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NEXT Black Sea Basin

AirQuest

AIRQUEST
INTERNATIONAL SYMPOSIUM

CLEAN AIR FOR A SUSTAINABLE AND HEALTHY FUTURE

ABSTRACT BOOK

Zonguldak, Türkiye
27-29 April 2026


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AirQuest
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INTERNATIONAL
SYMPOSIUM:
Clean Air for a Sustainable and Healthy Future
27-29 April 2026 | Sezai Karakoç Cultural Center
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DISCLAIMER

Project Name: Know What You Breathe: Mobilizing Communities for Air Quality in the Black Sea Basin

Contact Person: Gökhan GÜRBÜZ (gokhan.gurbuz@beun.edu.tr)

The responsibility for the content of this book is that of the leading partner (ZBEU).

The content of this book does not necessarily represent the official position of the European Union.

Symposium Information

AirQuest International Symposium
Clean Air for a Sustainable and Healthy Future

Date
27–29 April 2026

Venue
Sezai Karakoç Cultural Center
Zonguldak Bülent Ecevit University
Zonguldak, Türkiye

Keynote Speakers
Dascalu ANDREI
Assoc. Prof. Dr. Nilüfer AYKAÇ
Prof. Dr. Sibel MENTEŞE
Prof. Dr. Ülkü Alver ŞAHİN
Prof. Dr. Inna KHOMENKO
Prof. Dr. Aliihsan ŞEKERTEKİN
Prof. Dr. Çiğdem ÇAĞLAYAN

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INTERNATIONAL SYMPOSIUM
CLEAN AIR FOR A SUSTAINABLE AND HEALTHY FUTURE
27–29 APRIL 2026
27 NİSAN – 29 NİSAN 2026
ZONGULDAK BÜLENT ECEVİT ÜNİVERSİTESİ
SEZAİ KARAKOÇ CULTURAL CENTER
FACE-TO-FACE + ONLINE
IN-PERSON + ONLINE
PARTICIPATION IS FREE
NO REGISTRATION FEE
DAY 1 • 27 APRIL 2026 – MONDAY
KEYNOTE PROGRAMME
13:30 – 14:00 Registration & Welcome Coffee
14:00 – 14:15 Opening Ceremony
KEYNOTE SESSION
14:15 – 14:45 Dascalu ANDREI Air Pollution Dynamics in the Black Sea Basin: Sources, Transport, Chemistry, and Meteorological Controls
14:45 – 15:15 Assoc. Prof. Dr. Nilüfer AYKAÇ Health Effects of Air Pollution
15:15 – 15:45 Prof. Dr. Sibel MENTEŞE Seasonal Variability of Airborne Mold Concentrations in Relation to Dust in a Coastal Urban Area in the Eastern Mediterranean
15:45 – 16:00 Coffee Break
16:00 – 16:30 Prof. Dr. Ülkü Alver ŞAHİN Micropollutants in the Ambient Air
16:30 – 17:00 Prof. Dr. Inna KHOMENKO Coupled Climate – Air Pollution Dynamics: Key Mechanisms, Critical Feedbacks, and Systemic Impacts
17:00 – 17:30 Prof. Dr. Alihsan ŞEKERTEKİN Monitoring Air Quality from Space: A Remote Sensing Perspective
17:30 – 18:00 Prof. Dr. Çiğdem ÇAĞLAYAN Air Pollution and Environmental Justice
PANEL DISCUSSION
18:00 – 18:30 Panel Discussion & General Q&A
END OF DAY
HYBRID EVENT
IN-PERSON + ONLINE
FREE PARTICIPATION
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TECHNICAL SUPPORT
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27-29 NİSAN 2026
27-29 APRIL 2026
ZONGULDAK BÜLENT ECEVİT ÜNİVERSİTESİ SEZAİ KARAKOÇ KÜLTÜR MERKEZİ
YÜZ YÜZE + ONLINE
BY-PERSON + ONLINE
KATILIM ÜCRETSİZDİR
PARTICIPATION IS FREE
ONLINE OTURUM PROGRAMI / ONLINE SESSION PROGRAMME
SABAH OTURUMU / MORNING SESSION
SAAT / TIME
KİŞİ / PRESENTER
BİLDİRİ BAŞLIĞI / PRESENTATION TITLE
10:00 – 10:20
Gizem Tuna Uygun
10:20 – 10:40
Osman Keskin
10:40 – 11:00
Sinem Çolak
11:00 – 11:20
Ümit Furkan Akıner
11:20 – 11:40
Gülçin Demirel
11:40 – 12:00
Emirhan Özdemir
12:00 – 12:20
Osman Keskin
ÖĞLEDEN SONRA OTURUMU / AFTERNOON SESSION
14:00 – 14:20
Sinem Çolak
14:20 – 14:40
Osman Keskin
14:40 – 15:00
Sefa Kocabaş
15:00 – 15:20
Volkan Arslan
15:20 – 15:40
Adnan Akyüz
15:40 – 16:00
Esra Asuman Demirel
SABAH OTURUMU
MORNING SESSION
28 NİSAN 2026 – 09:45 (İSTANBUL)
ONLINE ACCESS
ÖĞLEDEN SONRA OTURUMU
AFTERNOON SESSION
28 NİSAN 2026 – 13:45 (İSTANBUL)
ONLINE ACCESS
ONLINE OTURUM BİLGİLERİ
ONLINE SESSION INFORMATION

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AIRQUEST
INTERNATIONAL SYMPOSIUM

CLEAN AIR FOR A SUSTAINABLE AND HEALTHY FUTURE

SOCIAL TOUR PROGRAMME

29 APRIL 2026 – WEDNESDAY

10:30	DEPARTURE FROM ZONGULDAK BÜLENT ECEVİT UNIVERSITY – AKADEMİ CAFE * Shuttle buses will depart in front of the Akademi Cafe.	
11:00 – 11:30	VISIT TO THE YAYLA LODGE	
11:40 – 12:10	VISIT TO THE GUEST HOUSE – TYPE A	
12:30 – 13:45	VISIT TO THE MINING MUSEUM AND MINING EXPERIENCE	
14:00 – 14:45	VISIT TO THE GÖKGÖL CAVE	
15:00 – 16:00	A TOUR FROM THE FENER DISTRICT AND THE VARAGEL TUNNEL TO THE PORT OF ZONGULDAK	

Explore the history, nature and culture of Zonguldak!

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Symposium Gallery


Thank you for your att


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Clean Air for a Sustainable and
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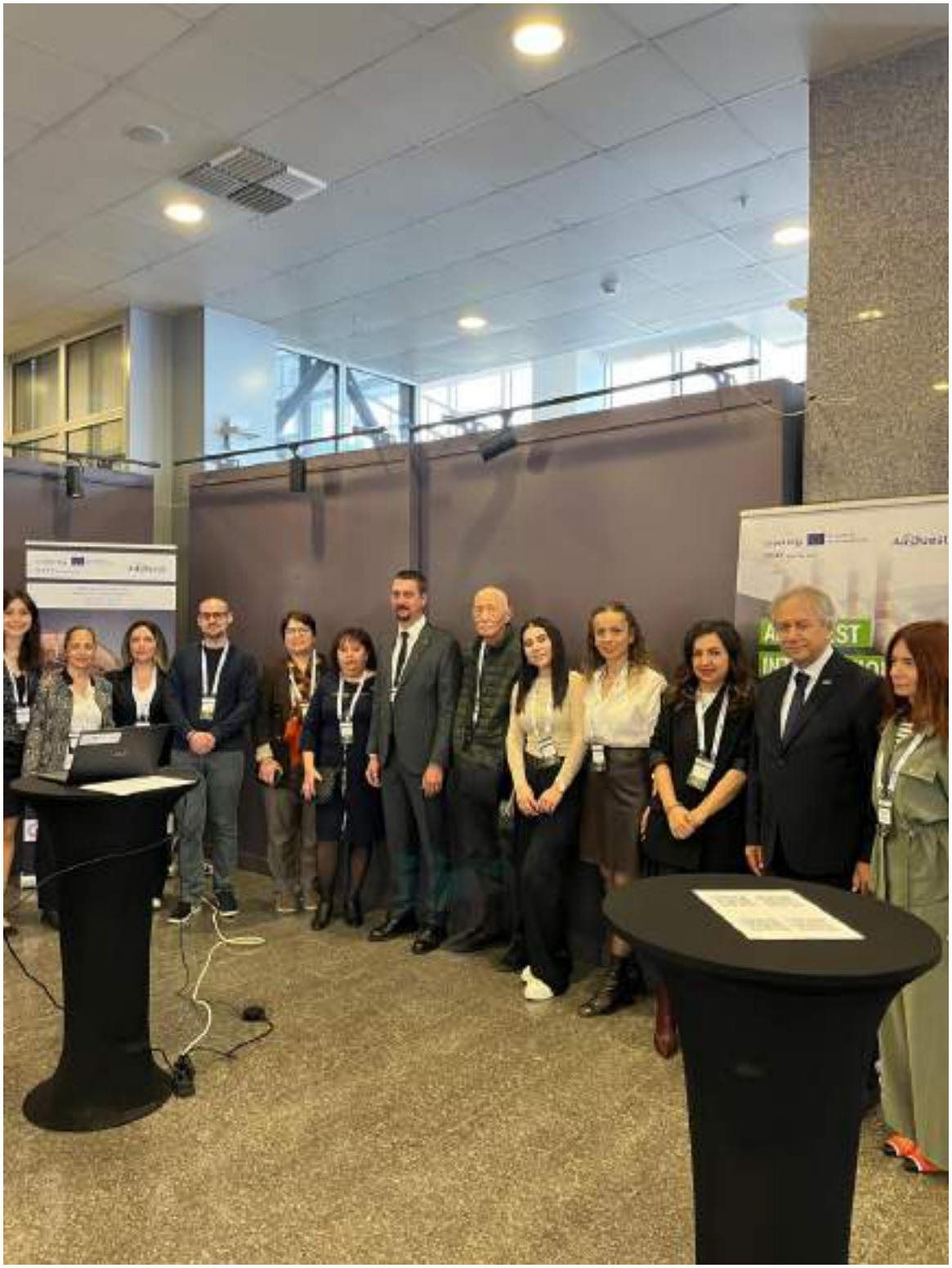
MANY THANKS & TEŞEKKÜRLER...

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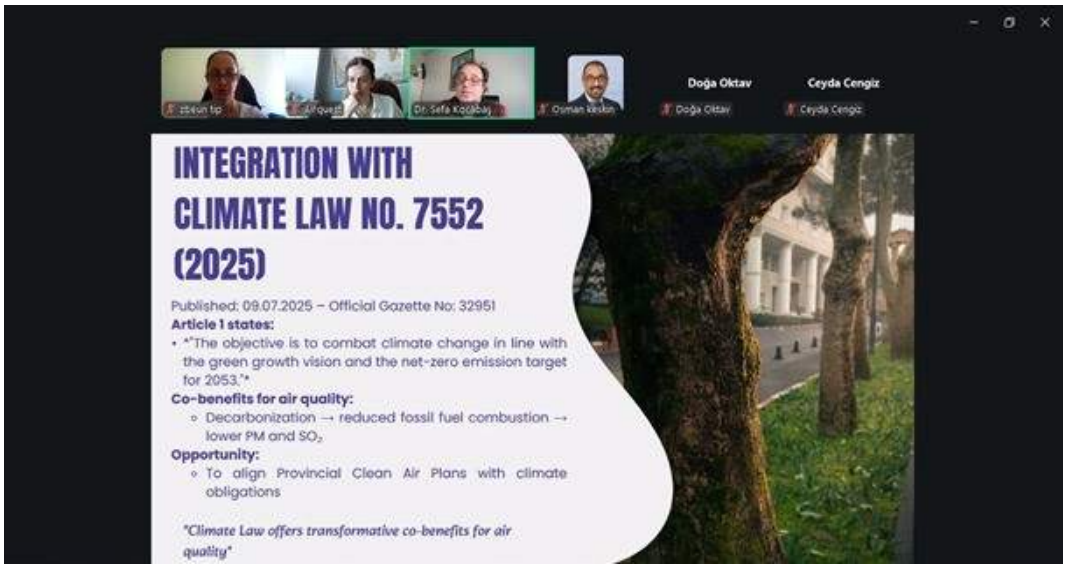
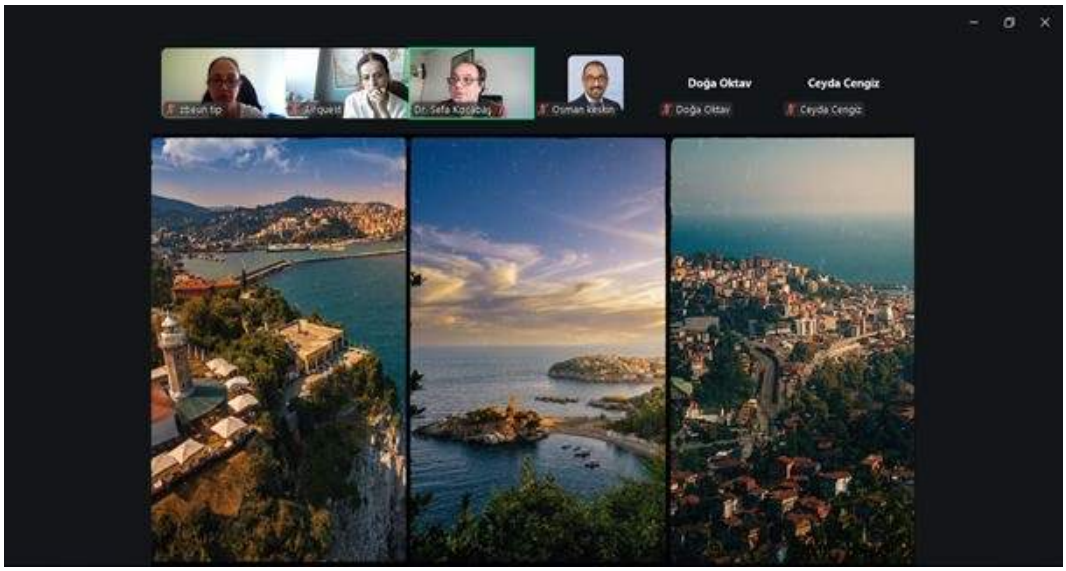
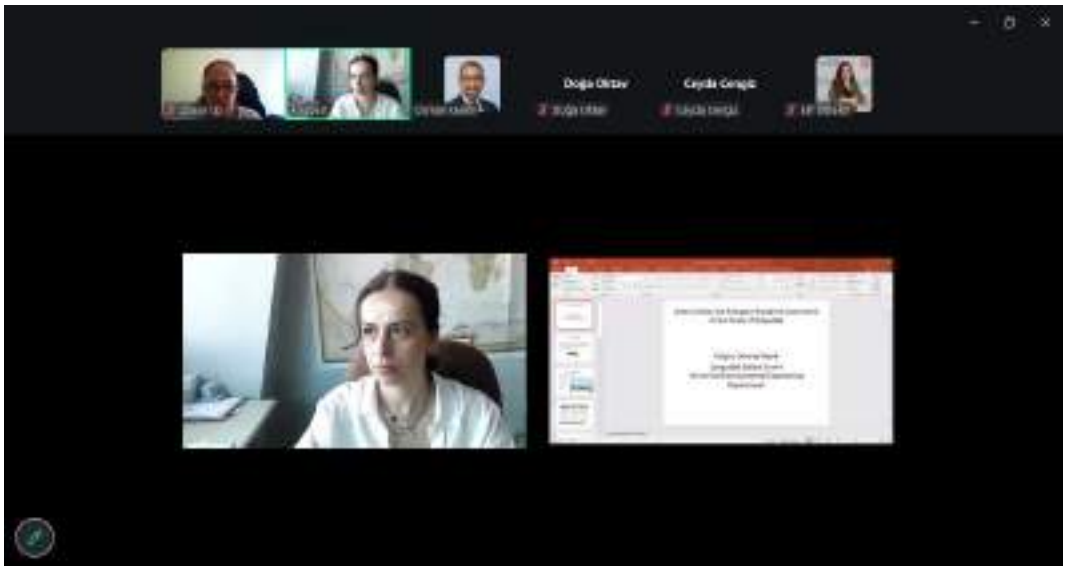
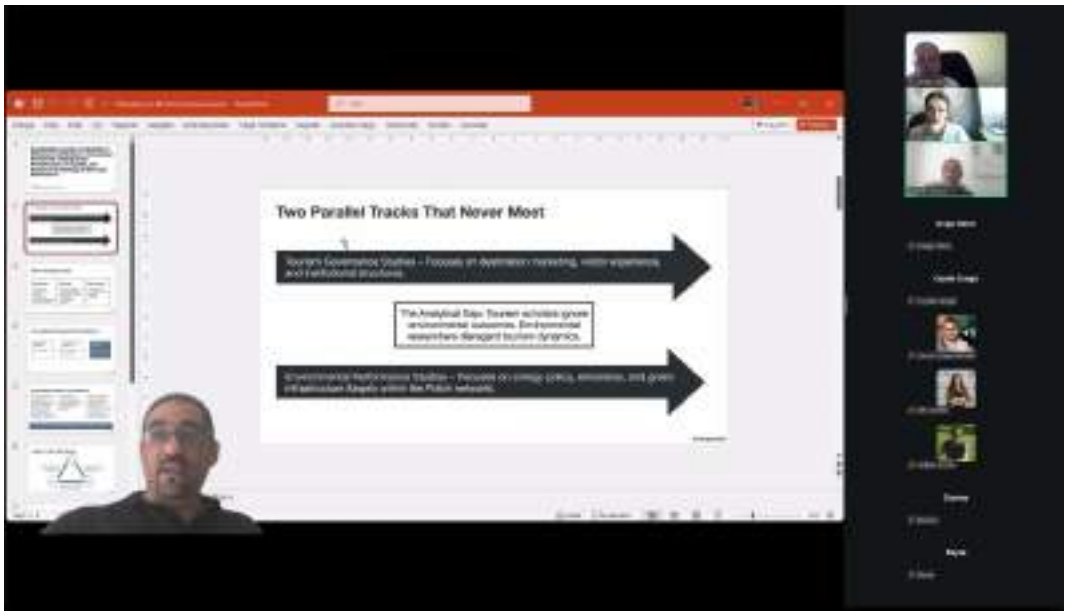
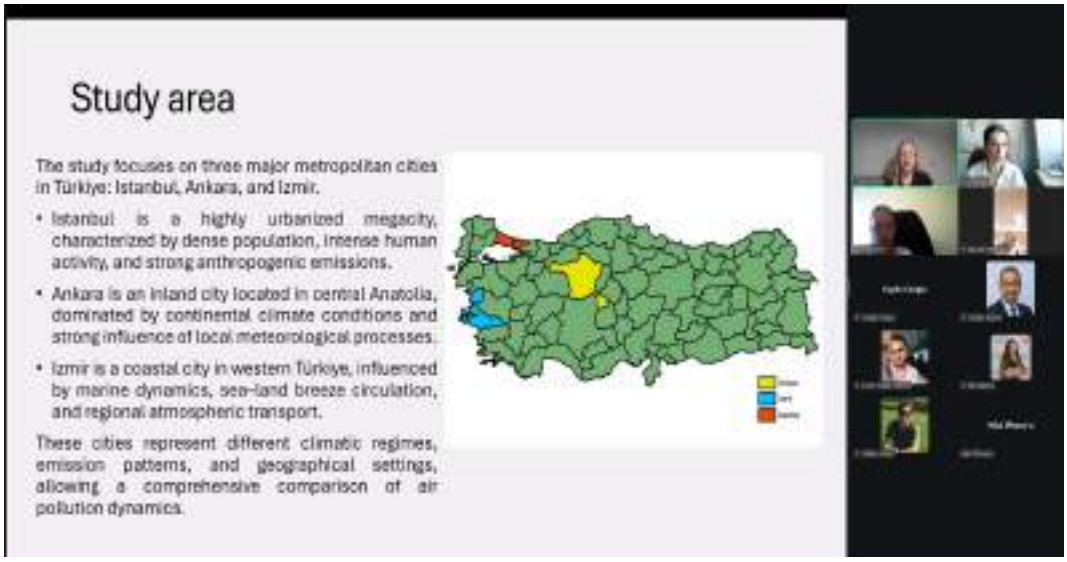

