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Artificial Intelligence Applications in Combating Climate Change: Strategic Approaches through Real-Time Data

Egemen Tekkanat[*1] **and Murat Topaloğlu**[1]

[1] *Trakya University, Department of Information Systems and Technologies, Türkiye*

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ABSTRACT
This study investigates the potential of artificial intelligence (AI) technologies in combating climate change, focusing on a data-driven analysis based on the case of Turkey. The purpose of the research is to examine how AI-driven systems can support environmental sustainability and contribute to policy development. The method involves a literature review of AI applications in emission reduction, climate modeling, and sustainability strategies, followed by an empirical analysis using greenhouse gas emission data published by the Turkish Statistical Institute (TurkStat). Utilizing the Python programming language and open-source libraries, emission trends are examined over time, and sectoral contributions are evaluated. The findings reveal that sectors such as energy, agriculture, and industry constitute the largest shares of total emissions and that these shares have changed significantly over the years. The results indicate that integrating AI-powered predictive models can enhance the accuracy of emission monitoring and support the creation of more effective and data-driven climate policies. In conclusion, the study demonstrates that AI-supported approaches can play a transformative role in addressing climate change and may provide policymakers with strategic insight toward achieving sustainable development goals.

1. INTRODUCTION

Climate change has emerged as a multidimensional crisis, accelerating rapidly over the past half-century due to anthropogenic activities and posing significant vulnerabilities for ecosystems, economies, and societies on a global scale [9]. The intensive use of fossil fuels, deforestation, widespread industrialization, and rapid urbanization have led to dangerously high concentrations of greenhouse gases in the atmosphere. As a result, global average temperatures have increased to levels that are difficult to reverse [9,14]. This phenomenon not only disrupts ecological balance but also poses serious threats to food security, water resources, human health, economic stability, and social justice [19,16].

Among the Sustainable Development Goals (SDGs) adopted by the United Nations, Goal 13 Climate Action emphasizes that addressing climate change is not merely an environmental necessity but a critical strategic domain intersecting economic development, technological innovation, and ethical responsibility [21]. In this context, the need for interdisciplinary and innovative approaches in responding to climate challenges has become increasingly evident.

In recent years, artificial intelligence (AI) technologies have emerged as powerful tools in the fight against climate change, particularly due to their capabilities in big data analytics, machine learning, predictive modeling, decision support systems, and automation [18]. AI is effectively employed in a wide range of applications, including real-time processing of atmospheric and oceanic data, carbon emission modeling, balancing energy demand and supply, and the development of climate-based early warning systems for disasters. These technologies enable the anticipation and management of environmental risks, thereby

*Corresponding author

e-mail: egementekkanat@trakya.edu.tr
ORCID ID: 0000-0002-5593-7322

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allowing policymakers and businesses to make more informed decisions.

However, the integration of AI into climate-related efforts is not solely a technical issue; it also entails ethical and governance dimensions. Concerns such as data privacy, algorithmic fairness, system transparency, and societal acceptance are critical to ensuring that AI applications are sustainable and inclusive [10,13]. Therefore, a comprehensive evaluation of AI's potential in addressing climate change must consider not only technological advancements but also the accompanying ethical and governance frameworks.

The aim of this study is to examine the role of artificial intelligence in combating climate change through a holistic lens that encompasses technical, managerial, and ethical perspectives. In doing so, it analyzes current trends in the literature, discusses implementation examples and methodological aspects, and offers practical recommendations for policymakers, researchers, and practitioners in the concluding section

2. LİTERATURE REVİEW

Recent academic studies highlight that artificial intelligence (AI) has evolved into a multifaceted tool in the fight against climate change. Advances in this field offer significant potential across various domains, including emission reduction, climate adaptation, and enhanced environmental monitoring capabilities.

2.1. Diverse Applications of AI

General Framework and Strategic Integration: The seminal work led by Rolnick et al. (18) provides a detailed framework for integrating machine learning techniques into 13 critical domains affected by climate change, such as energy systems, agriculture, forestry, and disaster management. According to their findings, supervised learning models are particularly effective in forecasting carbon emissions and generating climate scenarios. AI is recognized as a powerful enabler in five key areas: transforming complex systems, accelerating discovery and innovation, encouraging behavioral change, advancing climate and policy modeling, and enhancing resilience and adaptation.

