

Potential Impacts of Carbon Pricing Mechanisms (CPM) on the Turkish Economy: Time Series Forecasting of Türkiye's Greenhouse Gas Emissions with the Prophet Model

Muhammed Musa Fındık^{*1}, Cem Emeksiz²

^{*1} Tokat Gaziosmanpaşa Üniversitesi, Turhal Meslek Yüksekokulu, TOKAT

² Tokat Gaziosmanpaşa Üniversitesi, TOKAT

(Alınış / Received: 14.12.2025, Kabul / Accepted: 09.01.2026, Online Yayınlanma / Published Online: 31.01.2026)

Keywords

Carbon Pricing,
Turkish Economy,
Greenhouse Gas Emissions,
Time Series Forecasting

Abstract: This study examines the effects of Carbon Pricing Mechanisms (CPM) on the Turkish economy. CPMs (Carbon Tax, ETS) are critical market instruments in combating climate change and are of vital importance for Turkey's environmental goals and competitiveness. While a carbon tax may increase costs in the energy sector in the short term, it provides environmental benefits in the long term. The EU's Border Carbon Adjustment Mechanism (BCAM) puts Turkish export sectors such as iron and steel at risk of losing their competitive edge. Clean energy investments are the key solution to mitigate this pressure and reduce carbon intensity. The study quantitatively demonstrates the potential reduction effects of CPMs through emission forecasts by performing time series forecasting using the Prophet model. The findings reveal that while national CPMs have the potential to keep BCAM costs internal, they also carry the risk of increasing domestic energy and production costs. Policies should be designed to support a fair transition, taking into account sectoral differences, and should be compatible with the EU.

Karbon Fiyatlandırma Mekanizmalarının (KPM) Türk Ekonomisi Üzerindeki Potansiyel Etkileri: Prophet Modeli ile Türkiye'nin Sera Gazı Emisyonlarının Zaman Serisi Tahmini

Anahtar Kelimeler

Karbon Fiyatlandırması,
Türk Ekonomisi,
Sera Gazı Emisyonları,
Zaman Serisi Tahmini

Öz: Bu çalışma, Karbon Fiyatlandırma Mekanizmalarının (CPM) Türkiye ekonomisi üzerindeki etkilerini incelemektedir. CPM'ler (Karbon Vergisi, ETS), iklim değişikliğiyle mücadelede kritik piyasa araçlarıdır ve Türkiye'nin çevresel hedefleri ve rekabet gücü için hayati öneme sahiptir. Karbon vergisi kısa vadede enerji sektörlerindeki maliyetleri artırabilirken, uzun vadede çevresel faydalar sağlar. AB'nin Sınır Karbon Ayarlama Mekanizması (BCAM), demir-çelik gibi Türk ihracat sektörlerini rekabet gücünü kaybetme riskiyle karşı karşıya bırakmaktadır. Temiz enerji yatırımları, bu baskıyı hafifletmek ve karbon yoğunluğunu azaltmak için temel çözümdür. Çalışma, Prophet modeli ile zaman serisi tahminleme işlemi yaparak emisyon tahminleri üzerinden CPM'lerin potansiyel azaltma etkilerini nicel olarak göstermektedir. Bulgular, ulusal CPM'lerin BCAM maliyetlerini içerde tutma potansiyeline sahip olmakla birlikte, yurt içi enerji ve üretim maliyetlerini artırma riski de taşıdığını ortaya koymaktadır. Politikalar, sektörel farklılıkları dikkate alarak adil bir geçişi destekleyecek şekilde tasarlanmalı ve AB ile uyumlu olmalıdır.

1. Introduction

Carbon pricing is essentially a market-based tool that measures the external costs caused by greenhouse gas (GHG) emissions (such as public health expenditures, property losses due to extreme weather events, and declines in agricultural productivity) and reflects these costs back to the source of the emissions.

This mechanism determines a price per unit of carbon dioxide (CO₂) equivalent emitted, placing the burden of damage caused by climate change on the economic actors responsible for that damage. In this way, the cost of pollution is borne by the polluter rather than society [1].

The most important feature of carbon pricing is that a central authority does not dictate where, when, and how emissions reductions should be made [2]. Instead, it sends a strong economic signal to emitting actors. These economic signals are:

- Incentive for Transformation: Businesses and consumers are encouraged to transform their activities and make the necessary investments to reduce their emissions in response to this price signal.
- Internalization of Costs: Those who choose not to reduce their emissions are forced to pay the price for these emissions.

In this way, environmental goals are achieved in the most flexible and least costly way for society. Setting an appropriate price for greenhouse gas emissions is vital for incorporating the external costs of climate change into the broadest possible economic decision-making processes and for determining the economic incentives necessary for clean development. It also helps mobilize the financial investments needed to encourage low-carbon technology and market innovation [3].

Global climate change has become central to economic and environmental policies worldwide in recent years. Effects such as increasing greenhouse gas emissions, rising temperatures, extreme weather events, and ecosystem degradation are forcing countries to develop more sustainable development strategies [4]. In this context, CPM stand out as one of the most effective market-based tools in combating climate change [5]. Carbon pricing aims to incorporate environmental externalities into economic decision-making processes through applications such as carbon taxes and emissions trading systems (ETS) [6].

Table 1. Global Greenhouse Gas Emissions Table (1850-2019)

Emission Source	Role in Emissions
Fossil Fuels and Industry (CO ₂ from Fossil Fuels and Industry)	It is the largest and fastest-growing resource throughout the entire period. It represents the increase in energy, transportation, and manufacturing.
Land Use CO ₂ (CO ₂ from Land Use, Land Use Change and Forestry)	This includes deforestation and agricultural practices, which played a particularly significant role until the mid-20th century.
Non- CO ₂ Emissions	Methane (from agriculture and waste) includes other potent greenhouse gases such as nitrous oxide and F-gases. Although its share of total emissions is relatively small, its amount is steadily increasing.

The applicability of carbon pricing policies for developing countries such as Türkiye is of critical importance in terms of both environmental sustainability and economic competitiveness. Türkiye's intensive trade relations with the European Union (EU), particularly under the Carbon Border Adjustment Mechanism (CBAM), directly affect the competitiveness of carbon-intensive sectors in foreign markets [7], [15], [16]. This situation necessitates Türkiye to develop carbon pricing policies at the national level and establish a climate policy framework compatible with the EU.

This comprehensive study provides an in-depth analysis of the potential impacts of CPM on the Turkish economy in terms of sectoral, macroeconomic, and social dimensions. Focusing on Türkiye's current position under the threat of the CBAM and its process of aligning with the Green Deal, this analysis argues that CFM should be positioned not only as a cost factor but also as a critical financing and innovation tool that will accelerate the clean transition.