Doğa Oktav
Ceyda Cengiz
INTEGRATION WITH CLIMATE LAW NO. 7552 (2025)
Published: 09.07.2025 – Official Gazette No: 32951
Article 1 states:
• "The objective is to combat climate change in line with the green growth vision and the net-zero emission target for 2053."
Co-benefits for air quality:
◦ Decarbonization → reduced fossil fuel combustion → lower PM and SO_2
Opportunity:
◦ To align Provincial Clean Air Plans with climate obligations
"Climate Law offers transformative co-benefits for air quality"


Doğa Oktav
Ceyda Cengiz


Doğa Oktav
Ceyda Cengiz


Two Parallel Tracks That Never Meet


Doğa Oktav
Ceyda Cengiz
Önermeler ve Pratik Çıkarımlar
Teorik Önermeler (Gelecek Araştırmalar İçin)
P1: Açık hava gastronomi memnuniyeti, destinasyon düzeyindeki hava kalitesi göstergeleri ile pozitif korelasyon gösterir.
P2: Çevre politikasında yüksek puan alan kasabalar, gastronomi memnuniyetinde daha iyi performans gösterir.
P3: Bu dü etki, aynı destinasyonda açık havada k nlara göre çok daha güçlü hissedilir.
P4: Gıda a n yakınındaki düşük emisyo k yatırımları (meydanlar, adakatini artırır.
Pratik Çıkarımlar (Yerel Yönetimler İçin)
Taktiksel Zamanlama:
Polonya örneğindeki kışın artan kömür emisyonları göz önüne alınarak, gastronomik etkinlik takvimleri mevsimsel hava kalitesi verileriyle senkronize edilmelidir.
Mekansal Entegrasyon (Tek Bütçe, Çift Fayda):
Bisiklet yollarını, havayı filtreleyen yeşil koridorlar üzerinden yerel gastronomi rotaları ile birleştirerek çevresel ve turistik faydayı aynı anda üretin.


Study area
The study focuses on three major metropolitan cities in Türkiye: Istanbul, Ankara, and Izmir.
• Istanbul is a highly urbanized megacity, characterized by dense population, intense human activity, and strong anthropogenic emissions.
• Ankara is an inland city located in central Anatolia, dominated by continental climate conditions and strong influence of local meteorological processes.
• Izmir is a coastal city in western Türkiye, influenced by marine dynamics, sea-land breeze circulation, and regional atmospheric transport.
These cities represent different climatic regimes, emission patterns, and geographical settings, allowing a comprehensive comparison of air pollution dynamics.

Contents

Co-benefits of Climate and Air Quality Policies under Increasing Climate Extremes in Ukraine

I. Khomenko [(1)], L. Nedostrelova [(2)]

[(1)] *Corresponding Author, Odesa I. I. Mechnikov National University*

[(2)(3)] *Odesa I. I. Mechnikov National University*

1. Introduction. Climate change and air pollution are closely connected environmental and public-health challenges. Their connection is not only conceptual but also physical and practical. Fossil fuel combustion in energy production, transport, industry, and residential heating releases greenhouse gases and air pollutant precursors at the same time. Therefore, measures aimed at reducing carbon dioxide emissions can also reduce nitrogen oxides, sulphur dioxide, particulate matter, and other pollutants. This is the central logic of policy co-benefits: one well-designed intervention can simultaneously mitigate climate change, improve air quality, reduce health risks, and increase urban resilience.

However, the effectiveness of such interventions increasingly depends on climate extremes. Average warming alone does not fully describe the changing environmental conditions experienced by people, ecosystems, cities, and infrastructure. Extreme heat, warm nights, droughts, heavy precipitation, and stagnant weather episodes directly modify the chemical and physical processes that determine air quality. Hot and sunny weather accelerates photochemical reactions and favours the formation of ground-level ozone. Dry and stagnant conditions limit pollutant dispersion and support the accumulation of particulate matter. Precipitation can temporarily remove pollutants from the atmosphere through wet deposition, but this cleaning effect is short-lived and does not eliminate emissions. For this reason, air quality policy that ignores climate extremes is incomplete. Likewise, climate policy that ignores air pollution misses some of its most immediate benefits for society.

2. Data and methodological approach. The study is based on long-term daily meteorological observations from 16 stations across Ukraine: Ai-Petri, Askania Nova, Vinnytsia, Kerch, Kyiv, Lubny, Luhansk, Lviv, Mykolaiv, Odesa, Poltava, Uzhhorod, Uman, Feodosia, Chernivtsi, and Shepetivka. Depending on station data availability, the observational period extends from the late nineteenth century to 2018. This long temporal coverage is essential because climate extremes are inherently variable and cannot be reliably assessed using only short records. The use of stations from different physical-geographical regions also allows the results to be interpreted spatially, which is important for adaptation planning and regional policy design.

The assessment uses 25 extreme temperature and precipitation indices defined within the ETCCDI framework. Temperature indices include absolute extremes such as TXx, TXn, TNx, and TNn; percentile-based indices such as TX90p, TN90p, TX10p, and TN10p; threshold indices such as summer days, tropical nights, frost days, and icing days; and duration indices such as warm spell duration and cold spell duration. Precipitation indices include maximum one-day precipitation, maximum five-day precipitation, heavy precipitation days, very heavy precipitation days, consecutive dry days, consecutive wet days, simple daily intensity index, and annual wet-day precipitation. These indices were selected because they describe not only how strong extreme events are, but also how often they occur and how long they persist.

The methodological framework combines trend analysis, spatial-temporal assessment, empirical distribution analysis, and interpretation of climate extremes through an air-quality

pathway approach. Linear regression and the Mann-Kendall test were used in the underlying studies to identify significant tendencies in the indices over the full observation period and across standard climatological periods. For selected stations, spectral and harmonic analysis were also applied to estimate possible changes up to 2050 in mean annual temperature, annual maximum temperature, annual minimum temperature, annual precipitation, maximum one-day precipitation, and dry-spell duration. In this expanded interpretation, these climatological results are linked to the mechanisms of ozone formation, particulate matter accumulation, pollutant dispersion, and wet deposition.

3. Main results: intensification of climate extremes. The temperature-related results show a clear shift of the climate system in Ukraine toward higher temperature regimes. Annual mean temperature and absolute annual temperature extremes increase over time. Since the mid-twentieth century, mean annual temperature has increased substantially, and the underlying work indicates that, if linear trends continue, mean, maximum, and minimum temperatures may rise by approximately another 1 °C in the analysed regions by the middle of the twenty-first century. Warm indices such as TX90p, TN90p, summer days, tropical nights, and warm spell duration reach high values, while cold-related indices such as frost days, icing days, cold days, cold nights, and cold spell duration decrease. This means that warming is expressed not only in average values but also in the tails of the temperature distribution.

These changes have direct air-quality implications. Higher maximum temperatures increase the probability of ozone episodes because photochemical reactions become more active under warm and sunny conditions. The increase in warm nights and tropical nights is also important. Night-time cooling usually helps the lower atmosphere recover from daytime heat stress and can reduce exposure intensity. When nights remain warm, the population experiences more continuous thermal and pollution stress, while urban energy demand for cooling may also rise. Increased cooling demand can create an additional emissions burden where electricity production still depends on fossil fuels.

The precipitation-related results reveal a more complex pattern. The annual amount of precipitation has increased in many locations during the recent decades of the analysed record, but this does not necessarily mean a safer or more stable moisture regime. Extreme precipitation indices show a shift toward higher values, particularly for heavy and very heavy precipitation events, while dry-period indicators also remain important for several regions. This combination points to an intensification of the hydrological cycle: more water can fall during intense events, but dry periods may still become meteorologically and environmentally significant. Such alternation between heavy rainfall and dry spells is especially relevant for urban air quality, water management, soil erosion, flash-flood risk, and infrastructure resilience.

For air pollution, precipitation has a dual meaning. Heavy rainfall can wash out aerosols and soluble gases from the atmosphere, temporarily improving air quality. Nevertheless, this effect is episodic. It cannot compensate for continuous emissions, and it may be followed by rapid pollutant accumulation when dry and stagnant conditions return. Longer dry periods are particularly problematic because they support dust resuspension, reduce wet removal, and may increase fire-related or soil-related particulate emissions. In winter or transitional seasons, cold and stable conditions can additionally trap emissions from residential heating close to the surface. Thus, both heat extremes and precipitation extremes change the conditions under which pollution episodes occur.

4. Climate extremes as a policy-relevant link between climate and air quality. The most important implication of the study is that climate extremes act as a practical bridge between climate policy and air quality management. The same city or region may face several interacting

pressures: higher temperatures, more frequent heatwaves, increased ozone formation, longer dry periods, accumulated particulate matter, and short but intense rainfall events. If these processes are governed separately, policy effectiveness declines. For example, reducing emissions from transport can improve air quality, but the health benefit will be larger if it is combined with measures that reduce urban heat and exposure during heatwaves. Similarly, urban greening is often presented as an adaptation measure, but it can also produce air-quality and health co-benefits by lowering surface and air temperature, reducing heat stress, and improving the urban microclimate.

Energy transition is the clearest co-benefit pathway. Reducing fossil fuel use lowers greenhouse gas emissions while also reducing nitrogen oxides, sulphur dioxide, primary particulate matter, and other pollutants. Sustainable transport provides a similar effect by reducing combustion-related emissions and population exposure in densely populated areas. Electrification, public transport development, cycling infrastructure, and low-emission urban mobility become more valuable under climate extremes because they reduce both baseline pollution and the additional pollution burden during unfavourable meteorological conditions.

Nature-based solutions are another essential component. Trees, parks, green roofs, permeable surfaces, and restored urban green-blue networks cannot replace emission reductions, but they can strengthen them. Their role is particularly important in cities, where the urban heat-island effect can amplify extreme heat and ozone risk. Green infrastructure also contributes to stormwater regulation during heavy precipitation events and improves the quality of urban living environments. In the Ukrainian context, this is especially relevant for post-war reconstruction because rebuilding infrastructure without climate and air-quality integration would reproduce vulnerability. Reconstruction should not simply restore pre-war systems; it should reduce future climate, pollution, and health risks.

5. Discussion and conclusions. The expanded analysis confirms that climate extremes in Ukraine are intensifying and that these changes have direct and policy-relevant consequences for air quality. The observed shift toward higher temperature regimes is expressed not only through increasing average temperatures, but also through more frequent and persistent warm extremes. Increasing heat extremes favour ozone formation because high temperature and strong solar radiation accelerate photochemical reactions in the lower atmosphere. As a result, heatwaves may become accompanied by episodes of poor air quality, creating a combined risk for human health. This is especially important for urban areas, where high emissions, dense population, limited ventilation, and the urban heat-island effect can reinforce each other.

Warmer nights are also significant because they reduce the recovery capacity of both the atmosphere and the human body. Under normal conditions, night-time cooling helps decrease heat stress and partly restores thermal comfort after hot daytime conditions. When nights remain warm, exposure becomes more continuous, and vulnerable groups such as elderly people, children, and people with cardiovascular or respiratory diseases face higher risks. In addition, prolonged heat can increase electricity demand for cooling, which may create an additional emissions burden if energy systems remain dependent on fossil fuels.

