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Air Pollutants Emissions and Climate Change: The Ankara Case

Hava Kirletici Emisyonları ve İklim Değişikliği: Ankara Örneği

Kıvılcım Özge KARA YILMAZ[1]
[1]Ministry of Environment, Urbanization and Climate Change, Ankara, Türkiye

Ahmet Burçin YERELİ[2]
[2]Hacettepe University, Faculty of Economics and Administrative Sciences, Department of Public Finance, Ankara, Türkiye

ABSTRACT

Anthropogenic climate change and its struggle is an economic-political area that is expected to be prominent in terms of its effects in the future, although its importance is evident today. When it is accepted that the majority of the population lives in cities and that cities are at the center of crises, cities are again the most affected by these multiple and interconnected risks. Especially with rapid urbanization, the resilience of cities is weakening, and their exposure levels and vulnerabilities are increasing beyond their adaptive capacity. Therefore, combating climate change should be evaluated as a risk management process that includes not only technical adaptation and mitigation actions but also socioeconomic factors and environmental governance. In this study, it was emphasized that addressing the reduction of greenhouse gas and air pollutant emissions, which are the main causes of climate change, at a local scale as a risk management process will increase the effectiveness of this process. In this context, the distribution status of SOX, NOX, PM10 air pollutants was examined in Ankara districts and their relationship with the climate struggle was evaluated.

JEL Codes: H7, Q5, H8

Keywords: Climate change, Air pollutant emissions, Local governments

ÖZ

Antropojenik iklim değişikliği ve mücadelesi günümüzde önemi belirgin olmakla beraber sonrası süreçte de etkileri üzerinden öne çıkması beklenen ekonomi politik bir alandır. Nüfusun çoğunluğunun kentlerde yaşadığı ve kentlerin, krizlerin merkezinde yer aldığı kabul edildiğinde, çoklu ve birbirine bağlı bu risklerden en çok etkilenen yine kentler olmaktadır. Özellikle hızlı kentleşme ile beraber kentlerin dirençliliği zayıflamakta uyarlanabilir kapasitelerinin ötesinde maruziyet düzeyleri ve kırılganlıkları artmaktadır. Dolayısıyla iklim değişikliği ile mücadele, yalnızca teknik olarak uyum ve azaltım eylemlerinin değil sosyoekonomik faktörler ile çevresel yönetişimi de kapsayan bir risk yönetim süreci olarak değerlendirilmelidir. Bu çalışmada; bir risk yönetim süreci olarak iklim değişikliğinin başlıca nedeni olan sera gazı ve hava kirletici emisyonlarının azaltımının yerel ölçekte ele alınmasının bu süreçteki etkinliği artıracağına vurgu yapılmıştır. Bu çerçevede Ankara ilçeleri özelinde SOX, NOX, PM10 hava kirleticilerin dağılım durumları incelenerek iklim mücadelesi ile ilişkisi değerlendirilmiştir.

Jel Kodları: H7, Q5, H8

Anahtar Kelimeler: İklim değişikliği, Hava kirletici emisyonları, Yerel yönetimler

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Sorumlu Yazar/Corresponding author: Kıvılcım Özge KARA YILMAZ
E-mail: kivilcimozgekara@gmail.com

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Introduction

The main environmental risks in the Anthropocene period are caused by factors such as rapid urbanization, population growth, industrialization, etc. The common result of these and similar environmental problems is the increase in global emissions, which are frequently seen in ecosystem degradation, rapid depletion of natural resources, increased natural disasters, severe climate change and their consequences. The basis of this is that the increase in emissions due to anthropogenic factors increases global warming and deepens environmental damage. Today, the entire world is experiencing an ecological crisis that stems from the two-way interaction between nature and society advocated by Marx and Engels and is accelerating due to global warming (Foster, 2012). In fact, global warming is not just an ecological crisis; it is multidimensional, including political, economic and financial.

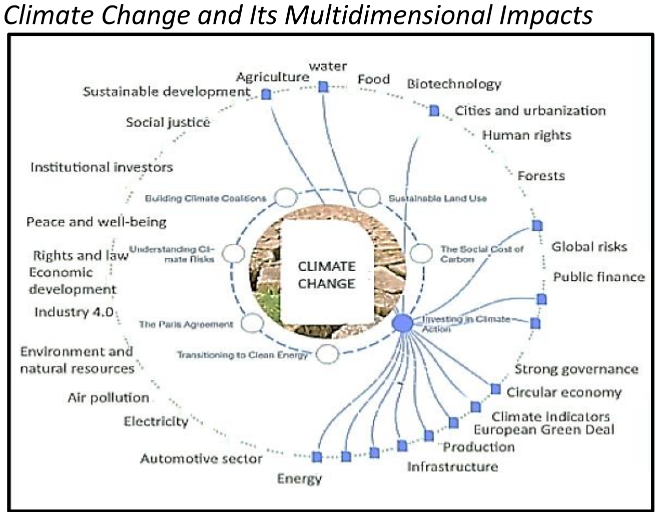
The increase in greenhouse gas and pollutant emissions caused by human activities is the most important of the main reasons for global warming. When viewed historically, global warming can be defined as the worst externality (Balsalobre-Lorente et al., 2022). Global warming, which is only one aspect of climate change, is sometimes used instead of climate change. According to Maslin, the most important issue that causes concern about global warming is the fact that global warming leads to change with a radical attitude and forms the basis for modeling the future (Maslin, 2011, p.92).

While it was accepted in previous scenarios that long-term global warming caused climate change, it is known that global warming is also occurring in short-term scenarios today. So much so that the validity of the average 30 year period, which constitutes the scope of the narrow definition of climate and is accepted by the World Meteorological Organization (WMO), is now being discussed over shorter periods. Although global warming is often used synonymously with climate change, conceptually it only represents one dimension of climate change. Global warming describes the long-term rise in average global temperatures due to increased greenhouse gas emissions, while climate change encompasses a broader and more multifaceted process including changes in precipitation patterns, drought, extreme weather events, sea level rise, ecosystem transformations, and structural shifts in the climate system. In this context, global warming is considered one of the fundamental indicators and triggers of climate change. In this context, considering the transitions at the center of climate change is important in terms of forming a basis for policies.

It has been accepted that atmospheric pollutants have caused climate change on the world's bio-physical system since the Industrial Revolution (Swyngedouw, 2011). However, it is also accepted that cities contain processes that increase atmospheric pollution emissions and are the places where pollutant emissions are most concentrated (Leffel et al., 2022). On the other hand, the climate change that the world has been struggling with in the last 50 years is intertwined with existential challenges (UN-Habitat, 2022). Considering that existential challenges require structural solutions, cities have important roles in reducing emissions from pollutants and achieving the climate neutrality goal (Vanhuyse et al., 2023). Otherwise, cities are at the center of multiple crises, further reinforcing these challenges with global problems.

Figure 1.

Climate Change and Its Multidimensional Impacts



Source: WEF, 2023

The rapid expansion of climate change, especially in urban areas, is causing intense pressure on resources. The estimate that the population of cities will triple by 2050 leads to the conclusion that crises and risks will also increase. Therefore, the need for climate-resistant structures to reduce possible exposures is higher than ever, and the need for long-term investments has become imperative. Accordingly, in a future where urban growth and environmental management act synergistically, the fate of cities will be possible with a resilient city plan that works in harmony with nature (UNU-EHS, 2024).