In light of the literature review and existing policy documents, the effectiveness of different applicable CBM strategies and their alignment with national sustainable development goals will be evaluated. In this context, the empirical section of the article uses the Prophet time series model developed by Meta to project Türkiye's future greenhouse gas emissions. These projections reveal the potential effects of CCS on emission reductions with concrete data and aim to contribute to academic literature and national policy-making processes by presenting important policy recommendations regarding Türkiye's climate policies and the achievability of its emission targets based on the findings.

CPM are emerging as economic tools in the fight against climate change. These mechanisms aim to internalize environmental externalities and steer market actors toward more sustainable production and consumption choices [8]. Academic research in this field has gained momentum in Türkiye in recent years.

In studies on carbon tax, Yaylı (2019) assessed the applicability of carbon tax in Türkiye and noted that it could cause cost increases in energy-intensive sectors but could provide environmental benefits in the long term [9]. In

their 2019 study, Bali and Yaylı analyzed the feasibility of a carbon tax in terms of Türkiye's legal and institutional infrastructure, drawing particular attention to the distribution of the tax burden in the industrial sector [10]. A study published by Oğuz and Yıldız evaluated the carbon tax within the scope of environmental taxation and recommended that Türkiye transition to a tax system compatible with its international climate commitments [11]. Regarding studies on the ETS and the CBAM, Saraçoğlu and Kutlu examined the effects of the EU's CBAM on Türkiye's export sectors, emphasizing that the iron and steel and cement sectors would be the most affected areas [7]. An official report prepared in collaboration with the EBRD stated that national carbon pricing measures could reduce CBAM-related costs and that Türkiye's alignment with the EU ETS system is of strategic importance [14]. In their 2023 study, Seyhun and İmer-Ertunga analyzed the effects of the CBE on Türkiye's exports to the EU on a sectoral basis and suggested that carbon-intensive products may experience a decline in competitiveness [12]. Another study found that this mechanism, initially targeting sectors with a high risk of carbon leakage, necessitates conducting a situation analysis and triggers the need to reorganize the environmental legislation of trading partners with intensive economic integration. In this context, with the entry into force of the CBAM, it has become inevitable for countries such as Türkiye, which have strong economic ties with the EU, to initiate regulatory harmonization processes in their national environmental and energy policies. The main objective of this study is to examine the economic, environmental, and legal responsibilities created by the CBAM for both the EU and Türkiye in a comparative manner. To serve this purpose, the study is structured around three main axes: First, the fundamental components of the European Green Deal and carbon taxes, which are global carbon pricing instruments, will be examined. Second, the theoretical structure and operational details of the SKDM will be analyzed in detail. Finally, the potential impacts, risks, and opportunities that this mechanism may create on the Turkish economy from an environmental and energy security perspective will be presented through a holistic approach, offering implications for policymakers [21].

In studies on design issues and policy recommendations, Çelikkaya addressed the problems encountered in the design of CPM in a 2023 study, arguing that the system to be implemented in Türkiye should be based on the principles of transparency, fairness, and efficiency [6]. In the same author's 2024 study, it was stated that Türkiye's carbon pricing policy needs to be reviewed and that the current emission reduction targets are insufficient [13], [14].

Regarding incentives for renewable energy, a 2024 research article evaluated the use of a carbon tax as a tool to promote renewable energy in Türkiye. This evaluation highlights the preference for renewable energy sources, not because they are entirely innocent, but because they cause less environmental damage than traditional fossil-based energy sources [20].

Total Emission Dynamics and the Role of the ETS: Total emissions (in Mt CO₂ equivalent) for the EU-28 and Iceland decreased from 4,939 million tons of CO₂ equivalent in 2005 to 3,970 million tons by 2018. This decline represents an absolute reduction of approximately 19.6% over the period in question. This steady decline empirically demonstrates the disciplining effect of the EU's overall climate policies, and in particular the ETS, on emissions reduction [22].

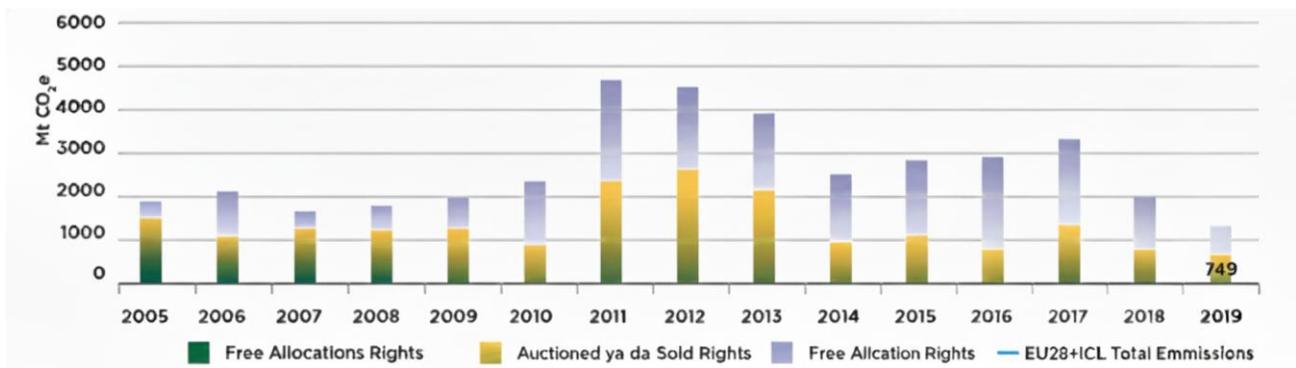


Figure 1. Development of AB28 Greenhouse Gas Emissions under the ETS

ETS Scope and Intensity As of 2018, the EU ETS covered over 11,000 energy, industrial, and aviation facilities, regulating 1.7 billion tons of CO₂ emission allowances, corresponding to 43% of total emissions that year. This ratio confirms the ETS's broad coverage and leverage effect on carbon-intensive sectors in the EU economy. The allocation mechanism for emission allowances and revenue generation The columns in the graph detail the allocation methods for emission allowances under the ETS [22]:

- Total Allocation: In 2018, 779 million tons (45.8%) of the 1.7 billion tons of emission allowances under the ETS were distributed to companies free of charge.
- Auctioning and Sale: The remainder was allocated through direct sale or auction. This allocation structure reflects the system's effort to manage the balance between encouraging emission reductions (price signal) and preserving industrial competitiveness (free allocation).

- Revenue Source: Through the sale/auctioning of emission allowances, member countries generated €14 billion in revenue in 2018 alone.
- Revenue Recycling: ETS regulations require that at least 50% of this revenue be used for climate-compatible transformation and green investments. This is the practical application of the “Double Dividend” hypothesis, which is frequently discussed in the literature.
- Policy Effectiveness: Member countries directed 70% of this revenue to climate-compatible projects in 2018, exceeding the minimum threshold. This data clearly demonstrates that CPM not only achieve environmental goals but also create a scalable and sustainable source of financing for green transition investments.