The analysis also shows that precipitation extremes have a more complex effect on air quality. Heavy precipitation can remove aerosols and soluble gases from the atmosphere, but this improvement is short-lived and does not solve the problem of continuous emissions. Moreover, intense rainfall can generate additional risks by overloading drainage systems, increasing surface runoff, and washing accumulated pollutants from roads and urban surfaces into water bodies. At the same time, dry and stagnant conditions support particulate matter accumulation, dust resuspension, and reduced atmospheric cleansing. Therefore, both the intensification of heat extremes and the changing precipitation regime should be treated as important factors

shaping future pollution episodes.

These findings demonstrate that air quality cannot be managed effectively without considering the changing regime of climate extremes. Traditional air-quality management, focused mainly on emission limits and monitoring, remains necessary but is no longer sufficient on its own. It must be complemented by climate-sensitive planning that accounts for heatwaves, drought periods, stagnant weather, heavy precipitation, and compound risks. In practice, this means that climate information should be incorporated into air-quality forecasting, urban development strategies, public-health warning systems, and infrastructure planning.

The key policy conclusion is that climate mitigation, air pollution control, urban planning, and public-health protection should be integrated. Isolated air-quality measures may become less efficient under more frequent climate extremes, because unfavourable meteorological conditions can amplify pollution even when emissions are partially reduced. At the same time, isolated climate policies may fail to deliver their full social value if air-quality and health co-benefits are not deliberately designed. A co-benefit approach is therefore more effective because it allows one intervention to address several problems simultaneously: greenhouse gas emissions, local air pollution, heat stress, health risks, and urban vulnerability.

For Ukraine, this approach is not only an environmental recommendation but also a recovery strategy. Post-war reconstruction will involve large-scale decisions about energy systems, transport networks, housing, public spaces, and urban infrastructure. If reconstruction simply restores outdated and emission-intensive systems, future vulnerability may increase. In contrast, reconstruction can become an opportunity to build cleaner, safer, and more climate-resilient cities and regions. Energy transition, sustainable transport, urban greening, energy-efficient buildings, and climate-sensitive spatial planning can reduce emissions, improve public health, and strengthen resilience at the same time.

Therefore, co-benefits should be embedded in national, regional, and municipal planning from the beginning. Such integration would help ensure that reconstruction contributes not only to physical rebuilding, but also to long-term environmental quality, climate resilience, and sustainable urban development.

6. References

[1] IPCC, 2023. Climate Change 2023: Synthesis Report. Contribution of Working Groups I–III to the Sixth Assessment Report. IPCC, Geneva.

[2] ECA&D, 2023. European Climate Assessment & Dataset. Available at: https://www.ecad.eu

THE DEVELOPMENT OF “GREEN INFRASTRUCTURE” AS A FACTOR IN IMPROVING AIR QUALITY IN THE ODESA

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(2)(3) Odesa I. I. Mechnikov National University

1. Introduction. In recent years, Odesa, like some large cities in Ukraine, has been characterized by a decrease in population, high levels of morbidity and mortality. One of the well-known climate risks is the urban heat island effect, which increases the warming and aridity of the climate in the city. To overcome the current crisis and increase the comfort of living in this urbanized environment, it is necessary to develop an urban development strategy that will provide for an increase in the share of “green infrastructure”, that is, a strategically planned and managed network of natural areas and open spaces. Green areas are a buffer between urban complexes and natural ecosystems. They are effective filters for cleaning the air pool, reduce wind force, regulate thermal conditions, humidify the air, reduce the level of acoustic load, etc. In addition, they improve the natural components of the urban environment and create aesthetic comfort for city residents, improving their physical and psychological health. Urban green areas, in particular parks, squares, gardens or sports and recreational areas, provide residents with opportunities for rest, relaxation and communication. Since, according to the UN (2019), it is expected that in 2050 68% of the world's population will live in cities, it is extremely important in urban planning to ensure the availability of a sufficient number and quality of green spaces to preserve natural recreation opportunities.
The purpose of the study is to analyze the prospects for the development of "green infrastructure" in the city of Odesa as a factor in improving atmospheric air quality.

2. Material and Method. The basis of the study was the analysis of the experience of developing "green infrastructure" in urbanized areas, presented in the works of Ukrainian and foreign researchers [1 – 4]. A structural analysis was carried out, which allowed to determine the adaptation strategy for this urbanized area. The system of indicators of urban greening, proposed by the authors of the work [5], was considered.

3. Results. The city of Odesa is located in the coastal strip, on the northwestern coast of the Black Sea, and is characterized by a temperate continental steppe climate. The area of green spaces in the city of Odesa is 742 hectares, which per 1 resident of the city is 7.4 m2/person and is 61.7% for the city compared to the current national standard of 12 m2/person for cities of the level of Odessa. At the same time, if in the city center each resident has about 4 m2 of green spaces on average (with a norm of 12 m2), then in large residential areas per capita there is no more than 1 m2 of green spaces. In some parts of the city, the specific amount of green spaces is even smaller and is only 17% of the national norm.
There are four administrative districts in Odessa: Kyivskyi, Khadzhibeyskyi, Prymorskyi and Peresypskyi. According to the Rules for the Maintenance of Green Spaces in Settlements of Ukraine, city gardens and parks, squares, boulevards, green areas on the slopes and along the city avenues are classified as public use areas by functional affiliation [6]. Information on the provision of green spaces in individual districts of the city as one of the indicators of the formation of “green infrastructure” is given in Fig. 1 – 2 [5].

It is worth noting that the World Health Organization proposes an even higher figure – 50 m2 per urban resident – as a necessary norm to ensure the health of the population.
Analysis of green areas in the districts of Odesa showed that the highest level of provision of the population with green spaces is observed in the Prymorskyi district - 7.89 m² per person. The second in terms of the indicator is Khadzhibeyskyi district, where 5.45 m² of green areas per inhabitant are allocated. Peresypskyi and Kyivskyi districts are characterized by almost the same level of provision - 2.0 and 1.9 m² per person, respectively. At the same time, the available areas of parks and squares are significantly inferior to the recommended WHO norms and current urban planning standards.
The species composition of urban flora is determined both by the geographical location (in the south of the Steppe zone of Ukraine) and by the applied approaches to planting.

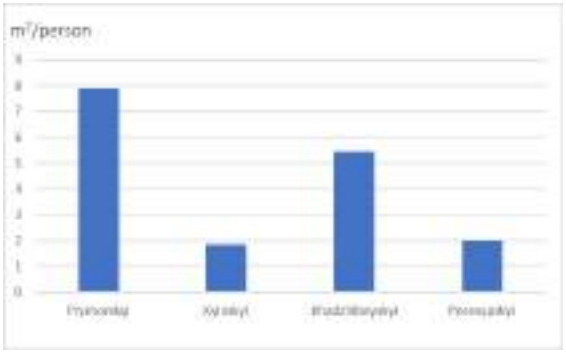

Figure 1. Providing districts of Odesa with green zones

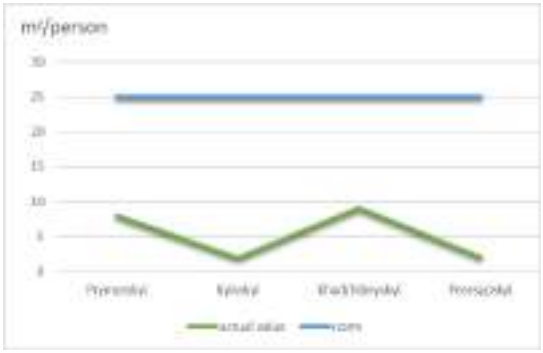

Figure 2. Provision of Odessa districts with public green spaces

The study of world and national practice for the purposes of this study makes it possible to find promising solutions to the issue of developing "green infrastructure" in Odessa.
Thus, the most effective way to expand green zones is to form a green belt of Odessa, that is, a system of ecological corridors around the city center, which would unite green spaces on the coastal slopes with all existing parks, gardens and squares by green links, strips of boulevards and greened streets (avenues), as well as by creating new recreation areas instead of abandoned industrial zones. In the future, it is advisable to expand the network of such green corridors to all areas of the city and suburbs. The prerequisites for this in the form of a number of parks, squares and gardens already exist.
In addition to ecological corridors, it seems promising to promote the creation of green roofs throughout the city, which contribute to adaptation to climate change and increase biodiversity, retain stormwater, improve air quality, absorb CO2, provide residents with space for urban agriculture and recreation, as well as green walls, which, in turn, reduce noise pollution and energy consumption for artificial air conditioning [7].
Regarding the issue of determining the types of plants that are best suited for creating green zones, it is necessary to take into account their ecological and climatic characteristics and resistance to anthropogenic load in the urbanized area.
In the city of Odesa, the predominant source of atmospheric air pollution is road transport. In addition, it is the main source of noise pollution (generating 60-80% of urban noise). According to observations during 2012-2015, at the intersections of the city's main transport highways, the noise level was 85-92 dB during the daytime, in 2021-2022, the permissible noise level standard (55 dB) for daytime was exceeded on all studied streets by 65-88 dB. The increase in the level of noise pollution may be due to the lack of vegetation of green spaces. Therefore, increasing the level of greening of the urban area will also contribute to reducing the acoustic load [7].
In order to neutralize a number of harmful substances in urban air, it is recommended to plant

such trees and shrubs that are capable of effectively absorbing noise and pollutants.

4. Discussion and Conclusion. The adaptation strategy for the city of Odesa should include a number of measures, the list of which also includes reducing emissions of pollutants into the air basin. Further development of "green infrastructure" will allow: to significantly reduce the level of noise and air pollution; to create better conditions for residents for health and recreation. In areas with insufficient provision of green areas, it is advisable to implement modern innovative solutions to expand green areas.

This may include vertical and planar greening of buildings - greening facades, roofs, creating green noise barriers and other structural elements that compensate for the shortage of open areas. In addition to quantitative indicators, the quality of green spaces is no less important. In order to ensure the long-term ecological stability of green spaces, systematic monitoring of their condition is necessary. This will allow for timely detection of signs of disease, damage or degradation of plants, as well as promptly implement appropriate restoration and care measures.

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Identifying Key Factors Influencing PM_{10} Concentrations in Three Major Cities of Türkiye Using LightGBM

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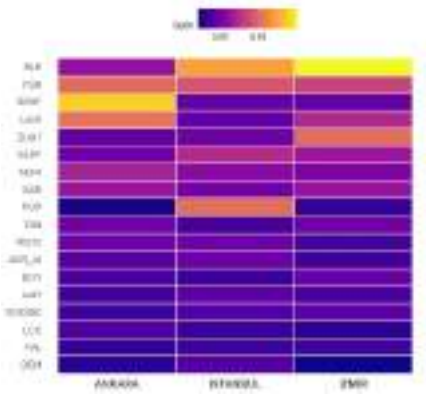
1. Introduction. Among the air pollutants, particulate matter with an aerodynamic diameter of 10 μm or less (PM_{10}) remains a major concern in large metropolitan areas due to complex emission sources and meteorological conditions. Satellite-derived aerosol indicators, such as Aerosol Optical Depth (AOD) and Aerosol Index (AI), provide effective tools for investigating aerosol behavior at large spatial scales [1]. However, the relationship between aerosol indicators and environmental variables may vary among cities due to local conditions. This study examines three major metropolitan cities in Türkiye (Istanbul, Ankara, and Izmir) to identify key factors influencing PM_{10} concentrations and assess how the importance of meteorological, land-use, and aerosol-related variables varies across cities.

2. Materials and Methods. This study uses hourly PM_{10} data from air quality monitoring stations in Istanbul, Ankara, and Izmir. Unrealistic values were removed, daily averages were calculated from valid hourly data, and satellite-derived aerosol parameters were used as predictors. AOD data from the MAIAC algorithm and AI data from TROPOMI were obtained using the Google Earth Engine (GEE) platform. Meteorological variables were retrieved from ECMWF datasets, while land-surface characteristics were represented using Digital Elevation Model (DEM), MODIS land cover, and NDVI datasets. All variables were harmonized to a 1 km spatial resolution, and geographic coordinates and Day of Year (DOY) were included to represent spatial and temporal variability. The final modeling dataset was created by spatially and temporally matching all predictors. Variable importance analysis was then performed using the LightGBM algorithm to determine the dominant factors affecting PM_{10} concentrations in each city.

3. Results. The variable importance results revealed both common and city-specific drivers of PM_{10} variability across the three metropolitan areas (Figure 1). In Ankara, surface sensible heat flux (SSHF) was identified as the most dominant predictor, indicating the strong influence of surface energy balance and local meteorological conditions. Aerosol indicators showed measurable but lower importance than meteorological drivers. In Istanbul, boundary layer height (BLH) emerged as the most influential factor, followed by population-related variables, highlighting the role of dense anthropogenic activity. AOD and AI contributed moderately, indicating their ability to



represent pollution variability in complex urban conditions. In Izmir, BLH and friction velocity (ZUST) were the leading predictors, reflecting the strong influence of atmospheric mixing and coastal dynamics. Meteorological variables dominated PM_{10} prediction, while AOD and AI remained consistently important predictors across all cities.

4. Discussion and Conclusion. AOD and AI were important predictors across all cities, while meteorological influences varied, highlighting the need for city-specific models and the value of satellite-based aerosol indicators in PM_{10} prediction.

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Sustainable Tourism Co-Benefits of Cittaslow Certification: A Conceptual Framework Linking Green Infrastructure, Air Quality, and Gastronomic Heritage in Slow City Destinations

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1. Introduction. The academic conversation on climate action in urban settings has overwhelmingly privileged large metropolitan areas. Carbon emissions, heat island effects, adaptation infrastructure: the evidence base for these concerns is dense where populations are densest. Small towns, particularly those below fifty thousand residents, occupy a peripheral position in this scholarship, even though they face environmental vulnerabilities that are structurally distinct from those of cities [1,2].

The Cittaslow movement complicates this picture in a productive way. Founded in Italy in 1999 and now spanning more than two hundred and fifty member towns across thirty three countries, the network provides small municipalities with a structured sustainability framework organized around seven macro areas and seventy two certification criteria [1,3]. These criteria span energy and environmental policy, local gastronomy and product policy, urban quality of life, and hospitality, among others. The philosophical foundation is explicit: local identity, gastronomic tradition, and environmental stewardship should function as engines of development rather than obstacles to it [4,5].

What has emerged in the research literature, however, are two parallel tracks that rarely acknowledge each other. One track examines Cittaslow through the lens of tourism governance, destination marketing, and visitor experience [6,7,8]. The other measures the movement's environmental and socio economic footprint, largely within the Polish national network [9,10,11]. Between these two tracks lies an analytical gap with practical consequences. Tourism scholars ignore environmental outcomes. Environmental researchers disregard tourism dynamics. No study asks whether the green infrastructure investments documented in one literature produce measurable effects on the tourism attractiveness documented in the other.

The gap is not merely academic. When a Cittaslow municipality invests in a cycling path, that investment simultaneously reduces transport emissions and creates a recreational asset for visitors. When it shortens local food supply chains, the intervention lowers food-mile emissions while reinforcing the gastronomic identity that draws tourists. When it expands green spaces, it mitigates urban heat while improving the experiential quality of the destination. These dual functions are intuitive, yet they have never been conceptually modeled or empirically tested.

This paper addresses that omission. Its objective is to develop a conceptual framework that traces the co-benefit pathways between Cittaslow's environmental policy interventions, its gastronomic heritage policies, and tourism destination sustainability. The framework generates testable propositions and outlines a methodological roadmap for future empirical work.

2. Material and Method. The study is conceptual in nature and does not involve primary data collection. Its analytical material consists of three source categories: peer reviewed articles examining Cittaslow certified municipalities, Cittaslow International's certification documentation, and theoretical work on destination sustainability and gastronomic tourism.

