# Satellite-Based Assessment of $NH_3$ and $CH_4$ Levels around Biogas Facilities in Izmir

Sedef Bayram [1,2], Merve Aydin [1], Aykut Mehmet Alban [1,3], Serra Saracoglu [1,4], Burcak Kaynak [1*]

[1] School of Civil Engineering, Department of Environmental Engineering, Istanbul Technical University, Istanbul, Türkiye – bayrams22@itu.edu.tr, aydinm20@itu.edu.tr, alban17@itu.edu.tr, saracoglu22@itu.edu.tr, kaynakbu@itu.edu.tr
[2] Engineering Faculty, Department of Environmental Engineering, Istanbul University Istanbul, Türkiye
[3] School of Civil Engineering, Department of Environmental Engineering, Yıldız Technical University, Istanbul, Türkiye
[4] School of Engineering, Department of Environmental Engineering, Gebze Technical University, Kocaeli, Türkiye

**Keywords:** Remote sensing, ammonia, methane, biogas facilities, Izmir

**Abstract**

This study investigates atmospheric ammonia ($NH_3$) and methane ($CH_4$) concentrations in relation to biogas and biomass facilities in Izmir, Türkiye, using satellite-based remote sensing data from 2019 to 2023. $NH_3$ levels were retrieved from IASI instrument, and $CH_4$ from TROPOMI instrument, complemented by meteorological observations and livestock production statistics. Results showed that Izmir exhibited the highest $NH_3$ concentrations across Türkiye, with annual mean levels rising by 43% between 2019 and 2023, and 2023 wintertime $NH_3$ nearly doubling relative to 2019. $CH_4$ concentrations also displayed marked increases, particularly after 2021, with maxima recorded in 2022–2023. Spatial and seasonal analyses revealed a persistent hotspot in the inland basin surrounded by the Bozdag Mountains, where intensive livestock farming and multiple biogas facilities are concentrated. Within a 12 km radius of three plants (B64, B67, B68), $NH_3$ concentrations rised following their operating, though overlap between neighbouring facilities complicates source attribution. While livestock farming and agricultural waste remain the dominant drivers, these findings indicated that biogas and biomass plants may also contribute to elevated $NH_3$ and $CH_4$ concentrations in their vicinity. These results emphasized the importance of balancing the renewable energy benefits of biogas expansion with its potential atmospheric impacts in Türkiye.

## 1. Introduction

In parallel with the continuous increase in the world population, rapidly developing technology and industrialization, energy use and produced waste are constantly increasing. Biogas is a type of renewable energy produced through the anaerobic digestion (AD) of the organic waste, such as animal manure, agricultural residues, and food waste. The process takes place in oxygen-free environment where microorganisms break down organic matter, generating a mixture of gases, primarily carbon dioxide ($CO_2$) and $CH_4$. AD, furthermore, is an organic waste treatment technology that is seen as recover heat and electricity from organic waste streams such as animal slurry and food wastes (Wulf et al., 2006). AD has been developed to provide multiple environmental benefits in waste processing, including replacement of fossil fuels with biogas, diversion of waste from landfill, and the abatement of $CH_4$ emissions from manure storage (Maranon et al., 2011). Despite the environmental advantages of anaerobic digestion, its implementation also brings secondary environmental challenges. One of the critical concerns is the emission of $NH_3$, particularly from the handling and storage of digestate. Among the various emissions associated with biogas production, $NH_3$ is of particular concern due to its volatility and environmental impact. During the pre-digestion phase, both $NH_3$ and $CH_4$ emissions can occur, $NH_3$ primarily from manure storage and handling (EMEP/EEA, 2025), and $CH_4$ especially from the anaerobic conditions in slurry storage prior to digestion (IPCC, 2006). $NH_3$ emissions are mainly linked to post-digestion phases such as digestate handling, storage and land application (Sommer & Hutchings, 2001).

Türkiye has a high energy potential, especially in terms of organic waste. In Türkiye, the existing organic waste generally constitutes 65% of the total waste which can be used for biogas production (Kumbur et al., 2015). As of 2023, Türkiye hosts over 100 operational biogas plants, primarily using livestock manure and agro-industrial wastes. Among these, Izmir and surrounding provinces are among the most significant areas in Türkiye for large scale biogas facilities, considering installed capacity.

In Türkiye, research focus on predominantly $CH_4$ levels from biogas plants, while $NH_3$ levels have limited concern. This study focuses on assessing the $CH_4$ and $NH_3$ levels together first time from biogas facilities operating in Izmir.