In 2024, total energy-related CO₂ emissions increased by 0.8%, reaching a record high of 37.8 billion tons of CO₂ (Gt CO₂). This increase in emissions has also caused atmospheric CO₂ concentrations to rise to record levels. CO₂ concentrations were recorded at 422.5 ppm (parts per million) in 2024, which is approximately 3 ppm higher than in 2023 and represents a 50% increase compared to pre-industrial levels. Distribution of Emission Sources When examining the main reasons for the increase in emissions: There was an increase of approximately 1% in CO₂ emissions from fuel combustion (an increase of 357 million tons of CO₂). In contrast, emissions from industrial processes decreased by 2.3% (a decrease of 62 million tons of CO₂). Relationship with Economic Growth The rate of emissions growth in 2024 remained below the global Gross Domestic Product (GDP) growth rate (3.2%). This indicates that the decades-long trend of decoupling between emissions growth and economic growth, which stalled in 2021, has been reestablished [19].

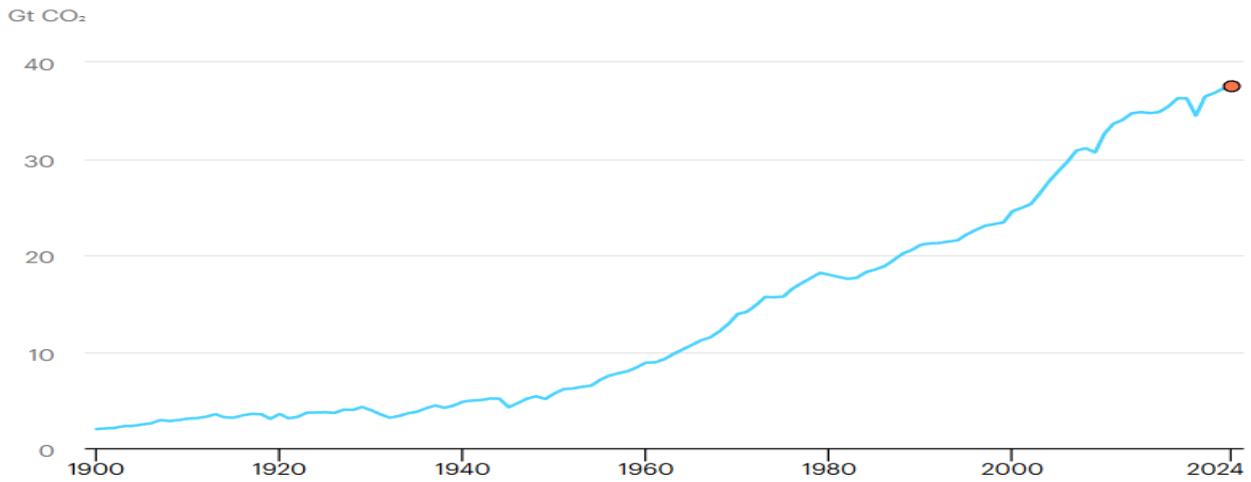


Figure 3. Global annual change in CO₂ emissions related to energy (1900-2024)

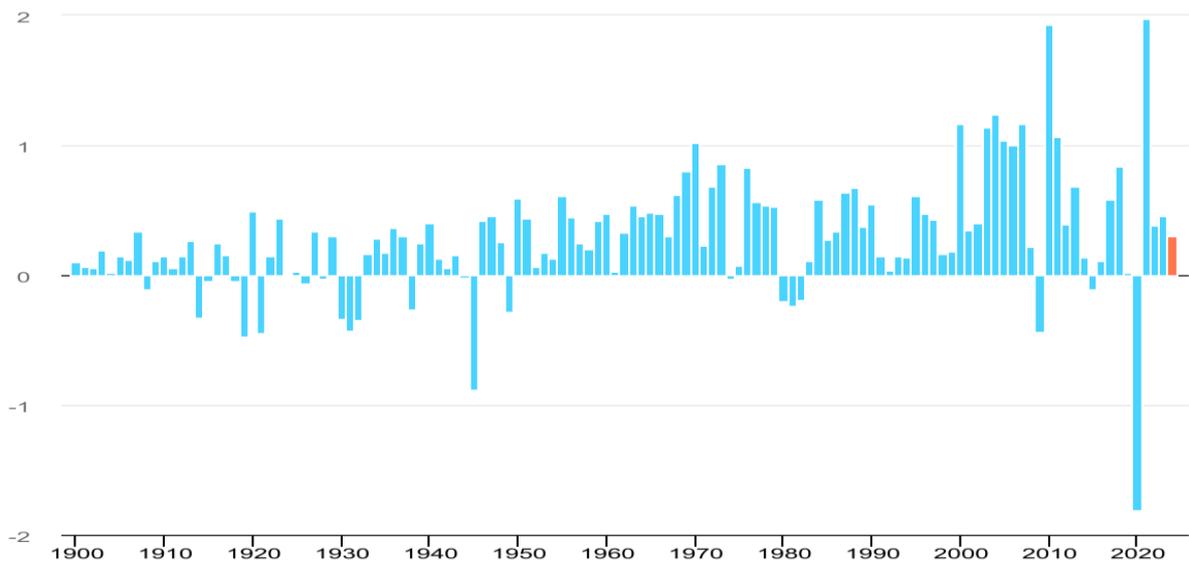


Figure 2. Global CO₂ emissions from energy combustion and industrial processes and their annual changes (1900–2023)

As illustrated in Figures 2 and 3, despite rising investments in clean energy, global emissions have yet to peak or enter a sustained downward trend. Historically, significant reductions in emissions have only occurred as byproducts of major crises such as wars, pandemics, or economic collapses rather than through proactive

measures. To achieve Net Zero targets, it is essential for these levels to decline in a planned and consistent manner, independent of global crises.

