in CO over north central China.

Air pollution, which is a major problem in many countries around the world and seriously affects human health, is also one of the most important problems in Türkiye. The Marmara Region, which is Türkiye's most important region connecting Europe and Asia geopolitically, is the region most affected by air pollution when considering urbanization, industrialization, and the diversity of trade routes. The fact that the landforms are less rugged compared to other geographical regions of Türkiye has made this region more livable. As a result, the Marmara region has become a region that receives more migration. The main aim of this study is to monitor the spread of NO_2, CO, and SO_2 pollutant gas values obtained from Sentinel-5P TROPOMI device on the GEE platform in the Marmara Region during the COVID-19 period. The first COVID-19 case in Türkiye was seen on March 11, 2020, and lockdown processes and strict inspections were started from this date. These measures have been gradually reduced after June 2020. In this study, the spread of pollutant gases was analyzed during the period between June 2019 and June 2021 including the pre-COVID-19, lockdown process, and post-lockdown period. The results obtained can be useful for research such as preventing air pollution and minimizing greenhouse gas effects and global climate change. This study also demonstrates that the GEE platform is a fast and convenient analysis tool for issues directly affected by air pollution such as environmental pollution, human health, and livable cities.

2. MATERIAL AND METHOD

1.1 Study area

In this study, the Marmara Region was selected as the study area. The Marmara Region has an area of approximately 67,000 km^2 and is one of Türkiye's seven geographical regions. The Marmara Region, with approximately 24,899,126 inhabitants, is the most populous region of Türkiye. The region is very important due to its geopolitical location, as it has connections to the Black Sea, Marmara Sea, and Aegean Sea, and is home to the Canakkale and Istanbul Straits. The region serves as a bridge connecting Asia and Europe. The increase in human population has led to many problems such as air pollution, environmental pollution, and sea and land traffic. The provinces in the Marmara region are listed as Balikesir, Bilecik, Bursa, Canakkale, Edirne, Istanbul, Kirklareli, Kocaeli, Sakarya, Tekirdag, and Yalova, and the air pollution levels in each province vary depending on several factors such as population, industry, and climate. The study area is shown in Figure 1.

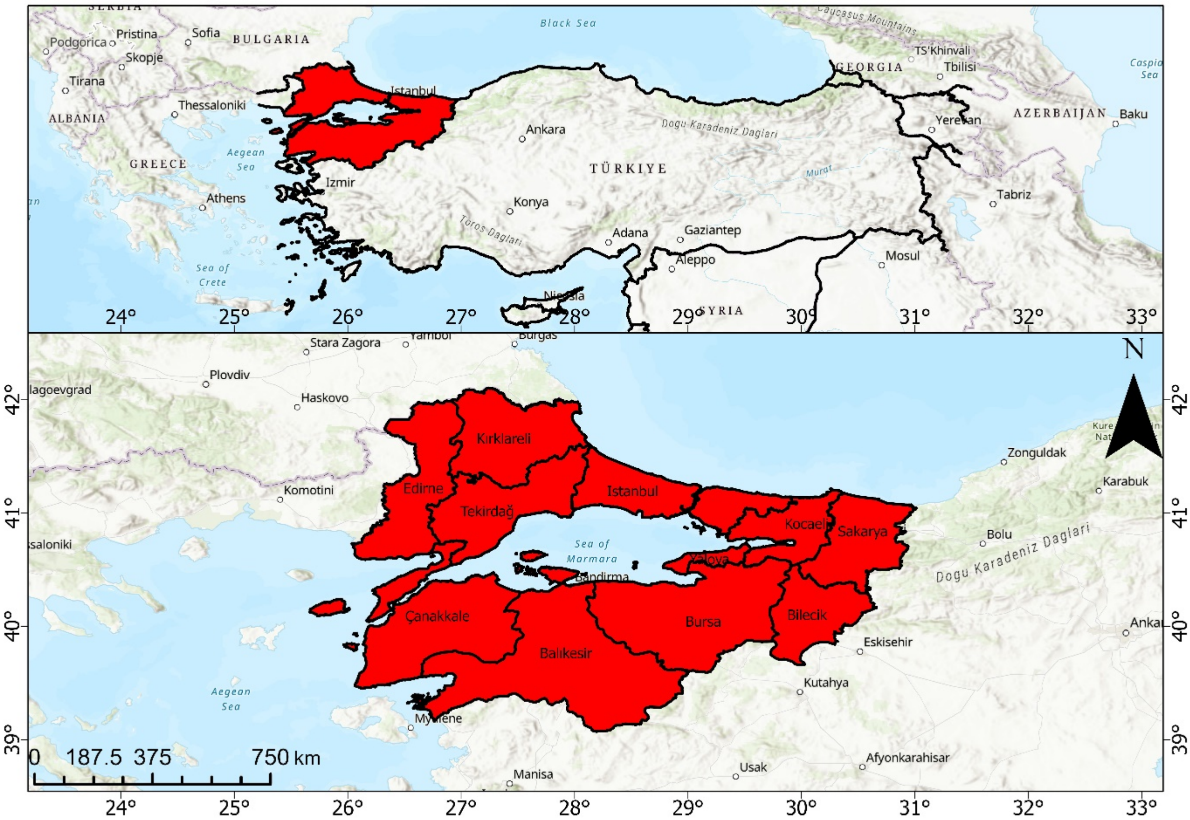


Figure 1. Study area

1.2 Data used

Sentinel-5P is the first Copernicus mission designed to monitor the atmosphere. It comprises of a satellite carrying the TROPOMI instrument, which is a space-based, nadir-viewing spectrometer that covers wavelength bands between ultraviolet and short-wave infrared. The TROPOMI instrument provides imaging capabilities for various atmospheric components.

