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ARAŞTIRMA MAKALESİ | RESEARCH ARTICLE

THE ENVIRONMENTAL CONSEQUENCES OF TURKIYE'S INDUSTRIAL DEVELOPMENT AND FOREIGN TRADE STRATEGIES

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Abstract

Turkiye's industrialization and foreign trade strategies have contributed significantly to economic growth but also led to environmental concerns due to rising carbon emissions. As a country heavily reliant on fossil fuel imports to meet its energy needs, Turkiye faces growing challenges in aligning its industrial development with environmental responsibilities. Especially under the increasing influence of international environmental regulations and carbon adjustment mechanisms, there is a pressing need to re-evaluate its current production structure. In this context, examining the relationship between industrial activity, trade flows, and carbon emissions becomes increasingly important. This study investigates the causal relationships between industrial output, exports, imports, and carbon emissions in Turkiye using time series data from 1989 to 2022. The empirical analysis employs a Vector Autoregression (VAR) model and Granger causality testing. The results reveal that imports significantly influence both industrial production and exports, while exports also affect industrial activity. However, carbon emissions are not found to have a direct causal impact on trade or industrial output within the studied period. These findings suggest that carbon emissions have not yet emerged as a binding constraint on Turkiye's production structure. Nonetheless, increasing investments in renewable energy is essential for ensuring energy security, environmental compliance, and long-term competitiveness. The study offers policy implications for developing countries with similar economic structures and provides both theoretical and practical contributions to the formulation of environmentally sustainable industrial strategies.

Keywords: Industrial Development, Foreign Trade, Export, Import, Carbon Emissions

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TÜRKİYE'NİN SANAYİLEŞME VE DIŞ TİCARET STRATEJİLERİNİN ÇEVRESEL SONUÇLARI

Öz

Türkiye'nin sanayileşme ve dış ticaret stratejileri ekonomik büyümeye önemli katkılar sağlamış, ancak artan karbon emisyonları nedeniyle çevresel sorunları da beraberinde getirmiştir. Enerji ihtiyacının büyük bir kısmını fosil yakıt ithalatıyla karşılayan Türkiye, sanayileşme sürecini çevresel sorumluluklarla uyumlu hâle getirme konusunda giderek artan bir baskı altındadır. Özellikle uluslararası çevre düzenlemeleri ve karbon uyum mekanizmalarının etkisiyle mevcut üretim yapısının yeniden değerlendirilmesi gerekmektedir. Bu çerçevede, sanayi faaliyetleri, dış ticaret akımları ve karbon emisyonları arasındaki ilişkinin incelenmesi önem taşımaktadır. Bu çalışma, 1989–2022 dönemine ait zaman serisi verileri kullanarak Türkiye'de sanayi üretimi, ihracat, ithalat ve karbon emisyonları arasındaki nedensellik ilişkisini analiz etmektedir. Ampirik analizde Vektör Otoregresyon (VAR) modeli ve Granger nedensellik testi uygulanmıştır. Bulgular, ithalatın hem sanayi üretimi hem de ihracat üzerinde etkili olduğunu, ihracatın ise sanayiyle ilişkili olduğunu ortaya koymaktadır. Ancak çalışılan dönemde karbon emisyonlarının sanayi ya da dış ticaret üzerinde doğrudan nedensel bir etkisi tespit edilmemiştir. Bu sonuçlar, karbon emisyonlarının henüz Türkiye'nin üretim yapısı üzerinde sınırlayıcı bir faktör haline gelmediğini göstermektedir. Buna rağmen, enerji güvenliği, çevresel uyum ve uzun vadeli rekabet gücü açısından yenilenebilir enerji yatırımlarının artırılması kritik önemdedir. Çalışma, benzer ekonomik yapıya sahip gelişmekte olan ülkeler için politika geliştirmeye yönelik çıkarımlar sunmakta; ayrıca çevresel sürdürülebilirliği gözeten sanayi stratejilerinin oluşturulmasına teorik ve uygulamalı katkılar sağlamaktadır.

Keywords: Endüstriyel Kalkınma, Dış Ticaret, İhracat, İthalat, Karbon Emisyonları

INTRODUCTION

Climate change represents one of the most urgent challenges of the contemporary era, with far-reaching implications for natural and human systems. According to the United Nations Intergovernmental Panel on Climate Change (IPCC), global warming reached approximately 1°C above pre-industrial levels, increasing at about 0.2°C per decade (IPCC, 2025). If this trend continues, the rise in global temperatures will exacerbate critical risks such as loss of biodiversity, threats to human health, and food security concerns, further complicating the management and mitigation efforts (Calvin et al., 2023).

Although industrial development has played a key role in economic growth worldwide, it has also intensified environmental challenges, making it one of the major factors contributing to climate change through greenhouse gas emissions, particularly in developing countries (Ojeaga & Posu, 2017; L.-Y. Zhang, 2011. Developing economies, whose economic activities—particularly in the industrial sector—have expanded significantly in recent years, face a dilemma between sustaining economic growth and managing rising environmental pollution, especially when this growth is driven by fossil fuel consumption that increases carbon emissions over time (Caglar et al., 2022). This is much more problematic for energy-importing countries, since the growth of industrial activities also increases energy imports while worsening countries' foreign trade figures.