Especially in regions where there is rapid urbanization, extreme weather events due to climate change erode the sustainability of cities and make their vulnerabilities more apparent. In this context, Krueger et al. have addressed cities with an approach that considers them as social-ecological-technological systems and takes sustainability into account, and have pointed out the importance of efforts at all administrative levels in urban transformation (Krueger et al., 2022). In this context, coordination and cooperation between all sectors and scales, especially with the multiple hazard events and their negative externalities, are becoming necessary. Therefore, new decision-making mechanisms such as environmental localization and environmental governance are important potentials.

Climate Change, Air Pollutants and Public Intervention

Since the second half of the 20th century, climate change has been largely defined as a permanent shift in weather patterns at both global and regional scales. Air pollutant emissions, one of the primary causes of climate change, are a critical environmental challenge that poses significant threats to natural ecosystems.

Marx and Engels listed ecological problems as; the disconnection between rural and urban areas, soil-related degradation, population density in cities, pollution, waste and recycling of waste, loss of forest resources, droughts and floods, water scarcity, local climate changes, difficulties in the field of energy, etc. According to Milanovic, " *In ecological terms, the world's climate and the life-supporting systems of the entire earth are being transformed by an increasingly global warming process."* (Foster, 2012, pp. 24-31). In fact, the externality and spreading effect of greenhouse gas and pollutant emissions, which are the main cause of global warming and the most rapidly accelerating types of environmental problems, can be evaluated as the trigger of the transformative effect all over the world in this context. Because the externalities of environmental problems within and beyond the borders are high. In fact, the negative externalities of climate change, which tends to transform the whole world in the context of environmental problems and is caused by global emissions, are also the subject of significant discussions.

Climate change, one of the fundamental parameters of the reproduction of urban space in the 21st century, is an important risk factor for nature and economies due to the externality and spillover effects of emissions. The risk and crisis dimension and the radical changes in the eco-ecological structure caused by climate change are the basic philosophy of the new economic paradigm. Similarly, according to Machen et al., climate imaginaries, which are a more comprehensive part of the environmental crisis, require a sustainable transformation (Machen et al., 2023). In a sustainable transformation, state intervention is inevitable in the Anthropocene Age.

In this context, while the fact that humans have created huge impacts on the entire world in the Anthropocene requires sustainable comprehensive transformations, environmental sustainability emerges as one of the most critical principles that activate the balance between nature and humans. Otherwise, it is one of the most critical trade-offs known that the capitalist mode of production can be realized at the expense of the environment. In this context, according to Foster, an ecological perspective plays a critical role in understanding the limits of capitalism in the struggle for egalitarian and sustainable development (Foster, 2012 ,p. 27).

In classical economics, while discussing how the economy works or should work, it adopts an approach that is far from long-term dynamics. In other words, while measuring the current production level, it does not include any determination as to whether its long-term results will be sustainable or not; the solutions produced to the problems related to the level of pollution and damage to the environment are quite limited (Ponting, 2000, p. 140). Therefore, one of the arguments for the sustainability principle to become operational, the fight against air pollution and climate change, makes sustainability functional with the responsibility of producing solutions at the local level.

Accordingly, it is predicted that emissions can be reduced with a sustainable environment, and reduction policies are included in all processes, especially within the scope of the fact that the effects of climate change are intensifying. Namely, climate change increases the frequency and intensity of extreme weather events and causes negative effects on air quality. However, the roles between the severity of air pollution and human-environment interaction have not yet been fully determined (Chen et al., 2024).

Air pollutants and greenhouse gases, as the two main components of total emissions, cause negative effects on the climate system. Atmospheric pollutants, which are a broader concept than air pollutants, are monitored as CO_2, NOX, SOX, PM10, PM2.5 in IPCC (Intergovernmental Panel on Climate Change) reports and EU legislation, and are known to be effective on a global scale due to natural and human origin.

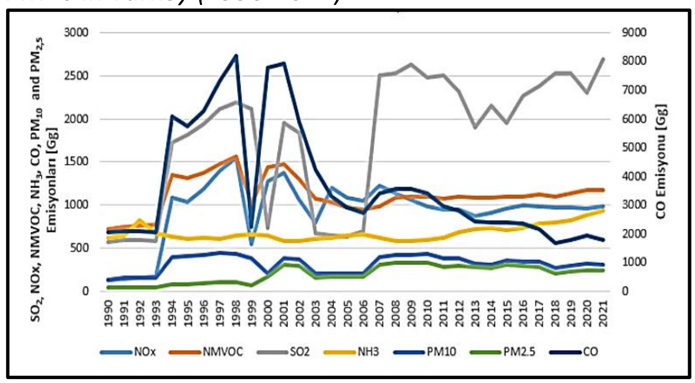
Air pollutants, which are generally considered to be local and regional, SOX, NOX, PM10 mostly occur due to fossil fuel use (Leffel et al., 2022), and their atmospheric lifetimes and effects vary according to geographical location. While the atmospheric lifetimes of CO_2 and N_2O are around 200 and 114 years, this gives them a global character; The effects of SO_2 can be removed from the atmosphere in 10 days. NOX can be eliminated in a shorter period of a few hours or a few weeks (Halkos & Paizanos, 2017). These periods show that the effects of pollutants can reach areas much farther from their sources, while externality and spreading effects indicate the power of transforming the entire atmosphere (Our Common Future, 1987, p. 60). In their study, they concluded that PM10, one of the air pollutants in North Africa, is effective in Southern Europe and 51% of them are caused by the increase in anthropogenic effects, and a solution was presented that a way to reduce local emissions would be possible by taking appropriate measures (Millan-Martínez et al., 2021). Primary pollutants such as particulate matter are sensitive to changes in climate. Then the relationship between PM10 concentrations and climatic factors plays a significant role in changing air pollution levels. Climatic factors such as global temperatures and precipitation affect the movement and concentration of PM10. However, changes in emissions of precursors to primary and secondary air pollutants also lead to changes in air quality. Therefore, monitoring PM10 levels while taking climatic factors into account has significant implications for the effectiveness of air quality management.

As can be understood, emissions affect air quality at the local level and climate change at the global level. In other words, the effects of emissions vary depending on the scale they affect at the international, regional and local levels.

When we look at the pollutant emissions for Turkey between 1990-2021, the situation in Figure 1 is recorded. Accordingly, within the framework *of the Long-Term Financing of the European Cooperation Programme for Monitoring and Evaluation of Long-Range Air Pollutants Transport* (EMEP) protocol, the reporting of emission inventories has been carried out since 2011, and emissions are currently monitored 2 years behind the calendar year, and as can be seen from Figure 1, it is understood that emissions are decreasing for more than one pollutant. However, the parameters in question, which can be monitored nationally, are not monitored at the local level. The fact that all air pollutants at the national level are also monitored for the province of Ankara and its districts will enable the study to be reproduced and expanded. In other words, having all the parameters in the data set available to include Ankara province and its districts could provide a more comprehensive framework for understanding the impact of air quality forecasts. In addition, the distribution of PM10, SOX and NOX for Ankara are shown in Figure 1.

Figure 1.