Sentinel 5P is a remote sensing device that utilizes passive sensing techniques. The instrument operates in a push-broom configuration with a scanning width of approximately 2600 km on the Earth's surface. For all spectral bands, except for the UV1 band (7x28 km²) and the SWIR bands (7x7 km²) near the nadir viewing angle, the typical pixel size is 7x3.5 km² (Kaplan and Yigit Avdan 2020). The primary objective of the Sentinel 5P mission is to collect atmospheric measurements for air quality, ozone, UV radiation, climate monitoring, and prediction, providing useful data to assess air quality (Grzybowski et al. 2023).

The TROPOMI instrument detects atmospheric concentrations of O_3, CH_4, HCHO, CO, NO_2, and SO_2 (Yilmaz et al. 2023). Nitrogen oxides such as NO_2 and NO are important trace gases present in both the troposphere and stratosphere and are released into the atmosphere due to human activities (especially fossil fuel combustion and biomass burning) and natural processes (forest fires, lightning, and microbiological processes in soil) (Hahn and Crutzen 1982). CO gas is a colorless, odorless, and poisonous gas in the air. CO is a byproduct of combustion and can be released from various sources such as fossil fuel combustion, vehicle exhausts, fires, and smoking (Dey and Dhal 2019). Short-term exposure to CO can cause symptoms such as headache, dizziness, weakness, nausea, and vomiting.

Long-term exposure can lead to brain damage, heart disorders, and death (Prockop and Chichkova 2007; Karalliedde and Keshishian 2012; Ng et al. 2018). SO2 is also an important air pollutant released from sources such as fossil fuel combustion and volcanic eruptions (Sharma et al. 2013). SO2 can cause respiratory problems, such as asthma and bronchitis, and can contribute to acid rain formation (Nduka et al. 2008).

3. RESULTS

On the GEE platform, column number density values for NO_2, CO, and SO_2 provided by the TROPOMI instrument on the Sentinel-5P satellite platform were provided separately for each province. A total of 825 maps were produced for these three gases in eleven provinces for 25 months. The monthly pixel averages of these raster format maps indicate the average gas concentration of each province. To calculate the average gas emission value for a province over 25 months, the average of these values was computed for a total of 25 months. The statistical values for these three gases are presented in Table 1.

Table 1. NO_2, CO and SO_2 column number density statistical information

Province	NO2			CO			SO2		
	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.
Istanbul	7.82E-05	1.37E-04	9.93E-05	2.93E-02	3.94E-02	3.34E-02	4.67E-05	2.48E-03	3.76E-04
Kocaeli	7.67E-05	1.43E-04	9.60E-05	2.93E-02	3.85E-02	3.26E-02	5.46E-05	1.53E-03	3.71E-04
Balikesir	6.75E-05	9.08E-05	7.70E-05	2.83E-02	3.69E-02	3.15E-02	4.93E-05	1.22E-03	4.03E-04
Bilecik	7.13E-05	9.59E-05	7.92E-05	2.71E-02	3.56E-02	3.01E-02	2.61E-05	9.34E-04	3.46E-04
Bursa	7.59E-05	1.07E-04	8.82E-05	2.83E-02	3.71E-02	3.14E-02	3.91E-05	1.23E-03	4.07E-04
Canakkale	6.91E-05	8.77E-05	7.64E-05	2.91E-02	3.80E-02	3.24E-02	4.58E-05	1.23E-03	3.73E-04
Kirklareli	5.87E-05	8.64E-05	7.30E-05	2.84E-02	3.85E-02	3.25E-02	4.32E-05	3.24E-03	4.13E-04
Sakarya	7.30E-05	1.02E-04	8.22E-05	2.93E-02	3.83E-02	3.24E-02	2.53E-05	1.28E-03	3.49E-04
Tekirdag	6.54E-05	9.03E-05	7.77E-05	2.90E-02	3.90E-02	3.30E-02	3.98E-05	1.82E-03	3.50E-04
Yalova	8.36E-05	1.30E-04	1.03E-04	2.92E-02	3.87E-02	3.28E-02	3.80E-05	9.78E-04	3.72E-04
Edirne	5.97E-05	8.70E-05	7.20E-05	2.92E-02	3.92E-02	3.33E-02	5.18E-05	2.08E-03	3.76E-04

Figure 2 displays the average NO_2 change graphs for all provinces in the Marmara Region, and Figure 3 presents the average NO_2 map. Based on the results, the minimum NO_2 column number density in the Marmara Region was calculated as 7.20E-05 mol/m^2 in Edirne Province and the maximum as 1.03E-04 mol/m^2 in Yalova Province. In Istanbul, the largest city in the region, the NO_2 column number density value was calculated as 9.93E-05 mol/m^2. The average NO_2 column number density value for the entire Marmara Region was calculated as 8.40E-05 mol/m^2. Based on this average value, it was observed that Istanbul, Kocaeli, Bursa and Yalova provinces remained above this value while Balikesir, Bilecik, Canakkale, Kirklareli, Sakarya, Tekirdag and Edirne provinces remained below the average.