The literature search was conducted using the Undermind AI assisted academic search platform. Search terms combined Cittaslow, climate change, environmental policy, tourism governance, and community resilience. The temporal scope covered publications from 2000 to 2025. Over

one hundred and sixty sources were screened; twelve core studies and fourteen supplementary references were retained based on three inclusion criteria: verified Cittaslow membership of the study site, presence of empirical data, and relevance to at least one of the three domains under investigation (environmental performance, tourism governance, gastronomic identity).
The analytical approach follows a conceptual framework development methodology. Existing empirical findings were reinterpreted through a cross domain lens, transmission mechanisms between policy areas were identified, and testable propositions were formulated. The original version of this paper was written in Turkish. The English translation was produced using Claude AI (Anthropic) and subsequently reviewed by the author for terminological accuracy, conceptual fidelity, and scholarly tone.

3. Results

3.1. Environmental Policy Performance in Cittaslow Town.

The strongest evidence on environmental outcomes comes from Wierzbicka's [9] comparative analysis of certification and five-year recertification scores across the Polish Cittaslow network. Towns showed measurable score improvements in the energy and environmental policy macro-area after joining the network. Energy efficiency programs, waste management reforms, and environmental monitoring mechanisms were among the documented interventions. This finding is significant because it establishes that certification is not simply a symbolic label; it drives institutional behavior change at the municipal level.
The picture is not uniformly positive. Batyk et al. [10] surveyed all thirty-five Polish Cittaslow municipalities on their support for renewable energy deployment and found a disconnect between strategic documents and actual practice. Municipal development strategies mentioned renewable energy targets, but practical support remained low. The researchers attributed this gap to binding statutory obligations and constrained quality of life indices. Certification, in other words, generates ambition in strategic rhetoric without necessarily translating that ambition into energy transition on the ground.
Gazińska et al. [12] documented the physical investments that followed certification in twenty-nine Polish Cittaslow towns between 2006 and 2019. Cycling paths, pedestrian trails, and recreational green areas were among the most common post membership interventions. Wierzbicka [13] reported similar patterns for the first five years of membership. These investments are classified in the existing literature as either environmental measures or tourism infrastructure, never as both simultaneously. That single-axis classification obscures their dual function.
As a contextual benchmark, Kalbarczyk and Roszyk [14] analyzed council resolutions in five small non Cittaslow towns in southern Wielkopolska and found that only four to six percent of resolutions addressed climate related topics, concentrated in transport, energy, and water sectors. This baseline indicates that small town environmental governance is generally modest, raising the question of whether Cittaslow certification produces a differentiation effect. The current evidence suggests it does, at least in the energy and environmental policy domain, but the absence of matched comparison groups prevents causal attribution.

3.2. Tourism Governance and Gastronomic Identity.

On the tourism side, Presenza and Perano [6] examined Cittaslow certified towns at the international level and found that certification structured and systematized sustainable tourism governance. Policy implementation became more organized, stakeholder participation increased, and destination management acquired an institutional framework it previously lacked.
The gastronomic dimension has received less systematic attention but carries strong conceptual weight. Nilsson et al. [7] positioned Cittaslow's eco gastronomic heritage as a core destination

development tool, arguing that local food identity and tourism attractiveness are structurally intertwined in slow city contexts. Emmendoerfer et al. [8] traced the co creation process of a local dish in Vizela, Portugal, demonstrating that gastronomic attractiveness in Cittaslow towns depends on community participation, not just professional marketing. The slow city initiative, they found, provided the institutional scaffolding for a gastronomic attraction that would not have emerged organically.

The gap between these findings and the environmental evidence is striking. No study in the reviewed corpus asks whether the green infrastructure investments documented by Gazińska et al. [12] affect the tourism governance outcomes documented by Presenza and Perano [6]. No study examines whether the gastronomic heritage practices described by Nilsson et al. [7] produce environmental co-benefits through shortened supply chains or reduced food-mile emissions. The three evidence streams exist in separate analytical compartments.

3.3. The Triple Co-Benefit Model.

The proposed framework rests on a straightforward premise: Cittaslow's certification criteria treat environmental policy, gastronomic policy, and tourism governance as separate macro areas, but in practice these areas generate reciprocal effects.

Component 1: Environmental-to-tourism co-benefits. Energy efficiency programs reduce heating related air pollutants, which improves the physical environment quality of the destination, particularly during winter tourism seasons. Cycling paths and pedestrian trails serve simultaneously as low emission transport infrastructure and as recreational tourism assets. Green space expansion reduces heat island effects while enriching the visitor's open air experience. These connections are implicit in the data reported by Wierzbicka [9] and Gazińska et al. [12] but have never been made explicit.

Component 2: Gastronomy-to-environment co-benefits. Shortened local food supply chains reduce transportation emissions. Traditional agricultural practices preserved through Cittaslow certification use fewer chemical inputs than industrial monoculture and maintain soil carbon sequestration capacity. Open air gastronomic events (farmers' markets, harvest festivals, food trails) depend on environmental quality for their experiential value, creating a feedback loop between gastronomic programming and environmental stewardship.

Component 3: Tourism governance as integrative feedback. Presenza and Perano's [6] finding that certification structures tourism governance implies an untapped capacity: the structured governance could serve as the institutional mechanism that tracks, evaluates, and reports on cross domain co benefits. That capacity is currently unrealized because tourism governance studies do not incorporate environmental performance indicators and vice versa.

The model generates four testable propositions:

Proposition 1: Cittaslow towns with high recertification scores in the energy and environmental policy macro-area will show stronger improvements in tourism attractiveness indicators compared to towns with lower scores.

Proposition 2: A negative association will exist between local food supply chain length and destination carbon footprint, and this association will strengthen as gastronomy tourism intensity increases.

Proposition 3: Cittaslow towns demonstrating simultaneous high performance in both environmental and gastronomic policy areas will produce stronger destination sustainability outcomes than towns excelling in only one area.

Proposition 4: Post-certification green infrastructure investments will exhibit independent explanatory power for tourism outcomes beyond their primary environmental benefits.

Table 1. Triple Co-Benefit Pathways and Supporting Evidence

Co-benefit pathway	Transmission mechanism	Supporting evidence
Environmental to tourism	Reduced emissions improve destination environmental quality; green infrastructure doubles as recreational assets	[9], [12], [13]
Gastronomy to environment	Shortened supply chains reduce transport emissions; traditional agriculture lowers chemical inputs	[7], [8] (indirect)
Tourism governance as integrator	Structured governance enables cross-domain monitoring and reporting	[6] (potential, unrealized)

4. Discussion and Conclusion. The triple co-benefit model proposed here represents the first conceptual attempt to bridge three research streams that have developed independently within the Cittaslow literature. Since Mayer and Knox's [1] foundational study on small-town sustainability, the field has accumulated substantial empirical evidence, yet it has not achieved an interdisciplinary synthesis. Wierzbicka's [9,11,13] systematic work on the Polish network measured environmental and socio-economic indicators without considering tourism effects. Presenza and Perano [6] analyzed tourism governance without engaging environmental performance data. Nilsson et al. [7] conceptualized gastronomic heritage without exploring its environmental dimensions. The framework proposed here is designed to break that isolation.

The methodological implications are direct. The most conspicuous weakness in the current evidence base is the absence of comparison groups. None of the ten core studies reviewed here implemented matched non-Cittaslow controls or quasi-experimental designs. Difference-in-differences analyses exploiting certification timing, or synthetic control methods using non-member towns as comparators, would represent a substantial advance. Testing the proposed framework empirically would require integrating secondary databases: Copernicus climate data, Eurostat tourism statistics, and national environmental agency reports could be combined with Cittaslow certification scores to construct multi-domain performance profiles.

For practice, the model offers two actionable implications. At the Cittaslow International level, recertification processes could incorporate cross-domain co-benefit indicators, enabling a more accurate assessment of each town's integrated performance. At the municipal level, planning environmental interventions with tourism co-benefits in mind could multiply the return on limited resources. A cycling path designed simultaneously as a gastronomy route connecting local producers' sales points would generate environmental, gastronomic, and tourism value from a single investment.

The study's principal limitation is its conceptual nature. The model has not been empirically tested. Its validity across different geographic and cultural contexts (Italy, Turkey, South Korea, Australia) remains an open question. Moderating variables such as climate conditions, tourism intensity, and the strength of local gastronomic tradition have not been incorporated. These limitations define the agenda for the next phase of research.

In sum, Cittaslow certification produces environmental, gastronomic, and tourism governance outcomes that the existing literature treats as independent. The framework proposed here suggests they are interdependent, and that recognizing their interdependence both advances theoretical understanding and creates practical opportunities for small-town sustainable development.

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The Slow City Brand Paradox: How Low Resident Awareness Constrains Gastronomic Tourism Identity and Destination Sustainability in Cittaslow Towns

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1. Introduction. A town joins the Cittaslow network, restructures its environmental policies, invests in cycling paths and green spaces, promotes local food production, and earns recertification five years later with improved scores across multiple domains. By institutional measures, the certification works. Then a researcher surveys the town's residents and discovers that most of them cannot explain what Cittaslow means or how it relates to their daily lives [1]. The institutional achievement and the societal reality occupy different planes.

This discrepancy is not a minor footnote in the Cittaslow literature. It sits at the center of a question the movement has not adequately confronted: can a sustainability framework succeed at the municipal level while remaining invisible at the community level? The empirical record suggests the answer is complicated. Wierzbicka [2] documented measurable improvements in energy and environmental policy indicators across the Polish Cittaslow network. Gazińska et al. [3] cataloged infrastructure investments in twenty-nine certified towns. Farelnik and Wierzbicka [4] reported that mayors perceived positive social, economic, and spatial effects of membership. At the governance level, the evidence points in a consistent direction.

The resident-level evidence tells a different story. Stanowicka et al. [1] found that brand awareness among Polish Cittaslow residents was insufficient to support the movement's sustainability objectives. Batyk and Woźniak [5] surveyed residents in ten member towns and reported that most respondents did not associate Cittaslow membership with any improvement in their quality of life. These findings, taken together, describe a paradox: institutional performance advances while societal ownership stagnates.

For gastronomy tourism, this paradox carries particular weight. Cittaslow towns position gastronomic heritage at the core of their destination identity [6,7]. Local producers, restaurant owners, market vendors, and ordinary residents are the primary actors who shape the tourist's gastronomic experience. When these actors are unaware of the Cittaslow identity that supposedly defines their town, the authenticity promise of gastronomic tourism lacks its most important transmission channel.

This paper analyzes the awareness paradox through a gastronomy tourism lens. Three research questions guide the analysis. First, through what mechanisms does low resident awareness weaken gastronomic tourism experience? Second, how does the awareness deficit constrain community-level sustainability mobilization? Third, what conceptual intervention points can be identified to address the paradox?

2. Material and Method. This study is conceptual and does not involve primary data collection. The analytical material comprises peer-reviewed articles published between 2006 and 2025 that examine Cittaslow-certified municipalities, with particular attention to studies addressing resident perceptions, brand awareness, quality of life assessments, and community participation. Literature identification was conducted through the Undermind AI-assisted academic search platform. The search combined Cittaslow, climate change, environmental sustainability, tourism governance, and community resilience as key concepts. Over one hundred and sixty sources were evaluated; twelve core studies addressing resident-level perceptions in verified

Cittaslow towns and eight supplementary references on gastronomic tourism identity were retained for analysis. Selection criteria required verified Cittaslow membership, empirical data content, and engagement with the awareness or perception dimension.
The methodology follows a conceptual framework development approach through critical narrative synthesis. Existing empirical findings were reinterpreted to identify paradox components, relationships between components were modeled, and testable propositions for future research were generated. The study does not employ meta-analytic or systematic review protocols. The original version of this paper was written in Turkish. The English translation was produced using Claude AI (Anthropic) and subsequently reviewed by the author for terminological accuracy, conceptual fidelity, and scholarly tone.

3. Results. Three components of the awareness paradox emerged from the literature synthesis. Each is presented with its supporting evidence below.

3.1. The Institutional-Societal Perception Gap

The evidence for institutional performance is robust. Wierzbicka's [2] comparative analysis of certification and recertification scores across the Polish network showed that member towns achieved measurable progress in the energy and environmental policy macro-area during their first five years. The improvements were not rhetorical; they reflected documented municipal actions in energy efficiency, waste management, and environmental monitoring. Gazińska et al. [3] corroborated this picture by mapping infrastructure investments (cycling paths, walking trails, recreational areas) that intensified after certification in twenty-nine towns between 2006 and 2019. Wierzbicka [8] recorded parallel developments in tourism, heritage conservation, and urban infrastructure during the initial membership period.
Resident perceptions did not mirror these institutional gains. Batyk and Woźniak [5] conducted surveys across ten Polish Cittaslow towns and found that most respondents failed to connect Cittaslow membership with tangible quality-of-life improvements. The changes happening around them, the new cycling paths, the greener spaces, the restructured waste systems, were either not perceived or not attributed to the Cittaslow framework. Farelnik and Wierzbicka [4] showed that mayors perceived multidimensional benefits from membership, but this executive-level awareness did not percolate to the citizen level. The governance layer and the lived-experience layer operated with different information sets.

3.2. Brand Awareness and Gastronomic Tourism Identity

Stanowicka et al. [1] provided the most direct evidence on brand awareness. Their survey of residents in Polish Cittaslow towns concluded that awareness levels were too low to support the sustainable development goals embedded in the certification. The implications for gastronomy tourism are immediate but have not been drawn in the existing literature.
Gastronomic tourism experience derives its authenticity from the quality of interaction between visitors and local communities. Nilsson et al. [6] framed Cittaslow's eco-gastronomic heritage as a destination development instrument, arguing that local food identity and destination branding form an integrated structure. Emmendoerfer et al. [7] traced the co-creation of a local dish in Vizela, Portugal, and showed that the process required active community engagement; the Cittaslow initiative provided institutional scaffolding, but the gastronomic attraction itself was a collective product. Çiçek et al. [9] demonstrated empirically that the Slow City movement strengthened place authenticity perceptions and that this strengthened authenticity positively influenced entrepreneurial opportunities and economic development.
The common thread across these studies is that gastronomic tourism identity cannot be manufactured by institutional decree alone. It requires residents who understand the brand,

identify with it, and communicate it through their daily interactions with visitors. A local producer at a farmers' market who knows what Cittaslow stands for tells a different story about the cheese she sells than one who has never heard the term. A restaurant owner who understands the movement's gastronomic philosophy curates a menu with intentionality; one who does not simply serves food. The brand awareness deficit, measured by Stanowicka et al. [1], means that this transmission channel operates at reduced capacity across the network.

3.3. Constrained Community Mobilization

The third dimension of the paradox concerns collective action. Sustainability transitions at the local level require community buy-in, and community buy-in requires awareness of what is being asked and why. Brodziński and Kurowska [10] studied resident surveys in Lidzbark Warmiński and found that Cittaslow membership had a positive but limited effect on participatory dynamics and quality-of-life perceptions. Park and Kim [11] reported from Goolwa, Australia, that Cittaslow philosophy enhanced community involvement and empowerment, though the mechanisms translating empowerment into concrete sustainability actions remained unclear.

The constraint operates in both directions. Low awareness limits residents' capacity to participate in sustainability initiatives because they do not recognize the institutional framework that organizes those initiatives. Simultaneously, the absence of resident participation weakens the municipality's capacity to implement ambitious environmental or gastronomic programs because those programs depend on voluntary community engagement for their effectiveness.