Emission Totals for SO2, NOX, NMVOC, NH3, CO and PM10 in Turkey (1990-2021)



Source: Ministry of Environment, Urbanization and Climate Change (MoEUCC), 2023

In this context, when emissions that differ at the local level are evaluated within the scope of postmodern discourses, they can be associated with the cornerstones of capitalist developments. While these developments include different social ontologies in the process, they separate social worlds, deepen injustices and require radical coalitions from the local to the global (Boelens et al., 2022).

In relation to this, a new development architecture that is compatible with the new global capitalist order should be established. This new development paradigm is a global process determined by the creation and renewal of the economy of needs and the global discourse (Sanyal, 2017, p. 266). On the other hand, there is a necessity for cooperation in the economy of needs approach. IPCC and other actors; transnational cooperation is expressed as part of the solutions to be offered (IPCC/AR5, 2014c), and the importance of local dynamics and local knowledge becomes apparent, as advocated by postmodern environmentalist approaches.

The importance of public interventions also emerges here. As Aristotle stated, "The *fundamental aim of both* *states and people is to live well. The reason for the establishment of a community is to provide this good life.*" The state should be the provider of good living (Aristotle, 2013). Accordingly, living in a good environment can be considered as one of the important reasons for public intervention as a right. In this context, climate change, which is a global public good, negatively affects the use of this right, indicating the necessity of evaluating public intervention and cooperation together.

However, the fact that climate change affects everyone and is closed to competition is also a factor in its marginal cost being zero. Therefore, from the perspective of public goods theory, public intervention plays a fundamental role in the management of climate change (Chong Xu et al., 2023). Because the market alone cannot internalize external costs, it leads to economic costs such as misallocation of resources, low social efficiency, etc.

As a result, the contribution of all economies to environmental improvement is possible by making their national strategies in line with this and updating the existing ones. In fact, the pollution intensity of countries is directly affected by government policies (Cole et al., 2005). Along with the target of halving global greenhouse gas emissions by 2030, the necessity of reducing the emissions of short-lived pollutants such as PM2.5, PM10, NOX, SOX, CH_4, O_3 compared to CO_2 is supportive and mandatory for the target of keeping the temperature increase below 2°C by limiting it to 1.5°C set by the Paris Agreement (Malley et al., 2022).

Air Pollutant Emissions and Local Governments

The increase in the frequency of extreme weather events from the 1950s to the present, especially after the 1970s (IPCC/AR6SYR, 2023), can mostly be associated with human-induced climate change due to increased global emissions. Climate change shapes the global environment. The interaction between greenhouse gases and air pollutant emissions sources is considered to be the main determinants of environmental degradation that shapes this process. Considering that air pollutants and greenhouse gases generally come from the same sources, addressing the two emission sources simultaneously provides a mutual benefit in turning the interaction into an opportunity.

"Emission" is defined in Article 1.4 of the United Nations Framework Convention on Climate Change (UNFCCC) as "*the release of greenhouse gases and/or their precursors into the atmosphere in a certain area and time period"* (UNFCCC, 1992). Accordingly, precursors affect sustainable development at national and regional levels with their emissions that directly affect human health and welfare loss (Liu et al., 2022). For this reason, central and local governments are given important roles in reducing the factors that will create the greenhouse effect. It is possible to establish a multifaceted and direct relationship between the reduction of total emissions and local governments. In their study, Bick and Keele accepted that municipalities are closely related to sustainability and climate change (Bick & Keele, 2022) and argued that sustainable development will start at the local level.

It is important for effective management to have local authority in both administrative and planning and implementation. When we evaluate the reasons for this within the scope of the duties and responsibilities of local governments; it is seen that the majority of air pollutant emissions occur at the local level due to factors such as solid waste, industrial facilities, and heating. When it is accepted that proximity to the source will provide the most optimal management, it can be said that local governments are effective actors in reducing these emissions. On the other hand, the responsibility of local governments for tasks such as zoning studies, urban planning, establishment and protection of green areas will contribute to the reduction of emissions in urban services. When looked at on a sectoral basis, the transportation sector has a high share in total emissions. The roles of local governments in urban transportation policies with both public transportation and other alternatives are evident. Accordingly, they can eliminate transportation-related emissions with environmental transportation strategies.

In our country, solid waste management, which is one of the duties and responsibilities stipulated in subparagraph (a) of the first paragraph of article 14 of the Municipality Law No. 5393, is carried out by municipalities on condition that they are local jointly owned. In subparagraph (g) of the first paragraph of article 15 titled "Powers *and privileges of the municipality" of the aforementioned law, it is stated that "To perform and have performed all services related to the collection, transportation, separation, recovery, disposal and storage of solid wastes."* Accordingly, metropolitan municipalities and other district municipalities have responsibilities arising from the Law in practices such as effective waste collection and recycling in reducing air pollutants generated during the management of solid wastes. In this context, local governments can strengthen their climate action efforts by making the reduction of air pollutants a priority target with the realization *of the Sustainable Development Goals (SDGs) and Local Climate Change Action Plans* (LCCAP); and they can carry out activities directly related to their duties such as planning, inspection, infrastructure development and development of participation. These activities support economic opportunities in providing basic public services in cities with better road, transportation, water, energy and housing policies of local governments. In this context, local governments can play an active role in the climate fight.

In the report titled *"Evaluation of Preparatory Processes for the Achievement of Sustainable Development Goals"* prepared by the Court of Accounts in our country; *It is thought that "Many of the activities carried out routinely by local governments are actually related to SDGs and since no additional resources will be required for them, there is no need for a special study on financing determination. However, it is important for the implementation process to conduct a study on the determination and planning of financing needs for non-routine projects and activities"* and it was suggested that "It *would be useful to have an organization that evaluates the compliance of the strategic plans and activities of local governments with the development plan or SDGs and provides guidance"* (Court of Accounts, 2020, p.14).

With these goals and objectives, environmental localization, which is accepted as improvement in local governments, can be considered as a factor that increases the effectiveness of the process. Namely, local governments will be able to reinforce localization processes in environmental management, control and monitoring by strengthening their authorities in taking environmental measures and determining pollution control strategies. Environmental regulation and improvement converge with the economic growth target and create an indirect effect on environmental pollution. In the study conducted by Ren et al.; It was concluded that the economic growth target indirectly contributes to environmental pollution at the local level, but environmental decentralization restricts this pollution. In other words, the economic growth target negatively affects environmental pollution both due to the production itself and due to the failure to improve the industrial structure and the failure to realize technological innovation and energy efficiency (Ren et al., 2023).

In this context, as stipulated in Articles 2 and 7 of the Paris Climate Agreement, the development of low greenhouse gas emissions will indirectly contribute to the reduction of air pollutants, even if there is no explicit provision in the Agreement. For this, local measures are required. Thus, the effect of interaction with adaptation and reduction efforts will increase and the climate struggle will be strengthened.

Literature Review

Increasing consumption worldwide leads to depletion of resources, accumulation of environmental pollutants and ultimately climate change (Won et al., 2023). Fossil fuel use, carbon and greenhouse gas emissions, aerosol production, pollution, toxic pollutants, etc. are monitored as factors causing climate change (Pal et al., 2023). The increase in SOX and NOX emissions, which are the main air pollutants in many countries, is due to transportation and energy. On the other hand, the uneven increase in SOX and NOX emissions makes it difficult to combat climate change by being a determinant of the air quality of countries (Siddiqui, 2022).

