Available online at: https://jtos.polban.ac.id/index.php/jtospolban
Journal of Tourism Sustainability
Volume 5 No 4, 2025: 243-255
DOI: 10.35313/jtospolban.v5i4.180

Evaluation of Air Pollution in Terms of Sustainability: The Example Case of İzmir Carbon Footprint

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Abstract
Air pollution is a global problem and significantly impacts every country. Therefore, this study aims to assess the future state of air pollution in Izmir. One of the key innovations of our study is demonstrating how PM (particulate matter) levels specifically influence tourists' destination choices. This study utilizes quantitative data analysis and preprocessing using the Pandas and NumPy libraries. The research methodology is based on data collected from the National Air Quality Monitoring Network. We evaluated the number of ships arriving at Izmir's port from 2008 to 2024 and created maps to visualize changes, including those during the COVID-19 period. Based on our findings, it can be concluded that annual CO (carbon monoxide) and NOX (nitrogen oxide) levels in Izmir are high and are significantly higher in industrial areas than in rural areas. The scenario analysis conducted in this research indicates that if air pollution continues to increase by 15%, air travel will be more severely affected than sea travel. Implementing effective waste management strategies in port cities is believed to benefit both the environment and public health. Practical implications: Key actions to combat air pollution include encouraging local travel habits, increasing the appeal of green transportation options, and raising environmental awareness. Green travel supports a more sustainable transportation system by reducing residents' environmental impact. In the future, informing travelers about ecological damage could lead to changes in travel behavior.

Keywords: Carbon Footprint, Air Quality In Tourism, Turkey Air Quality

INTRODUCTION

Air pollution is a major global health risk factor that not only poses a serious challenge to human health and well-being but also hinders economic development (The Ministry of Health of Türkiye, 2022). The prediction of air quality has emerged as a crucial agenda, particularly given its significant social implications, especially in developing nations (Liang et al., 2023). An estimated 6.7 million individuals have died as a result of exposure to environmental and household air pollution (World Health Organization, 2025), which is believed to adversely affect human health (World Health Organization, 2021). Understanding the effects of air pollution on tourism is essential for promoting sustainable tourism development. Air pollution can pose a significant risk for travelers, influencing their decisions and potentially leading to a decline in tourism revenue for various countries (Xiao et al., 2024). Air quality is a crucial factor in travelers' destination selection. A review of push and pull factors revealed that the ambiance of a tourist location is a key factor in attracting visitors. Additionally, it has been established that environmental elements have a greater impact than other factors, such as attractions and infrastructure (Lise & Tol, 2002).

Tourism, a sector sensitive to environmental changes, can be significantly impacted by haze pollution over time. The long-term effects of significant haze pollution can influence individuals' willingness to travel in two conflicting ways. Firstly, the serious health risks associated with haze pollution can drive people away from areas where it is prevalent. Haze is composed of harmful fine particles that may lead to severe health issues, including respiratory problems and cardiovascular and cerebrovascular disorders. Concerns about health and the desire for clean air motivate individuals to flee from contaminated regions.

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Conversely, haze pollution can diminish the quality of the tourism experience and shorten tourists' stays. In tourist destinations, haze pollution leads to adverse outcomes, including health risks, reduced visibility, and emotional distress. The decline in the quality of the desired tourism experience undermines individuals' enthusiasm for travel (Sun et al., 2019).

Jean-Baptiste Fourier introduced the concept of the carbon footprint in the 19th century, and Svante Arrhenius' research by the century's end further supported it, outlining the connection between CO_2 and temperature. The rise in fossil fuel use after the Industrial Revolution increased global temperatures and contributed to climate change, leading to regional variations. In 1979, CO_2 emissions from fossil fuels were identified as the most significant environmental threat and have continued to rise since then (Republic of Turkey Ministry of Environment, 2025). Sustainable tourism in Türkiye involves developing tourism activities that protect and use environmental, social, and cultural assets. The primary reason for measuring tourism sustainability is that the data produced enables better management of both the industry and its destinations (Miller and Torres-Delgado, 2023). The paper questions why we need to understand air pollution in sustainable tourism, the risk of becoming overly focused on the future, and the danger of losing sight of what is really important to sustainability. While various studies exist across Turkey, studies on the Aegean Region are quite limited. Since no study addresses the air pollution burden in İzmir, the largest province in the Aegean Region, given its location within the touristic region, the situation in İzmir will be analyzed using the existing literature.

LITERATURE REVIEW

The overall greenhouse gas emissions produced by an individual, institution, activity, or product are referred to as the 'carbon footprint'. The carbon footprint is a measure of the environmental harm caused by human activities, such as transportation, heating, energy use, and the purchase of goods, expressed as total greenhouse gas emissions quantified in units of carbon dioxide (Republic of Turkey Ministry of Environment, 2025). Carbon is an essential element in maintaining Earth's temperature balance and is closely connected to ecosystems. The carbon cycle describes the movement of carbon between the atmosphere, land, oceans, and living organisms. Through photosynthesis, plants transform carbon dioxide into biomass, thereby removing carbon from the atmosphere. However, climate change can influence plant growth. Increasing the number of plants helps absorb carbon from the atmosphere and reduces temperatures, but excessive heat can hinder plant growth and elevate carbon emissions, potentially raising temperatures (NASA, 2025). The Kyoto Protocol identifies greenhouse gases as Carbon Dioxide (CO_2), Methane (CH_4), Nitrous Oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs), Nitrogen Trifluoride (NF_3), and Sulfur Hexafluoride (SF_6). The aggregate emission of these gases is referred to as greenhouse gas emissions.