## 2. Methodology

In this study, atmospheric levels of $CH_4$ and $NH_3$ around biogas facilities in Izmir were assessed using satellite-based remote sensing measurements. $CH_4$ levels were retrieved from the TROPOMI instrument aboard the Sentinel-5P satellite with 13:30 local crossing time (GES DISC, 2025), while $NH_3$ data were obtained from the Infrared Atmospheric Sounding Interferometer (IASI) with a morning pass of a temporal resolution of twice a day (9:30) (AERIS, 2025). Both datasets were processed to extract spatial and temporal variations over the study region. Hourly meteorological parameters from the Ministry of Environment, Urbanization and Climate Change, General Directorate of Meteorology (MoEUCC, 2025) such as temperature (T), relative humidity (RH), wind speed (WS), and wind direction (WD) were incorporated into the analysis to understand the potential influences of meteorology. In addition, annual district level data on livestock and poultry production, as well as associated organic waste amounts, were obtained from the Turkish Statistical Institute (TURKSTAT, 2025) to estimate the potential for biogas production and to support the spatio-temporal analysis of $CH_4$ and $NH_3$.

Izmir, with 40.5% of its land covered by forests and 28.4% consisting of arable land, possesses a significant potential. An examination of the utilization of its total 343 thousand hectares of agricultural land reveals that 41.8% is allocated to field crops, 28.1% to olives, 11% to vegetables, 9.7% to fruit orchards, and 3.6% to vineyards (CLC, 2018) (Figure 1).

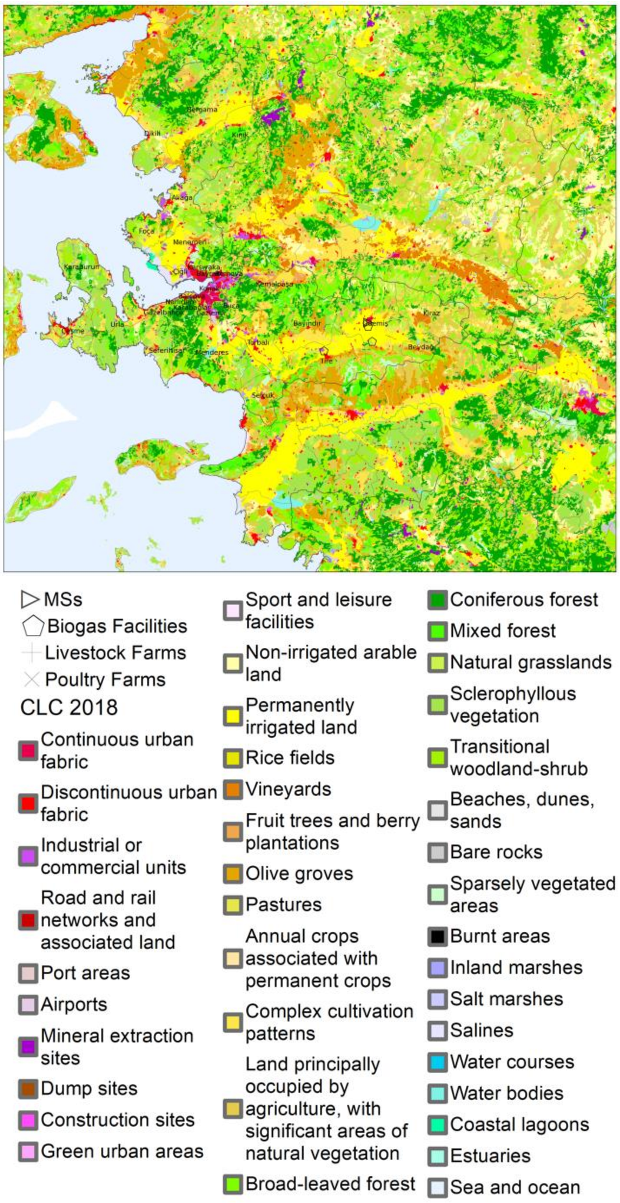


Figure 1. Study area with CORINE Land Cover/Land Use (CLC, 2018)


Figure 2. Study area including the districts of Kiraz, Odemiş, Tire, Bayindir, and Torbali, which are located around the Bozdag Mountains.