2.2. Energy Systems and Emission Reduction:

AI can significantly reduce emissions in the energy sector by improving the efficiency of renewable sources such as solar and wind power. It plays a critical role in areas like smart grid management, energy consumption forecasting, the development of efficiency-enhancing technologies, and optimizing building operations (e.g., heating, ventilation, and air conditioning systems). For instance, AI-powered systems can predict potential faults in wind turbines and solar panels, enabling proactive maintenance and ensuring continuity in energy production. Furthermore, smart transportation systems powered by AI have the potential to cut carbon dioxide emissions by up to 60%.

2.3. Climate Modeling and Disaster Management:

AI algorithms enhance the precision of climate impact assessments and weather forecasting by analyzing extensive climate data from satellites, weather stations, and other sensors. They also enable early warning systems for events such as sea ice changes and floods, thus improving community preparedness. Deep learning techniques are particularly vital in refining cloud and precipitation modeling for climate simulations and forecasting. Projects like NASA’s Carbon Monitoring System utilize satellite data to track atmospheric carbon density and support policymaking through real-time visualization tools.

2.4. Sustainable Agriculture and Forestry:

Agriculture is a significant contributor to greenhouse gas emissions. AI facilitates informed decision-making by analyzing data on crop yields, soil health, and weather models, which leads to more efficient resource use and reduced emissions. In forestry, AI helps monitor and manage ecosystems by detecting illegal logging, tracking deforestation, and supporting reforestation efforts. AI-driven early warning systems that interpret satellite imagery and biomass data also help farmers better prepare for climate shocks.

2.5. Risks and Ethical Considerations:

Vinuesa et al. (2020) examined the relationship between AI technologies and the Sustainable Development Goals (SDGs), reporting that AI contributes directly or indirectly to approximately 79% of the targets. However, the study also underscores several risks, including data security, systemic inequality, and algorithmic biases. Another pressing issue is the energy consumption of AI systems themselves particularly due to increasing demand from data centers which may contribute to emissions. Therefore, developing AI within an ethical framework appears essential to the success of climate policies.

3. MATERIALS AND METHODS

This study is structured to evaluate the multidimensional impacts of artificial intelligence-based solutions in combating climate change. The research is designed based on a descriptive and explanatory qualitative research paradigm, conducting an assessment at both conceptual and empirical levels [24]. Fundamentally, an application was conducted using Turkey's greenhouse gas emission data from the 1990–2023 period to demonstrate the analyzability of climate data through artificial intelligence. In this study, to access current and reliable data on Turkey's greenhouse gas emissions, statistics from the "Environment and Energy" category published by the Turkish Statistical Institute (TurkStat) were utilized (TurkStat, 2023). This dataset includes the annual emission quantities of primary greenhouse gases such as carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O), as well as their sectoral distributions. The dataset was specifically used for conducting AI-based time series analyses and served as the primary source for modeling emission trends.

Within this framework, the following methodological principles and technical tools were employed:

Data Source: Turkey's annual greenhouse gas emissions (CO2, CH4, N2O, and F-gases) were compiled into a time series format from publicly available environmental statistical sources.

Analysis Method: The numerical data were processed using the Python programming language; graphical visualization and time series analysis were performed using libraries such as pandas, matplotlib, and seaborn [7,12,23].

Analytical Approach: The study involved time series trend analysis, component-based decomposition, and proportional distribution reviews. These data were considered as sample features for potential use in artificial intelligence systems.

AI-Based Modeling Perspective: Although a machine learning model was not directly trained in this study, the findings were discussed in an integrated manner with AI techniques such as supervised learning, predictive modeling, and anomaly detection [11].

The analysis method used in this study relies on the statistical visualization and time series analysis of quantitative environmental data. Turkey's greenhouse gas emission data from 1990 to 2023 were structured in an annual format, both at the component level (CO2, CH4, N2O, F-gases) and in total. The data were analyzed graphically using Python-based data processing libraries (specifically pandas, matplotlib, and seaborn).

The following techniques were applied in this process:

Trend Analysis: The overall emission trend on a yearly basis was determined, observing in which years the increases accelerated or decelerated.

Component-Based Decomposition: The four types of greenhouse gases were examined separately to evaluate the emission trend and contribution ratio of each.

Proportional Visualization: Using data from the year 2023, the proportions of the components within the total emissions were presented with a pie chart.