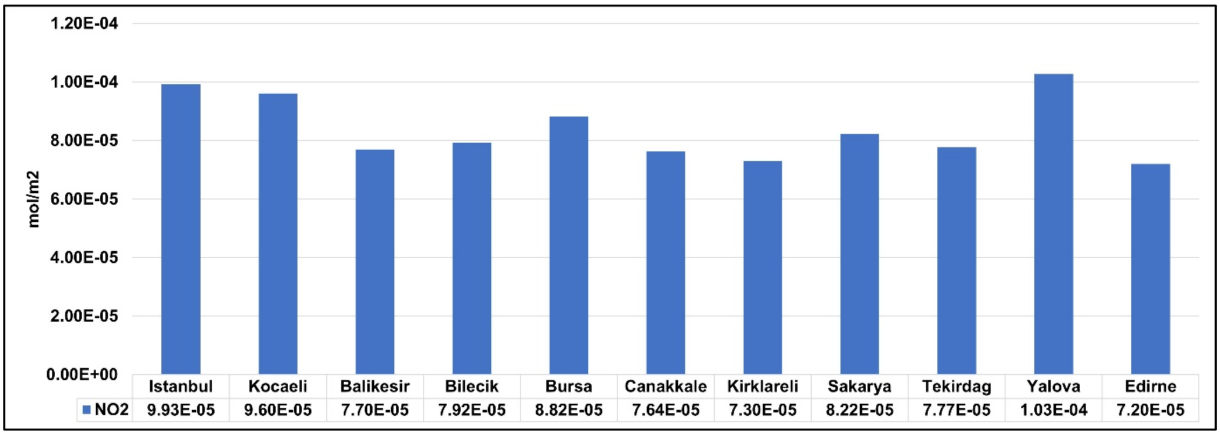


Figure 2. NO_2 column number density of the provinces in the Marmara Region between 2019-2022

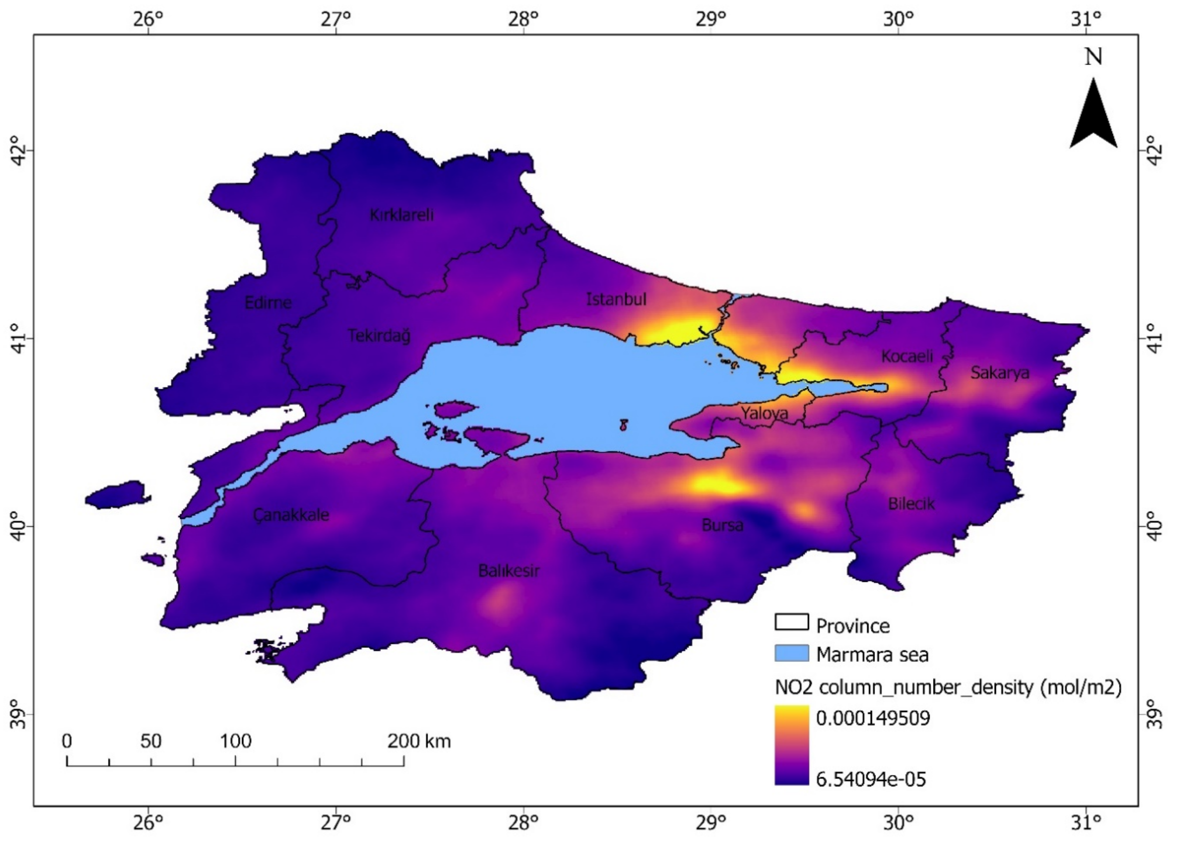


Figure 3. 2019-2022 average NO_2 map

The CO column number density change graphs for all provinces in the Marmara Region are shown in Figure 4, and the average CO map is shown in Figure 5. According to the results, the minimum CO column number density in the Marmara Region was calculated as 3.01E-02 mol/m^2 in Bilecik Province and the maximum as 3.34E-02 mol/m^2 in Istanbul Province. The average CO column number density value for the entire Marmara Region was calculated as 3.23E-02 mol/m^2. Considering the average CO value, Istanbul, Kocaeli, Canakkale, Kirklareli, Tekirdag, Yalova, and Edirne provinces remained above the average, while Balikesir, Bilecik and Bursa provinces remained below the average.