Kalbarczyk and Roszyk [12] offer an indirect benchmark. In five small non-Cittaslow Polish towns, only four to six percent of council resolutions addressed climate-related topics. Whether Cittaslow towns significantly outperform this baseline in terms of community-level climate engagement cannot be established with current data, precisely because existing studies measure institutional outputs rather than community-level participation in environmental action.

Wierzbicka [13] documented substantial socio-economic heterogeneity across twenty-eight Polish Cittaslow towns, which suggests that the paradox does not manifest uniformly. Towns with stronger economic bases and higher quality-of-life indices may have residents more receptive to brand engagement, while towns facing structural constraints may struggle to generate awareness even when institutional performance is strong.

Table 1. Components of the Awareness Paradox and Supporting Evidence

Component	Core finding	Supporting sources
Institutional-societal perception gap	Certification produces measurable institutional improvements that residents neither perceive nor attribute to Cittaslow	[2], [3], [4], [5], [8]
Brand awareness and gastronomic identity	Low awareness prevents residents from functioning as brand ambassadors in gastronomic tourism encounters	[1], [6], [7], [9]
Constrained community mobilization	Awareness deficit weakens the societal base needed for sustainability and environmental action	[10], [11], [12], [13]

The model operates as follows. Cittaslow certification generates environmental and gastronomic policies at the municipal level. These policies produce institutional outputs: infrastructure investments, energy efficiency gains, local food support mechanisms. The translation of these outputs into gastronomic tourism experience and community sustainability action depends on resident awareness as a mediating variable. When awareness is low, a fracture opens between institutional outputs and societal ownership. That fracture weakens both the

gastronomic authenticity perceived by visitors and the community's capacity to mobilize around sustainability objectives.

4. Discussion and Conclusion. The awareness paradox identified here exposes a structural vulnerability in the Cittaslow model. The movement's certification system is designed to evaluate and improve municipal-level performance across seven macro-areas, and the evidence from the Polish network confirms that it does so with measurable effect [2,8,13]. What the system does not evaluate, and what this analysis reveals as a critical gap, is whether institutional performance resonates at the community level.

The theoretical implication is that Cittaslow research needs to treat resident perspective as an independent unit of analysis rather than a secondary data point. Wierzbicka's [2,8,13] body of work provides an invaluable institutional baseline but does not systematically examine how residents experience, interpret, or engage with the changes happening around them. Presenza and Perano [14] analyzed tourism governance as an institutional phenomenon without questioning its societal legitimacy base. The paradox concept proposed here suggests that institutional governance and societal ownership are not redundant categories; they can diverge, and when they do, the consequences for destination sustainability are tangible.

For gastronomy tourism specifically, the paradox touches the authenticity question directly. Tourists seeking gastronomic experiences in Cittaslow destinations encounter local communities as the primary mediators of authenticity. The vendor at the farmers' market, the family running a traditional restaurant, the resident sharing a local recipe: these interactions constitute the gastronomic experience in ways that institutional marketing cannot replicate. When these mediators are unaware of the Cittaslow identity, the destination's gastronomic narrative reaches visitors in fragmented and inconsistent form. Over time, that inconsistency risks eroding the destination brand itself.

Three conceptual intervention points emerge from the analysis. The first targets the certification mechanism itself. Incorporating resident awareness and participation indicators into the recertification process would connect institutional performance with societal legitimacy. The second targets gastronomic tourism programming. Local food events, farmers' markets, and gastronomy routes could be redesigned as vehicles for communicating the Cittaslow identity to residents, not only to tourists. The third targets communication strategy. Awareness campaigns addressing residents specifically, framing certification not as an abstract international label but as a concrete value proposition relevant to daily life, could begin closing the awareness gap.

The principal limitation of this study is its conceptual character. The paradox's magnitude, mechanisms, and contextual variations require empirical investigation through mixed-methods research at the resident level. The evidence base draws predominantly from the Polish network, which constrains generalizability. Comparative research across Turkish, Italian, and South Korean Cittaslow networks would clarify whether the paradox is universal or context-dependent.

The Cittaslow movement offers small towns an institutional framework of genuine value. Whether that value reaches the people who live in those towns, and whether their awareness shapes the gastronomic tourism experience that visitors seek, are questions that the current literature has only begun to ask. The awareness paradox described here suggests that the distance between institutional achievement and societal ownership is wider than the movement's advocates have acknowledged, and that closing it may be the single most consequential step toward authentic destination sustainability.

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Urban Carbon and Ecological Footprint Assessment: A Case Study of Zonguldak

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1. Introduction. Cities are major contributors to environmental sustainability challenges, particularly through greenhouse gas (GHG) emissions, with carbon dioxide (CO_2) being the primary driver of climate change. Therefore, accurately quantifying and reporting the carbon footprint (CF) of urban areas is essential for developing effective mitigation and adaptation strategies [1]. Urban carbon footprint assessment methods are generally classified into three categories. The territorial-based approach measures emissions within city boundaries (Scopes 1 and 2) and is the most widely used method [2–4]. In contrast, the consumption-based approach accounts for emissions embedded in goods and services consumed within the city, capturing global supply chain impacts [5,6]. Hybrid approaches combine both perspectives, integrating direct and indirect emissions (Scopes 1–3) to provide a more comprehensive assessment. These methods are aligned with international frameworks such as the GHG Protocol for Cities (GPC) and IPCC Guidelines.

2. Material and Method. In this study, the carbon footprint of Zonguldak was estimated using a territorial-based approach in line with the IPCC Guidelines and the GHG Protocol for Cities (GPC), focusing on Scope 1 and Scope 2 emissions within city boundaries. The analysis was based on activity data, including energy consumption, transportation, water use, and waste generation, obtained from official reports.
Emissions were calculated using IPCC-based emission factors according to the equation:The carbon footprint was calculated using IPCC-based emission factors. The formula used: $E = AD \times EF$
The activity data and estimated vehicle distribution by fuel type are summarized in Table 1 and Table 2, respectively.
Table 1. Urban Activity Data for Zonguldak

Parameter	Value	Unit	Description
Population	588,510	persons	Total population
Coal consumption	7,930,697	tons/year	Industrial + energy sector
Natural gas consumption	619,784,617	m³/year	Residential + industrial
Electricity consumption (per capita)	5,582	kWh/person-year	Average consumption
Total electricity consumption	3,285,000,000	kWh/year	Estimated total
Water consumption	135	L/person-day	Domestic water use
Total water consumption	~29,000,000	m³/year	Annual estimate
Solid waste generation	162,082	tons/year	Municipal waste
Number of vehicles	174,507	vehicles	Total registered vehicles

Table 2. Vehicle Distribution by Fuel Type

Fuel Type	Percentage (%)	Number of Vehicles
Gasoline (Petrol)	30%	52,352
Diesel	50%	87,254
LPG	18%	31,411
Electric/Hybrid	2%	3,490
Total	100%	174,507

3. Results. Total emissions were estimated at approximately 22 million tons CO_2e as presented in Table3.

Table 3. Estimated carbon emissions by sector

Source	Emissions (tCO2e)	Share (%)
Coal	19,000,000	86
Natural Gas	1,180,000	5
Electricity	1,370,000	6
Transportation	349,000	1.5
Waste	81,000	0.4
Water	14,500	0.1

The analysis of urban activity data indicates that Zonguldak has a highly energy-intensive emission profile, primarily driven by fossil fuel consumption. The total carbon footprint was estimated to be approximately 22 million tons of CO_2 equivalent (tCO_2e) per year**,** with a clear dominance of coal-based emissions**,** which account for nearly 85–90% of total emissions. This is largely attributed to the presence of thermal power plants and heavy industrial activities**,** particularly in the iron–steel sector.

Natural gas and electricity consumption contribute a smaller but still significant share, representing approximately 5–6% each of total emissions. In contrast, emissions from transportation, waste generation, and water use remain relatively limited, collectively accounting for less than 3% of total emissions. The distribution of vehicles by fuel type indicates a predominance of diesel-powered vehicles, followed by gasoline and LPG, which further supports the contribution of fossil fuels to urban emissions.

4. Discussion and Conclusion. The findings indicate that Zonguldak exhibits a coal-dominated carbon emission structure, largely driven by its industrial activities and energy production systems. Compared to other urban areas, where transportation and electricity consumption are typically the main contributors, the overwhelming share of emissions from coal highlights a distinct regional energy profile.

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Seasonal Analysis of NO_2 Concentrations over Zonguldak Province Using Sentinel-5P Data

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1. Introduction – Air pollution is one of the most critical environmental problems affecting human health and ecosystems worldwide. Rapid industrialization, urbanization, and increasing energy demand have significantly increased atmospheric pollutant concentrations over recent decades [1]. Among these pollutants, nitrogen dioxide (NO_2) is particularly important due to its role in atmospheric chemistry, contribution to ozone formation, and adverse effects on respiratory health [2]. Although ground-based air quality monitoring stations provide accurate measurements, their spatial distribution is often limited due to high installation and maintenance costs [3]. This limitation restricts the ability to analyze pollution patterns over large areas, especially in regions with complex terrain or industrial activities. In this context, satellite-based remote sensing has become a powerful alternative, enabling continuous and large-scale monitoring of atmospheric pollutants [4]. The Sentinel-5 Precursor (Sentinel-5P) satellite, equipped with the TROPOMI sensor, provides high-resolution measurements of atmospheric trace gases, including NO_2, with near-daily global coverage [5]. Zonguldak province, located in the Black Sea region of Türkiye, is characterized by intensive coal mining, thermal power plants, and industrial activities. These characteristics make the region particularly important for air pollution studies. This study aims to analyze the seasonal variation of NO_2 concentrations over Zonguldak using Sentinel-5P data for the year 2025. The analysis was conducted using the Google Earth Engine (GEE) platform, focusing on spatial distribution and temporal variability of NO_2 levels.

2. Material and Method - This study aims to analyze the spatial and temporal distribution of nitrogen dioxide (NO_2) concentrations over Zonguldak province, located in the northern part of Türkiye, a region characterized by intensive coal mining, thermal power generation, and industrial activities. The administrative boundaries of the study area were obtained from the FAO GAUL dataset and utilized within the Google Earth Engine (GEE) platform to spatially constrain the analysis. Satellite-based atmospheric observations were derived from the Sentinel-5 Precursor (Sentinel-5P) satellite, launched by the European Space Agency (ESA) in 2017 and equipped with the Tropospheric Monitoring Instrument (TROPOMI). This sensor provides high spatial resolution measurements (approximately 7 × 3.5 km^2), enabling the detection of atmospheric pollutants at the urban scale. In this study, the Level-3 dataset (COPERNICUS/S5P/OFFL/L3_NO2), which provides tropospheric NO_2 column number density values in units of $\mu mol/m^2$, was employed. The dataset was temporally filtered to cover the year 2025, and pixels with a cloud cover fraction exceeding 30% were excluded. All datasets were spatially clipped to the administrative boundaries of Zonguldak. To assess seasonal variability, the dataset was categorized into four distinct periods: winter (December 2024–February 2025), spring (March–May 2025), summer (June–August 2025), and autumn (September–November 2025). For each period, mean NO_2 concentration values were computed using image collection averaging functions (mean()) available within GEE. Furthermore, spatial statistical analyses were conducted using region-based reduction techniques (reduceRegion), through which minimum, maximum, mean, and standard deviation values were derived to comprehensively evaluate the spatial distribution of NO_2 concentrations. The

results were visualized using a standardized color scale ranging from low (green) to high (red) concentration values to ensure consistency and comparability across seasonal maps. In addition, temporal variability was examined through the generation of a daily time-series dataset for the year 2025, enabling the identification of short-term fluctuations and episodic pollution events. All spatial outputs were generated at an approximate spatial resolution of 1 km, providing a detailed representation of NO_2 distribution patterns across the study area.

3. Results – The seasonal analysis of NO_2 concentrations over Zonguldak province reveals a pronounced spatial and temporal variability throughout the year 2025. Daily time-series analysis further indicates fluctuations between 4.0×10^{-5} and 2.5×10^{-4} μmol/m², reflecting both seasonal trends and short-term pollution episodes (Figure 1).

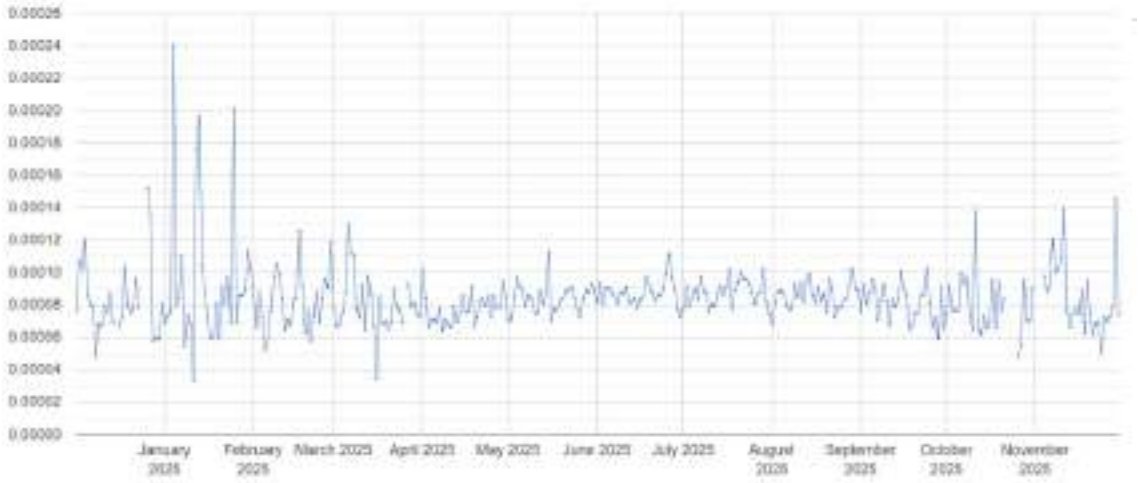

Figure 1. Daily variation of NO_2 column density over Zonguldak Province during 2025

These values are consistent with ranges reported in the literature for polluted urban and industrial regions, where NO_2 concentrations typically vary between 1×10^{-5} and 6×10^{-5} μmol/m², although higher values may occur in areas with intensive industrial activity [6]. Seasonal mean NO_2 concentrations demonstrate a clear pattern: winter exhibits the highest average values (1.10×10^{-4} μmol/m²), followed by autumn (9.5×10^{-5} μmol/m²), spring (8.5×10^{-5} μmol/m²), and summer (7.5×10^{-5} μmol/m²). These results indicate that winter NO_2 levels are approximately 45–50% higher than those observed in summer, highlighting a strong seasonal dependency. The spatial distribution of NO_2 concentrations shows that elevated values are predominantly concentrated in coastal and industrial zones, consistent with the presence of coal mining activities, thermal power plants, and other anthropogenic emission sources in the region (Figure 2).

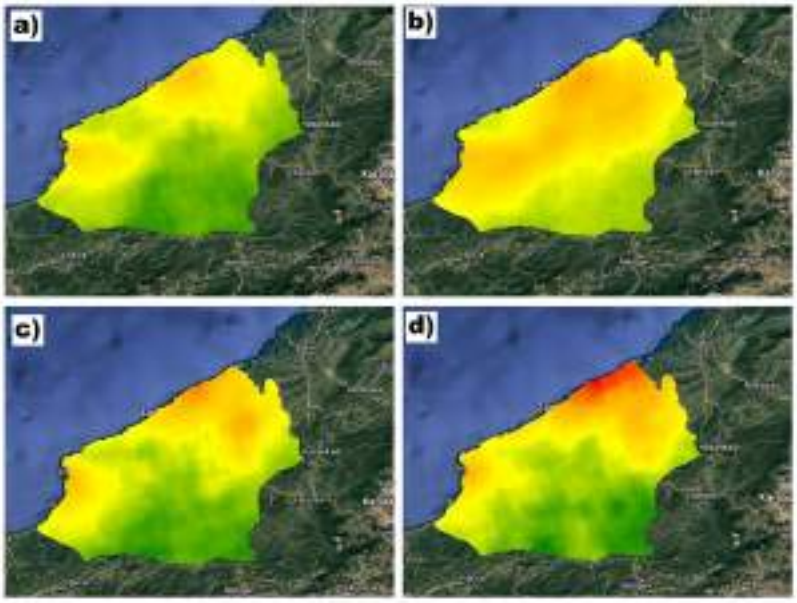

Figure 2. Seasonal spatial distribution of NO_2 concentrations over Zonguldak Province derived from Sentinel-5P data: (a) Spring, (b) Summer, (c) Autumn, (d) Winter 2025.