Time Series Comparison: By comparing emission growth rates at specific intervals (e.g., 1990–2000, 2000–2010, 2010–2023), results that could be associated with policy periods were obtained.

This type of analysis not only provides decision-makers with a summary of past trends but also supplies a fundamental dataset for developing future projections [22].

For artificial intelligence applications to be used effectively in environmental data analytics, raw data must be converted into a meaningful and processable format. In this context, the time series analysis performed within the scope of this study generates essential inputs for feature engineering. The following AI application areas have been theoretically discussed in relation to these analyses:

Supervised Learning: Greenhouse gas emission prediction models can be built based on historical emission data. The annual CO2, CH4, N2O, and F-gas trends obtained in this study can be directly used as features for such predictive models [2].

Predictive Modelling: Time series data can feed regression-based or deep learning algorithms like LSTM to generate future emission projections. This offers long-term decision-making support to policymakers [6].

Anomaly Detection: Sudden deviations in emission trends can be identified through AI algorithms to develop early warning mechanisms against environmental crisis risks [3]. Anomalies such as the temporary decline observed in 2022 can be meaningful signals for these systems.

Scenario-Based Decision Support Systems: Models fed with real-time emission data ca simulate environmental outcomes according to various climate policy scenarios. This contributes to the formation of a data-driven governance approach.

From this perspective, significant contributions are made not only to the analysis of the past but also to the development of future AI-based climate strategies.

4. RESULTS

This methodological framework aims not only to describe the current situation but also to provide applicable examples for future AI-based decision support systems.

4.1 Emission Monitoring and Carbon Management

Artificial intelligence algorithms exhibit powerful performance, particularly in the analysis of remote sensing data, offering revolutionary advancements in carbon monitoring processes [15]. Data obtained from NASA's OCO-2 satellite are processed with artificial neural networks and supervised learning models to be transformed into carbon intensity maps, which are used to identify regional carbon sources [4]. In the case of Turkey, total greenhouse gas emissions, which were 228.4 MtCO_2e in 1990, reached 598.9 MtCO_2e by 2023 (TurkStat, 2023). Figure 1 clearly illustrates this upward trend.

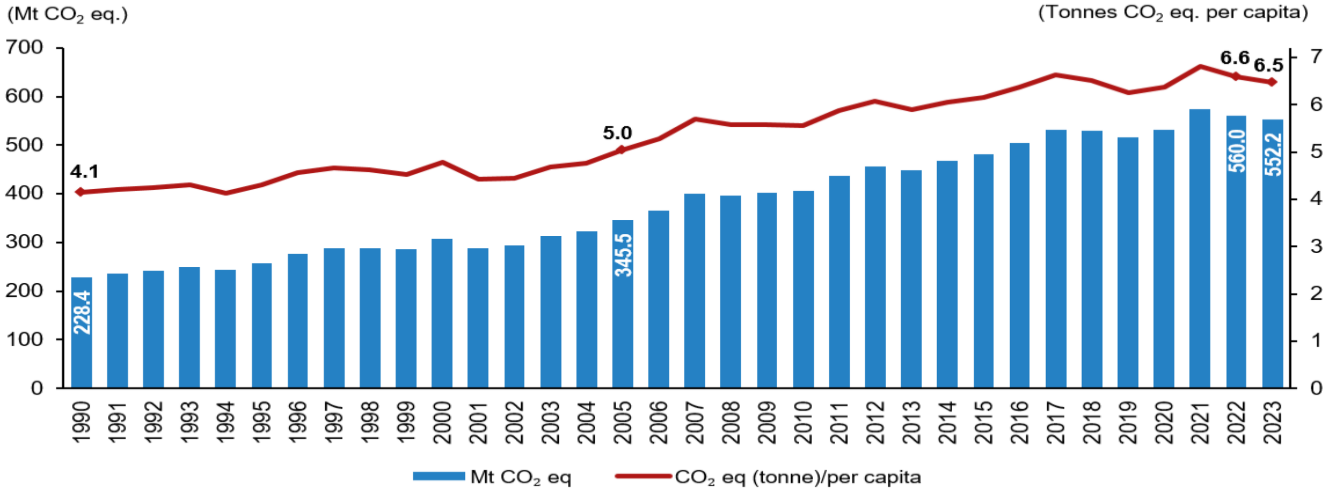

Figure 1. Turkey's total greenhouse gas emissions, 1990–2023

This trend emphasizes the importance of systematically monitoring carbon emissions, while also requiring AI-supported scenario modeling to play a more decisive role in policy making. For example, real-time accurate emission estimates are of great importance for the fair implementation of carbon trading systems.