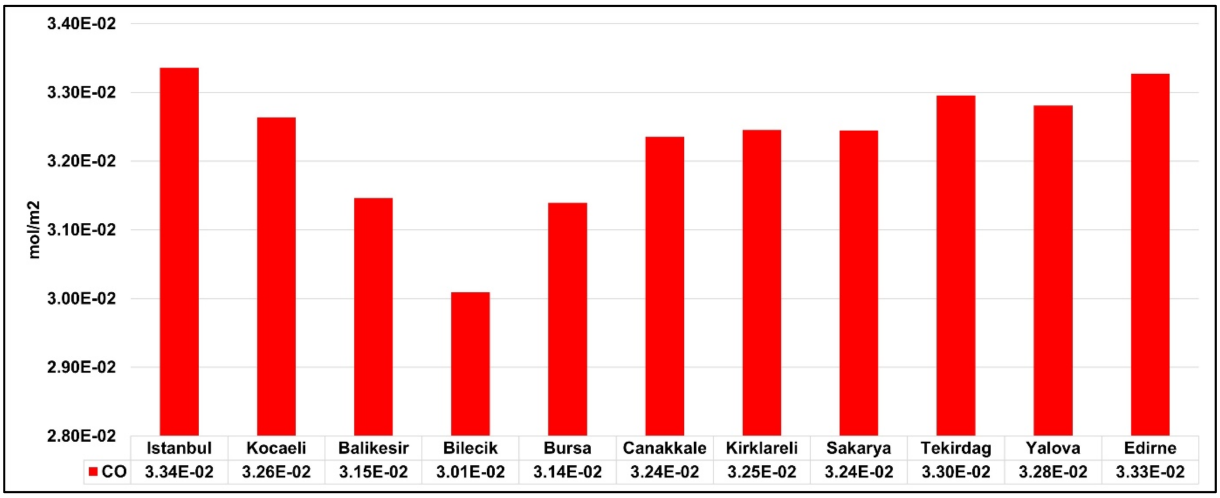


Figure 4. CO column number density of the provinces in the Marmara Region between 2019-2022

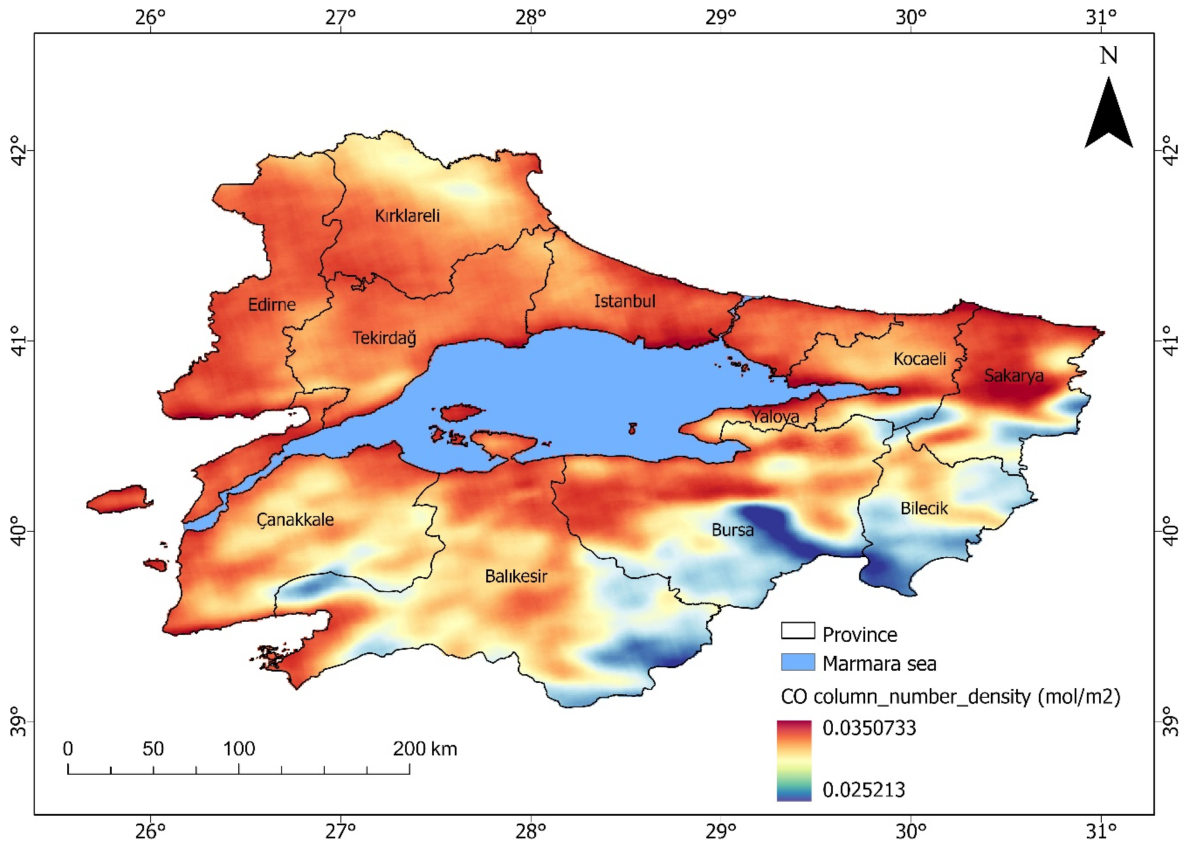
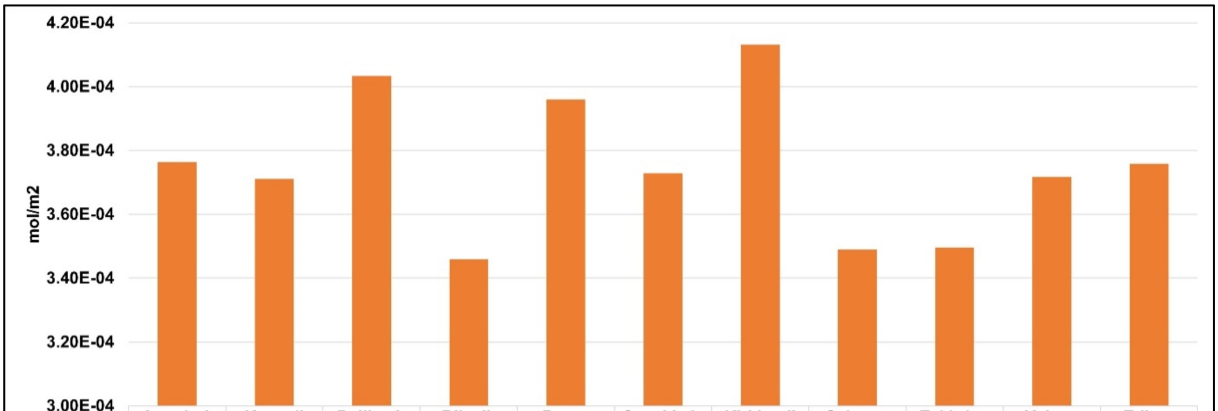