Among all seasons, autumn presents the most pronounced hotspot patterns, whereas summer is characterized by more homogeneous and comparatively lower concentration levels. Temporal variation supports these findings by revealing distinct peak periods during winter months and autumn. These peaks indicate episodic pollution events likely associated with increased fossil fuel consumption, residential heating, and intensified industrial emissions. In addition, unfavorable meteorological conditions, such as temperature inversions and reduced atmospheric mixing, contribute to the accumulation of pollutants during these periods. In contrast, summer exhibits lower NO_2 concentrations, reduced variability, and fewer extreme peaks. This pattern can be attributed to enhanced atmospheric dispersion, increased vertical mixing, and photochemical processes that facilitate the breakdown of NO_2. Overall, the results demonstrate that both anthropogenic emission sources and meteorological conditions play a critical role in shaping the seasonal dynamics of NO_2 concentrations over Zonguldak.

4. Discussion and Conclusion - The findings of this study reveal that NO_2 concentrations over Zonguldak exhibit pronounced seasonal variability and reflect a hybrid “industrial–urban” air pollution profile. Elevated NO_2 levels observed during winter can be attributed to increased fossil fuel consumption combined with topographically driven temperature inversion conditions, which trap pollutants near the surface. This pattern is consistent with findings reported in the literature for industrialized regions. In contrast, lower and more homogeneous NO_2 concentrations during summer reflect enhanced atmospheric mixing and the influence of photochemical processes. Spatial analysis indicates that higher NO_2 concentrations are primarily concentrated in industrial zones and coastal areas, closely associated with coal mining activities, thermal power plants, and other anthropogenic emission sources in the region. The high spatial resolution provided by Sentinel-5P data enables not only the monitoring of urban centers but also the detection of pollution patterns in rural and industrial corridors beyond the coverage of ground-based monitoring stations. This highlights the effectiveness of satellite-based observations as a complementary tool for regional air quality assessment. From a sustainable urban planning perspective, the results suggest several practical implications for improving air quality in Zonguldak. These include the expansion of centralized heating systems

within urban transformation projects, the optimization of flue gas treatment technologies (SCR/SNCR) in industrial facilities, and the development of green corridors within transportation networks. Furthermore, this study demonstrates that satellite-based monitoring systems can serve as a cost-effective and efficient decision-support mechanism for local authorities. For future research, integrating satellite observations with ground-based measurements and incorporating detailed meteorological parameters would enhance the accuracy and interpretability of the results. Additionally, the inclusion of other air pollutants (e.g., $PM_{2.5}$, SO_2) and the use of long-term datasets would contribute to a more comprehensive understanding of air pollution dynamics in the region.

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Academic Resume

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The Invisible Determinant of Open-Air Gastronomy Experience: Air Quality as a Moderator of Gastronomic Destination Attractiveness in Cittaslow Towns

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1. Introduction. Consider a tourist at a farmers' market in a Cittaslow-certified town. She samples local cheese from a producer who has been making it for three generations. The cheese is exceptional. But the market is set up in the town square, and on this particular morning the air carries a faint acrid note from coal-fired residential heating two streets away. The sensory environment in which the tasting occurs is part of the tasting itself, whether or not the tourism literature acknowledges it.

The Cittaslow movement, founded in 1999 and now encompassing over two hundred and fifty certified towns worldwide, places gastronomy at the heart of its destination identity [1,2]. Certification criteria explicitly require support for local food production, protection of traditional culinary heritage, and promotion of gastronomic events [3,4]. A parallel set of criteria addresses energy and environmental policy, including energy efficiency, low-emission mobility, and green space expansion [5]. These two policy domains, gastronomic governance and environmental governance, coexist within the same certification framework, are implemented by the same municipal authorities, and affect the same physical spaces. Yet no study has examined how they interact, and specifically, no study has asked whether the environmental quality of a Cittaslow destination affects the quality of the gastronomic experience it offers.

The omission is not unique to Cittaslow research. Gastronomy tourism scholarship has overwhelmingly treated gastronomic experience as a content-driven phenomenon: the food's taste, its cultural meaning, its narrative, its preparation ritual [6,7]. The physical environment in which eating, tasting, and culinary exploration take place has been analyzed in aesthetic or architectural terms but rarely in environmental quality terms. Air quality, the most basic atmospheric condition shaping any outdoor experience, has received essentially no attention in the gastronomy tourism literature.

There are reasons to believe this oversight matters. Gastronomy tourism in small towns, and Cittaslow towns in particular, is disproportionately an open-air activity. Farmers' markets operate in squares and streets. Harvest festivals take place in fields and vineyards. Terrace restaurants and outdoor cafés define the dining landscape. Food trails connect producers across rural terrain. The atmospheric quality of these settings is not a background condition that visitors can ignore; it is a sensory input that shapes the experience itself.

On the environmental side, Cittaslow certification criteria generate interventions with direct air quality implications. Energy efficiency programs reduce heating-related emissions. Cycling path investments displace motorized traffic from town centers. Green space expansion increases vegetative air filtration capacity [5,8,9]. These interventions have been documented in environmental terms but never linked to their effects on the gastronomic tourism experience that takes place in the same physical spaces.

This paper proposes a conceptual model that positions air quality as a moderator variable in the relationship between gastronomic governance capacity and destination attractiveness in Cittaslow towns. The objectives are threefold: to map the air-quality-relevant intervention repertoire embedded in Cittaslow certification, to conceptualize the open-air dependency of gastronomy tourism, and to develop testable propositions linking air quality conditions to

gastronomic destination outcomes.

2. Material and Method. The study is conceptual and involves no primary data collection. Three categories of source material inform the analysis: peer-reviewed studies on Cittaslow-certified municipalities, Cittaslow International's certification criteria documentation, and theoretical work on gastronomy tourism and destination attractiveness.

Literature was identified through the Undermind AI-assisted academic search platform, using search terms that combined Cittaslow, climate change, environmental policy, tourism, and community resilience across the 2000 to 2025 publication window. From over one hundred and sixty screened sources, twelve core studies and three supplementary references were selected based on verified Cittaslow membership, empirical content, and relevance to either environmental interventions or gastronomy tourism dynamics.

The analytical approach is conceptual framework development through critical narrative synthesis. The process unfolded in three stages. First, Cittaslow certification criteria were analyzed for their air quality relevance through document review. Second, gastronomy tourism's dependency on open-air conditions was conceptualized by reinterpreting existing empirical findings. Third, these two analytical layers were integrated into a moderator variable model, and testable propositions were formulated. The original version of this paper was written in Turkish. The English translation was produced using Claude AI (Anthropic) and subsequently reviewed by the author for terminological accuracy, conceptual fidelity, and scholarly tone.

3. Results. **3.1. Air Quality Interventions Within the Cittaslow Certification Framework**

Cittaslow's energy and environmental policy macro-area contains criteria that bear directly on air quality, even though the term "air quality" does not appear explicitly in the certification language. The connection operates through specific intervention types.

Wierzbicka [5] analyzed how Polish Cittaslow towns performed in this macro-area between initial certification and five-year recertification. Score improvements reflected documented actions in energy efficiency, environmental monitoring, and resource management. Energy efficiency programs targeting residential and public buildings reduce fossil fuel combustion for heating, which is the dominant source of particulate matter and sulfur dioxide emissions in small Central European towns during winter months. The air quality benefit is a direct physical consequence of the intervention, even though neither the certification system nor the research literature frames it in those terms.

Gazińska et al. [8] mapped post-certification investments in twenty-nine Polish Cittaslow towns and found cycling paths, pedestrian trails, and recreational green areas among the most common interventions. These investments reconfigure mobility patterns within the town. When residents and visitors shift from motorized transport to cycling or walking, traffic-related nitrogen dioxide and particulate emissions in the town center decline. The magnitude of this effect depends on the displacement ratio, which has not been measured in any Cittaslow study, but the directional logic is unambiguous.

Green space expansion, documented by both Gazińska et al. [8] and Wierzbicka [9], contributes to air quality through vegetative filtration of particulate matter, absorption of gaseous pollutants, and reduction of urban heat island effects that concentrate ground-level ozone. These functions are well established in the urban ecology literature but have never been connected to the Cittaslow context.

Batyk et al. [10] examined renewable energy support across all thirty-five Polish Cittaslow municipalities and found practical support lagging behind strategic ambitions. This finding indicates unrealized potential: a transition from fossil fuels to renewable sources would eliminate combustion-related emissions at their origin, producing the most direct air quality

benefit available to municipal governance. That the transition has not materialized despite strategic rhetoric suggests a constraint that recertification processes might address.

A contextual reference point comes from Kalbarczyk and Roszyk [11], who studied five non-Cittaslow small towns and found that climate-related content appeared in only four to six percent of council resolutions, concentrated in transport, energy, and water management. Whether Cittaslow membership elevates this proportion remains unmeasured, but the certification framework's structured attention to energy and environmental policy suggests a plausible differentiation mechanism.

Table 1. Cittaslow Certification Interventions and Air Quality Transmission Mechanisms

Intervention type	Mechanism linking to air quality	Evidence source
Energy efficiency programs	Reduced fossil fuel combustion lowers particulate matter and SO_2 emissions	[5]
Low-emission mobility investments	Displacement of motorized traffic reduces NO_2 and PM in town centers	[8], [9]
Green space expansion	Vegetative filtration of particulates; ozone precursor absorption; heat island mitigation	[8], [9]
Renewable energy support	Elimination of combustion emissions at source	[10] (potential present, implementation weak)
Local food supply chain shortening	Reduced long-distance food transport emissions	[6], [7] (indirect)

3.2. The Open-Air Dependency of Gastronomy Tourism

Gastronomy tourism research has treated the gastronomic encounter as primarily a content phenomenon. The food, its story, its preparation, its cultural embedding: these are the variables that receive analytical attention. The spatial and atmospheric conditions under which eating, tasting, and culinary exploration occur have remained largely unexamined.

Nilsson et al. [6] positioned eco-gastronomic heritage as a destination development instrument but did not analyze the physical environments where that heritage is presented to visitors. Emmendoerfer et al. [7] examined the social process of co-creating a local dish in a Cittaslow town, focusing on community participation dynamics without engaging the spatial conditions of the co-creation process. Çiçek et al. [12] demonstrated that Slow City membership strengthened place authenticity perceptions, yet authenticity was operationalized through social and economic indicators without environmental quality dimensions.

What these studies share is a content-centered analytical frame. The gastronomic experience is examined for what happens on the plate and in the social interaction around it, not for what happens in the air, the light, and the sensory surround of the setting. This frame is incomplete for Cittaslow destinations, where gastronomic encounters are embedded in open-air environments by design rather than by accident. The Slow City philosophy actively promotes public squares, pedestrian zones, outdoor markets, and rural landscapes as the stages on which local life, including gastronomic life, unfolds [3,4,13].

The dependency operates through multiple sensory channels. Olfaction is the most obvious: food aromas at an outdoor market compete with, or are contaminated by, ambient odors that include vehicle exhaust, industrial emissions, or agricultural burning residues. Respiratory comfort affects the duration and quality of outdoor dining, particularly for visitors with respiratory sensitivities. Visual atmosphere, which includes haze, clarity, and light quality, shapes the aesthetic experience of eating outdoors. Thermal comfort, influenced by green

infrastructure and heat island effects, determines whether outdoor gastronomic settings are pleasant or oppressive.

3.3. The Moderator Variable Model

Synthesizing the two preceding findings produces the paper's central proposition: air quality functions as a moderator variable in the relationship between gastronomic governance capacity and destination attractiveness.

The model's independent variable is the Cittaslow town's gastronomic governance capacity, operationalized through the certification criteria relating to local food policy, gastronomic events, traditional production support, and culinary heritage preservation. The dependent variable is gastronomic destination attractiveness, measurable through visitor satisfaction, repeat visitation intention, gastronomic authenticity perception, and destination loyalty.

The moderating variable is air quality. It conditions the strength of the relationship between governance capacity and attractiveness. In a Cittaslow town with strong gastronomic governance and good air quality, open-air gastronomic experiences realize their full experiential potential and destination attractiveness is strong. In the same town with poor air quality, the gastronomic content remains identical, but the experiential environment degrades the encounter, and attractiveness weakens.

The model integrates Presenza and Perano's [14] finding that certification structures tourism governance, Wierzbicka's [5] evidence on environmental policy improvements, and Nilsson et al.'s [6] conceptualization of eco-gastronomic heritage. In the existing literature, these three elements occupy separate analytical compartments. The moderator model connects them through a specific causal pathway: environmental governance produces air quality effects; air quality conditions the experiential translation of gastronomic governance into destination attractiveness.

Four propositions are derived from the model:

Proposition 1: Tourist satisfaction with open-air gastronomic experiences in Cittaslow towns will correlate positively with destination-level air quality indicators.

Proposition 2: Cittaslow towns with high recertification scores in the energy and environmental policy macro-area will outperform low-scoring towns on gastronomy tourism satisfaction measures.

Proposition 3: The moderating effect of air quality will be significantly stronger for open-air gastronomic experiences than for indoor dining experiences within the same destination.

Proposition 4: Cittaslow towns with concentrated low-emission mobility investments in areas where gastronomic tourism activity is densest (market squares, restaurant districts, festival grounds) will exhibit higher environmental comfort levels and stronger gastronomic destination loyalty.

The model's logic can be summarized as follows. Cittaslow certification generates two parallel policy output streams. The first is gastronomic governance (local food support, gastronomy events, traditional production preservation). The second is environmental governance (energy efficiency, low-emission mobility, green infrastructure). These two streams produce independent effects on destination attractiveness. But a portion of the environmental governance stream directly affects air quality, and air quality in turn conditions how effectively gastronomic governance translates into destination attractiveness. This indirect and conditional relationship defines the moderator function.

4. Discussion and Conclusion The model developed in this paper makes a claim that is simultaneously straightforward and absent from the literature: the air that visitors breathe while

eating outdoors in a Cittaslow town is part of the gastronomic experience, and the quality of that air is shaped by the same certification framework that governs the gastronomic content. Straightforward as this claim may seem, its implications for both research and practice are substantial.

For Cittaslow scholarship, the moderator model bridges two research tracks that have developed without mutual reference. Wierzbicka's [5,9,15] sustained investigation of the Polish network measured environmental and socio-economic indicators with precision but did not extend the analysis to tourism experience outcomes. Presenza and Perano [14] examined tourism governance without incorporating environmental variables. Nilsson et al. [6] and Emmendoerfer et al. [7] explored gastronomic heritage and identity without considering the environmental conditions under which gastronomic encounters occur. The air quality concept provides a concrete mechanism through which environmental governance and gastronomic governance interact, and the moderator model provides a testable structure for investigating that interaction.

For gastronomy tourism research more broadly, the paper introduces an environmental quality dimension that the field has not engaged. Gastronomy tourism scholarship has analyzed food, culture, narrative, and social interaction in considerable depth. The physical environment of the gastronomic encounter, and specifically its atmospheric quality, has remained a blind spot. This oversight may be less consequential for indoor dining in metropolitan settings, but it is difficult to justify for open-air gastronomic tourism in small towns, where the boundary between the meal and the environment dissolves entirely.