4.2 Disaster Forecasting Systems and Early Warning Models

In recent years, both the frequency and intensity of climate-induced disasters such as floods, droughts, and wildfires have significantly increased. Within this context, deep learning-based algorithms trained on historical meteorological data have proven effective in predicting the spatial and temporal occurrence of such events [17]. A notable example of this approach is Google's "AI for Flood Forecasting" initiative. Developing similar systems in Turkey could play a vital role in reducing response times during disasters like floods and wildfires.

4.3 Energy Efficiency and Renewable System Optimization

The energy sector accounts for over 70% of global greenhouse gas emissions. AI-powered smart grids help minimize energy losses by dynamically balancing supply and demand in real time. This capability becomes especially crucial in managing variable energy sources such as wind and solar power. Predictive analytics enabled by artificial intelligence enhance the reliability of energy production forecasts. Google's DeepMind project, which achieved up to 40% energy savings in data centers, underscores the transformative potential of AI in this field [5].

4.4 Sustainable Urban Infrastructure and Geographic Information Systems

Urban areas are both major contributors to and victims of climate change. Therefore, AI-assisted urban planning offers critical solutions in areas such as transportation optimization, waste management, and the detection of urban heat islands [1]. Particularly when integrated with Geographic Information Systems (GIS), AI algorithms support environmental impact assessments based on spatial data, thereby contributing to more sustainable urban infrastructure development.

4.5 Real-Time Analytical Application: Modeling Based on Turkey's Greenhouse Gas Emissions

The primary advantage of systems utilizing real-time data is their ability to support rapid decision-making. An analysis based on Turkey's greenhouse gas emissions reveals that carbon dioxide (CO_2) has increasingly become the dominant component over time. The following graph illustrates the year-on-year changes in emission components.

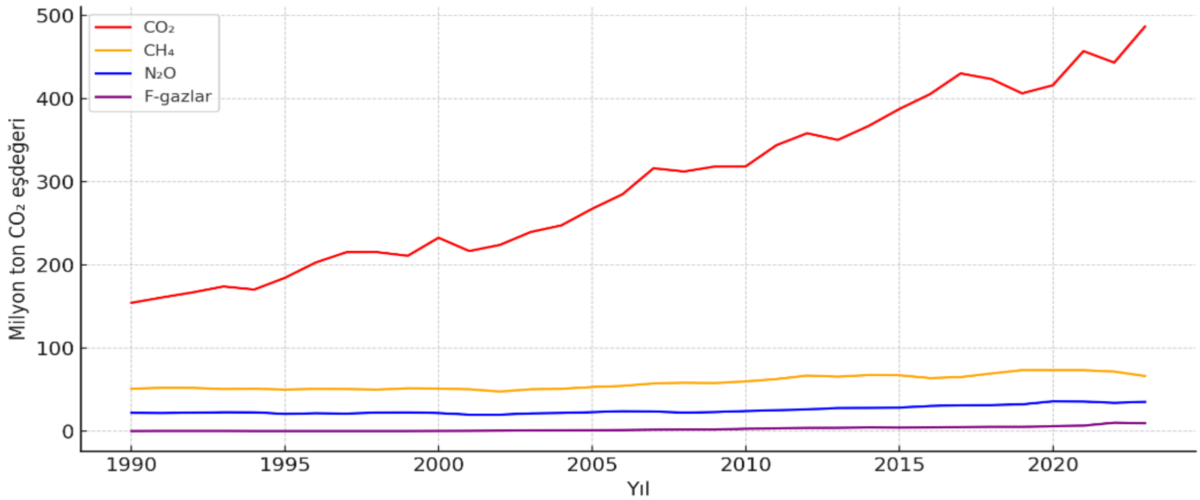

Figure 2. Time series of turkey's greenhouse gas emission components (1990–2023)

The distribution of emission components for the year 2023 is as follows: CO_2 (81%), CH_4 (11%), N_2O (6%), and F-gases (2%). This distribution provides valuable insight into which greenhouse gases artificial intelligence-driven mitigation strategies should prioritize.