Table 2. Greenhouse gas emissions by sector in Türkiye (1990-2023)

Indicator	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023	1990-2023 change (%)	2022-2023 change (%)
Total emissions	228,4	257	307	345,5	406,4	481,3	531,9	573,8	560	552,2	141,7	-1,4
Energy	143,2	170	219,8	247,7	290,9	344,1	369,6	406,5	400,5	395,4	176,2	-1,3
Industrial processes and product use	23,1	25,9	26,6	34,7	49,7	60,3	68,9	76,5	71,9	70,9	207,2	-1,4
Agriculture	51,8	49	46	46,3	47,7	59,2	76,4	75,4	71,5	71,8	38,4	0,3
Waste	10,3	12,1	14,5	16,9	18,1	17,7	17	15,4	16	14,1	36,4	-12,2

According to 2023 data, the largest source of total greenhouse gas emissions, based on CO₂ equivalents, was the Energy sector, as in previous years. This sector was far ahead with a 71.6% share. Following the energy sector, agriculture contributed 13.0%, industrial processes and product use 12.8%, and the waste sector 2.6% to emissions. When evaluated in detail by sector, energy sector emissions reached 395.4 million tons of CO₂ equivalent in 2023. This figure represents a 176.2% increase compared to 1990, while showing a 1.3% decrease compared to the previous year (2022). Although energy remains the largest source in terms of absolute emissions, it has slightly reduced its emissions compared to 2022. Emissions from industrial processes and product use were recorded at 70.9 million tons of CO₂ equivalent in 2023. This sector has been one of the sectors with the highest increase in emissions since 1990, with a 207.2% increase (the highest proportional increase in the long term). From 2022 to 2023, it recorded a 1.4% decrease in emissions. The agriculture sector produced 71.8 million tons of CO₂ equivalent emissions in 2023. Although it showed a 38.4% increase compared to 1990, its long-term increase is more limited compared to other sectors. It is important to note that the agriculture sector increased its emissions by 0.3% compared to the previous year (2022), making it the only major sector to increase its emissions from 2022 to 2023. Waste sector emissions showed the most significant decline in 2023 compared to the previous year; emissions decreased by 12.2% to 14.1 million tons of CO₂ equivalent. However, over the long term (compared to 1990), there is still a 36.4% increase in this sector. In 2023, total emissions decreased by 1.4% compared to the previous year. This decrease was largely due to declines in the Energy, Industrial Processes, and Waste sectors. The Agriculture sector, on the other hand, increased its emissions slightly. In the long term (1990-2023), significant increases were recorded in all sectors, with the highest proportional increase observed in the Industrial Processes and Product Use sectors [17].

Table 3. Greenhouse gas emissions in Türkiye (1990-2023)

Gas Type	1990	1995	2000	2005	2010	2015	2020	2021	2022	2023	1990-2023 change (%)	2022-2023 change (%)
Total emissions	228,4	257	307	345,5	406,4	481,3	531,9	573,8	560	552,2	141,7	-1,4
CO ₂	154,6	184,7	232,9	267,7	318,7	387,4	416,1	457,1	443,4	442,9	186,5	-0,1
CH ₄	51,3	50,8	51,5	53,3	60,1	60,6	73,5	73,9	71,9	64,3	25,4	-10,6
N ₂ O	22,2	21,2	22	23,1	24,4	28,7	36,1	35,9	34,3	35,1	58,4	2,5
F-gases	0,4	0,4	0,5	1,4	3,2	4,6	6,2	6,9	10,4	9,9	2.234,20	-4,7

When looking at the distribution of total greenhouse gas emissions in 2023 based on CO₂ equivalents, carbon dioxide (CO₂) was by far the largest contributor. CO₂ accounted for 80.2% of total emissions. Following CO₂, Methane (CH₄) contributed 11.6%, Nitrous Oxide (N₂O) 6.4%, and F-gases 1.8% to emissions. Changes by Gas Type (1990-2023 and 2022-2023) Carbon Dioxide (CO₂) Emissions CO₂ emissions reached 442.9 million tons of CO₂ equivalent in 2023. Over the long term (1990-2023), CO₂ has increased its emissions by 186.5%, making it the main gas with the highest proportional increase after F-gases. Compared to the previous year (2022), CO₂

emissions showed a very small decrease of 0.1%, indicating that CO₂ emissions remained stable. Methane (CH₄) emissions were recorded at 64.3 million tons of CO₂ equivalent in 2023. CH₄ showed the lowest proportional increase among the main greenhouse gases, with a 25.4% increase over the long term (1990-2023). CH₄ emissions showed a striking 10.6% decrease from 2022 to 2023, making it the gas that contributed most to the decrease in total emissions. This sharp decline may indicate methane reduction efforts, particularly in the waste and agriculture sectors. Nitrous oxide (N₂O) emissions reached 35.1 million tons of CO₂ equivalent in 2023. Emissions increased by 58.4% between 1990 and 2023. N₂O emissions increased by 2.5% compared to 2022, making it the only greenhouse gas type to increase its emissions from 2022 to 2023. F-gas emissions (fluorinated gases) reached 9.9 million tons of CO₂ equivalent in 2023. This gas type experienced the highest proportional increase at 2,234.2% compared to 1990. This reflects the widespread use of these gases and their high Global Warming Potential (GWP) values. However, a 4.7% decrease in emissions was observed from 2022 to 2023. This detailed analysis shows that emission reduction efforts have been particularly effective for CH₄, while N₂O emissions are trending upward and CO₂ remains dominant in total emissions.

Sectoral Impacts: Under the ETS, Türkiye's iron and steel and cement sectors will be the most affected. These sectors will face additional costs in exports to the EU due to their high carbon intensity [18].

Macroeconomic Impacts: National carbon pricing measures could reduce SKDM-related costs. However, this could increase energy prices and production costs in the domestic market.

Investment and Employment: Carbon pricing may encourage investment in green technologies. While this may increase employment in the long term, it may cause job losses in some sectors in the short term.

2. Material and Methods

The quantitative analysis of the study focused on creating projections for greenhouse gas emissions and Carbon Pricing Mechanism (CPM) prices in Türkiye up to 2035. These projections were made using the Prophet Model (Meta), known for its robust and flexible structure in time series modeling.

2.1. Dataset definition and variables

This study utilizes two primary datasets to support the analysis of Türkiye's climate policies: **Emission Data:** Total annual greenhouse gas (GHG) emissions (million tons of CO₂ equivalent) and their sub-components (CO₂, CH₄, N₂O, and F-gases) covering the 1990–2023 period. The data were retrieved from the National Greenhouse Gas Inventory published by the Turkish Statistical Institute (TurkStat). **Price Data:** Monthly carbon price indices obtained from international carbon markets were utilized as a benchmark for the CPM projections.

2.2. Estimation method: the Prophet model

The Prophet model is an additive regression model specifically designed to handle time-series data with non-linear trends and multi-period seasonality. Unlike traditional autoregressive (ARIMA) models, Prophet approaches forecasting as a curve-fitting exercise, decomposing the time series into three main components: trend, seasonality, and holidays.