Figure 5. 2019-2022 average CO map

The SO_2 change graphs for all provinces in the Marmara Region are shown in Figure 6, and the average SO_2 map is shown in Figure 7. According to the results, the minimum SO_2 column number density in the Marmara Region was calculated as 3.46E-04 mol/m^2 in Bilecik Province and the maximum as 4.13E-04 mol/m^2 in Kirklareli Province. In Istanbul, the mega city of the region, the SO_2 column number density value was calculated as 3.76E-04 mol/m^2. The average SO_2 column number density value for the entire Marmara Region was calculated as 3.75E-04 mol/m^2. Considering the average SO_2 value, Istanbul, Balikesir, Bursa, Kirklareli, and Edirne provinces remained above the average, while Kocaeli, Bilecik, Canakkale, Sakarya, Tekirdag, and Yalova provinces remained below the average.



	Istanbul	Kocaeli	Balikesir	Bilecik	Bursa	Canakkale	Kirklareli	Sakarya	Tekirdag	Yalova	Edirne
SO2	3.76E-04	3.71E-04	4.03E-04	3.46E-04	3.96E-04	3.73E-04	4.13E-04	3.49E-04	3.50E-04	3.72E-04	3.76E-04

Figure 6. SO_2 column number density of the provinces in the Marmara Region between 2019-2022