The Intergovernmental Panel on Climate Change (IPCC) indicates that the most responsible gases for climate change are Carbon Dioxide and Methane. According to the IPCC, human-caused greenhouse gas emissions rose significantly during the Industrial Revolution, which began around 1750. The levels of carbon dioxide in the atmosphere have exceeded critical thresholds, driven by industrial development. Crossing the 350-ppm threshold in 1988, reaching 400 ppm in 2014, and attaining a CO_2 concentration of 413.2 ppm in 2020 have all fueled the rapid increase in global temperatures. Studies indicate that this concentration was last observed 4.5 million years ago, when global temperatures were 3-4°C higher than today and sea levels were 5-40 meters higher (Ministry of Culture and Tourism, 2022).

Based on the Air Quality Index (AQI), the countries with the poorest air quality are Bangladesh (79.9), Pakistan (73.7), and India (54.4). Conversely, the nations with the best air quality are French Polynesia (3.2), Mauritius (3.5), and Iceland (4). Turkey is positioned 44th on this list, with an average air quality score of 68. The air quality in Turkey was measured at 21.9 in 2018, 20.6 in 2019, 18.7 in 2020, 20 in 2021, 21.1 in 2022, and 20.3 in 2023. In Turkey, inhaling polluted air can lead to health issues, particularly from fine particles such as PM2.5. Elevated pollution levels can lead to severe health conditions, including respiratory illnesses, heart disease, strokes, and lung cancer. Pregnant women are especially at risk, facing potential complications such as low birth weight, premature labor, and higher rates of infant mortality when exposed to high levels of pollution. The accumulation of PM10 and PM2.5 in the body can cause organ damage and harm blood vessels. The primary causes of air pollution in Turkey include nitrogen dioxide (NO2) and sulfur dioxide (SO2) emitted from vehicles, carbon monoxide (CO) from burning organic materials, and fine silica dust from construction. Additionally, microplastics and toxic metals like mercury, lead, and cadmium are significant pollutants. These contaminants not only pose risks to human health but also adversely affect the environment, ecosystems, and climate (IQ Air, 2025).

Motor vehicles are recognized for emitting CO and NO2. It is believed that people prefer private cars to public transportation. Therefore, individuals should be motivated to choose public transit options.

Furthermore, exposure to carbon monoxide can lead to carbon monoxide poisoning in humans (which interferes with the binding of oxygen to hemoglobin), as well as chest pain, heart problems, reduced cognitive function, visual issues, and contributes to smog formation. NO2 is emitted into the atmosphere by car exhaust, electricity generation, fuel combustion, and various industrial activities.

Additionally, it is generated by the combustion of materials such as coal. This emission rate is thought to be influenced by the amount of coal burned during winter. Soil ozone disrupts plant respiratory processes, making them more susceptible to environmental stress. Breathing in ozone results in diminished lung capacity, airway inflammation, and irritation of the eyes, nose, and throat (Prana Air, 2025). Moreover, to safeguard the ozone layer and lead an eco-friendly lifestyle, products containing harmful chemicals such as chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) should be avoided, and "ozone-friendly" and energy-efficient alternatives should be used instead. Cooling appliances like refrigerators and air conditioners should be used thoughtfully and maintained regularly; qualified professionals should dispose of outdated units in an environmentally safe manner. Thermostat settings should not be adjusted to unnecessarily low temperatures, and devices that are not in use should be turned off to conserve energy. Additionally, the placement and maintenance of devices are crucial for energy efficiency. Other potential sources, such as automotive air conditioners and packaging materials, should also be carefully selected, avoiding substances that harm the ozone layer (Republic of Turkey Ministry of Environment, Urbanization and Climate Change, 2025b).

Tourists from China place considerable emphasis on weather conditions for their travel and overall holiday enjoyment. Favorable weather not only makes transportation easier, but it also enhances the enjoyment of popular activities like photography. Research shows that at least 90% of tourists believe their positive holiday experiences are due to favorable weather. They report that on inclement-weather days, such as cloudy or rainy days, the options for sights and photography are significantly reduced. This clearly illustrates how the weather affects tourism and influences holiday choices among travelers (Wu et al., 2018). In Thailand, air pollution from PM remains an issue affecting tourism numbers; thus, it is suggested that the agricultural sector and other industries that contribute to air pollution focus on reducing pollution by limiting practices such as waste burning, industrial production, and agricultural burning. Such measures not only promote environmental sustainability but also influence tourist arrivals (Nonthapot et al., 2024).

Furthermore, research by (Wang & Chen, 2020) indicates that air quality, as measured by PM2.5 concentrations, negatively affects both inbound and domestic tourist numbers. This suggests that rising levels of PM2.5 have led to a decline in tourist arrivals. (Ulutaş et al., 2021) examined air quality in Ankara across seasons and found that the highest CO/NOX and SO/NOX ratios occurred in winter.

Air Population Parameters

Parameters affecting air quality are various. The Air Quality Index (AQI) categorizes air pollution levels into the following ranges: 0–50 (Good), 51–100 (Moderate), 101–150 (Unhealthy for Sensitive Groups), 151–200 (Unhealthy), 201–300 (Very Unhealthy), and 301–500 (Hazardous) (Republic of Turkey Ministry of Environment, 2025b). Particulate Matter (PM10) refers to particles with aerodynamic diameters less than 10 µm. These airborne particles are composed of complex mixtures. Particulate matter originates from both natural and human-made activities. Significant sources include factories, energy generation plants, combustion processes, construction work, wildfires, and wind. Once released into the environment, these particles can exacerbate air pollution and harm human health (Republic of Turkey Ministry of Environment, 2025a; Cengiz, 2023). PM can generally infiltrate deeply into the lungs and make its way into the bloodstream, leading to cardiovascular (ischemic heart disease), cerebrovascular (stroke), and respiratory issues. Both short-term and long-term exposure to particulate matter is linked to increased morbidity and mortality from cardiovascular and respiratory conditions. (World Health Organization, 2025a).