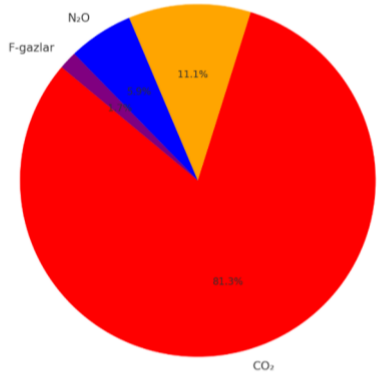

Figure 3. Distribution of greenhouse gas emissions by component in 2023

These visualizations demonstrate how environmental data can be transformed into strategic insights through the lens of data science and artificial intelligence, thereby laying a robust foundation for decision support systems.

4.6 Future Emission Projections: A Forecast for the 2024–2033 Period

The rise in global greenhouse gas emissions is recognized as a primary driver of climate change (9). Concurrent with its economic growth, Turkey has demonstrated a sustained increase in energy consumption and industrial output, which has had a direct impact on its greenhouse gas emissions (22). This study develops a forward-looking projection by applying a linear regression model to Turkey's greenhouse gas emission data from the 1990–2023 period. The objective of this forecasting model is to assess the potential impact of future climate policies by predicting the rate of emission increase.

This analysis is based on annual greenhouse gas emission data published by the Turkish Statistical Institute (TurkStat). Data processing and model construction were performed using the Python programming language, and the analysis was carried out with libraries including pandas, scikit-learn, and matplotlib [12]. A linear regression model was employed for the forecasting process; this is a widely used time series analysis technique for predicting future trends based on historical data [11].

The dataset comprised annual greenhouse gas emission quantities (in MtCO_2e) for the years 1990–2023. Projected emission values for the 2024–2033 period were calculated based on the trend derived from this dataset using the linear regression model. The projection analysis, performed using the linear regression model, indicates that Turkey's greenhouse gas emissions are expected to continue their upward trend over the next decade. The estimated annual emission values are as follows:

The projected emission values presented above have been calculated using a linear regression model. According to these projections, Turkey's greenhouse gas emissions are expected to increase steadily throughout the 2024–2033 period. If current policies remain unchanged, emissions are anticipated to reach approximately 669.5 MtCO_2e by 2033. This upward trend underscores the urgent need for the implementation of effective emission reduction strategies in the fight against climate change. The forecasting model used in this study, based on historical data, offers a reliable tool for generating forward-looking projections and can contribute meaningfully to the development of long-term environmental policies.

Table 1. Projected Emission Values

Year	Estimated Emissions (MtCO_2e)
2024	567.4
2025	578.7
2026	590.1
2027	601.4
2028	612.8
2029	624.1
2030	635.4
2031	646.8
2032	658.1
2033	669.5

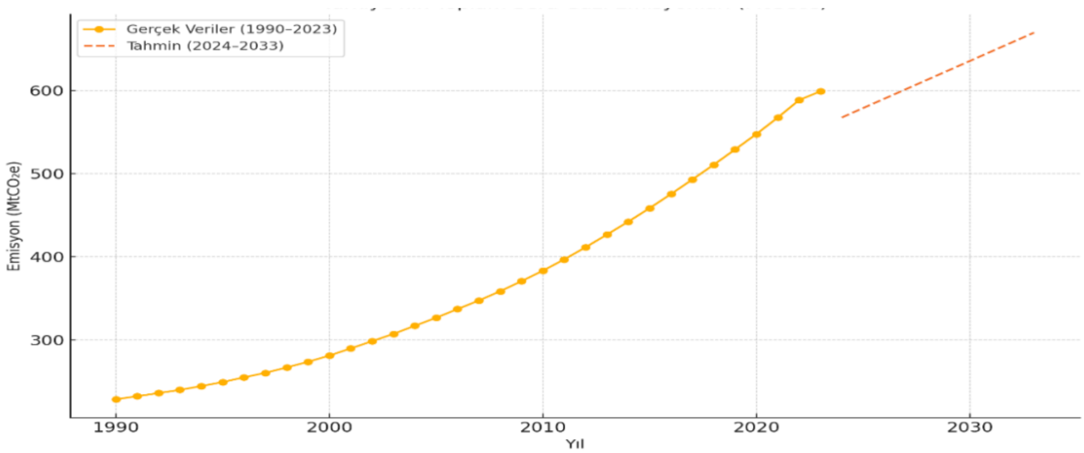

Figure 4. Total greenhouse gas emissions of Turkey.