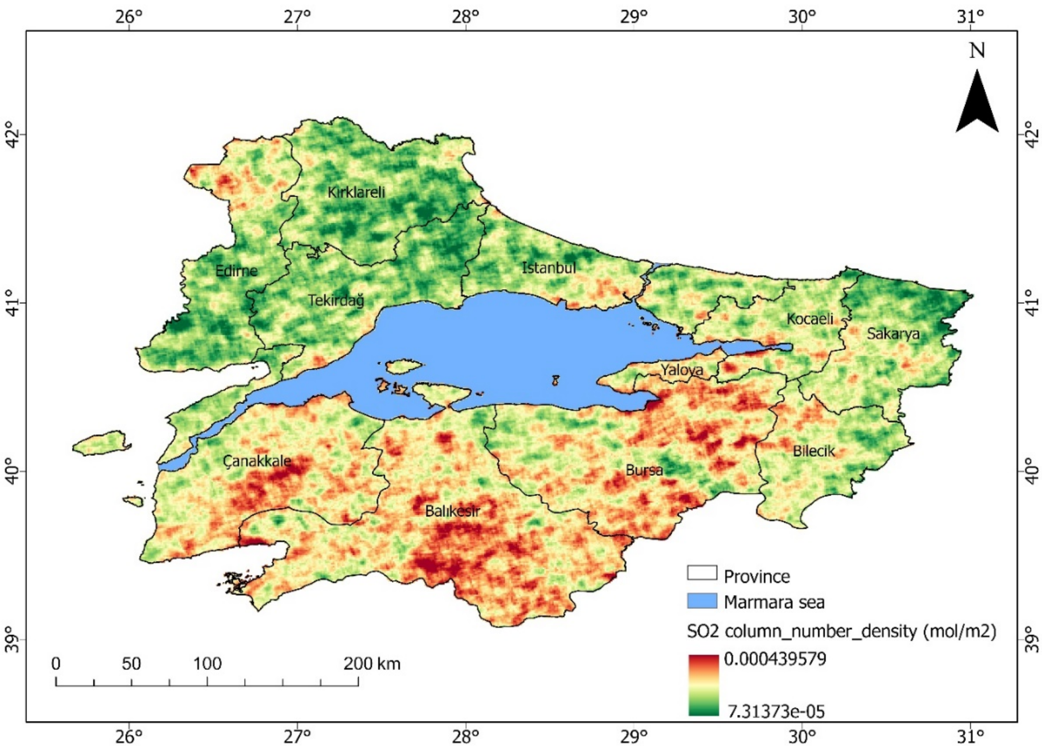


Figure 7. 2019-2022 average SO_2 map

In the study that covered all provinces in the Marmara Region, trend graphs were produced for 25 months between June 2019 and June 2021. The distribution of NO_2 gas according to the provinces in the region is shown in Figure 8. When the graph is examined, an increasing trend in NO_2 column number density value is observed in all provinces except Canakkale and Edirne. According to the chart, there is a decrease in NO_2 value in all provinces, especially in the first months of 2020 and the last months of 2020. It is noteworthy that these periods coincide with the COVID-19 pandemic period. The decreases during this period are explained by the lockdown processes applied then. After the end of the lockdown period, a rapid upward trend in gas levels has been observed since October 2020.

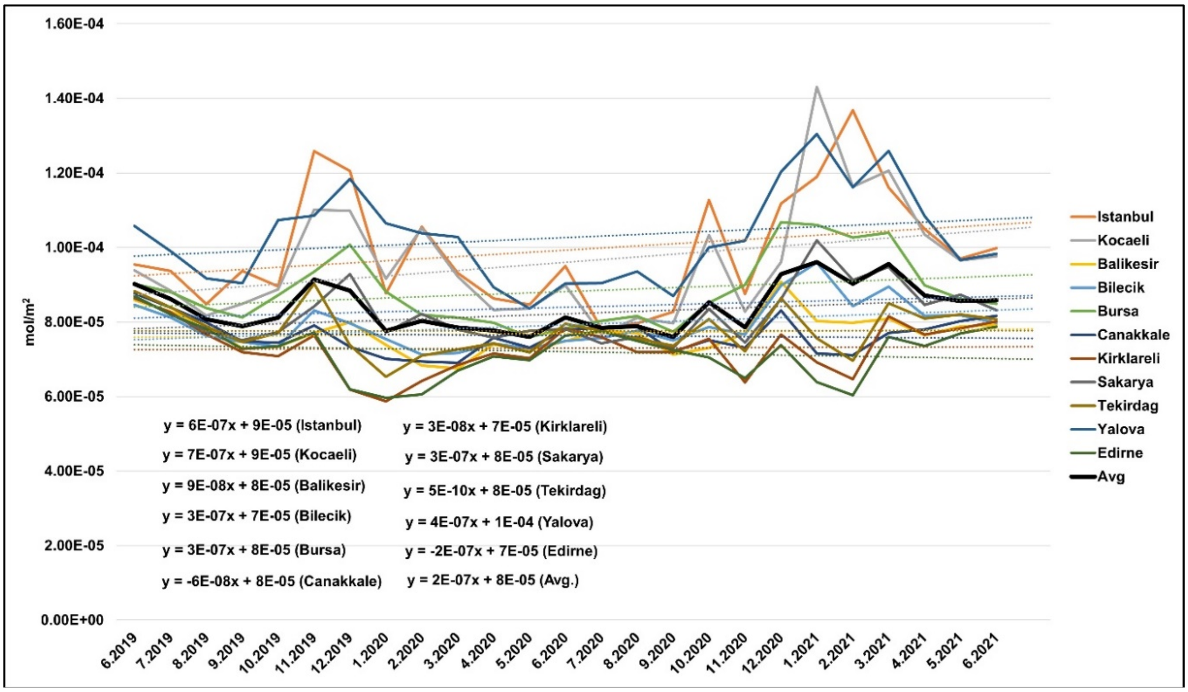


Figure 8. Trend chart of NO_2 gas by provinces

The distribution of CO column number density in the provinces of the region is shown in Figure 9. Upon examination of the graph, an increasing trend in CO column number density is observed in all provinces of the Marmara Region. Similar to NO_2 gas, CO column number density decreased during the COVID-19 lockdown period. After the lockdown period, CO column number density, which had started to increase again, decreased due to the lockdown processes caused by the 2nd wave of the COVID-19 outbreak since January 2021.