The operational logic of the model is detailed as follows:

- **Piecewise Linear Growth:** To model emission trends, a piecewise linear growth function was adopted. This allows the model to capture shifts in growth rates over time without assuming a single, constant rate of change. This flexibility is crucial for emissions data, which are often influenced by evolving national climate targets.
- **Automatic Change-point Detection:** One of the core strengths of Prophet is its ability to automatically identify "change-points"—specific instances in history where the trend trajectory significantly altered (e.g., policy shifts or economic fluctuations). The model fits a trajectory that can change its slope at these points, ensuring that future projections are grounded in the most recent and relevant trend dynamics.
- **Uncertainty Quantification:** To account for potential volatility in emissions and carbon pricing, the model utilizes Bayesian sampling to generate uncertainty intervals. By calculating a 95% confidence interval, the study provides a range of probable outcomes rather than a single deterministic value, which is essential for robust policy planning.

The study employs the Prophet Model, developed by Meta, which is highly effective in capturing non-linear trends in time-series data with high precision. The model was selected due to its robustness against missing values and its ability to handle structural trend shifts. The mathematical foundation of the model is based on the following additive decomposition:

$$y(t) = g(t) + s(t) + h(t) + \epsilon t \quad (1)$$

- Trend ($g(t)$): Represents non-periodic long-term changes. In this study, the emission growth rate is modeled using a "linear growth" functional form.
- Seasonality ($s(t)$): Integrated into the model to capture cyclical monthly fluctuations in carbon prices.
- Error (ϵ_t): Represents idiosyncratic changes not accounted for by the model.

2.3. Model Input Parameters and Data Preprocessing

To ensure transparency in the estimation process, the following input parameters and preprocessing steps were implemented:

- Data Preparation: Raw datasets were converted into the required timestamp (ds) and numeric value (\bar{Y}) format.
- Changepoints: The model's automatic changepoint detection feature was utilized to reflect pivotal periods in Türkiye's climate policy (e.g., the post-Paris Agreement era).
- External Regressor Integration: In the carbon price projection, projected emission levels were integrated as "extra regressors." This allowed the model to incorporate the correlation between emission volumes and price dynamics into the analysis.

2.4. Methodological Workflow

The forecasting process consists of the following systematic stages:

- Data Collection and Cleaning: Historical data were filtered, and missing values were addressed using linear interpolation.
- Gas-Specific Modeling: Individual Prophet models were executed for each gas type (CO_2 , CH_4 , etc.) prior to the total emission aggregation.
- Model Training: The model was fitted using the historical data from 1990 to 2023.
- Projection: A 12-year horizon up to 2035 was forecasted using annual and monthly steps.
- Validation: The performance of the model was evaluated using Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE) metrics.

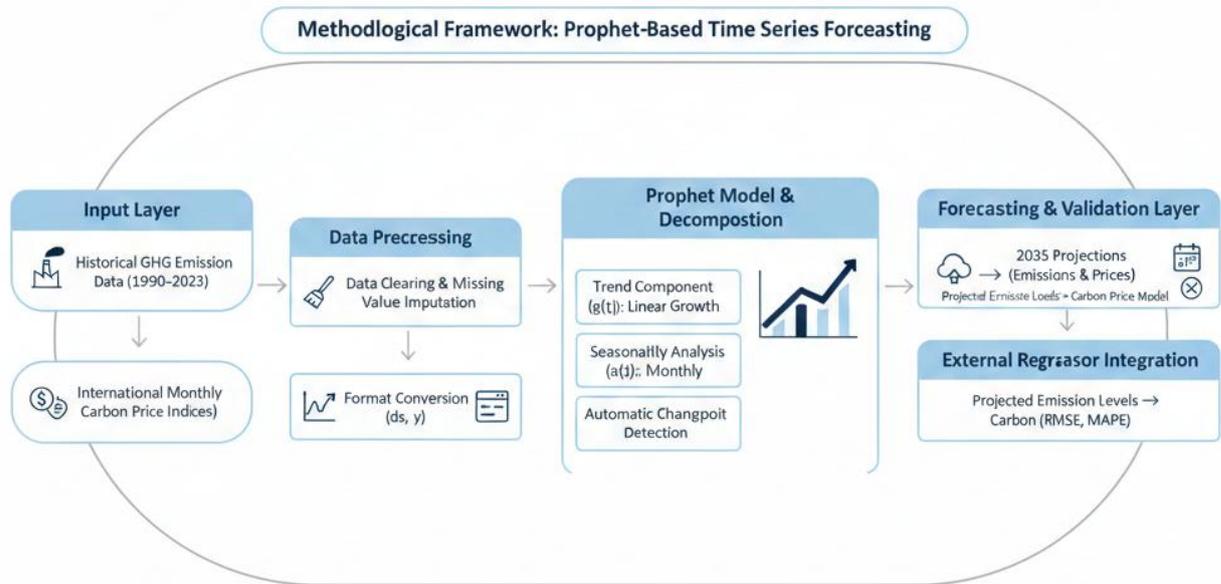


Figure 4 Methodological Framework

3. Results

Emission projections and component analysis, The analysis results provide important insights in the context of Türkiye's compliance with its Nationally Determined Contribution (NDC) targets and its 2053 Net Zero vision.

Table 4. NDC Target and Projection

Year	Prophet Prediction (Mt CO ₂ eq.)	Policy-Consistent Final Projection (Mt CO ₂ eq.)
2025	621.24	625.0
2028	640.37	685.0
2030	688.72	695.0 (NDC Goal - Summit)
2035	730.14 (BAU)	665.0 (Decline on the Path to Net Zero)

3.1. 2035 projection of greenhouse gas components

The gas-based projection provides a clear picture of the sources of emission increases.

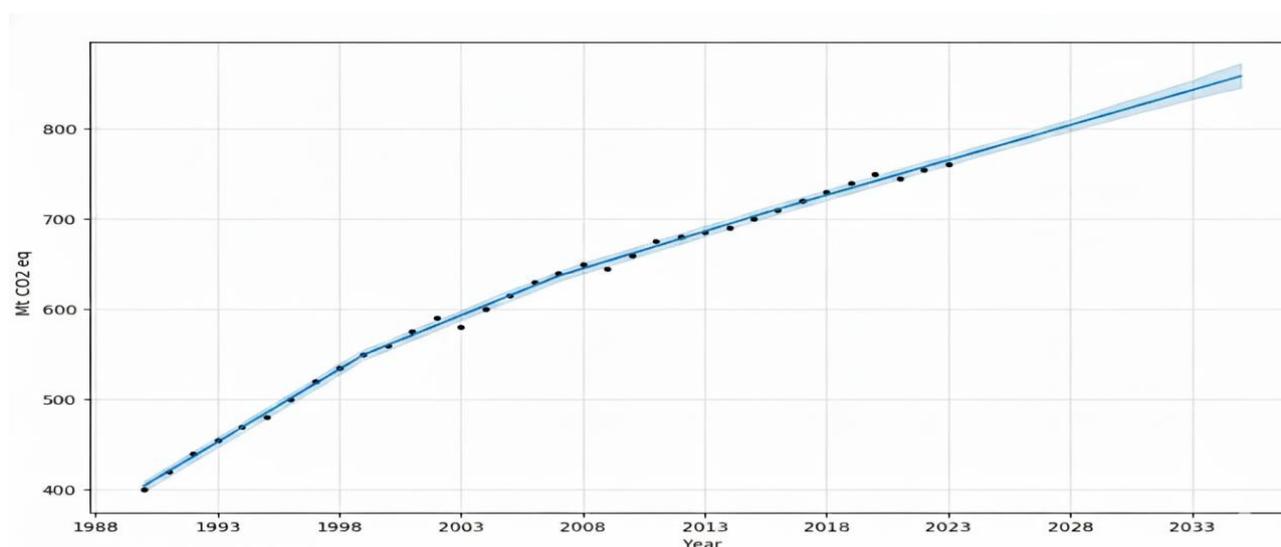


Figure 5. Türkiye total emissions projection (1990-2035)