To identify the locations of biogas plants in Izmir, data were compiled from multiple sources, including the Biomass Energy Potential Atlas (BEPA) of the Ministry of Energy and Natural Resources, the Animal By-Products Facilities List of the Veterinary Public Health Department under the Ministry of Agriculture and Forestry (MoAF), the Electronic Environmental Impact Assessment (eÇED) System of the Ministry of Environment, Urbanization and Climate Change, the Environmental Permit and License Document Inquiry system, and the registry of the Biogas Investors and Industrialists Association (BiyogazDER). The listed addresses were cross-checked using Google Earth to verify the actual plant locations. Based on these verified sites, the latitude and longitude coordinates were determined, and the geographic distribution of biogas facilities in Izmir was mapped. Similarly, to identify the locations of livestock and poultry farms, the Approved Dairy Farms List obtained from the MoAF was utilized. In addition, the positions of cattle, dairy, and poultry farms marked on Google Maps and Google Earth were individually verified, and based on the validated coordinates, a map showing their geographic distribution was created.

Agricultural activities in the region include crop production, livestock production. Considering their contribution to overall biogas production, livestock farming ranks first with a share of 47% (Izmir Development Agency, 2020). In Izmir, livestock statistics show that the number of cattle increased by 41.6% between 2012 and 2023, but has declined by 3.99% since 2019. A rise was recorded in 2020, followed by gradual decreases in the subsequent years. Poultry numbers, on the other hand, displayed a different trend: while they increased by 7.2% compared to 2012, they have consistently declined since 2019. Between 2019 and 2023, poultry populations fell by 19.2%, with the sharpest drop occurring between 2022 and 2023 at 13.2%. These results indicate that cattle farming in Izmir has shown long-term growth but has stabilized in recent years, whereas poultry farming has entered a clear decline after 2019 (Turkstat, 2025).

Izmir was selected as the study area due to its distinctive combination of agricultural capacity, livestock density, and existing biogas investments. Furthermore, Izmir already has several active biogas plants, showing that biogas use is both possible and supported in the region. Biogas plants are operational in locations such as Foca, Tire, Odemiş, and Halilbeyli. These facilities process cattle and poultry manure, agricultural and food industry residues, and sewage sludge to produce electricity, heat, and organic fertilizer.

## 3. Result and Discussion

Several biogas plants are located in Izmir, particularly in the districts of Odemis, Bayindir, and Torbali, where elevated $NH_3$ levels are spatially matched with these facilities (Figure **3**). These plants are also surrounded by a number of livestock and poultry farms. Between 2019 and 2023, elevated $NH_3$ and $CH_4$ levels were observed primarily in the Odemis, Tire, Bayindir, and Torbali districts of Izmir (Figure 3, Figure 4) where biogas facilities are also located, including two plants in Odemis and two in Torbali (Figure 1,Figure 2, Figure 3).

Izmir showed the highest $NH_3$ concentrations over Türkiye (Tokgoz et al., 2025). Since 2019, an increase in annual average $NH_3$ concentrations has been observed, reaching 43% in Izmir by 2023. In particular, during the winter seasons of 2021 and 2022, $NH_3$ concentrations in Izmir exhibited an 100% increase compared to the winter of 2019. Between 2019 and 2023, $NH_3$ concentrations in Tire, Torbalı, and Odemis exhibited distinct seasonal and interannual variations, with the highest levels generally occurring during summer. In Tire, mean concentrations increased from $7.29\times10^{15}$ molecules/cm$^2$ in winter 2019 to

$1.65\times10^{16}$ molecules/cm$^2$ in summer 2023, while maximum values reached $2.69\times10^{16}$ molecules/cm$^2$ in the same period. Similarly, Torbali recorded mean levels rising from $2.58\times10^{15}$ molecules/cm$^2$ in winter 2019 to $1.28\times10^{16}$molecules/cm$^2$ in summer 2023, with peak of $2.57\times10^{16}$ molecules/cm$^2$ in winter 2021. Odemis consistently exhibited the highest $NH_3$ levels among the three districts, mean concentrations increased from $5.61\times10^{15}$ molecules/cm$^2$ in winter 2019 to $1.67\times10^{16}$ molecules/cm$^2$ in summer 2023, with maximum values peaking at $4.25\times10^{16}$ molecules/cm$^2$ in winter 2023. The Mann–Kendall trend test was applied to evaluate the temporal evolution of $NH_3$ levels across the districts of Izmir.