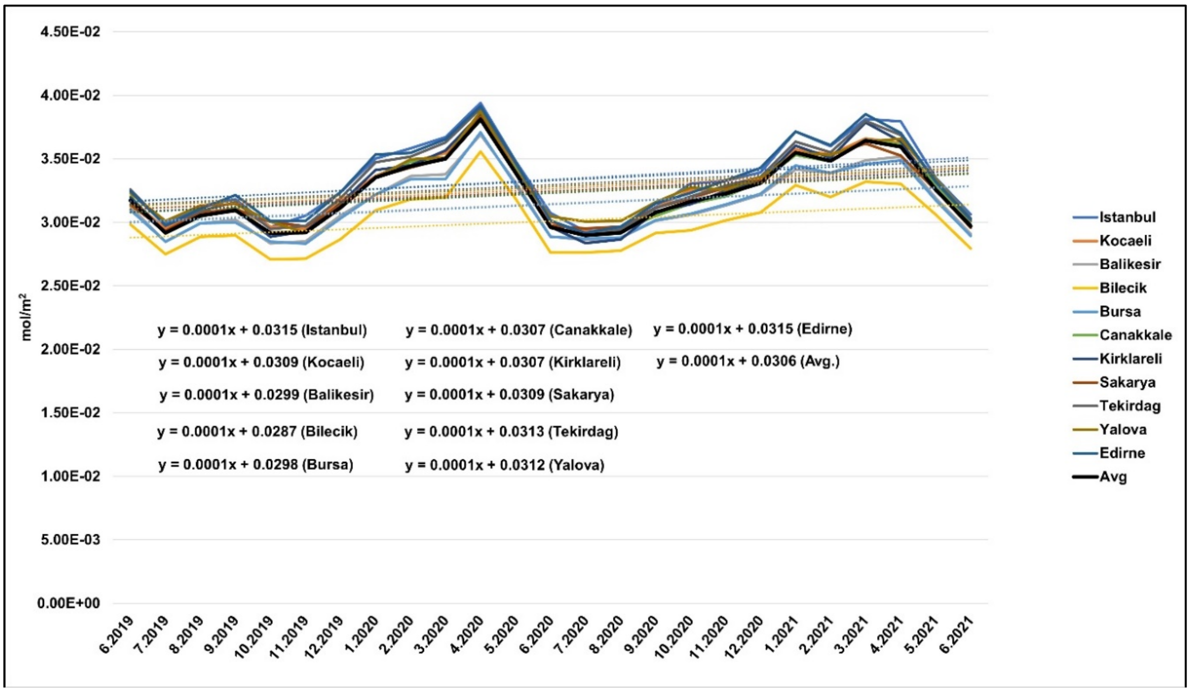


Figure 9. Trend chart of CO gas by provinces

The distribution of SO_2 column number density according to the provinces in the region is shown in Figure 10. When the graph is examined, an increasing trend in SO_2 column number density is observed in all provinces except Istanbul, Kocaeli, and Kirklareli. The SO_2 column number density increased excessively to its maximum level in approximately two months, from January 2019 to the end of February 2019. Following this peak, the COVID-19 lockdown processes led to a decline in the levels of SO_2. However, with the end of the first lockdown period in Türkiye, there was a rapid increase in SO_2 gas levels, which decreased again to minimum levels during the second lockdown period. Similar to other gases, the level of SO_2 gas is also increasing in the Marmara Region.