For example, in Lima, the capital of Peru, the sectors with the highest emissions were identified as waste (38%), energy & buildings (35%), and transportation (27%). Despite traffic congestion and poor air quality caused by car-dependent development, the Climate Action Plan is making progress. With limited bicycle and pedestrian infrastructure, the city faces pressure to adopt cleaner and more accessible mobility. Solutions such as integrating climate priorities into transportation planning and strengthening stakeholder participation with the Climate Action App support inclusive, accessible, and climate-resilient strategies. In long-term climate action, the greenhouse gas inventory is completed, the city's emission monitoring capabilities are improved, and the basis for mitigation planning is formed. The city is undergoing a transformation to reduce air pollution through *the Cyclo-Inclusive Strategy.* This strategy, marked by the expansion of newly constructed bicycle paths, aims to support vulnerable groups such as low- and middle-income women and young students who are involved in the process of ensuring their needs are met. In the scenario where appropriate measures are implemented for bicycle infrastructure and micro mobility, it is reported that the number of new users could reach approximately 1.8 million by 2040 and that more than 1,000 premature deaths could be prevented due to the increase in physical activity, thus ensuring a healthy environment for residents. Because if pedestrian flow increases by 15% in the center; NOX emissions will decrease by 370 kg per year, 890 tCO2 per year It is estimated that savings will be made, 3 deaths per year will be prevented, and life expectancy per pedestrian will increase by 2 months (UCAP, 2025).

In their study in China, Guangzhi et al. (2023) found that the concentrations of six air pollutants, including PM2.5, PM10, SO_2, NO_2, CO, and O_3, were higher in areas with high population and higher economic development levels between 2013 and 2020, while they were lower in standard areas (Qi et al., 2023).

In the study conducted by Har Even-Levi & Kissinger (2023), it was reported that neighborhoods with predominantly peripheral characteristics cause more greenhouse gas emissions from transportation compared to those in the center (Har Even-Levi & Kissinger, 2023).

By Jiang et al. (2023) on determining the joint benefit of SO_2 reduction to total emission reduction in China, it was understood that this rate was over 60%, and NOX and PM2.5 emissions followed SO_2 values. Accordingly, it was stated that economic development and industrial structure differences should be taken into consideration for climate conditions in different regions, and separate measures were needed for different dynamics (Jiang et al., 2023).

Countries experience joint exposure to air pollution and climate change. For example, Pakistan experiences air pollution and climate change together; South Asia, which is in the process of intense urbanization, was recorded as the second most polluted country in 2020. Although the country's contribution to global greenhouse gas emissions is <1%, it produces the highest emissions compared to its South Asian neighbors. Ultimately, the issue of whether there is a co-benefit or a co-benefit between climate change and air pollution reduction is political, but the widespread acceptance of co-benefit remains valid (Mir et al., 2022).

High concentrations of pollutants such as SOX, NOX, and PM10 make it difficult to establish sustainable cities and are known to have negative impacts on welfare and economic growth. Developing countries rely on fossil fuels for production purposes for economic growth and development, and greenhouse gas and pollutant emissions remain high in this context (Ai et al., 2023). The growth of cities, both in terms of population and spatial extent, confirms Bookchin's observation that capitalist cities tend to expand continuously. However, this growth increases energy demand, intensifies fossil fuel use and related emissions, and creates significant pressures on the environment. According to Bookchin, a focus solely on renewable energy sources is deemed sufficient to overcome environmental crises such as urban growth, pollution, and fossil fuel use; a decentralized, decentralized approach is crucial (Bookchin, 2017). In this context, considering the distribution of pollutants at the local level and their reductions is critical.

As a result, emissions affect the climate system. The interaction between climate change, pollutant emissions, and atmospheric concentrations is one of the most debated topics. The development of emission inventories is an important component of air quality modeling and climate action. Thus, the spatial distribution of emission inventories can be established. Therefore, many interrelationships need to be investigated to understand and accurately predict changes in future climate conditions and pollutant levels at different spatial scales.

An application for Ankara districts

It is generally accepted that greenhouse gas and pollutant emissions must be reduced in the management of climate change. Therefore, it is a valid statement that total emission reduction efforts in the fight against climate change and air pollution reduction are mutually beneficial, as advocated by Mir et al. (2022). Since it is known that cities are the places where greenhouse gas and air pollutant emissions are commonly high, reducing emissions in these places is an issue that can be solved through cooperation in the fight against climate change. Reduction policies in different parts of cities vary according to the scale of the cities, population, economic activities, geographical location, etc. In this context, analyzing administrative units at micro scales for sustainable and climate-resilient cities will increase the implementation capability of policies and contribute to the determination of pollution loads.

On the other hand, micro-based establishments are associated with democracy as a form of administrative and social life (Foucault & Chomsky, 2012, p. 43). In order to ensure a structure towards an ecological democracy, the transition to decentralized management is one of the most possible ways (Pickering et al., 2022). According to Bookchin, a human-centered environment and a structure that provides the basis for people to understand the environment and be more participatory is a decentralized structure. Accordingly, a green perspective will be formed with a localist articulation (Bookchin M., 2017). In support of this; "The *COP has always been seen as an event reserved for national governments, but this has changed to include cities as well. Cities have different vulnerabilities and different emissions. We need a local dimension and localized solutions for climate action."*

(Rudiger Ahrend, Cities&Regions in the UNFCCC) are expressions that show that climate action and resilience start locally. In other words, multiple governance plays a leading role in solving climate-related problems (Liu et al., 2022). In other words, local and traditional knowledge systems and practices of the local population provide easier solutions for climate adaptation (Ling et al., 2022; IPCC, 2014).

When the effects and course of climate change in Türkiye are examined, the importance of closely monitoring pollutants and emissions, as in the rest of the world, becomes apparent. Especially when it is considered that cities are the priority areas of climate change, it is concluded that the fight should begin in cities and more micro administrative units. Indeed, the potential impact of air pollutant emissions in cities on environmental damage and subsequent climate change cannot be ignored.

According to the IPCC, annual average temperatures in Turkey are projected to increase by 2.5-4°C by 2050 (IPCC, 2014). Accordingly, in revealing the interaction between temperature increases caused by emissions and climate change, the assessment of pollutant emissions will guide the assessment of total emissions. For this purpose, the districts of Ankara were selected for the study.

Method

Analysis Method and Description of the Study Sample

In this study, a GIS-based spatial analysis was conducted using a quantitative research method. QGIS software was used for data reading and preprocessing, while ArcMap software was used for spatial analysis and mapping of the obtained data. In other words, basic visualization techniques in GIS were used to show the spatial distribution and intensity of each pollutant. The following spatial analysis procedure was applied using ArcMap to evaluate the spatial distribution of major air pollutants (NO_x, SO_x, and PM_{10}) across Turkey:

1. Data Extraction: Air pollutant emissions data were obtained from Ministry of Environment, Urbanization and Climate Change (MoEUCC). From this dataset, the variables corresponding to NO_x, SO_x, and PM_{10} were extracted for further analysis.

2. Spatial Overlay: Administrative boundaries for Turkey and, specifically, for the Ankara province, were transferred to ArcMap as digital maps. Air pollutant emission data were spatially overlaid on the maps of Turkey and Ankara province using spatial overlay techniques. This made it possible to align the pollutant data with the country's geographical boundaries and ensure accurate spatial representation.