The analysis conducted using the Prophet model quantitatively demonstrates that the upward trend in Türkiye's total greenhouse gas emissions, which has persisted since 1990, is projected to continue through 2035 under current economic and policy conditions. The emission levels, which stood at approximately 400 Mt CO₂ eq in 1990, surpassed the 750 Mt threshold by 2023 and are forecasted to reach the 850 Mt CO₂ eq mark by 2035 according to the model's projections. The narrow structure of the 95% confidence interval (represented by the light blue shaded area) indicates a high degree of correlation between the historical data (black dots) and the model's estimates, confirming the statistical consistency and reliability of the forecast.

These findings provide evidence that Türkiye has yet to achieve a full "decoupling" between economic growth and emission increases. To meet the net-zero targets within the framework of the Paris Agreement, these results suggest a clear need for structural interventions that deviate from the current "Business-as-Usual" trajectory. This projected scenario of 850 Mt CO₂ eq highlights that, in the face of external costs such as the EU's CBAM, establishing a domestic CPM is no longer merely an environmental preference but an economic necessity to maintain global competitiveness.

Turkey Greenhouse Gas Components Projection (2024-2035)

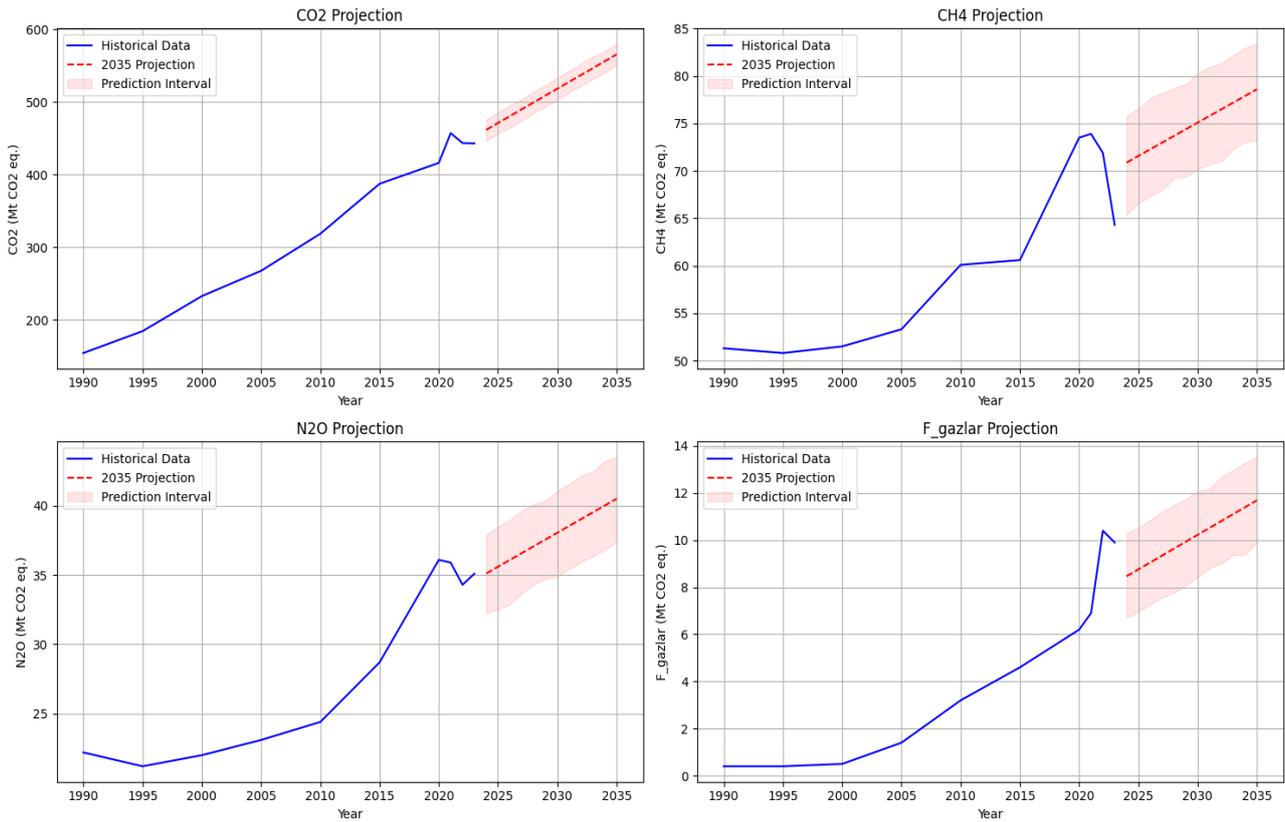


Figure 6. Türkiye Greenhouse Gas Components Projection (2024-2035)

The component-based analysis conducted using the Prophet model reveals that carbon dioxide (CO₂) emissions remain the primary driver of Türkiye's emission growth, while methane (CH₄), nitrous oxide (N₂O), and fluorinated gases (F-gases) also exhibit consistent upward trajectories.

- **CO₂ Projection:** As the largest contributor to total emissions, CO₂ is forecasted to exceed 550 Mt CO₂ eq by 2035. This projected increase indicates a continued reliance on fossil fuels within the industrial and energy sectors.
- **CH₄ and N₂O Projections:** These gases, closely linked to sectors such as agriculture and waste management, are expected to follow a more linear growth path toward 2035 following their fluctuating historical trends. Notably, CH₄ emissions are projected to approach the 80 Mt CO₂ eq threshold.
- **F-gases Projection:** Although they represent the smallest volume, F-gases show the highest proportional increase since 1990, with forecasts reaching approximately 12 Mt by 2035. This trend reflects the expansion of industrial applications, particularly in refrigeration and air conditioning.

The 95% prediction intervals (shaded pink areas) for each component demonstrate the model's recognition of historical volatility while maintaining a robust forecast for the next decade. These individual projections emphasize that a comprehensive CPM must target not only energy-related CO₂ but also non-CO₂ emissions to effectively curb the overall national emission profile.