Particulate Matter (PM2.5) consists of particles that have an aerodynamic diameter of less than 2.5 µm and are made up of various complex mixtures suspended in the atmosphere. These particles are generated from both natural phenomena and human activities. Major sources of PM2.5 include industrial facilities, power plants, waste incineration, construction work, wildfires, and wind-blown dust. PM2.5 is a significant indicator of environmental air pollution, with its European Environment Information and Observation Network (EIONET) code 6001, and is measured in $\mu g/m^3$ (Republic of Turkey Ministry of Environment, 2025a). Research has shown that PM2.5 can have adverse effects on Chronic Obstructive Pulmonary Disease (COPD) and can impair lung function (Wang & Liu, 2023).

Sulfur dioxide (SO2) primarily originates from the combustion of oils, coal, and lignite, all of which have high sulfur content. Additionally, the melting of materials such as bronze, which contains significant sulfur, contributes to the emission of this gas. SO2 is a prevalent pollutant, particularly in regions with heating, industrial operations, and higher traffic volumes. When this gas is released into the environment, it can adversely impact air quality and pose serious risks to human health (Republic of Turkey Ministry of Environment, 2025a; Environmental Impact Assessment, 2023). Exposure to sulfur dioxide can result in health issues such as narrowing of the airways, breathing difficulties, and heart and lung diseases. To mitigate these harmful effects, proper ventilation systems should be installed in buildings, industrial activities should be located away from residential neighborhoods, central heating systems should be promoted, and unleaded fuel options should be preferred in vehicles (Cengiz, 2023).

Carbon monoxide (CO) is an invisible, odorless, and tasteless gas generated by the incomplete burning of carbon-containing fuels. As a major air pollutant, carbon monoxide (CO) forms in place of carbon dioxide (CO2) when combustion is incomplete due to insufficient factors, such as a lack of oxygen, low ignition temperature, gas retention at higher temperatures, or turbulence in the combustion chamber. This gas, identified by the EİONET code of 10, is measured in mg/m^3 (Republic of Turkey Ministry of Environment, Urbanization and Climate Change, 2025a). When inhaled, CO enters the bloodstream via the lungs and attaches to hemoglobin, impairing its capacity to transport oxygen. Consequently, this results in a decrease in blood oxygen levels, which can lead to respiratory disorders, poisoning, headaches, and damage to essential organs such as the brain and heart. Prolonged exposure can lead to significant health risks. (Cengiz, 2023).

Nitrogen dioxide (NO2) is the nitrogen oxide that poses the greatest risk to human health and is a significant air pollutant in urban settings. This pollutant is generated by vehicular traffic, heating systems, and industrial activities, adversely impacting air quality and harming the environment. Its EİONET identifier is 8, and it is measured in $\mu g/m^3$ (Republic of Turkey Ministry of Environment, 2025a). NO2 can enter the body through breathing and is particularly hazardous for individuals with asthma. Even at low levels, it can provoke health issues in these vulnerable groups. Health effects linked to NO2 exposure include irritation of the eyes, nose, and throat, bronchitis, headaches, lung infections, and potentially lung cancer after significant exposure (Cengiz, 2023).

Nitrogen oxides (NOx) are significant air pollutants in urban regions that can negatively impact human health. This pollutant is generated by vehicle emissions, heating, and industrial activities, thereby deteriorating air quality. The unit of measurement for nitrogen oxides, identified with an EİONET code of 9, is expressed in $\mu g/m^3$ (Republic of Turkey Ministry of Environment, 2025a). NOx components primarily enter the atmosphere through the burning of fossil fuels, natural wildfires, and various modes of transportation (Air, sea, and land), which account for 50% of total emissions, as well as from industrial processes, particularly fossil-fuel-based energy plants, especially thermal power stations. In enclosed spaces, sources of NOx emissions include cigarette smoke, aerosol sprays, and the combustion of fossil fuels. In the atmosphere, NOx components exhibit acidic properties and can lead to the formation of acidic precipitation, which may have detrimental effects on ecosystems and result in environmental and structural damage (Cengiz, 2023).

Nobelium (NO) is a radioactive, toxic metal. It is produced by bombarding curium with carbon in a cyclotron (Periodic Table, 2025). Ozone (O3) pollution does not enter the atmosphere directly; instead, it is created through intricate chemical reactions between nitrogen oxides and volatile organic compounds in the presence of sunlight. Consequently, nitrogen oxides and volatile organic pollutants are identified as precursors to ozone. The primary sources of these pollutants include traffic, solvent use, and industrial operations, which indirectly contribute to ground-level ozone pollution. Ozone, classified with the EIONET code 7, is measured in micrograms per cubic meter ($\mu g/m^3$) (Republic of Turkey Ministry of Environment, 2025).

Nevertheless, rising levels of ozone near Earth's surface can negatively impact human health (Environmental Impact Assessment, 2023). The depletion of the ozone layer may increase ultraviolet radiation, heightening the risk of skin cancer and eye disorders. Significant sources of ozone include motor vehicles, thermal power stations, refineries, chemical manufacturing plants, and volatile substances such as perfumes. Moreover, ozone concentrations tend to spike during the summer months, on sunny days, and when temperatures rise. Increased ozone levels in the atmosphere near Earth's surface can cause lung damage when inhaled (Cengiz, 2023).

Carbon footprint in tourism

As air pollution has become a significant issue, tourism officials and policymakers must establish and enforce more rigorous environmental regulations to manage it and mitigate its adverse effects on tourism. Implementing such measures will be essential for ensuring the long-term viability of tourism (Wang et al. 2020:444). Governments, non-governmental organizations, and other stakeholders can collaborate to reduce pollution and alleviate various environmental pressures. This partnership is vital to minimizing environmental impacts and achieving sustainable development objectives. Creative solutions can enhance environmental sustainability and help decrease carbon footprints. Ultimately, diversifying a nation's energy sources will accelerate decarbonization by reducing excessive reliance on fossil fuels. These approaches can initiate the transformative changes necessary to fulfill environmental targets (Agyeman et al., 2022:19).