3. Attribute-Based Selection and Classification: A spatial query was performed using the “Select by Attribute” tool in ArcMap to classify the extracted pollutants.

Each pollutant (NOX, SOX, and PM10) was categorized according to emission intensity or concentration levels. Classification schemes such as natural breaks (Jenks) or equal intervals were applied to facilitate visualization and interpretation. This study does not aim to directly calculate an econometric impact factor (causal inference); rather, it aims to reveal the spatial typology and distribution profile of emission loads and environmental vulnerabilities across Ankara using the Jenks Natural Breaks method.

4. Density Visualization: The classified data were visualized on the digital map of Turkey and Ankara province to illustrate the spatial distribution and density of each pollutant. This enabled identification of high- and low-emission areas and provided insights into regional patterns of air pollution.

Furthermore in this study, the Jenks Natural Breaks classification method was chosen to accurately reflect the heterogeneous distribution and outliers in the emission and socio-economic structures of Ankara's districts. The Jenks method inherently groups similar values and maximizes the differences between classes. By utilizing this approach, non-artificial natural groupings between districts were revealed, allowing intra-city inequalities to be reflected more clearly in the analysis results.

This methodology provides a robust framework for analyzing the spatial variability of air pollutants and supports subsequent environmental assessments and policy planning.

The districts of Ankara were selected for the study. Ankara, the capital of the Republic of Turkey, is located in the Central Anatolia region. With a surface area of 25,437 km^2, it is Turkey's third-largest city and its second-most populous city with a population of 5,782,286 as of 2022. The population density is concentrated in the city center. Industrial zones, sector campuses, and transportation infrastructure are widely located, mostly in the central districts. In this context, Ankara plays a significant role in climate change as a region with a high economic, social, and human capital density (AMM LCCAP, 2022; TSI, 2023).

Data

The latest 2020 data for air pollutant emissions in Ankara and its 25 districts were analyzed. These emission data were obtained from map outputs on the Air Emission Management (AEM) portal of the Ministry of Environment, Urbanization and Climate Change. These data were analyzed using geographic information systems (QGIS), providing a visual basis for the strategy plan. Because the data was not raster, interpolation techniques were not applied. Data converted using QGIS were displayed on thematic maps. Because the data did not require normalization, there was no margin of error.

Ankara districts were monitored as grids using the QGIS. The grid resolution in the AEM portal represents a maximum of 1*1 kilometer. The districts' 2020 emission distributions of sulfur oxide (SOX), nitrogen oxide (NOX), and particulate matter (PM10) pollutants come from point, areal, and mobile sources. Industrial activities, including information on more than 12,000 facilities and more than 50,000 chimneys, are point sources. Those originating from heating, excavation, organized industrial zones (OIZs), production and consumption, gas stations, filling facilities, mines, quarries, and solid waste storage are areal sources. Those originating from highway, construction equipment, seaway, railway and air transportation are determined as mobile sources. While the high concentrations of pollutants such as SOX, NOX, and PM10 make it difficult to establish sustainable cities, it is known that they have negative effects on welfare and economic growth. So much so that developing countries are producing based on fossil resources for economic growth and development, and greenhouse gas and pollutant emissions are high in this context (Ai et al., 2023). The growth of cities in terms of both population and space confirms Bookchin's determination that capitalist cities tend to expand continuously. However, this growth increases energy demand, intensifies fossil fuel use and related emissions, and creates serious pressures on the environment. According to Bookchin, in order to overcome environmental crises such as growth of cities, pollution, and fossil fuel use, only turning to renewable energy sources is considered sufficient; it is important to implement a decentralized approach away from centralization (Bookchin, 2017). In this context, it is critical to consider the distribution of pollutants at the local level and their reductions.

Results

Figure 2.

Distribution of National Total Emission Amounts for NOX (tons/year) (2020)

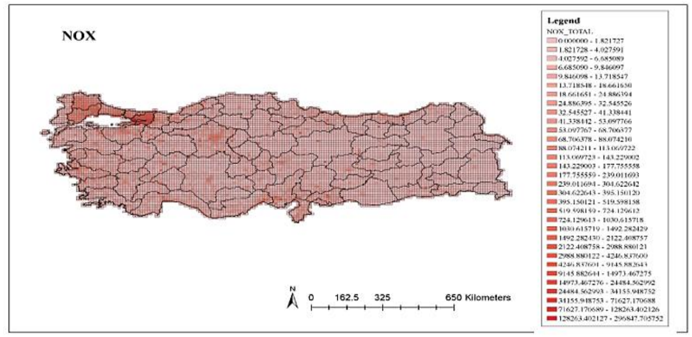


Figure 3.

Distribution of National Total Emission Amounts for SOX (tons/year) (2020)

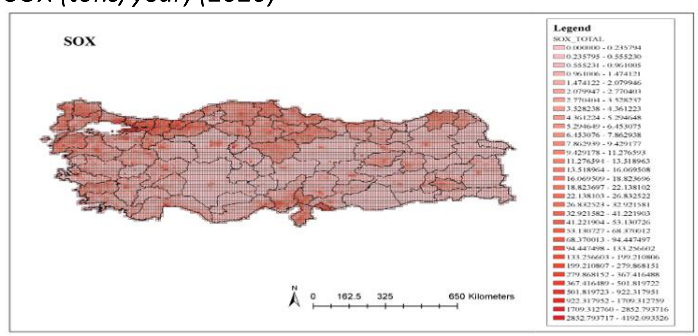
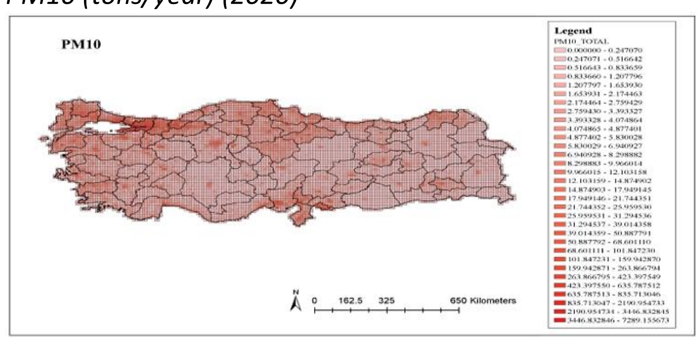


Figure 4.