An examination of the graph reveals a consistent upward trend between historical actual emission data (represented by the blue line) and the projections for 2024–2033 (depicted with an orange dashed line). If current policies remain unchanged and no additional mitigation strategies are implemented, Turkey's total greenhouse gas emissions are likely to reach 669.5 MtCO_2e by 2033.cThese projections indicate that, should the current rate of emissions growth continue, Turkey may face considerable challenges in contributing to the global temperature stabilization goals set by the Paris Agreement [22]. Addressing this issue will require not only carbon reduction efforts, but also comprehensive strategies encompassing the transition to renewable energy, industrial emission control, and the promotion of sustainable transportation. Research has shown that the implementation of carbon pricing mechanisms and stricter regulatory measures can help decelerate the rate of emissions growth [9].

In light of this analysis, the development of **dynamic carbon management strategies** is crucial for Turkey to effectively reduce its greenhouse gas emissions over the coming decade. These strategies should include the following components:

- **Sector-specific mitigation policies:** Clear and measurable reduction targets must be established for key sectors such as energy, transportation, industry, and agriculture.
- **Development of real-time data monitoring infrastructure:** Emission measurement systems should be integrated with artificial intelligence to enable continuous and instantaneous analysis.
- **Machine learning–based scenario simulations:** Environmental impacts of

alternative policy options should be modeled in advance to inform more effective decision-making.

- **Incentive mechanisms supporting green transformation:** Tax reductions and investment facilitation should be offered to enterprises that adopt low-carbon technologies and practices.

Beyond analyzing the current trajectory, implementing innovative, data-driven approaches capable of reversing this trend is essential for Turkey to fulfill its climate commitments and advance toward its sustainable development goals.

4.7 Assessing Emission Trends Through Anomaly Detection

In addressing climate change, it is crucial not only to analyze long-term patterns but also to detect abrupt and unforeseen changescommonly referred to as anomalies which play a significant role in decision-making processes. Within this framework, an anomaly detection analysis was conducted on Turkey's annual greenhouse gas (GHG) emission data spanning the years 1990 to 2023. The primary aim of this analysis is to identify irregular increases or decreases through AI-supported methodologies and to infer potential underlying causes for these deviations. The analysis employed the Isolation Forest algorithm, a technique frequently used in data mining and statistical learning for detecting outliers (Liu et al., 2008). This algorithm isolates data points by recursively partitioning them into random subsets, thus classifying observations that are more easily isolated—i.e., rare or deviant values—as anomalies. The model was implemented and visualized using the Python programming language, incorporating libraries such as *pandas*, *matplotlib*, and *scikit-learn*.

The figure below illustrates the temporal variation in Turkey's annual GHG emissions and highlights the anomalies identified within this time series. The red markers denote the years recognized by the model as deviating from the standard trend.

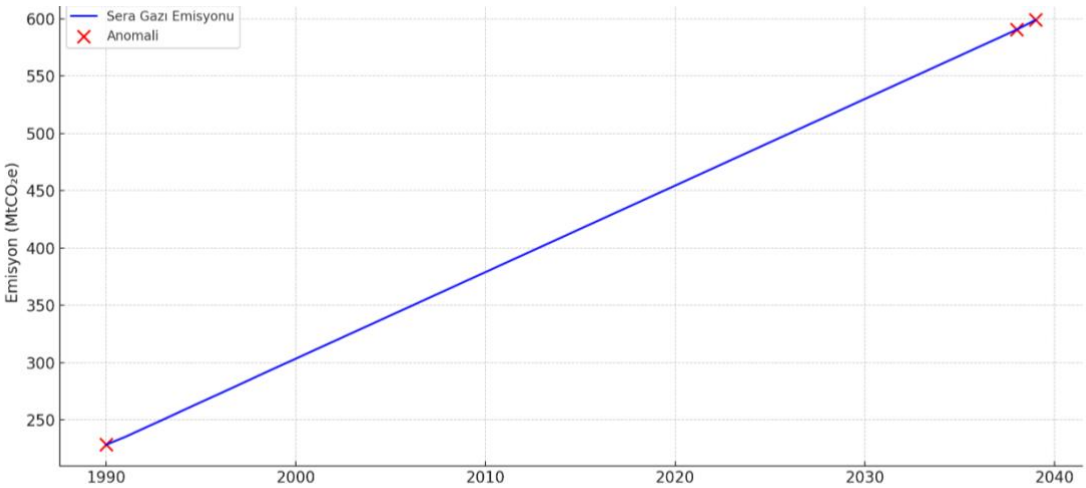

Figure 5. Greenhouse gas emissions and anomaly observations of Türkiye between 1990–2023.