To reduce the global carbon footprint, conscious actions such as using renewable energy sources, minimizing waste, conserving water, and adopting environmentally friendly habits — such as choosing public transportation or walking instead of driving — can increase biodiversity. Furthermore, supporting the planting of local vegetation and protecting natural ecosystems can increase biodiversity. Consumption can be reduced by using resources such as energy, food, and water more efficiently (Olivadese and Dindo, 2023). However, as travel trends increase, the direct and indirect carbon footprint increases, which can affect tourism products and services (Filimonaua et al., 2013). In this context, to understand the current situation, the first hypothesis of the research was formulated as follows: "H1: There is no significant relationship between air pollutants and tourism indicators." Subsequently, in response to the interannual increase, the second hypothesis was formulated as "H2: Increasing air pollution has no negative impact on tourism performance indicators." Kitamura et al. (2020) decompose the carbon footprint by life cycle stage, revealing the contribution of each stage to the overall impact. Their results show that transportation accounts for 56.3% of the carbon footprint, while air transportation accounts for 24.7%. Accordingly, the relevant hypothesis regarding how this situation may increase in the future is as follows: "H3: Air pollution data is not a determining factor in future tourism performance."

METHODS

Research Approach

Urban areas are critical hubs for global communication, trade, and culture. Nonetheless, they are also major contributors to energy consumption and the rise in greenhouse gas (GHG) emissions. A city's effective response to climate change and its ability to monitor progress heavily rely on the availability of quality data. GHG emissions from urban activities fall into six primary categories: stationary energy; transportation; waste; industrial processes and product use (IPPU); agriculture, forestry, and other land use (AFOLU); and other emissions originating outside the city's geographic limits. The transportation sector can be divided into categories such as roads, railways, water transport, aviation, and off-road transport. These categories are the primary sources of GHG emissions in urban areas (Global Protocol for Community-Scale Greenhouse Gas Inventories, 2021). In this study, the air quality in Izmir, the city experiencing the most significant growth in industry, tourism, and natural occurrences in the Aegean region of Türkiye, was analyzed through a scenario assessment focused on air pollution.

Research Sampling Method and Data Collection

Data collection

Using a quantitative research method, this study collected and analysed data to make future predictions. Quantitative methods were used to identify trends, correlations, and changes over time based on measurable indicators (Creswell, 2014; Merriam, 2018). Relevant data were obtained from the website of the Ministry of Environment, Urbanization, and Climate Change of the Republic of Turkey; the port authorities in the city of İzmir (Aliağa, Çeşme, Dikili, and İzmir), and the Turkish Statistical Institute (TUİK). The analysis on pollutants based on annual data collected between 2008 and 2024 from official stations in İzmir (Aliağa, Aliağa, Bozköy, Alsancak İBB (Izmir Büyükşehir Belediyesi), Alsancak, İBB, Bayraklı, İBB, Bornova, Bornova, İBB, Çeşme, Çiğli, İBB, Eğitim, Gaziemir, Güzelyalı, İBB, Karabağlar, Karaburun, Karşıyaka, Ödemiş, Şirinyer, İBB, Torbalı, Yenifoça). In the analysis, pollution measurements covered annual average concentrations (in $\mu g/m^3$) of carbon monoxide (CO), nitrogen oxides (NO, NO_2, NO_x), ozone (O_3), particulate matter ($PM_{2.5}$, PM_{10}), and sulfur dioxide (SO_2). The tourism indicators include the number of ship passengers (ship pass), international air traffic (airway_t), and international air traffic (airway_f).

All variables were harmonized by annual averages ($\mu g/m^3$ for pollutants; number of passengers for tourism). Missing data were imputed using the forward-fill method to preserve temporal consistency. Implausible or extreme values (e.g., PM2.5 = 15,859 $\mu g/m^3$ in 2020) were flagged as outliers, and years 2020 and 2021 were excluded from the data modeling stage due to the global COVID-19 crisis. The data structure is shown in Table 1.

Table 1. Variables, Units, and Sources

Variable	Description	Unit	Source

$PM_{2.5}$, PM_{10}, SO_2, CO, NO, NO_2, NO_x, O_3	Annual mean air pollutant concentrations	μg/m³	Ministry of Environment / Air Quality Monitoring Network
airway_f	Total international flight departures	number	TÜİK / DHMİ
airway_t	Total international flight arrivals	number	TÜİK / DHMİ
ship pass	Total international ship passengers	number	İzmir Port Authority

Source: Research data, 2025

Data Processing

We analyzed the data using the pandas and NumPy libraries for preprocessing. To maintain temporal integrity, we addressed missing air pollution data using the forward-filling method (Hyndman and Athanasopoulos, 2018). We computed annual averages for air pollution variables and yearly totals for tourism indicators, aligning them with the reporting schedule. For correlation analysis and local-level forecasting, we organized the data by individual station. All data was then normalized using the standard scaler package.

Statistical tests were performed using hypothesis-testing software. First, Pearson Correlation: Using the Scikit-learning library, the binary relationships between tourism indicators and air pollution variables were analyzed using the Pearson correlation coefficient (r); the statistical significance of the relationships was assessed at $p < 0.05$ (Field, 2013). The Matplotlib library was used to visualize significant correlations at each station, and only variables with significant coefficients were included in subsequent model development.

Second, Model Selection: We designed a learning model using air pollution measurements as independent variables was applied to estimate tourism indicators (target variable) using the Scikit-learn library (Peng et al., 2021). The Random Forest Regressor (RFR) was chosen as the primary model due to its superior ability to capture nonlinear and multidimensional relationships without assuming a fixed data distribution—unlike linear regression or ARIMA, which are less effective with irregular temporal and multivariate data. The RFR model also provides feature importance scores, enabling the identification of which pollutants most strongly affect tourism indicators.