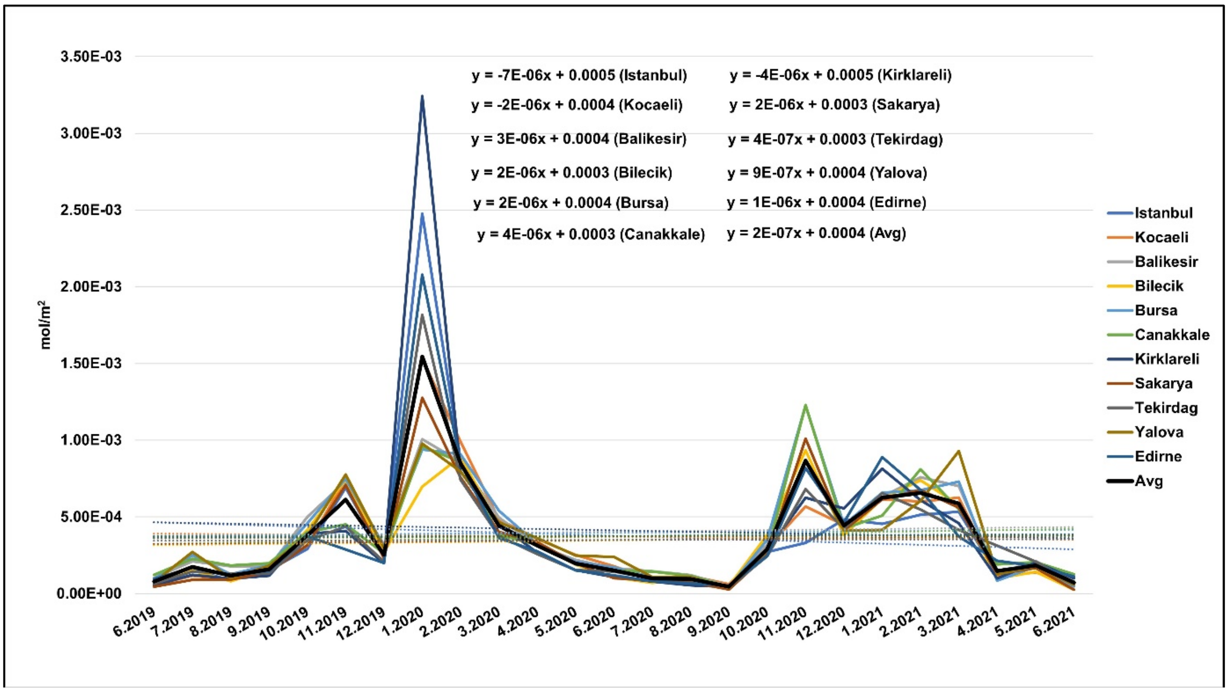


Figure 10. Trend chart of SO_2 gas by provinces

4. DISCUSSION

During the COVID-19 lockdown process in Türkiye, there was a decrease in activities that could cause polluting gases, especially traffic and heavy industry. These reductions have led to changes in the levels of certain gases in the atmosphere that could contribute to pollution. In this study, it is found that NO_2 gas was particularly unstable in the Marmara Region compared to other gases. NO_2 gas has reached significant levels, especially in regions where industry and population are dense in the Marmara Region, and it has been observed that it is at its maximum level in Yalova province. However, especially during the lockdown period, it is easily observed that there has been a decrease in this gas level in all provinces. Before the lockdown period, between June 2019 and February 2020, the column number density value was 8.39E-05 mol/m^2, while during the lockdown period, from March 2020 to June 2020, this value decreased to 7.84E-05 mol/m^2. After the end of the lockdown period and when the restrictions began to be gradually relaxed, NO_2 column number density values quickly increased to an average of 8.59E-05 mol/m^2. When previous studies were examined by Ghasempour et al. (2021), they reported a significant decrease in NO_2 values during lockdown using Sentinel-5P TROPOMI data for Türkiye. Studies conducted in different countries also confirm this study's results (Fan et al. 2020; Mesas-Carrascosa et al. 2020; Metya et al. 2020). In the Marmara region, the concentration of CO gas has either increased or decreased in the same proportion in all provinces. Before the lockdown period, the column number density value was approximately 3.21E-02 mol/m^2; during the lockdown period, this value decreased to approximately 3.05E-02 mol/m^2. After the end of the lockdown period and when the restrictions began to be gradually relaxed, CO column number density values reached an average of 3.36E-02 mol/m^2. In this study, SO_2 gas changed steadily in all provinces in the Marmara Region. A serious increase is noticeable in the winter months of 2019. This increase is due to the warming, industrial and traffic-induced increase. Before the lockdown period, the column number density value was 4.63E-04 mol/m^{2,} while during the lockdown period, this value decreased to 2.75E-04 mol/m^2. After the end of the lockdown period, SO_2 column number density values quickly increased to an average of 3.42E-04 mol/m^2. The results of this study are consistent with previous studies, e.g. Gautam et al. (2021) examined eight of India's most polluted cities (Mumbai, Delhi, Bangalore, Hyderabad, Lucknow, Chandigarh, Kolkata, and Ahmedabad). In their study, they found a decrease of about 50%, 59%, and 9%, respectively, in NO_2, CO, and SO_2 gases during the pandemic period at Major Dhyan Chand Stadium. Similarly, at Chhatrapati Shivaji International Airport, during the first lockdown stage, they detected a decrease of 36%, 41%, and 16%, respectively in NO2, CO, and SO2 gases within just one week. Similarly Schiavo et al. (2023) determined that there was a decrease of 14.9%, 9.8%, and 41.9% respectively in NO_2, CO and SO_2 gases during the lockdown period. All the studies have shown that there has been a significant decrease in various polluting gases during the lockdown period, and our results are consistent with those (Vîrghileanu et al. 2020; Oo et al. 2021; Faisal and Jaelani 2023; Sakti et al. 2023; Suhardono et al. 2023).

5. CONCLUSION

In this study, pollutant gas emission maps of NO_2, CO, and SO_2 gases were created using Sentinel 5P TROPOMI data on the GEE platform for the provinces in the Marmara Region of Türkiye, the most developed region in terms of the industry, during the COVID-19 pandemic period. Firstly, the GEE platform calculated monthly gas density ratios between June 2019 and June 2021 using Java Script codes of NO_2, CO, and SO_2 gases, which are air pollutants. According to the results, the NO_2 column number density value was minimum in the Edirne province and maximum in the Yalova province. The CO column number density value was minimum in the Bilecik province and maximum in the Istanbul province. Similarly, the minimum SO_2 value was observed in the Bilecik province and the maximum value in the Kirklareli province. For the observed 25 months in the Marmara Region, the average NO_2, CO, and SO_2 column number density values were calculated as 8.40E-05 mol/m^2, 3.23E-02 mol/m^2, and 3.75E-04 mol/m^2, respectively. Although there was a significant decrease in all gas ratios during the COVID-19 pandemic, column number density values continued to increase with the end of the lockdown period. In general, there is an increasing trend in all gases when the region is examined. Although this study explains the reason for the increase in air quality with the lockdown process, it should be used to develop strategies for improving air quality. Although the restrictions are related to preventing the spread of the virus, significant increases in air quality have shown that atmospheric air quality can be improved with various measures. In the future, strategies and public policies should favor green nature and the environment more. In this respect, using renewable energy sources will not only contribute to the reduction of fossil fuels but will also significantly reduce environmentally friendly and atmospheric gas emissions. In addition, using filtering systems for polluting gases released in factories, using catalytic converters, and improving the quality of fuels used can reduce gas levels released into the atmosphere. Furthermore, promoting public transportation and environmentally friendly micromobility for transport and providing necessary infrastructure designs are required.

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