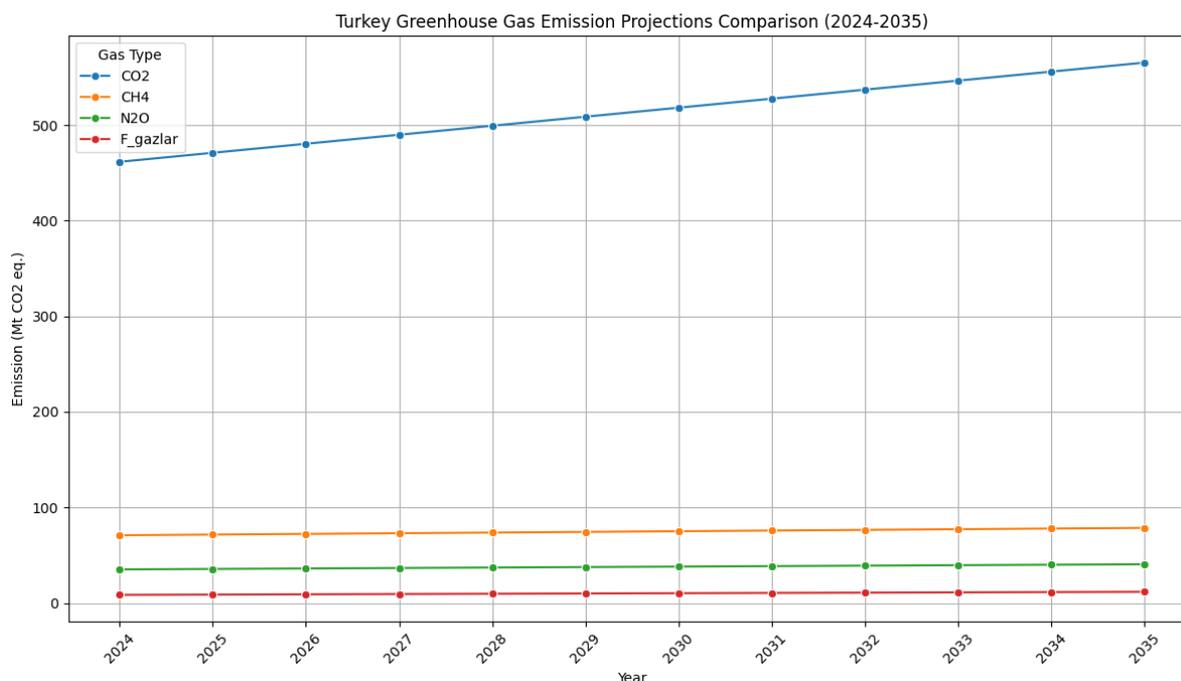


Figure 7. Türkiye Greenhouse gas emission projection comparison (2024-2035)

This comparative visualization illustrates the hierarchy of gas components within Türkiye's emission structure and highlights the disproportionate weight of each gas on the total projected volume:

- **Dominance of CO₂:** Carbon dioxide (CO₂) exhibits a volume several times higher than the combined total of all other gas components. Starting from approximately 460 Mt in 2024, the CO₂ projection shows the steepest growth curve, reaching nearly 570 Mt by 2035. This confirms that CO₂ reduction in the energy and industrial sectors must remain the cornerstone of Türkiye's decarbonization strategies.
- **Secondary Components (CH₄ and N₂O):** Methane (CH₄) and Nitrous Oxide (N₂O) emissions follow a much lower and relatively more stable trajectory compared to CO₂. By 2035, CH₄ is projected to hover around 80 Mt, while N₂O reaches approximately 40 Mt. The slower growth rate of these gases relative to CO₂ suggests that emissions from agriculture and waste management may expand at a more gradual pace than those from industrial sources.
- **F-Gases:** Despite having the lowest volumetric impact, Fluorinated gases maintain a consistent upward trend throughout the 2035 forecast period.

Summary Conclusion: The model results demonstrate that the overall national emission trajectory is almost entirely sensitive to CO₂ fluctuations. Therefore, any CPM to be implemented must prioritize the power and manufacturing sectors, where CO₂ intensity is highest, to achieve significant mitigation results.

4. Discussion and Conclusion

The projections generated by the Prophet model for Türkiye's greenhouse gas emissions and potential Carbon Pricing Mechanism (CPM) trajectories up to 2035 provide a quantitative basis for several strategic policy considerations. The model results suggest that Türkiye's emission trends and the anticipated carbon price levels will necessitate a structural transformation, particularly to mitigate the economic pressures associated with the EU's CBA).

Based on the model's forecasted data, the implementation of a national CPM appears to offer a dual impact, presenting both opportunities for green growth and challenges regarding industrial competitiveness. From an environmental perspective, the projected increase in emission-intensive activities suggests that a carbon price signal could serve as a vital tool to align market actors with the most cost-effective reduction pathways. Such a mechanism could facilitate Türkiye's progress toward its Nationally Determined Contribution (NDC) targets under the Paris Agreement by making high-carbon production more costly. Furthermore, the model-based price projections indicate that the fiscal revenues generated through a "Revenue Recycling" principle could potentially provide an additional budget source to finance renewable energy infrastructure and energy efficiency projects.

However, the forecasted carbon price levels also point toward certain economic risks that require careful management. The model suggests that in the absence of a gradual transition, high carbon costs might temporarily affect the competitiveness of export-oriented sectors, such as iron-steel, cement, and aluminum. This situation

carries a potential risk of "carbon leakage," where production might shift to regions with less stringent environmental regulations. Additionally, the quantitative projections imply that the reflection of carbon costs on energy prices could impose a burden on low-income households. Therefore, integrating social protection mechanisms and "Just Transition" policies is suggested to ensure the social acceptance of these climate measures.

A critical strategic finding derived from the model is the importance of aligning national carbon pricing with EU standards. Implementing a domestic ETS or carbon tax could allow the carbon costs—which exporting companies would otherwise pay under CBAM—to remain within the national economy as public revenue. This "cost offset" potential, indicated by the projected price differentials, reinforces the argument for a robust national system to maintain economic sustainability.

Furthermore, the model's projections highlight the strategic role of renewable energy (solar, wind, and geothermal) in mitigating carbon-related economic risks. As carbon prices are projected to rise, transitioning to domestic renewable sources could reduce dependence on fossil fuel imports and enhance energy security. The long-term competitiveness of Turkish industry appears to be closely linked to this transition, as it would effectively reduce the carbon intensity of production and minimize the carbon costs imposed by external markets.