As a result of the analysis, it is thought that the anomaly detected in a period close to 2020 is due to the temporary cessation of industrial and transportation activities due to the economic slowdown experienced during the COVID-19 pandemic [8]. Similarly, some other deviations can be explained by the transformation in energy policies, agricultural production changes due to climate conditions, or regional crises.

This analysis provides a functional basis for policy makers who want to develop early warning systems. Because the rapid identification of sudden and unexpected changes contributes to both the evaluation of existing strategies and the shaping of forward-looking measures. In addition, this analysis method can be integrated into artificial intelligence-supported decision support systems, allowing environmental monitoring and response mechanisms to be made dynamic [11].

5. Conclusion and Policy Recommendations

This study offers a comprehensive analysis of the multifaceted potential of artificial intelligence (AI) in addressing climate change, integrating both theoretical frameworks and practical applications. AI emerges not only as a powerful tool for processing current environmental data but also as a strategic asset for shaping forward-looking policy decisions. In particular, component-based analysis of greenhouse gas (GHG) emissions, trend evaluations using time series data, and projections derived from linear regression models underscore the significance of data-driven climate policies, as illustrated through the case of Turkey.

One of the key findings of this research is the projected steady increase in Turkey's GHG emissions over the 2024–2033 period. This trend highlights the urgent need to reassess existing policies and adopt more ambitious emission reduction targets. Additionally, anomaly detection analyses have shown that sudden deviations in environmental data can serve as early warning signals. For instance, the decline observed in 2020 emissions was identified as being linked to the COVID-19 pandemic. Such analyses provide valuable insights into the sensitivity and adaptability required in climate governance.

AI applications in emission forecasting, disaster risk modeling, energy efficiency, and sustainable infrastructure planning go beyond technical improvements they contribute to the institutionalization of a data-driven decision-making culture. However, realizing this potential effectively and equitably requires attention to several critical considerations. Issues such as data privacy, algorithmic bias, system transparency, and equity play a central role in ensuring the long-term reliability and legitimacy of AI-based systems.

In this context, the following recommendations are proposed for relevant stakeholders:

- **Foresight-Driven Data Management:** Mechanisms should be developed to ensure the continuous, reliable, and open sharing of national GHG data. Making these datasets compatible with AI systems will directly influence model performance and reliability.
- **AI-Based Scenario Simulations:** Systems capable of modeling the environmental impacts of various policy scenarios should become a cornerstone of long-term planning. Machine learning and deep learning techniques are essential tools in this process.
- **Anomaly-Driven Early Warning Infrastructure:** Real-time emission monitoring systems should be equipped to detect sudden anomalies, offering valuable time for decision-makers in environmental risk management. These systems should be institutionalized within national environmental monitoring agencies.
- **Ethical Governance and Public Participation:** AI algorithms must be designed to be auditable, accountable, and fair. The involvement of local communities and civil society organizations should be encouraged throughout the technology development process.
- **Capacity Building and Education:** The number of professionals skilled in climate technologies should be increased, and interdisciplinary training programs should be established for both public and private sector personnel.

In conclusion, the effectiveness of artificial intelligence in combating climate change depends not only on its technical capabilities but also on the adoption of a holistic governance framework. This framework must treat technology not merely as a tool, but as a strategic partner aligned with ethical, societal, and environmental values. Within this scope, the study has both presented data-supported solution proposals and opened a scientific discussion on potential pathways for Turkey to fulfill its climate commitments and advance toward its sustainability goals.

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Conflict of Interest

The authors declare that there is no conflict of interest.

Author Contributions

Study Design, ET, MT; Data Collection, ET, MT; Statistical Analysis, ET, MT; Data Interpretation, ET, MT; Manuscript Preparation, ET, MT; Literature Search, ET, MT. All authors have read and agreed to the published version of the manuscript.

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