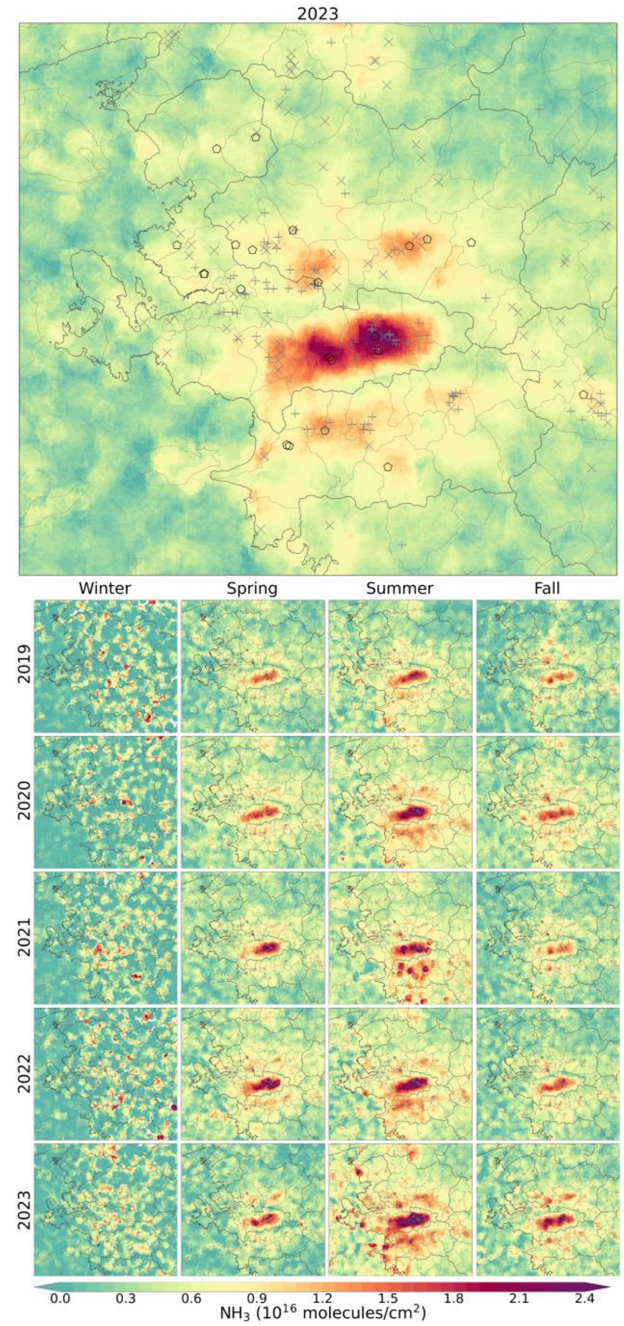


Figure 3. 2023 Annual (top) and 2019-2023 seasonal (bottom) average IASI $NH_3$ (molecules/cm$^2$) levels over the study area with biogas plants (⬠), livestock farms (+), and poultry farms (×).

The results revealed statistically significant increasing trends in most rural and livestock intensive districts, which was clearly observed in Odemiş, Tire, and Bayindir, while no significant trends were detected in several urbanized central districts.

Between 2019 and 2023, $CH_4$ concentrations in Tire, Torbali, and Odemis showed distinct seasonal and annual variations, with an overall tendency toward higher values in recent years. In Tire, mean $CH_4$ concentrations increased from 1869 ppb in fall 2019 to 1918 ppb in winter 2023, with maximum levels peaking at 1944 ppb in fall 2022. Torbali exhibited a similar pattern, where mean values rise from 1873 ppb in fall 2019 to 1916 ppb in summer 2023, and maximum concentrations reached 1939 ppb. Odemis consistently recorded the highest $CH_4$ levels among the three districts mean concentrations reached 1917 ppb in winter 2023, while peaked at 1925 ppb in fall 2022.