Distribution of National Total Emission Amounts for PM10 (tons/year) (2020)

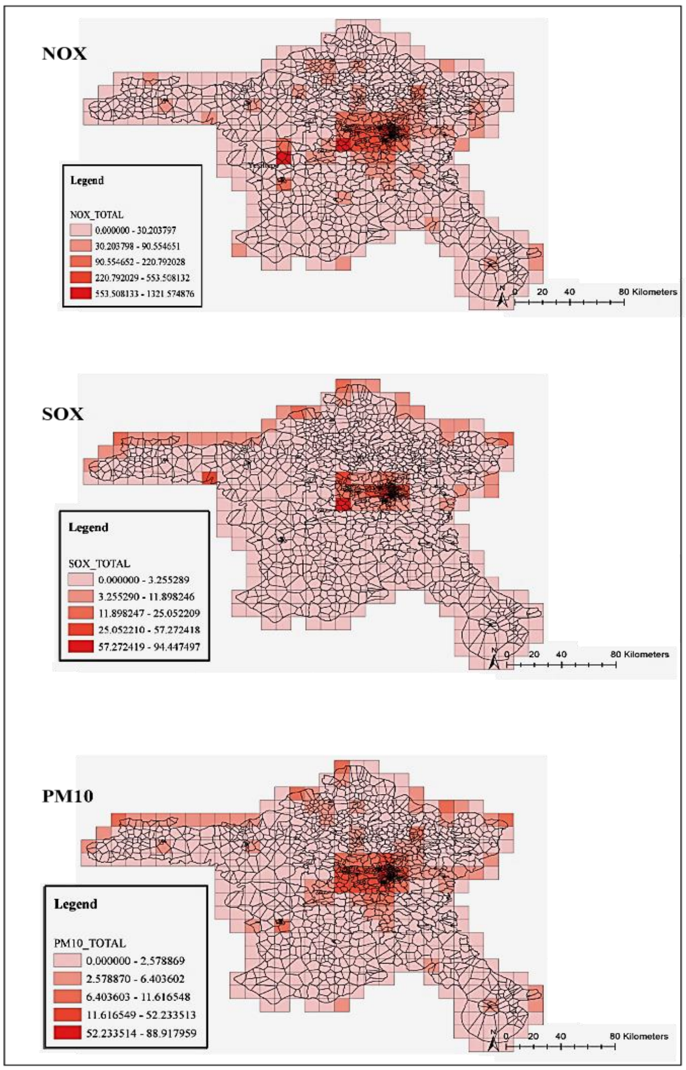


Source: Prepared by the author within the framework of data obtained from the Ministry of Environment, Urbanization and Climate Change.

When Figure 2-4 is examined, the distributions of total emission data of SOX, NOX and PM10 are seen. The data that form the basis of the distribution are raw data and activity-based mappings have been made. It has been understood that emissions are concentrated in the Marmara, Central and Western Black Sea, and Eastern Mediterranean Regions for all three pollutants throughout the country. In order to be able to evaluate the air quality for the three pollutants, the variables should be modeled and then determined in accordance with the Air *Quality Assessment and Management Regulation* and *the Air Quality Assessment and Management Circular No. 2013/37*. The aim of the legislation in question is to harmonize the air quality limit values determined by the European Union with national legislation. Although there is *a National Air Quality Index in Turkey;* calculations are made for five basic pollutants. (PM10, CO, SO_2, NO_2 and O_3) (EIA Report, 2022).

Figure 5.

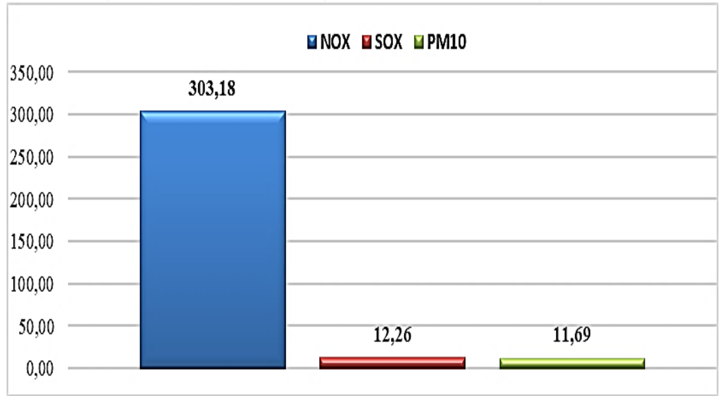
Thematic Map of Total Emission Distribution of Selected Air Pollutants for Ankara (tons/year) (2020)



Source: Prepared by the author within the framework of data obtained from the Ministry of Environment, Urbanization and Climate Change.

Figure 6.

Average of Spatial Distribution of Total Emission Values for Pollutants of Ankara (tons/year) (2020)



Source: Prepared by the author within the framework of data obtained from the Ministry of Environment, Urbanization and Climate Change.

When Figure 1-6 are evaluated together; It is seen that the NOX distribution of Ankara, the second most populous metropolitan city in Türkiye.

It is understood from the details obtained through the AEM portal used in the study that NOX emissions mainly originate from transportation, industrial activities, and the density of power plants, whereas SOX emissions are largely associated with solid fuel consumption and PM10 emissions arise from industrial activities, construction activities, and transportation. According to Graph 2, which presents the average total emissions and their spatial distribution, NOX emissions were determined as 303.18 tons/year, while SOX and PM10 emissions were considerably lower at 12.26 tons/year and 11.69 tons/year, respectively. The substantially higher NOX values may be explained by the widespread and continuous nature of combustion-based activities such as traffic, industrial production, and energy generation, which intensively produce nitrogen oxides during high-temperature combustion processes. In contrast, SOX and PM10 emissions can be relatively limited through the use of low-sulfur fuels, emission control technologies, and particulate filtering systems.

In this context, the determinations that will affect pollution and climate change for Ankara districts are as follows:

- The distribution of emissions is relatively high in central districts with high populations due to sectors such as industry and services.
- Considering that natural gas is not available in Ayaş, Çamlıdere, Güdül, Evren, Nallıhan for 2020, it can be evaluated that the use of other fossil resources has an effect on emissions. Although natural gas is known

as the cleanest fossil fuel, it still emits CO_2.

- In terms of transportation, Ankara is located at the intersection and main line point on the center of the North West, North and North East, South, West lines. This situation has a guiding feature on the distribution of SOX, NOX and PM10.
- Ankara, which is among the provinces with a predominantly industrial sector, has functional facility infrastructure in Sincan, Yenimahalle, Kahramankazan, Gölbaşı, Çankaya, Etimesgut, Akyurt, Çubuk. Also, many industrial services are carried out with 12 Organized Industrial Zone (OIZs) and small and medium-sized enterprises (SME) status enterprises, primarily Anadolu OIZ, Ankara ASO 1 OIZ, Ankara ASO 2-3 OIZ, Başkent OIZ, Ankara Çubuk Livestock Specialization OIZ, İvedik OIZ, Ostim OIZ, Polatlı OIZ (EIA Report, 2022).
    - From the details on the AEM portal, In conclusion, rather than aiming it has been understood that there are 538 industrial facilities and 1605 chimney information belonging to these facilities from the Annex 1 and Annex 2 lists within the scope of *the Environmental Permit and License Regulation for Ankara,* and that these belong to industrial activities and facilities.

When looking at Table 1, it can be understood that the recycling, iron and steel, and mineral sectors are the leaders among all sectors. It was understood that 100 of the 538 facilities are in the Annex 1 list with "*Businesses with high polluting effects on the environment"; 438 of them* are in the Annex 2 list with " *Businesses with polluting effects on the environment".*

- The increase in emissions arising from different sources related to Ankara's economic activities, as mentioned here and more, directly affects the risk of climate change and changes the current and potential results. Central districts were found to have high emissions across all parameters. In surrounding districts, where green spaces predominate, the distribution is observed to be sparser and concentrations to decrease. However, long-term monitoring is necessary to understand the effects of changing years. A study by İslam et al. also noted that PM10 concentrations decreased significantly due to the presence of green spaces (İslam et al., 2024). Therefore, considering that the population density in cities will increase by 2050, increasing green areas in cities will contribute to the reduction of air pollutants such as PM10, which negatively affect air quality and human health through respiratory and cardiovascular diseases, while also indirectly influencing climate change by altering atmospheric processes and radiation balance. Accordingly, natural ecosystems such as forest areas and nature parks in Çubuk, Çankaya, Kızılcahamam, Çamlıdere, Nallıhan, Şereflikoçhisar, Bala districts will contribute to the climate struggle due to their nature of sink areas.