Third, Model Training Process: The dataset was split into 80% for training and 20% for testing, preserving chronological order. Model hyperparameters were optimized via grid search (e.g., number of trees = 100; maximum depth = auto; random_state = 42). Model performance was assessed using R^2, RMSE, and MAE, and validated with 10-fold cross-validation to minimize bias. (Chai and Draxler, 2014). Fourth, Pollution Growth Scenarios: Three hypothetical pollution growth scenarios—5%, 10%, and 15% annual increases—were simulated for five years using the validated RFR model. For each case, tourism performance indicators were projected, and trends were visualized to illustrate the sensitivity of tourism activity to air quality degradation.

RESULTS AND DISCUSSION

In the station group in the data set obtained from the National Air Quality Monitoring Network, Aliağa Bozköy, Aliağa, Alsancak, Bayraklı IMM, Bornova IBB, Bornova, Çeşme, Çiğli IMM, Gaziemir IBB, Güzelyalı IBB, Karabağlar, Karaburun, Karşıyaka IBB, Karşıyaka, Kemalpaşa, Konak, Menemen, Ödemiş, Seferihisar, Şirinyer, Torbalı, and Yeni Foça districts of İzmir province were examined on a district basis, and averages were taken. Selecting all districts, all monthly and daily data, and all measurement parameters (PM10/PM2.5/SO2/CO/NO2/NOX, NO/O3) yielded normalized values for the years 2008-2024 (Table 2).

Table 2. 2008-2024 Air Pollution and Tourism in Izmir (Standardised)

Year	CO (μg/m³)	NO (μg/m³)	NO2 (μg/m³)	NOx (g/m³)	O3 (μg/m³)	PM10 (μg/m³)	PM2.5 (μg/m³)	SO2 (μg/m³)	Airway f	Airway t	Ship pass
2008	3,93	2,48	3,22	3,54	3,56	4,37	3,6	3,02	1,33	1	3,16
2009	4,66	2,63	3,41	3,7	3,61	3,97	3,79	2,57	1,3	1,38	3,07
2010	4,69	2,63	3,41	3,7	3,61	3,94	3,7	2,52	1,58	2,02	3,43
2011	4,69	2,63	3,41	3,7	3,61	4	4,21	2,64	2,11	2,54	4,61
2012	3,82	2,63	3,41	3,7	3,61	3,88	3,68	2,2	2,06	2,96	5
2013	4,27	2,87	3,71	3,92	3,61	3,78	3,68	2,15	2,14	2,96	4,96
2014	4,37	2,58	3,3	3,54	3,61	3,69	3,68	2,18	2,3	3,77	3,27
2015	4,28	2,15	2,79	3,02	3,61	3,71	3,68	2,35	2,43	4,38	2,93
2016	4,17	2,55	3,34	3,55	3,61	3,72	3,68	2,37	1	4,32	1,38
2017	4,25	2,06	3,23	3,44	3,55	3,89	3,67	2,87	1,38	4,71	1,21
2018	4,78	1,27	3,11	3,23	3,83	3,84	3,6	2,92	2,11	5	1,1
2019	4,1	2,42	2,99	3,36	3,54	3,71	3,46	2,75	3,32	4,47	1,09
2022	4,38	2,26	3,21	3,5	3,62	3,91	3,66	2,8	4,39	3,2	1,1
2023	4,42	2,29	3,26	3,56	3,7	3,72	3,58	2,68	4,46	3,57	1

Year	CO ($\mu g/m^3$)	NO ($\mu g/m^3$)	NO2 ($\mu g/m^3$)	NOx (g/m^3)	O3 ($\mu g/m^3$)	PM10 ($\mu g/m^3$)	PM2.5 ($\mu g/m^3$)	SO2 ($\mu g/m^3$)	Airway f	Airway t	Ship pass
2024	2,18	1,81	2,1	2,58	1,92	2,85	0,44	1,66	5	4,04	2,02

Source: Research data, 2025

Between 2008 and 2024, significant air pollutant concentrations (CO, NO, NO_2, NOx, O_3, PM10, PM2.5, SO_2) remained largely stable with minor reductions in 2024, while tourism indicators responded asymmetrically, with air traffic peaking and ship passenger numbers steadily declining over the same period.

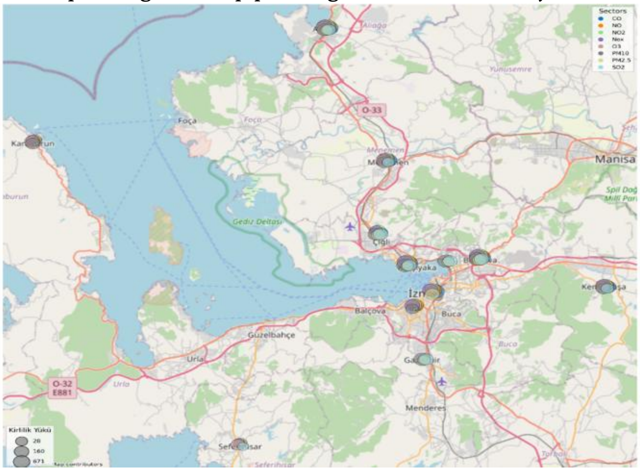

Figure 1. Pollution Load by Location (2008-2024)

Source: Research data, 2025

Pollution load statistics from 2008 to 2024 show that NO, NO2, NOx, O3, PM10, SO2, and CO levels were the highest. Based on pollution load, the smallest ring measures 28, the middle ring measures 160, and the most extensive ring measures 671 (Figure 1).