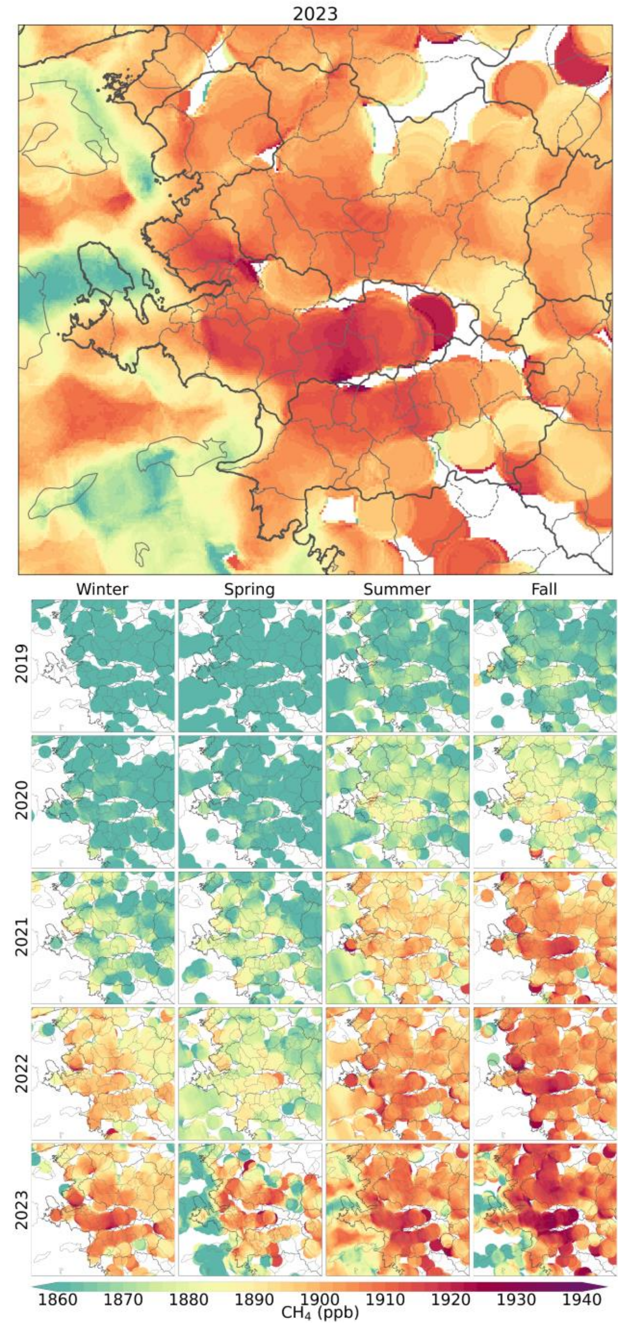


Figure 4. 2023 Annual (top) and 2019-2023 seasonal (bottom) average TROPOMI (ppb) $CH_4$ levels over the study area.

These increases indicated that much like $NH_3$ levels, can be attributed to several factors, including the expansion of intensive livestock production, increased land application of organic waste, and potential shortcomings in digestate management practices within biogas facilities.

In recent years, and particularly in 2023, both $CH_4$ and $NH_3$ reached their highest recorded levels. The seasonal and annual spatial distributions of these species clearly revealed a hotspot (Figure 3, Figure 4) located in the inland basin region surrounding by the Bozdag Mountains (Figure 2). While gaps in satellite retrievals limited the visibility of $CH_4$ trends before 2021, a strong increase has been consistently observed in the subsequent years. In contrast, $NH_3$ levels showed a more continuous and pronounced rise throughout the last five years, reflecting the cumulative effects of livestock farming, organic waste management, and biogas-related activities.

A closer examination of this hotspot area further highlighted the spatial match among elevated $NH_3$ concentrations, intensive livestock, and biogas facilities (Figure 3).

In addition to Odemis and Tire, neighboring districts located in close proximity to biogas facilities, such as Bayindir, Kiraz, and Beydag (Figure **5**), also showed similar seasonal increasing patterns. These districts showed increasing $NH_3$ and $CH_4$ concentrations particularly during the summer months.

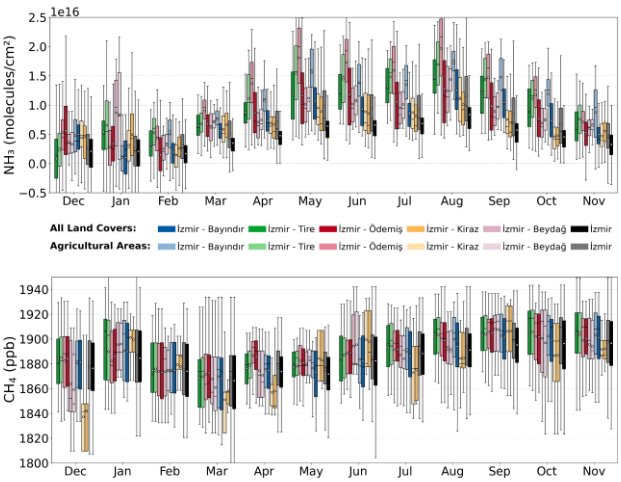


Figure 5. Monthly distributions of $NH_3$ (molecules/cm$^2$, top) and $CH_4$ (ppb, bottom) in some Izmir districts (2019–2023).