Table 1.

Distribution of Industrial Facilities

Activity (sector)	%	Type		Activity (sector)	%	Type
Glass industry	1.48	Annex-1		Woodworking industry	1.37	Annex-2
Cement industry	5.19	Annex-1		Glass industry	0.46	Annex-2
Iron and steel industry	8.89	Annex-1		Cement industry	2.05	Annex-2
Non-ferrous metals industry	20.00	Annex-1		Use of solvent	4.79	Annex-2
Other industrial production sector	25.9	Annex-1		Iron and steel industry	9.82	Annex-2
Electricity production	3.7	Annex-1		Non-ferrous metals industry	5.94	Annex-2
Recycling industry	18.5	Annex-1		Other industrial production	23.29	Annex-2
Food industry	3.7	Annex-1		Electricity production	0.46	Annex-2
Paper industry	1.48	Annex-1		Recycle	2.28	Annex-2
Chemical industry	5.19	Annex-1		Food industry	4.11	Annex-2
Minerals industry	4.44	Annex-1		Pharmaceutical industry	1.37	Annex-2
Automotive industry	1.48	Annex-1		Paper industry	0.68	Annex-2
Total	100	Annex-1		Chemical industry	7.53	Annex-2
				Lime industry	1.6	Annex-2
				Mining industry	0.23	Annex-2
				Minerals industry	31.74	Annex-2
				Automotive industry	1.37	Annex-2
				Textile industry	0.91	Annex-2
				Total	100	Annex-2

Source: MoEUCC,2020

- However, the decrease and destruction of forests, which are carbon sink areas due to reasons such as urbanization and population growth, will cause an increase in pollutant emissions and climate exposure. In addition, some of the factors that deepen this increase can be listed as improper and unintended use of agricultural areas, limited soil protection and revegetation practices, and loss of momentum in ecosystem restoration, which also bring economic losses.
- In terms of resource efficiency and solid waste management, the landfill dependency of

solid waste continues intensively. There are facilities as integrated solid waste dumping areas in Mamak and Sincan districts. Domestic wastes taken from Çankaya, Mamak, Altındağ, Keçiören, Yenimahalle, Gölbaşı districts are dumped in Mamak landfill and electricity is generated from the resulting methane gas. Domestic solid wastes from districts such as Etimesgut, Ayaş, Sincan, Kahramankazan and Kızılcahamam are dumped in Sincan Çadırtepe Regular Solid Waste Landfill and electricity is generated from there. Solid waste dumping areas belonging to Akyurt, Çubuk, Elmadağ, Kalecik, Bala, Ayaş, Kahramankazan districts have not yet been rehabilitated (EIA Report, 2022, p.76). The implementation of circular economy for climate struggle can be achieved by recycling and reuse and by reducing the emissions produced by burning solid waste. By 2053, it is aimed to process 100% of municipal waste and accept only waste such as slag and ash generated in processing facilities into storage facilities. Apart from this, it will not be possible to store unprocessed municipal waste.

In these contexts, Ankara's urbanization policies affect the climate and the policies are shaped according to the climate. The fact that Ankara has different economic, environmental and local policies for different districts brings about different development levels. The fact that different districts facing the same or similar environmental problems produce different solutions and make different expenditures shows that there are differences in the risk perceptions of these districts.

Theoretical Discussion of Spatial Inequalities

The spatial distribution of polluting emissions in Ankara's districts is not merely a technical or meteorological result; rather, it reflects the theoretical framework established in the introduction, corroborating deep-rooted socio-economic structures and a theoretical interpretation of spatial inequalities.

Marxist Ecology and the Urban Metabolic Rift: The concentration of 538 industrial facilities and 1,605 chimneys predominantly in central and specific industrialized areas, contrasting with fragile carbon sinks in peripheral regions, provides concrete spatial evidence of Marxist socio-ecological interaction. This polarization demonstrates a local "metabolic rift" within Ankara. Capital accumulation and industrial clustering heavily burden the atmosphere with emissions, causing negative externalities on the local environment.

Public Goods Theory and Transboundary Externalities: Empirical findings regarding Ankara's transportation geography offer a classic empirical example of negative externalities within public goods theory. Significant amounts of NO_X, SO_X, and PM10 emissions from inter-regional traffic flows demonstrate that air quality degradation in specific areas is a transboundary phenomenon. Since a significant portion of these emissions originate from mass transit mobility rather than local residential activities, the costs of environmental degradation are borne by local populations and ecosystems. This spatial mismatch between those who utilize mass transit services and those who bear the health and environmental burdens further exacerbates the public interest issue of environmental management at the municipal level.

Infrastructure Deficits and Local Government Capacity Finally, spatial inequalities in energy infrastructure – particularly limited access to natural gas in specific environmental or low-income areas – highlight structural inequalities embedded within the urban system. The resulting reliance on carbon-intensive fuels demonstrates that environmental vulnerability is structurally produced. Addressing these localized emission clusters requires considering Ankara not as a uniform administrative unit, but as a complex socio-ecological-technological system as conceptualized by Krueger et al. (2022). Overcoming these infrastructure-related inequalities depends directly on improving local government capacity and environmental management, and on adopting targeted, region-specific mitigation measures instead of top-down, uniform policies.

In summary, as James O'Connor also argues, rising emissions, the climate crisis, and the collapse of urban ecosystems are a process of self-destruction for the system.

Conclusion

Environmental problems are not confined to a single economy or administrative unit; rather, they function as economic and political phenomena with significant transboundary externality effects. The findings of this study for Ankara's districts demonstrate that air pollution and its impacts on climate change are strongly shaped by spatially differentiated socio-economic, industrial, and infrastructural conditions. This underscores the need for multi-level and regionally differentiated climate management that integrates local dynamics into broader climate policy frameworks. The results show that central districts with higher population density and intensive service and industrial activity exhibit higher emission levels across all parameters. In contrast, peripheral districts with a relatively higher share of green space tend to show lower pollutant concentrations. This pattern highlights the mitigating role of natural ecosystems in improving air quality, but this advantage remains vulnerable to ongoing urban expansion pressures, making continuous monitoring necessary.

Sectoral structure emerges as a key driver of emissions in Ankara. Industrial activities, particularly concentrated in recycling, iron and steel, and mining-based sectors, contribute significantly to local emission loads. The presence of 538 industrial facilities and 1,605 chimneys within the scope of environmental permit regulations further reflects the intensity of industrial pressure on air quality. These findings demonstrate that industrial clustering supports economic activity while simultaneously creating local environmental burdens that require targeted emission control policies. Transportation geography is another significant determinant of pollutant distribution. Ankara's status as a major transit hub increases exposure to NO_X SO_X, PM10 emissions due to interregional traffic flows. This confirms that air pollution in the city is not only locally generated but also shaped by broader regional mobility patterns, reinforcing the importance of transboundary externalities in environmental management.