In conclusion, the quantitative evidence provided by this study indicates that Türkiye's goal should be to transform carbon pricing from a potential economic burden into a strategic policy tool. While the model results provide a clear roadmap for emission and price trajectories, the success of these policies depends on a balanced sectoral transition plan, the prioritization of renewable energy, and the strengthening of institutional capacity in alignment with global climate standards.

References

- [1] Agnolucci, P., Fischer, C., Heine, D., Montes de Oca Leon, M., Pryor, J., Patroni, K., & Hallegatte, S. (2024). Measuring total carbon pricing. *The World Bank Research Observer*, 39(2), 227-258.
- [2] İ. R. Aksu, G. Kuruderse, A. N. Altın, and O. Derse, "Greenhouse Gas Emission Estimation and Risk Assessment for Sectors", *ISVOS*, vol. 9, no. 1, pp. 81–93, 2025, doi: 10.47897/bilmes.1666752.
- [3] World Bank Group (2025). What Carbon Pricing. <https://carbonpricingdashboard.worldbank.org/what-carbon-pricing>. [Accessed: 29, Kasım, 2025].
- [4] IPCC. (2023). *Climate Change 2023: Synthesis Report*. Intergovernmental Panel on Climate Change. <https://www.ipcc.ch/report/ar6/syr/>. (Accessed: 19/10/2025).
- [5] Döbbling-Hildebrandt, N., Miersch, K., Khanna, T.M. et al. Systematic review and meta-analysis of ex-post evaluations on the effectiveness of carbon pricing. *Nat Commun* 15, 4147 (2024). <https://doi.org/10.1038/s41467-024-48512-w>
- [6] Çelikkaya, A. (2023). Karbon Fiyatlandırması Seçenekleri ve Tasarım Sorunları. *Maliye Araştırmaları Dergisi*, 9(1), 1-26.
- [7] Saraçoğlu, F., & Kutlu, M. (2025). Sınırdaki Karbon Düzenleme Mekanizması ve Türkiye'ye Olası Etkileri. *Ankara Hacı Bayram Veli Üniversitesi İktisadi ve İdari Bilimler Fakültesi Dergisi*, 27(1), 1-26. <https://doi.org/10.26745/ahbvuidfd.1593438>
- [8] Digitemie, W. N., & Ekemezie, I. O. (2024). Assessing the role of carbon pricing in global climate change mitigation strategies. *Magna Scientia Advanced Research and Reviews*, 10(2), 022-031.
- [9] Yaylı, G. (2019). Karbon Vergisi Teorisi: Türkiye Üzerine Bir Değerlendirme (Master Thesis). Bursa Uludağ Üniversitesi. <https://acikerisim.uludag.edu.tr/server/api/core/bitstreams/d75808fa-4d89-4c1a-a055-521518a5b41f/content>. (Accessed: 12/10/2025).
- [10] Bali, S., & Yaylı, G. (2019). Karbon Vergisinin Türkiye'de Uygulanabilirliği. *Üçüncü Sektör Sosyal Ekonomi Dergisi*, 54(1), 302–319. <http://doi.org/10.15659/3.sektor-sosyal-ekonomi.19.03.1104>.
- [11] Oğuz, N. S., & Yıldız, S. (2024). Bir Çevre Vergisi Olarak Karbon Vergisi. *Anadolu University Journal of Faculty of Economics*, 6(1), 19-35. <https://doi.org/10.54737/aujfe.1475971>
- [12] İmer-ertunga, E., & Seyhun, Ö. K. (2022). Sınırdaki Karbon Düzenleme Mekanizması Ve Türkiye'nin İhracatına Olası Etkileri. *Ege Stratejik Araştırmalar Dergisi*, 13(1), 1-13. <https://doi.org/10.18354/esam.1119230>
- [13] Çelikkaya, A. (2024). Türkiye'nin Karbon Fiyatlandırma Politikasının Yeniden Gözden Geçirilmesi. *Maliye Çalışmaları Dergisi*(71), 15-27. <https://doi.org/10.26650/mcd2023-1453538>

- [14] T.C. Çevre, Şehircilik ve İklim Değişikliği Bakanlığı. (2023). Sınırdaki Karbon Düzenleme Mekanizmasının Türkiye Ekonomisine Potansiyel Etkileri. <https://iklim.gov.tr/sinirda-karbon-duzenleme-mekanizmasinin-turkiye-ekonomisine-potansiyel-etkileri-calismasi-tamamlandi-haber-4147>. (Accessed: 12/12/2025).
- [15] Eurapian Union. (2023). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv%3AOJ.L_.2023.130.01.0052.01.ENG&toc=OJ%3AL%3A2023%3A130%3ATOC. (Accessed: 12/12/2025).
- [16] T.C Ticaret Bakanlığı. (2025). <https://ticaret.gov.tr/dis-iliskiler/yesil-mutabakat/ab-sinirda-karbon-duzenleme-mekanizmasi/ab-skdm-bilgi-notu>. (Accessed: 12/12/2025).
- [17] TÜİK. (2023). <https://data.tuik.gov.tr/Bulten/Index?p=Sera-Gazi-Emisyon-Istatistikleri-1990-2021-49672&dil=1>. (Accessed: 12/12/2025).
- [18] İklim Değişikliği Başkanlığı. (2023). [https://iklim.gov.tr/db/turkce/haberler/files/20230523%20Impacts%20of%20CBAM%20on%20Turkiye%20phase%20%20report%20FV3%20\(2\)-sayfalar-1,3,5-16%20\(1\)%20\(1\).pdf](https://iklim.gov.tr/db/turkce/haberler/files/20230523%20Impacts%20of%20CBAM%20on%20Turkiye%20phase%20%20report%20FV3%20(2)-sayfalar-1,3,5-16%20(1)%20(1).pdf). (Accessed: 12/12/2025).
- [19] International Energy Agency. (2025). <https://www.iea.org/reports/global-energy-review-2025/co2-emissions>. (Accessed: 12/12/2025).
- [20] Artun, E. S. (2024). Karbon Vergisinin Türkiye'de Yenilenebilir Enerjiye Yönlendirme Aracı Olarak Kullanılması. *Yaşar Hukuk Dergisi*. c. 6, sy. 1, ss. 15-48.
- [21] Z. Karaçor, B. Güvenek, ve R. Gevher. (2023). "Avrupa Birliğinde Sınırdaki Karbon Düzenleme Mekanizması: Türkiye Ekonomisine Olası Etkileri," BİLTEK-VIII INTERNATIONAL SYMPOSIUM ON CURRENT DEVELOPMENTS IN SCIENCE, TECHNOLOGY AND SOCIAL SCIENCES, Paris, Fransa.
- [22] Aşıcı, M. A. (2021). Avrupa Birliği'nin sınırdaki karbon uyarlaması mekanizması ve Türkiye ekonomisi. İstanbul: IPM-Mercator.