Both $NH_3$ and $CH_4$ levels were found to be particularly high in this inland basin not only due to intensive livestock and biogas activities, but also may influenced by the topography and prevailing meteorological conditions. The highest concentrations were generally observed during the summer and fall seasons. This pattern was particularly evident in the recent years, when seasonal mean temperatures in Izmir often remained above 25 °C.

temperatures and higher precipitation may be associated with reduced concentrations. These patterns suggested that meteorological conditions, such as temperature influence the seasonal variability of $NH_3$ in the region, with agricultural areas showing consistently higher values than urban zones.

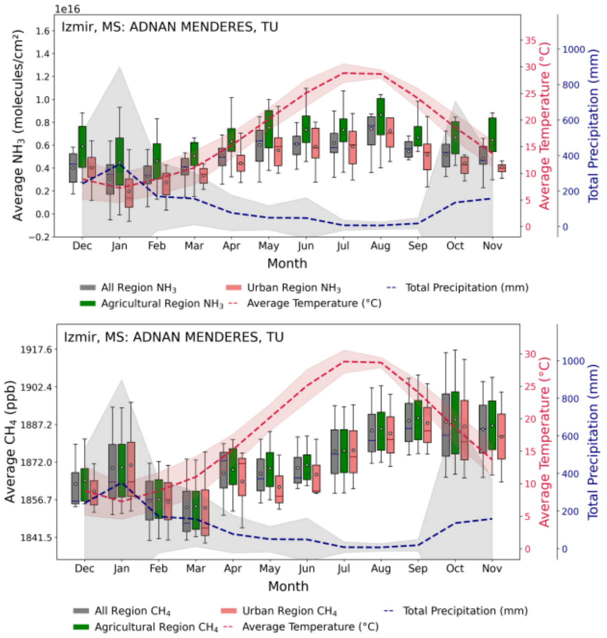


Figure 6. Monthly variations of $NH_3$ (top) and $CH_4$ (bottom) concentrations across agricultural, urban, and all regions, compared with average temperature (°C) and total precipitation (mm) from the nearest meteorological station (Adnan Menderes, Izmir) during 2019–2023.

Seasonal changes in $CH_4$ were closely related to weather conditions. Concentrations became higher in summer and fall, when temperatures are high and rainfall is low (Figure 6). This suggested that warm and dry conditions lead to more emissions from livestock waste and biogas activities.

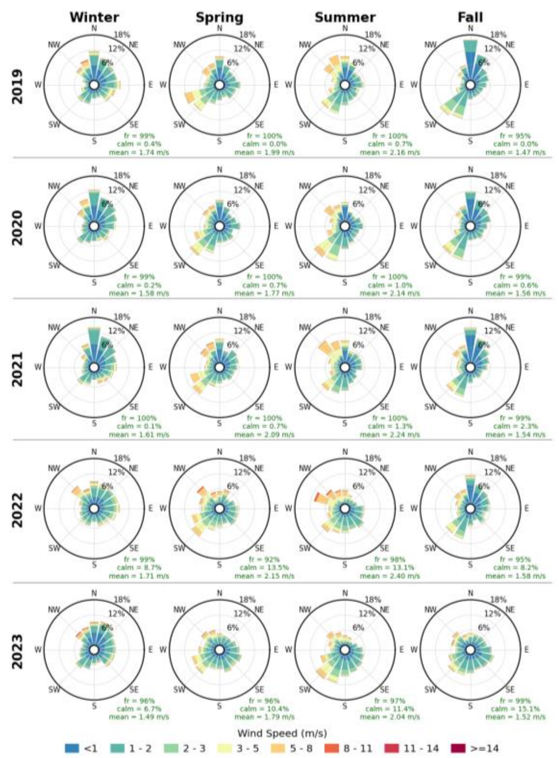


Figure 7. Seasonal wind rose plots from the Odemiş meteorological station (2019–2023).