Energy use patterns also contribute to spatial disparities in emissions. Limited access to natural gas in some areas leads to an increased reliance on more carbon-intensive fuels, elevating local emission levels. The findings also highlight the importance of ecosystem services in mitigating environmental pressures. Districts with forested and natural areas function as carbon sinks and contribute to improved air quality. However, these ecological benefits are increasingly threatened by urbanization, land-use change, and ecosystem degradation, which reduce the overall resilience of the urban environment. This underscores the need for stronger land-use regulations and ecosystem protection as integral components of climate change mitigation strategies. Overall, the study reveals significant intra-urban inequalities in environmental performance across Ankara's districts, stemming from differences in industrial density, transportation density, energy infrastructure, waste management systems, and ecological capacity.

The choice of the Jenks Natural Breaks classification method played an important role in revealing these spatial differences. Consequently, districts sharing similar emission characteristics were grouped without imposing arbitrary thresholds, allowing spatial inequalities and concentration patterns to emerge more clearly. In particular, the distinction between highly industrialized and transportation-intensive central districts and relatively lower-emission peripheral districts became more visible. This methodological choice strengthened the interpretation of district-level environmental vulnerabilities and provided a more reliable basis for identifying priority areas for climate mitigation and air quality management policies.

The gradual and moderate differentiation observed among the districts on the map demonstrates the capacity of the Jenks Natural Breaks method to accurately capture realistic, non-artificial transitions in the dataset, rather than forcing arbitrary or exaggerated polarizations. Consequently, these findings suggest that climate and environmental policies should not be uniform, but rather tailored to district-specific emission profiles and vulnerability conditions.

From a policy perspective, strengthening integrated environmental monitoring systems, improving data transparency, and enhancing coordination among district-level authorities are essential for effective climate management. Such mechanisms will support evidence-based policy-making and enable more targeted mitigation strategies. In conclusion, the data highlight that strengthening local government capacity and adopting spatially differentiated climate policies are critical for improving environmental quality and advancing sustainable urban development in Ankara.

In conclusion, rather than aiming to measure econometric causal impacts, this study establishes a comprehensive spatial profile and baseline typology of emission distributions across Ankara's districts. The empirical data highlight that strengthening local government capacity and adopting spatially differentiated climate policies are critical for improving environmental quality and advancing sustainable urban development. The gradual and moderate differentiation observed among the districts on the map demonstrates the capacity of the Jenks Natural Breaks method to accurately capture realistic, non-artificial spatial transitions in the dataset, rather than forcing arbitrary or exaggerated polarizations. By mapping the descriptive distribution of NO_X, SOX, PM10 emissions alongside industrial density, transportation infrastructure, and ecological capacities, this study provides a crucial diagnostic tool for local authorities. Consequently, these findings suggest that climate and environmental policies should not be uniform, but rather tailored to district-specific emission profiles, structural vulnerabilities, and baseline spatial conditions. Ultimately, balancing regional mobility, industrial clustering, and urban expansion with targeted land-use regulations and ecosystem protection emerges as the definitive pathway toward environmental sustainability in Ankara.

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Genişletilmiş Özet

Amaç: İçinde bulunduğumuz 21. yy çevre sorunları bağlamında iklim değişikliği ve etkilerinin belirgin bir hal aldığı durumu ile teknik ve sosyo-ekonomik boyutta tüm sektörlerin orjininde kaygı konusu olan bir mücadele şeklini almıştır. Özellikle nüfusun çoğunluğunun kentlerde yaşadığı göz önünde bulundurulduğunda, kentlerin krizlerin merkezinde yer alması yaygın olarak kabul edilmektedir. Diğer taraftan hızlı kentleşme ve kentlerin dirençliliğindeki zayıflama iklim mücadelesinde azaltım ve uyum eylemlerinin birlikte güçlendirilmesini gerektirmektedir. Bu bağlamda, ekonomilerin gerek yapısal zorlukları gerekse mali boyuttaki eksiklik ve aksaklıkları sürecin yönetiminde alternatif yönetsel süreçlere ihtiyacı artırmakta, sadece çevre boyutu ile değil sosyo-ekonomik boyutu ile riskin göz önünde bulundurulmasına işaret etmektedir. Bu anlamda çalışmada, iklim değişikliğinin başlıca nedeni olan toplam emisyonların iki ana bileşeninden biri olan hava kirletici emisyonları, Ankara’nın 25 ilçesi özelinde incelenmiş, azaltımına yönelik iklim mücadelesine katkısının değerlendirilmesi amaçlanmıştır.

Yöntem ve veriler: Hava kirleticilerden kükürt oksit (SOX), azot oksit (NOX), partikül madde (PM10) analize dahil edilmiş hava kirleticilerin dağılımlarına altlık oluşturacak toplam emisyon verileri Çevre, Şehircilik ve İklim Değişikliği Bakanlığı’nın Hava Emisyon Yönetimi (HEY) portalındaki son versiyon olarak 2020 harita çıktılarından temin edilmiştir. Quantum Geographic Information System (QGIS) programı kullanılarak; Ankara’nın 25 ilçesi gridler halinde izlenmiştir. HEY portalında grid çözünürlüğü maksimum 1*1 kilometreyi ifade etmektedir. İlçelerin 2020 yılı için SOX, NOX ve PM10 kirleticilerinin emisyon dağılımları noktasal, alansal ve hareketli kaynaklardan gelmektedir. 12.000’den fazla tesis ve 50.000’den fazla baca bilgisini içeren endüstriyel faaliyetler; noktasal kaynaklardır. Isınma, hafriyat, organize sanayi bölgesi (OSB), üretim ve tüketim, benzin istasyonu, dolum tesisi, maden taş ocakları, katı atık depolama kaynaklı olanlar; alansal kaynaklardır. Karayolu, iş makineleri, denizyolu, demiryolu ve havayolu ulaşımından kaynaklananlar ise hareketli kaynaklar olarak belirlenmiştir.

Bulgular ve sonuç: Çalışmanın sonunda, iklim değişikliğini pekiştiren hava kirleticilerin toplam emisyona kayda değer bir katkı sağladığı ve bu durumun iklimle ilgili mücadeleyi zorlaştırdığı değerlendirilmektedir. Emisyonların yüksek düzeyde negatif dışsallık içerdiği bilinmektedir ve özellikle şehirler ile çevresinde benzer kirlilik dağılımlarının ortaya çıktığı gözlemlenmektedir. Bu bağlamda, şehirlerin başlıca aktörleri olan yerel yönetimlerin mevcut ve taslak halindeki mevzuatlarında görev ve sorumluluklarını yeniden değerlendirerek ayrıntılı düzenlemelere yer vermesi önem arz etmektedir. Ren vd.’nin de belirttiği gibi, ortak kirlilik platformlarının oluşturulması ve bilgi paylaşım mekanizmalarının geliştirilmesi, çevre kirliliği ile yerel yönetimler arasındaki ilişkiyi güçlendirecektir. Böylelikle, yerel yönetimlerin kirlilik konusundaki farkındalığı, sorumluluğu ve müdahale kapasitesi artacak; çevresel yerelleşme yetkinlikleri gelişecektir. Bu çerçevede, yerel ölçekte hava kirleticilerin takibi ve izlenmesi daha etkin hale gelecektir. Bu durum aynı zamanda hava kirletici emisyonları ile yerel iklim politikalarıyla bağlantılı güncel bir mevzuat altyapısına duyulan ihtiyacı da açıkça ortaya koymaktadır.