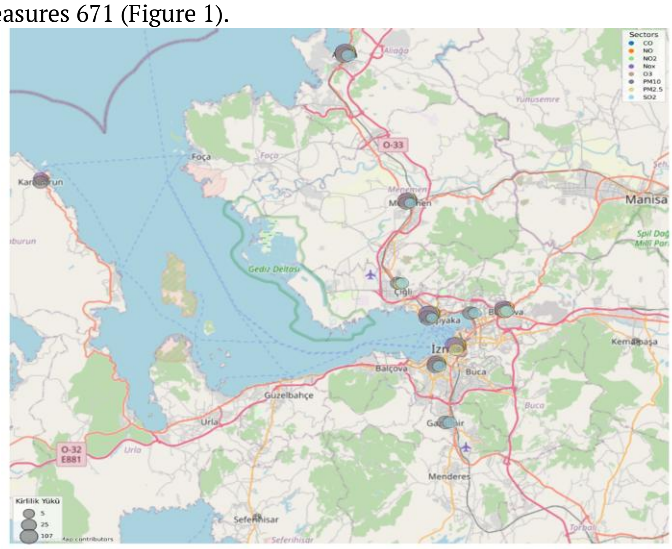

Figure 2. Pollution Load by Location (2021)

Source: Research data, 2025

According to 2021 findings, CO, NO, NO2, NOx, O3, PM10, PM2.5, and SO2 are elevated. Based on the pollution load, the smallest ring is 5, the middle ring is 25, and the largest ring is 107. (Zeydan, 2021) examined PM10 levels in Turkey at the provincial level. It was stated that Karşıyaka and Alsancak were among the cleanest stations in Izmir. It was noted that it exceeded the nationwide annual limit. However, in Figure 1, the 2008-2024 pollution load was observed in Izmir, Bornova, Torbalı, Seferihisar, and Menemen; during the COVID period, the pollution load decreased (Figure 2).

Figure 3 shows the results for the year 2024. Accordingly, CO, O3, NO2, NO, SO2, and PM2.5 are the highest among all. In the pollution load map, the smallest ring is 7, the middle ring is 27, and the largest ring is 77. Based on the map, it can be inferred that pollution levels are higher in the Bornova, Karşıyaka, Ödemiş, Kemalpaşa, and Aliağa districts.

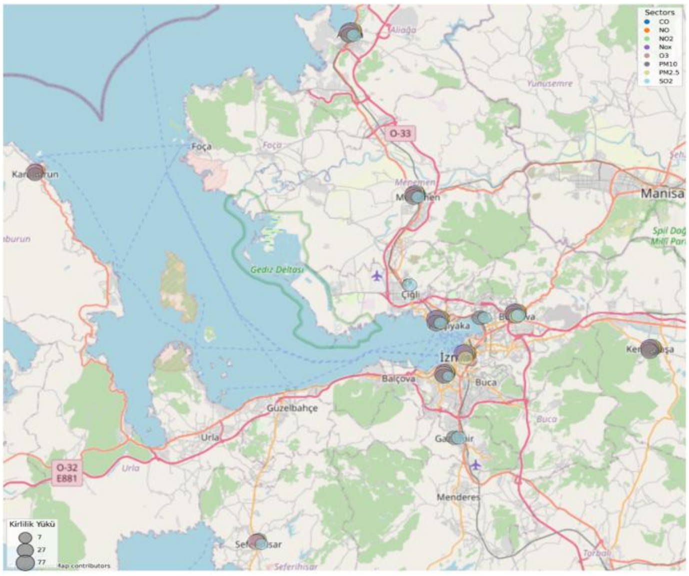

Figure 3. Pollution Load by Location (2024)

Source: Research data, 2025

According to the findings, the pollution load is volatile. There are notable variations in both years and locations. The reduction of pollution in industrial areas may be linked to the impact of COVID-19. Pollution levels increase over the years, particularly in urban areas.

Table 3. Variables and Correlation Coefficients for Data Modeling

Variable 1 (Unit)	Variable 2	r (Correlation Coefficient)	p-value	Significance
PM10 (μg/m³)	Airway_f	-0.627	0.0124	*
PM2.5 (μg/m³)	Airway_f	-0.589	0.0210	*
NO_2 (μg/m³)	Airway_f	-0.588	0.0211	*
NO (μg/m³)	Airway_t	-0.603	0.0173	*
PM10 (μg/m³)	Airway_t	-0.535	0.0399	*
NO (μg/m³)	Ship_pass	0.625	0.0127	*

Source: Research data, 2025

To evaluate the influence of air pollution on tourism indicators, Random Forest Regressor models were developed using pollutant variables that demonstrated significant correlations (Table 3): PM10, PM2.5, and NO2 for airway_f; NO for ship_pass; and NO and PM10 for airway_t. Model performance was assessed across three experimental scenarios, with the corresponding results presented below.