The practical implications follow two paths. For Cittaslow International, integrating air quality indicators into the recertification assessment, or at minimum evaluating the environmental policy and gastronomy policy macro-areas for cross-domain synergies, would align the certification system with the experiential reality of its member towns. For municipal planners, the spatial co-location of environmental and gastronomic investments offers an efficiency gain: a cycling infrastructure project that connects local producers along a gastronomy route, passing through a green corridor that filters air and reduces traffic noise, generates environmental, gastronomic, and tourism returns from a single budget line.

One practical suggestion deserves specific mention. Gastronomic event scheduling could incorporate seasonal air quality data. In Polish Cittaslow towns, winter months bring elevated particulate concentrations from residential heating. Scheduling signature gastronomic events during periods of better air quality, or investing in heating transition programs that reduce winter emissions in advance of winter food festival seasons, would operationalize the moderator relationship identified in this paper.

The study carries limitations that define the next research frontier. The model is conceptual and untested. Empirical validation requires two types of data that do not currently exist in integrated form: air quality measurements at the municipal level (particulate matter, nitrogen dioxide, ozone) and gastronomy tourism satisfaction data (visitor surveys, repeat visitation statistics, online review scores) for the same Cittaslow destinations. Copernicus atmospheric monitoring services and national environmental agency datasets could supply the environmental side; primary survey research would need to supply the tourism side. The model's validity should be tested across different climate zones because air quality patterns differ substantially between Mediterranean, Northern European, and East Asian Cittaslow networks, and the moderating effect may vary in strength and mechanism accordingly.

A further limitation is the Polish concentration of the evidence base [5,8,9,10,15]. Poland's Cittaslow towns face winter heating-related air pollution that amplifies the moderator effect for cold-season gastronomy tourism. Whether the same mechanism operates with comparable

strength in Mediterranean towns, where summer ozone pollution is the dominant concern, or in East Asian towns with industrial emission profiles, requires separate investigation.

The air that surrounds a gastronomic experience is as much a part of that experience as the food on the plate. Cittaslow certification shapes both the gastronomic content and the atmospheric environment, yet these two outcomes have been studied as if they belonged to different realities. The moderator model proposed here is an attempt to reconnect them, grounded in the evidence that already exists but has not previously been read together. Whether the model survives empirical testing is a question for the next study. That the question itself has not been asked until now is, perhaps, the most telling finding of all.

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Environmental Distribution and Ecotoxicological Effects of Rare Earth Elements

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1. Introduction. The increasing use of rare earth elements (REE) in various industries has led to higher rates of release into the environment, drawing widespread attention to these elements as significant new-generation pollutants. The aim of this study is to summarize the distribution of REE in global soil and water resources in line with sustainability goals and to contribute to the field by examining their effects on plant physiology and development. [1].

2. Material and Method. As part of this study, the current status of rare earth elements (REEs) in the context of plant ecotoxicology was assessed using a literature review methodology. Searches were conducted using the Web of Science, Google Scholar, and ScienceDirect databases with keywords such as "rare earth elements," "plants," "bioavailability," and "growth and development." Articles published primarily between 2005 and 2026 in peer-reviewed environmental and toxicology journals were reviewed [1-3].

3. Results. Mining activities and the agricultural use of NTE are the primary sources of the accumulation of these elements in soil. While more than 99.5% of exogenous NTE entering the soil is absorbed by the soil's solid phase, ecosystems near mining waste sites are more significantly affected by contamination.

The key findings from the study of interactions with plants are as follows:

Under normal conditions, the transfer/bioavailability factor of NTE from soil to plants is less than 1. However, some hyperaccumulator fern species, such as Dicranopteris dichotoma, can accumulate NTEs equivalent to 0.17% to 0.38% of their dry weight.

The effect of NTE on plant growth is dose-dependent; while low concentrations promote seed germination and seedling growth, high concentrations exhibit an opposite effect beyond a certain threshold, leading to cellular damage and necrosis.

NTE applications at appropriate doses increase antioxidant enzyme activities, thereby enhancing plants' resistance to abiotic stresses such as drought, low temperature, and salinity.

At the cellular level, NTEs compete for calcium-binding sites due to their structural and chemical similarities; they can pass through Ca+ channels in the cell membrane, displace calcium in the chloroplast matrix, and affect photosynthetic efficiency.

4. Discussion and Conclusion. NTE have multifaceted and complex physiological effects on plants. While they have been observed to increase plant stress tolerance at low doses, their slow and continuous accumulation in the environment can pose a significant ecological problem in potential contamination zones. Elemental monitoring studies conducted in laboratory settings using advanced analytical spectroscopic techniques provide a critical foundation for elucidating

bioavailability mechanisms and developing more sustainable strategies for the use of rare earth elements.

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Green Analytical Approaches to the Monitoring of Air Pollutants Using Spectroscopic Methods

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1. Introduction. Air sampling filters are widely used in industrial work environments to monitor air pollution, particulate matter concentrations, and respirable hazardous components. The detailed chemical characterization of pollutants requires filters that meet important analytical constraints, such as resistance to chemical extraction processes and permeability to electromagnetic waves. Today, advanced analytical techniques such as Fourier Transform Infrared (FTIR) and Raman spectroscopy stand out as non-destructive methods that enable the direct examination of particles collected on membrane filters [1,2,3].

2. Material and Method. The objective of this study was to identify filters that can be used to determine the mass concentration of air pollutants and subsequently analyze their chemical composition using FTIR and Raman spectroscopy. To this end, the relevant literature was reviewed, and the chemical and physical properties of 12 different commercially available filter materials were examined in a comparative analysis.

3. Results. The results of the studies revealed that PTFE (Teflon) and PVC membrane filters have very low infrared (IR) absorbance and, as a result, perform well in FTIR analyses (Figure 1). In Raman spectroscopy measurements, it was found that polycarbonate and silver membrane filters do not cause spectral interference (Figure 2). Furthermore, it was observed that porous silver membrane filters can improve analytical sensitivity and signal quality by enhancing Raman scattering. For spectral analyses conducted using FTIR and Raman instruments to be successful, it is essential that the filters are spectrally neutral.

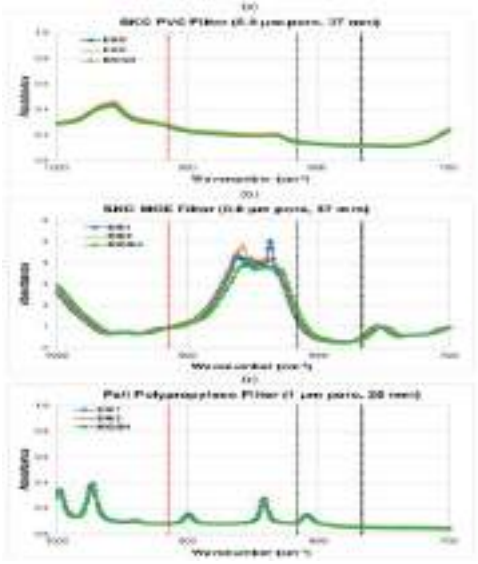

Figure 1. Comparison of blank membrane filters for FTIR [1]

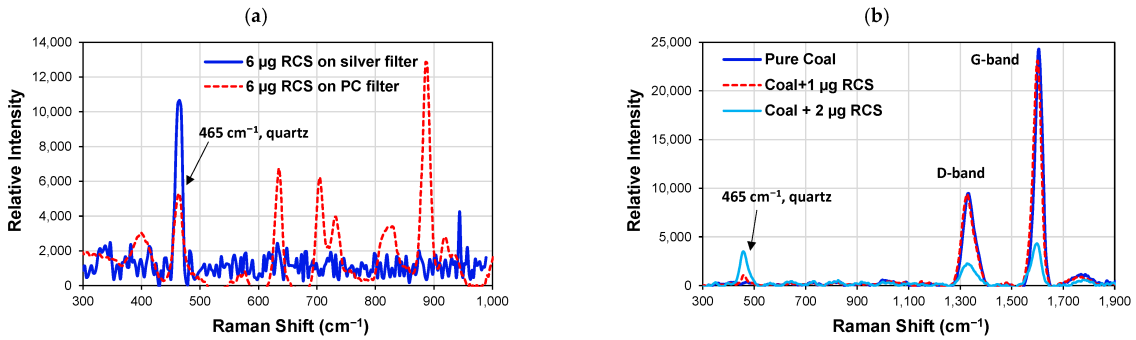

Figure 2. Raman spectras [1]

4. Discussion and Conclusion. Traditional methods for measuring air pollutants typically involve steps such as burning the sample (ashing) to destroy the organic matrix. However, by selecting suitable membrane filters (e.g., PTFE, PVC, or polycarbonate) that prevent spectral interference in the analysis region, an environmentally friendly measurement concept is achieved that is non-destructive, reduces chemical consumption, and provides rapid data. Aligned with the "Green Analytical Chemistry" vision, these direct-on-filter measurements provide an innovative infrastructure for industrial hygiene applications and environmental monitoring.

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Türkiye's Air Quality Legislation for a Sustainable and Healthy Future and the Case of Zonguldak

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1. Introduction. Air pollution remains a major environmental health threat globally, with the WHO estimating millions of premature deaths annually from poor ambient air quality [1]. In Türkiye, rapid urbanisation, industrial expansion, and rising motor vehicle density have driven the development of a comprehensive air quality management framework aligned with the EU environmental acquis [2]. The 2025 Climate Law No. 7552 has further integrated air quality with the national net-zero target [3]. This study analyses Türkiye's current air quality legislation and its local implementation, using Zonguldak — a Black Sea coastal city with distinctive topographical and industrial features — as a case study.

2. Material and Method. A qualitative document analysis was conducted covering: the Air Quality Assessment and Management Regulation (2008), source-specific control regulations (heating, industry, exhaust, fuel quality), Climate Law No. 7552 (2025). The technical assessment examined the HEY Emission Management System (1 km × 1 km resolution modelling) and the national monitoring network (urban, traffic, industrial, rural stations) with real-time public data via www.havaizleme.gov.tr. Historical Zonguldak data were retrieved from the HEY and World Air Quality database (aqicn.org).

3. Results. The regulatory framework imposes progressively tightening limit values, alert thresholds, mandatory clean air plans (Art. 10), and short-term action plans (Art. 11) with public information obligations (Art. 13). Institutionally, regional Clean Air Centres coordinate between relevant General Directorates, while the HEY system enables GIS-based street-level air quality mapping. The monitoring network continuously measures SO_2, PM_{10}, $PM_{2.5}$, NO_x, O_3, and CO,.

Table 1. Key factors affecting air quality in Zonguldak Province

Factor	Impact	Data Requirement
Topography	Restricts dispersion; valley inversions	High-resolution meteorological modelling
Solid fuel use	Major PM_{10} and SO_2 source in winter	Neighbourhood fuel consumption data
Traffic density	Elevated NO_x and PM in urban	Traffic count and fleet

Critical data gaps identified include the absence of neighbourhood-scale fuel use ratios, incomplete small enterprise emission inventories around stations, and insufficient integration of traffic and port data into the HEY platform. The 2025 Climate Law binds air quality improvement to the 2053 net-zero pathway.

4. Discussion and Conclusion. Türkiye possesses a robust and progressively structured air quality legislative framework with expanding technical infrastructure. However, Zonguldak exemplifies the implementation gap: topographical constraints, persistent solid fuel dependency, and multiple emission sources create a complex profile demanding locally tailored strategies beyond generic regulation. The Climate Law's integration of air quality and decarbonisation

policies offers transformative co-benefits. Priority actions include local emission inventories integrated with HEY, neighbourhood fuel surveys, expanded monitoring at traffic and port hotspots, and alignment of provincial clean air plans with climate obligations.

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Academic Resume

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Design of Positive Energy Sports Facilities: The Case of Zonguldak Tennis and Marine Sports Club

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1. Introduction. Sports facilities are among the building types that generate considerable environmental impacts due to their intensive energy use, water consumption, operational demands, and associated transportation activities. Heating, cooling, lighting, ventilation, and service functions increase the operational footprint of such facilities, making them a critical field for green transformation and climate action. In recent years, sustainable sports architecture has evolved from isolated interventions toward integrated strategies that combine renewable energy systems, passive design, efficient building envelopes, operational sustainability, and urban integration [1–5].

The literature reveals that renewable energy integration, especially solar and geothermal systems, plays a major role in reducing fossil fuel dependence in sports buildings [1,2,6]. In parallel, passive design strategies and high-performance building envelopes have been shown to reduce heating and cooling loads significantly [4,7]. Beyond the building scale, sustainable sports facilities are increasingly assessed in relation to urban accessibility, land use, water management, and stakeholder expectations [3,5,8]. This broader perspective is especially important for existing urban recreational facilities, where sustainable upgrading can support both climate action and more efficient land use without requiring new construction.

Within this context, the present study focuses on the Zonguldak Tennis and Marine Sports Club, an existing coastal recreational facility in Zonguldak, Türkiye. The study aims to evaluate the sustainability improvement potential of the club building and to develop a retrofit-oriented decision framework for its green transformation. Unlike generic or purely theoretical studies, this research is grounded in a real case and combines architectural layout information, site conditions, and sustainability scenario development. The study therefore may contribute to the green transformation and climate action and urban greening and sustainable land use by investigating how an existing urban sports facility can be upgraded into a more energy-efficient, environmentally responsible, and context-sensitive building.

2. Material and Method. This study was designed as a case-based sustainability assessment focusing on the Zonguldak Tennis and Marine Sports Club, an existing recreational sports facility located in Zonguldak, Türkiye. The material of the study consists of the satellite-based site information of the facility, its architectural floor plan, and a three-dimensional digital model developed to evaluate possible sustainability interventions. The methodological framework is based on Building Information Modeling (BIM), building energy simulation, and scenario-based sustainability assessment, which are widely used approaches in sustainable building and sports facility research [1–4].

Figure 1 presents the satellite view of the Zonguldak Tennis and Marine Sports Club and its surrounding site context. The image shows that the facility is located within an existing coastal recreational area, in close relation to tennis courts, vegetation, open spaces, and the shoreline. This spatial condition is significant because the study focuses on improving an already existing urban sports facility rather than proposing a new land-consuming development. In this respect, the case is directly related not only to energy efficiency and climate action, but also to sustainable land use and urban greening. Previous studies emphasize that the environmental performance of sports facilities should be evaluated not only at the building scale, but also in relation to urban integration, accessibility, and land-use context [5,6].

Figure 1. Zonguldak Tennis and Marine Sports Club

Figure 2 shows the architectural floor plan of the facility. According to the plan, the building has a total construction area of 249 m² gross and a net usable area of 220 m². The internal layout includes an administrative office, men's and women's changing rooms, bathrooms, entrance spaces, a main hall, a coach office, an archive, kitchens, a buffet area, and WC units. This plan provides the spatial basis for understanding the building's functional zoning, occupancy characteristics, wet areas, and service spaces. Such spatial information is essential for defining the baseline energy model, since different functional zones may have different heating, cooling, ventilation, lighting, and water-use patterns. Similar case-based studies on sustainable sports facilities indicate that building function, envelope characteristics, and operational use should be considered together to obtain reliable performance assessments [2,4,7].

Figure 2. Architectural floor plan of the facility

Figure 3 presents the three-dimensional model of the facility with rooftop photovoltaic panels. This visual represents one of the key sustainability scenarios considered in the study and illustrates the potential of the building roof for renewable energy generation. Solar energy integration has been widely discussed in the literature as one of the most effective strategies for reducing fossil fuel dependence and supporting the transition toward net-zero or positive-energy sports facilities [3,8]. In this study, the 3D model also provides a visual and analytical basis for evaluating the building form, roof suitability, and retrofit potential. Within the broader

project framework, the building model is intended to be developed in Autodesk Revit and used as a BIM-based basis for energy performance simulations through Autodesk Insight.