As temperatures rise, $NH_3$ emissions from manure and agricultural waste tend to increase. Higher temperatures cause the conversion of ammonium ($NH_4^+$) in soils and waste into gaseous $NH_3$, thereby elevating atmospheric concentrations (Kuttippurath et al.,2020; Shen et al., 2011). The seasonal distribution of $NH_3$ concentrations aligned with temperature and precipitation patterns observed at the nearest NOAA meteorological station (Figure 6). $NH_3$ levels were generally higher during summer and early fall, coinciding with periods of elevated temperatures and relatively low rainfall, while winter months with lower

Analysis of the wind rose data from the Odemis meteorological station (MS), the closest station to the nearby biogas facilities, for the period 2019–2023 showed that the dominant wind directions were primarily from the southwest (SW) and northwest (NW), particularly during the summer and fall seasons (Figure 7). When winds come from the south or west, the basin topography around the Bozdag Mountains may limit how far air can move. Instead of spreading out, pollutants can stay in the basin, causing elevated concentrations of $NH_3$ and $CH_4$.

To better understand the local changes, we analyzed $NH_3$ concentrations within a 12 km radius of three biogas and biomass plants in Izmir the ARF Odemis Biogas Plant (B67), the Odemis Biomass Plant (B64), and the Tire Biogas Power Plant (B68). The analysis covers the period since 2012, which provides a baseline for comparison. The Odemis Biogas (B67) and Tire Biogas (B68) plants started operation in 2019, while the Odemis Biomass Plant (B64) began operating in 2022. The results showed that $NH_3$ concentrations around the Odemis and Tire plants increased after 2019, and stayed high in the following years. Around the Odemis Biomass Plant, a rise has been visible since 2022, matching the start of its operation.

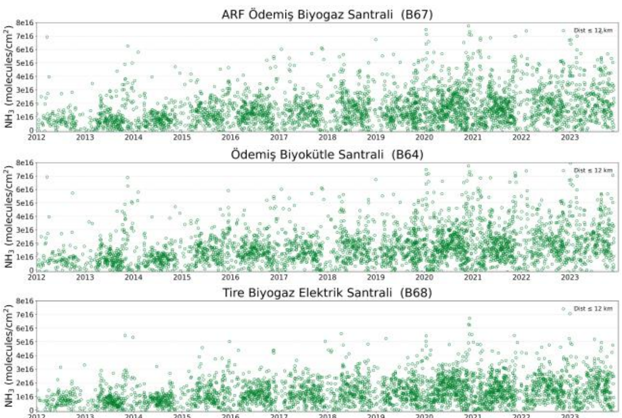


Figure 8. Temporal variation of $NH_3$ concentrations (molecules/cm²) around selected biogas plants in Izmir between 2012 and 2023.

While B67 showed a clear increase in $NH_3$ concentrations after 2019, a similar pattern was also visible around B64, even though it only received its biogas production license in 2022. This is likely due to the 12 km observation radius, which caused the data from these two neighboring plants to overlap. Still, no distinct additional rise was observed at B64 after 2022, as the overall trend continues similarly. In contrast, B68 showed moderate increases in $NH_3$ levels after 2019, indicating that even smaller facilities contribute to the regional rise in concentrations. Livestock farming and agriculture remain the main sources in the region, but the increases around these areas suggested that biogas and biomass plants may also contribute to higher $NH_3$ concentrations nearby.

To assess the changes between years and the potential contribution of biogas facilities, $NH_3$ and $CH_4$ levels were also examined within 6 km and 9 km radius of the plants. These ranges were selected to examine whether the observed increase occurred near the sites or also at extended further distances while taking into account the resolution limits of satellite observations as well. At the B64 facility, the highest $NH_3$ concentration was recorded in January 2023 within the 0–6 km distance, reaching $5.25 \times 10^{16}$ molecules/cm². This was followed by high mean values in November 2021 ($4.48 \times 10^{16}$ molecules/cm²) and February 2021 ($4.07 \times 10^{16}$ molecules/cm²). During 2022, concentrations mostly remained in the range of $1.8–3.0 \times 10^{16}$ molecules/cm², whereas in 2023, increases were observed, particularly in January, February, August, and September. These results indicate a clear upward trend in $NH_3$ levels in 2023 compared to 2022.

$CH_4$ levels were also investigated around three selected biogas sites using monthly distributions for the study years and evaluated across 6 km, 9 km, and 12 km spatial ranges. The analysis showed a clear increasing trend along with a seasonal pattern in $CH_4$ concentrations at all three sites. For B64, average concentrations increased from about 1864 ppb in 2019 to 1912 ppb in 2023, corresponding to an overall rise of nearly 50 ppb across all spatial ranges. At this site, the monthly maximum levels exceeded 1920 ppb after 2022 and continued to increase toward 1930 ppb by 2023. Similarly, at B67, average concentrations increase from approximately 1860 ppb in 2019 to 1921-1923 ppb in 2023, representing an increase of about 60 ppb across all spatial ranges. At B68 also showed a similar trend with average levels increasing from 1863-1864 ppb in 2019 to 1921-1924 ppb in 2023.