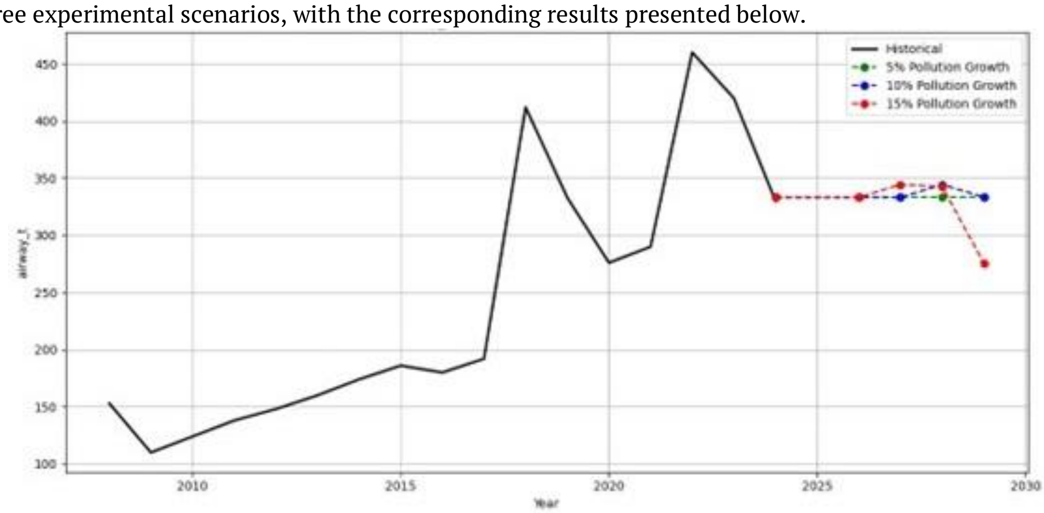

Figure 4. Estimates Of The Total Number Of Passengers Traveling By Air

Source: Research data, 2025

As shown in Figure 4, passenger traffic remains normal until 2030 when the pollution rate increases by 5%; however, it decreases significantly when the pollution rate increases by 15%. (MSE: 46.4737 and R^2 Score: 0.9226).

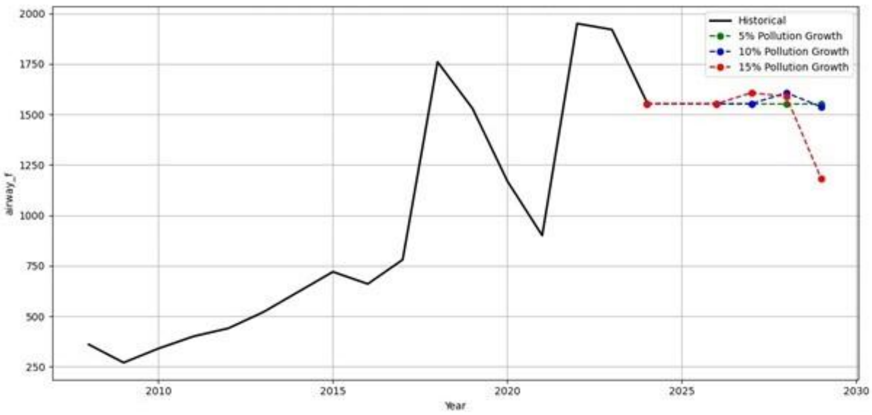

Figure 5. Estimates Of The Number Of International Passengers Traveling By Air

Source: Research data, 2025

In Figure 5, statistics for all international airline passengers were analyzed to develop a scenario of increased pollution. Accordingly, it can be said that passenger numbers will continue to follow the same trend as the pollution rate increases by 5% until 2030; however, passenger traffic will decrease when the pollution rate increases by 15%. (MSE: 39.2433 and R^2 Score: 0.8329).

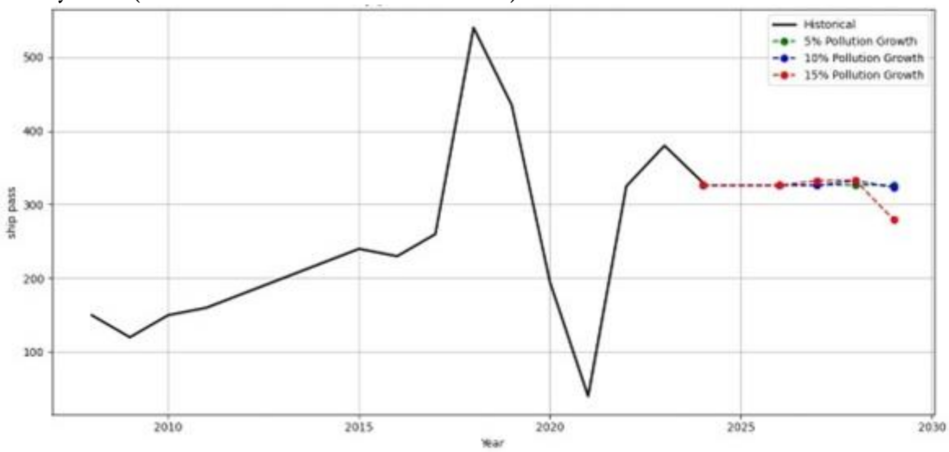

Figure 6. Estimates Of The Total Number Of Passengers Traveling By Ship

Source: Research data, 2025

When pollution rates are compared with ship passenger numbers, the 5% and 10% pollution increases are not significant, but the 15% increase is slightly significant (MSE: 1853.8074, R^2 Score: 0.1057). As for the hypotheses assessed in light of the data obtained, H1 and H3 were rejected, and H2 was partially supported. Although air pollution decreased in 2024 (Figure 3), in the scenario analyses conducted as of 2008 (Figure 4 and Figure 5), it is thought that if the situation worsens by 15%, air transportation will be affected rather than ship transportation. (Campos et al., 2022) found that using a car rather than a plane to the same destination results in lower CO2 emissions.

Discussion

Managing air quality with accuracy presents considerable difficulties. In many nations, the standard of corporate governance is a key factor in assessing environmental quality (Agyeman et al., 2022;3). The transportation sector is the most significant contributor to the carbon footprint, with air travel accounting for about 12% of tourism's overall emissions. Additionally, it accounts for 40% of total CO_2 emissions from tourism. Thus, it is essential to evaluate carbon emissions from air transportation within tourism, as this helps identify the primary sources of the carbon footprint and create effective strategies for reduction (Jiménez-Islas et al., 2025). (Ulutas et al., 2021) analyzed air quality across seasonal cycles in a study conducted specifically for Ankara. According to the findings, the highest CO/NOX and SO2/NOX ratios occurred in the winter months. According to Table 1, the highest values in İzmir were for CO and PM2.5.