Figure 3. Three-dimensional model of the facility with rooftop photovoltaic panels

Following the interpretation of the site, plan, and three-dimensional model, the sustainability assessment framework was structured around several improvement scenarios. These scenarios include:
(i) rooftop photovoltaic panel integration,
(ii) improvement of the building envelope and thermal insulation,
(iii) use of energy-efficient HVAC and service systems,
(iv) water-saving and rainwater management strategies, and
(v) operational optimization supported by life-cycle-oriented evaluation. These interventions were selected in line with previous studies on renewable energy systems, high-performance envelopes, passive design strategies, water management, and operational sustainability in sports and recreational facilities [1–4,7–9].

In the next stage of the study, the BIM model of the facility will be transferred to a building energy simulation environment to analyze the effects of alternative retrofit scenarios on energy demand, environmental performance, and life-cycle cost. The simulation model is also planned to be calibrated through real consumption data obtained from sensors and monitoring devices. Finally, the alternative sustainability scenarios will be compared using a Multi-Criteria Decision Analysis (MCDA) approach. This will allow technical, environmental, and economic criteria to be evaluated together in order to determine the most appropriate sustainability package for the Zonguldak Tennis and Marine Sports Club. This integrated approach is consistent with recent literature, which highlights the need to move beyond isolated sustainability measures toward holistic and data-supported decision frameworks for sports facilities [2,4,6].

3. Results. The sustainability work carried out for the Zonguldak Tennis and Marine Sports Club demonstrates that the facility has a strong potential for retrofit-based green transformation. The first and most visible finding concerns the applicability of rooftop solar energy systems. As illustrated in Figure 3, the roof geometry of the building allows the integration of photovoltaic panels without requiring a major structural reconfiguration. This makes solar energy one of the most feasible and symbolically important interventions for reducing the facility's environmental footprint and supporting climate action.

The floor plan analysis shown in Figure 2 also indicates that the building contains several functionally different zones, including wet areas, service spaces, offices, and a large central hall. This spatial diversity suggests that energy use is not homogeneous throughout the facility and that a sustainability assessment should consider differentiated operational patterns. For example, changing rooms, bathrooms, and kitchen-related spaces are more likely to generate water and thermal loads, whereas offices and the main hall may have different occupancy profiles and energy-use schedules. Such zoning-based understanding is essential for the creation of an

accurate baseline model and for identifying the most effective improvement packages.

The site-based evaluation further highlights the importance of the club's location. As seen in Figure 1, the facility is already embedded within an established coastal and recreational landscape in Zonguldak. This means that sustainability action should prioritize upgrading the existing building stock rather than promoting additional land consumption through new construction. In this respect, the study aligns with the principles of sustainable land use by preserving the current recreational function of the area while improving building performance. The coastal and open-site context may also support solar utilization and landscape-based environmental strategies, including water-sensitive improvements and outdoor ecological enhancements.

Preliminary evaluation of the retrofit options indicates that PV integration, envelope enhancement, and efficient system modernization form the most relevant strategy package for the case-study building. In addition, water management measures such as rainwater harvesting and water-saving fixtures can support the operational sustainability of the club. When considered together, these interventions create a pathway toward a more energy-conscious and environmentally responsive sportsfacility.

4. Discussion and Conclusion. This study presents an extended abstract of the sustainability work conducted for the Zonguldak Tennis and Marine Sports Club and proposes a case-based framework for the green transformation of an existing sports facility. The main contribution of the study lies in combining building-scale sustainability measures with site-sensitive and land-use-conscious thinking. In doing so, the research moves beyond single-issue solutions and adopts an integrated perspective consistent with recent developments in sustainable sports architecture.

The study contributes to green transformation and climate action by addressing renewable energy integration, energy-efficiency improvements, operational sustainability, and the reduction of environmental impacts in an existing facility. At the same time, it contributes to urban greening and sustainable land use by emphasizing the sustainable upgrading of a functioning recreational building within an existing urban-coastal landscape rather than encouraging new resource-intensive development.

The findings suggest that the Zonguldak Tennis and Marine Sports Club can serve as a local prototype for the sustainable transformation of similar small- and medium-scale sports facilities. The proposed BIM-based and scenario-driven approach has the potential to support future scientific studies, feasibility analyses, and investment decisions in sports buildings located in comparable climatic and urban contexts. In this regard, the study not only addresses the sustainability performance of a single tennis club, but also offers a transferable methodological perspective for broader climate-responsive facility management and urban recreational planning.

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Spektral Filtreleme Ve Sensör Kontrollü Akıllı Fotobiyoreaktörde Karbondioksit Dönüşüm Verimliliğinin İncelenmesi

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1. Introduction. Bu çalışmanın temel amacı, küresel ısınmayla mücadelede stratejik öneme sahip olan *Spirulina platensis* mikroalglerinin karbondioksit (CO_2) tutma kapasitesini; pasif spektral filtreleme ve sensör kontrollü akıllı bir kapak mekanizmasıyla optimize eden hibrit bir fotobiyoreaktör geliştirmektir. Sanayi Devrimi'nden bu yana atmosferdeki CO_2 konsantrasyonunun 280 ppm'den 430 ppm seviyelerine ulaşması, küresel sıcaklık artışını tehlikeli boyutlara taşımıştır. Mikroalgler, yüksek fotosentetik verimlilikleri (karasal bitkilerden 10-50 kat daha yüksek) sayesinde CO_2'yi biyokütleye dönüştürme potansiyeline sahiptir [1]. Bu çalışma, spektral verimliliğin teknolojik otomasyonla birleştirildiği sürdürülebilir bir karbon yakalama modeli sunmaktadır.

2. Material and Method. Araştırmada raceway (yarış pisti) tipi yarı açık bir havuz modeli tasarlanmış ve 3 litre hacminde *Spirulina platensis* içeren mikroalg sıvısı kullanılmıştır. Projenin teknolojik aşamasında, ortamdaki CO_2 yoğunluğunu anlık izleyen NDIR ve MG811 sensör teknolojileri ile bu verilere göre hareket eden 28 BYJ-48 step motor kontrollü bir kapak sistemi entegre edilmiştir. Deneysel süreçte, güneş ışığının farklı dalga boylarını simüle etmek için kırmızı, mavi ve yeşil pasif filtreler kullanılmış; CO_2 konsantrasyonu 30 dakikalık periyotlarla kaydedilerek üç set halinde tekrarlanmıştır. Kontrol algoritması Arduino Uno tabanlı olarak geliştirilmiştir.

3. Results. Elde edilen bulgular, ışık spektrumunun CO_2 dönüşüm hızı üzerinde belirleyici bir etkisi olduğunu kanıtlamıştır [2]. Kırmızı filtreli düzenek, başlangıçta 1430 ppm olan CO_2 konsantrasyonunu 11. ölçüm sonunda 364 ppm seviyesine düşürerek yaklaşık %74,5 oranında en yüksek verimliliğe ulaşmıştır. Kırmızı spektrumu %66 azalma (1385 ppm'den 469 ppm'e) ile mavi filtre takip ederken, yeşil filtre %49 azalma (1526 ppm'den 778 ppm'e) ile en düşük performansı sergilemiştir. Ayrıca akıllı kapak mekanizmasının, dış ortamdan kontrolsüz hava girişini engelleyerek reaktör içi gaz dengesini stabilize ettiği ve sirkadyen ritme uygun bir çalışma ortamı sağladığı gözlemlenmiştir [3].

4. Discussion and Conclusion. Sonuçlar, mikroalglerdeki klorofil pigmentlerinin kırmızı (630–675 nm) ve mavi (450–475 nm) dalga boylarında yüksek soğurma kapasitesine sahip olduğu literatür verileriyle örtüşmektedir [4]. Pasif spektral optimizasyonun teknolojik otomasyonla birleştirilmesinin, ek enerji harcamadan karbon fiksasyon kapasitesini önemli ölçüde artırdığı saptanmıştır. Geliştirilen bu akıllı sistem, manuel müdahaleye gerek duymadan süreci optimize ederek sızdırmazlığı artırılmış sürdürülebilir bir model sunmaktadır. 1 kg mikroalg biyokütlesi üretimiyle yaklaşık 1,83 kg CO_2'nin atmosferden uzaklaştırılabildiği gerçeğiyle birleştiğinde [1], bu tasarım iklim kriziyle mücadelede pratik ve ölçeklenebilir bir çözüm potansiyeline sahiptir.

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Ambient Particulate Matter and Migraine: Does Air Pollution Trigger Attacks or Amplify Their Severity?

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1. Introduction – Migraine is a disabling neurological disorder ranked second in the global burden of disease, affecting approximately 1 billion individuals worldwide. Its pathophysiology is multifactorial, and environmental factors (including meteorological variables and air pollutants) have been increasingly implicated as potential triggers. Among these, particulate matter (PM), particularly fine particles (PM2.5, aerodynamic diameter ≤2.5 μm), has attracted growing attention owing to its capacity to induce systemic and neuroinflammatory responses [1].
Prior studies examining ambient PM and migraine onset have yielded inconsistent results [2, 3]. Critically, no published study has simultaneously tested whether PM acts as a trigger (i.e., precedes attack occurrence) versus a severity modulator (i.e., amplifies the intensity of an attack once initiated). This distinction carries substantial clinical relevance: a modulating — but not triggering — role would direct attention toward attack management under high-pollution conditions rather than prevention. The present study was designed to address this gap using prospective, real-world diary data from a single-city cohort.

2. Material and Method - A prospective, diary-based observational cohort study was conducted in Tekirdağ province, northwestern Turkey. Thirty patients with physician-diagnosed migraine (ICHD-3 criteria) who completed a minimum 90-day observation period were included. Patients recorded daily headache data (presence/absence of attack; VAS severity score, 0–10) in structured diaries. The total observation period yielded **5,055 patient-days** (335 attack days; 4,720 control days).

Ambient PM concentrations (PM10, PM2.5; 24-hour means) were obtained from the Tekirdağ Regional Monitoring Station (Turkish Ministry of Environment). Each observation day was matched to the lag-1 PM value (pollutant concentration on the preceding 24 hours). Ethics committee approval was obtained prior to data collection.

Two analytical layers were applied: (1) Mann–Whitney U tests compared PM concentrations between attack and control days to assess a potential triggering role; (2) Spearman rank-order correlations and hierarchical linear regression (covariates: age, sex, BMI in Block 1; PM10 and PM2.5 added in Block 2) examined PM associations with VAS severity scores restricted to attack days (n = 297 with complete data), to assess a potential severity-modulating role. Statistical analyses were performed in SPSS v26.0. Significance threshold: $\alpha = .05$.

3. Results – The analytic sample comprised 30 patients (60.0% female; mean age 33.5 ± 9.4 years; mean BMI 26.0 ± 4.8 kg/m²). Attack-day VAS scores had a mean of 6.44 (SD = 2.31; median 7.00, IQR: 5.00–8.00), indicating predominantly moderate-to-severe attack intensity.

Descriptive statistics for PM10 and PM2.5 on attack and control days are summarized in Table 1.

Table 1

Descriptive Statistics for PM10, PM2.5, and VAS Scores on Migraine Attack and Control Days

	Attack Days (n = 335)				Control Days (n = 3,310)			
Variable	**M**	***SD***	**Mdn**	***IQR***	**M**	***SD***	**Mdn**	***IQR***
PM10 (µg/m³)	22.03	7.77	20.46	16.31–25.67	22.55	8.33	20.67	16.21–27.00
PM2.5 (µg/m³)	14.55	6.70	12.63	10.14–16.08	15.01	6.04	13.71	10.54–17.33
VAS	6.44	2.31	7.00	5.00–8.00	—	—	—	—

Note. *M = mean; SD = standard deviation; Mdn = median; IQR = interquartile range. VAS is reported for attack days only (n = 335). PM values reflect 24-hour means on the preceding day (lag-1).*

Mann–Whitney U tests (Table 2) revealed no significant difference in PM10 concentrations between attack and control days (U = 540,569, p = .450, r = .025). Paradoxically, PM2.5 was significantly lower on attack days relative to control days (U = 481,770, p = .006, r = .092), arguing against a direct triggering role for fine particulate matter.

In contrast, among attack days, both PM10 and PM2.5 correlated positively with VAS severity. PM2.5 demonstrated a more pronounced association (r_s = .211, p < .001) compared to PM10 (r_s = .109, p = .048). Hierarchical regression confirmed PM2.5 as an independent predictor of attack severity (B = .056, SE = .025, p = .027, ΔR^2 = .046 for the PM block; final R^2 = .125). PM10 did not reach significance, likely due to collinearity with PM2.5 (r = .65). These findings are presented in Tables 2 and 3.

Table 2

Comparison of PM10 and PM2.5 Between Attack and Non-Attack Days, and Spearman Correlation with VAS

	Mann–Whitney U Test			Spearman Correlation	
Variable	**U**	***p***	***r***	r_s	***p***
PM10 (µg/m³)	540,569	.450	.025	.109	.048*
PM2.5 (µg/m³)	481,770	.006**	.092	.211	<.001***

Note. *r = rank-biserial correlation. r_s = Spearman correlation with VAS (attack days only, n = 327). * p < .05 ** p < .01 *** p < .001*

Table 3
Hierarchical Linear Regression Predicting Migraine Severity (VAS) on Attack Days

Variable	*B*	*SE*	*t*	*p*
Block 1: Demographic Predictors				
Age (years)	.052	.011	4.697	<.001***
Sex (female = 1)	.827	.491	1.683	.093
BMI	−.040	.025	−1.608	.109
R^2 = .079, R^2adj = .070, F(3, 293) = 8.40, p < .001				
Block 2: + Particulate Matter Predictors				
Age (years)	.051	.011	4.690	<.001***
Sex (female = 1)	.667	.482	1.383	.168
BMI	−.034	.025	−1.379	.169
PM10 (24-h, µg/m³)	.021	.022	0.944	.346
PM2.5 (24-h, µg/m³)	.056	.025	2.225	.027*
R^2 = .125, R^2adj = .110, ΔR^2 = .046, $\Delta F(2, 291) = 7.59$, p < .001				

Note. *B = unstandardized coefficient. SE = standard error. Sex coded 1 = female, 0 = male. BMI = Body Mass Index (kg/m²). * p < .05 *** p < .001*

4. Discussion and Conclusion - The central finding of this study is a dissociation between PM's role as a trigger and as a severity modulator: lag-1 PM2.5 did not precede attack occurrence — indeed, PM2.5 was paradoxically lower on attack days — yet the same pollutant independently predicted greater attack intensity once an attack was underway. This pattern is consistent with a neuroinflammatory modulatory mechanism rather than direct trigeminovascular activation.

The paradoxical inverse PM–attack occurrence finding may reflect behavioral adaptation (patients remaining indoors on high-PM days, suppressing observable attacks), lag-time misspecification (PM effects may extend to 2–3 days or cumulative exposure dynamics not captured by a single lag [2]. Mechanistically, fine particulate matter may amplify the severity of an ongoing migraine through TRPA1 channel activation, oxidative stress, and increased blood–brain barrier permeability — all more plausible during an already-active trigeminal cascade than as initiating events [4].
The present study is, to our knowledge, the first to formally test the trigger–modulator distinction using within-person prospective data. The independent PM2.5 effect on VAS after demographic adjustment (ΔR^2 = .046, p < .001) suggests a clinically meaningful relationship: during elevated PM2.5 periods, clinicians managing migraine patients may consider earlier initiation of abortive therapy. Validation in larger, multi-city cohorts with multi-lag exposure assessments is warranted.

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