## 4. Conclusions

This study demonstrated that atmospheric $NH_3$ and $CH_4$ concentrations in Izmir have significantly increased in recent years, with 2023 showing the highest levels recorded. Concentrations were highest in summer and fall, especially in the inland basin around the Bozdağ Mountains. Within 12 km of the studied plants (B64, B67, B68), increases in $NH_3$ can be seen, but overlap between nearby facilities makes it hard to quantify exactly how much each one contributed. Livestock farming and agricultural waste are still the main sources, but biogas and biomass plants may also increase local $NH_3$ and $CH_4$ pollution. More detailed studies are needed to confirm these effects and to support future assessments.

Overall, the spatiotemporal assessment of $NH_3$ and $CH_4$ levels around biogas facilities indicated that these plants may contribute to local and regional atmospheric variability. The examination of $NH_3$ revealed distinct increases in 2023 compared to 2022, particularly within the 0–6 km range at the B64 site, where concentrations reached their highest levels. Similarly, $CH_4$ analyses around three representative sites (B64, B67, and B68) showed a consistent upward trend of approximately 50–60 ppb between 2019 and 2023, with maximum values steadily rising beyond 1920 ppb after 2022.

## Acknowledgements

This study was supported by the Scientific and Technological Research Council of Turkey under the grant number 123Y364. IASI is a joint mission of EUMETSAT and the Centre National d'Etudes Spatiales (CNES, France). We acknowledge the AERIS data infrastructure for providing access to the IASI data in this study (https://iasi.aeris-data.fr/nh3/).

## References

AERIS, 2025. IASI $NH_3$ data. https://iasi.aeris-data.fr/nh3/, (last accessed 17.05.25).

EMEP/EEA, 2025. EMEP 5.B.2 Biological Treatment of Waste Guidebook, https://www.eea.europa.eu/publications/emep-eea-guidebook-2023/part-b-sectoral-guidance-chapters/5-waste/5-b-biological-treatment-of-waste-2023/ (last accessed 18.05.2025).
Enerji Atlas, 2025. Biogas power plants. Republic of Türkiye Ministry of Energy and Natural Resources. https://www.enerjiatlasi.com/biogaz/ , (last accessed 17.05.25).

GES DISC, 2025. TROPOMI $SO_2$, $NO_2$, HCHO, $CH_4$ Satellite Retrievals. https://disc.gsfc.nasa.gov/, (last accessed 17.05.25).

IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories – Volume 4: Agriculture, Forestry and Other Land Use, Chapter 10: Emissions from Livestock and Manure Management. Intergovernmental Panel on Climate Change (IPCC), https://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html (last accessed 18.05.2025).

Kumbur, H., Özer, Z., Özsoy, H. D., & Avcı, E. D. (2015). A comparison of the potential and environmental impacts of conventional and renewable energy sources in Türkiye. 3rd Renewable Energy Symposium, October 19–21, Mersin, Türkiye.

MoEUCC, 2025. Wind Speed and Direction, Temperature, and Relative Humidity Meteorological Parameter Data. https://www.mgm.gov.tr/eng/forecast-5days.aspx, (last accessed 17.05.25).
Kuttippurath, J., Singh, A., Dash, S. P., Varikoden, H., et al. (2020). Record high levels of atmospheric ammonia over India: Spatial and temporal analyses. Science of the Total Environment, 740, 140023. https://doi.org/10.1016/j.scitotenv.2020.140023

Shen, J., Liu, X., Zhang, Y., Zhang, F., et al. (2011). Atmospheric ammonia and particulate ammonium from agricultural sources in the North China Plain. Atmospheric Environment, 45(29), 5033–5041. https://doi.org/10.1016/j.atmosenv.2011.02.031

Sommer, S. G., & Hutchings, N. J. (2001). Ammonia emission from field applied manure and its reduction—invited paper. *European Journal of Agronomy*, 15(1), 1–15. https://doi.org/10.1016/S1161-0301(01)00112-5

TURKSTAT, 2025. District Base Livestock, Poultry and Crop Production Statistics, https://data.tuik.gov.tr/Kategori/GetKategori?p=tarim111&dil=1, (last accessed 12.05.25).