Data from recent years suggests that Türkiye has seen slight improvements in overall pollution levels. While some cities saw better air quality in 2019 than the previous year, the situation worsened in other provinces. For example, Ankara decreased from 19.6 μg/m³ in 2018 to 18.4 μg/m³ in 2019, while Istanbul decreased from 21.7

μg/m³ to 19.9 μg/m³. However, pollution levels increased in cities such as Amasya and Giresun, with Amasya increasing from 34 μg/m³ in 2018 to 35.9 μg/m³ in 2019. This suggests that improvements in pollution levels are inconsistent across cities, and that cities with poor results should be improved first (IQ Air,2025). Karşıyaka, Bornova, Alsancak, Seferihisar, and Karaburun have the highest density; on the other hand, the density in Torbalı and Menemen is thought to be high due to being industrial areas. Karşıyaka, Bornova, Alsancak, Seferihisar, and Karaburun have the highest density; on the other hand, the density in Torbalı and Menemen is thought to be high due to being industrial areas.

Although Figure 3 indicates a decrease in air pollution in 2024, the scenario analyses (Figures 4 and 5) suggest that a 15% increase in pollution would have a greater impact on air transportation than on ship transportation. Encouraging green travel can reduce carbon emissions. Green travel directs people to travel in ways that have less impact on the environment, such as public transportation, walking, and cycling (Li et al., 2024). For this reason, it is thought that bicycle use can be encouraged by expanding bicycle infrastructure in Turkey's urban transportation system. Also, Policymakers can penalize businesses that cause air pollution through new regulations. Regulations can be implemented to filter and control air pollution from factories in industrial zones. Tourism operators can raise public awareness by advertising and encouraging green travel. Urban planners can specifically consider building industrial zones farther from the city.

Theoretical Implications

Aircraft engines emit pollutants like carbon dioxide, nitrogen oxides, and water vapor into the atmosphere, contributing to climate change and air pollution. Furthermore, aircraft can contribute to environmental issues, such as ozone depletion, by releasing pollutants at elevated altitudes. Emissions from ships due to fossil fuel consumption are carried by wind and other weather events and negatively affect the health of people living in coastal cities, especially port cities (Aygül & Baştuğ, 2020). Our research suggests that ships should be promoted as an eco-friendly alternative to planes for overseas package tours. Tourists should be encouraged to explore cruise tourism, and port cities should implement regulations to ensure that ships' waste is appropriately disposed of and take measures such as filtration to reduce environmental harm.

Tourism, the environment, and sustainable development are interconnected. Three main criteria can be used to define tourism carbon inventories: 1) production, 2) consumption, and 3) destination (Sun et al., 2020). A second limitation is that our model is conducted only on a per-destination basis. Future studies should consider each of these factors. Also, case studies of companies with effective management practices that lead to better environmental outcomes could include a discussion of regulatory frameworks that promote corporate responsibility for air quality. Significant levels of pollution worldwide result in approximately 30,000 annual deaths from air pollution-related illnesses, accounting for 8% of total fatalities (IQ Air, 2025). Many cities in Turkey experience serious air quality issues, but while pollution levels can peak at certain times of the year, some cities manage to maintain better air quality. Recently, air pollution has emerged as a pressing concern for Turkey.

Practical Implications

According to the research carried out by Malkoçoğlu (2024; 333-338), forests annually eliminate 5,014.68 kg of pollutant gases and particulate matter from the air, sequester 183,000 kilograms of carbon, and the trees within these forests store a cumulative total of 4,596,680 kg of carbon. The results highlight both the ecological and economic significance of urban forests, indicating that incorporating them into landscape and urban planning is vital to addressing the climate crisis, one of the 21st century's significant challenges. Consequently, it is believed that the ongoing urbanization in Izmir could pose substantial risks, particularly since it hosts an international port. It is suggested that regions with ports and airports should be equipped with substantial forests supported by government policies. Moreover, forest fires cause significant environmental damage. Fires increase air pollution from PM10, PM2.5, and nitrogen oxides. The negative impacts on air quality in this situation should be explained to citizens as additional information.

Limitations and further research

This prediction relies on various data sources, such as ground monitoring stations, weather satellites, and airways data. Although some regions have established numerous air quality monitoring stations and even installed interconnected street-level micro-monitoring stations, many areas still lack a comprehensive air quality monitoring system. This results in limited, sparse data in certain regions. In addition, the formation of air pollutants involves complex chemical processes that vary significantly in time and space (Zhang et al., 2024). However, in some years, the data is not consistent with the station and measurement parameters.

Therefore, this factor should be considered in future research. In recent years, more people have become interested in environmental protection and have begun to participate in related activities. Obviously, when residents believe that ecological and economic benefits can be achieved through green travel behavior, they are more willing to participate in it (Govindan, et al., 2022). For this reason, future studies can investigate the extent to which travel preferences may change after people who travel by plane are informed about the environmental damage caused by air travel. The data was analyzed for Izmir. However, future studies could explore all of Türkiye using panel data.

CONCLUSION

This study examined the relationship between air pollution and tourism performance in İzmir, Türkiye, with a focus on sustainability and the carbon footprint. The analysis, based on data from 2008 to 2024, revealed that air pollution—particularly concentrations of $PM_{2.5}$, NO_2, and CO—have a significant negative impact on air travel indicators. Conversely, maritime tourism was found to be less sensitive to fluctuations in pollution levels. The research showed that a 15% increase in air pollution leads to a marked decline in international air passenger numbers, while the effect on ship passengers remains relatively minor. These findings suggest that sustainable environmental management is not only vital for public health but also essential for the long-term viability of tourism, especially in urban and industrial port cities like İzmir.

Practical measures, such as promoting green transportation, expanding urban forests, strengthening industrial regulations, and increasing public awareness, are critical to reducing the city's carbon footprint. Furthermore, the development of comprehensive environmental policies that prioritize improvements in air quality can enhance the tourism sector's resilience to ecological threats. In conclusion, maintaining clean air and reducing greenhouse gas emissions are imperative for sustaining tourism development. Future research should expand this analysis to a national scale and consider behavioral responses from tourists once they are informed about the environmental consequences of their travel choices.

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