As a developing country, Turkiye has the 17th largest GDP in the world and holds a significant geostrategic position due to its proximity to Europe, Asia, and Africa (World Bank, 2024c). Energy imports constitute a significant component of Turkiye's current account and foreign trade deficits (Erkılıç et al., 2019; Saçık et al., 2020), as the country's economy is heavily dependent on fossil fuel imports, which increase its carbon footprint and pose environmental sustainability challenges (Önder, 2021). Turkiye ratified the Paris Agreement in 2021, with a pledge to reduce greenhouse gas emissions by 41% by 2030 and a long-term goal of achieving net zero emissions by 2053 (Demir, 2022). Achieving the targets set by the Paris Climate Agreement requires reducing carbon emissions, aligning export and import processes with sustainability principles, and expanding environmentally friendly practices in industrial production (WEF, 2023). Moreover, international regulations, such as the European Union's (UN) Carbon Border Adjustment Mechanism (CBAM), set to take full effect in 2026, is one the key instrument for enforcing environmental sustainability in international trade (European Commission, 2025). Considering that the EU was Turkiye's largest trading partner in 2023—accounting for 29.3% of its imports and 40.8% of its exports (Turkish Statistical Institute, 2024b), Turkiye may face a dilemma: aligning its trade-dependent industrial sector with CBAM requirements while managing the economic impact of carbon regulations (Bayat et al., 2025; Magacho et al., 2024). In this context, examining the environmental impacts of Turkiye's industrial development and foreign trade strategies has significant implications for aligning economic growth with emission reduction targets.

In the literature review conducted at this point, many studies have explored the environmental effects of trade and its links to energy use, particularly renewable energy, in the context of Turkiye (e.g. Cetin et al., 2018; Karasoy & Akçay, 2019; Önder, 2021; Topcu, 2021). However, the interconnected relationships among carbon emissions, foreign trade (exports and imports), and industrial growth remain relatively underexplored in the Turkish context. This study aims to fill this gap by analyzing the short- and long-term dynamics among these variables using data from 1989 to 2022. This period is selected for several reasons. After adopting liberal policies and fully opening its economy to global markets after the 1980s, Turkiye expanded its role in global supply chains, increased industrial production and carbon-intensive activities, and accelerated foreign trade. The dataset covers major economic shocks such as the 1994 and 2001 financial crises, the 2008 global recession, and the 2020 COVID-19 pandemic. These events provide a valuable opportunity to examine how trade and industrial activity respond to crises and how such shocks influence emission patterns. Moreover, Turkiye's commitments to global climate agreements—particularly the Paris Agreement (2015)—have triggered notable structural shifts in its industrial policies and environmental strategies. Understanding these shifts is crucial to developing sustainable trade and industrial frameworks.

By exploring the short- and long-term relationships between these factors, it was aimed to address the above-mentioned gap in the existing research and generate original insights not only for Turkiye but also for other developing countries with similar economic structures. To achieve this objective, we first tested the stationarity properties of the variables. Then, the long-term relationships were examined using the Pantula principle, followed by the estimation of a VAR model. Within this model, we tested for autocorrelation, variance stability, and the normality of residuals. The model's stability was also assessed by checking whether the autoregressive roots lie within the unit circle. Variable ordering was determined using variance decomposition, and impulse response functions were applied after performing Granger causality analysis to examine dynamic causal relationships.

The structure of the paper is as follows: The first section presents an overview of Turkiye's trends in exports, imports, industrial development, and carbon emissions, discussing their interconnections. The second section reviews existing studies that examine the relationships among the key variables of this study, with a particular focus on findings from both developing countries and the Turkish context. The third section explains the data sources, econometric methodology, and empirical findings. Finally, the fourth section discusses the key findings derived from the analysis, highlights the study's original contributions, and offers policy implications based on these findings.

1. CONTEXTUAL BACKGROUND

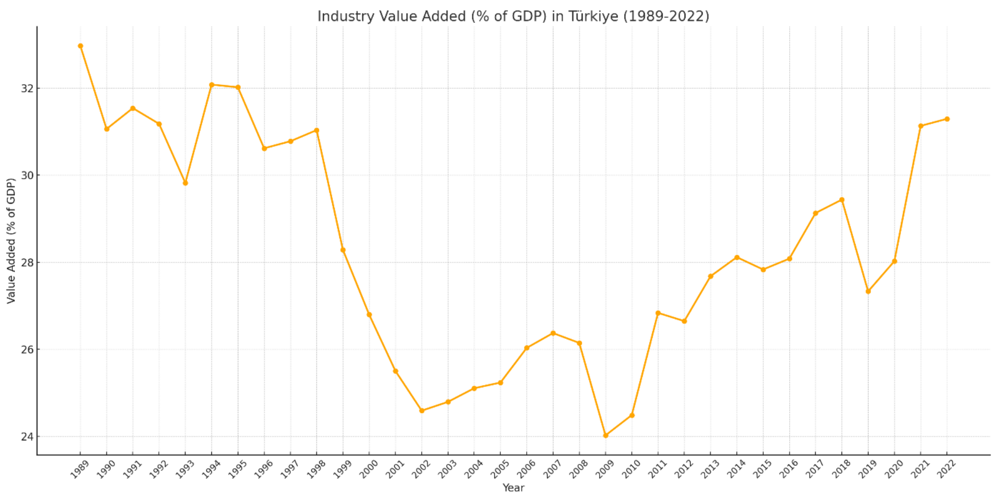
Turkiye's economic development since the late 1980s has been shaped by industrial growth, trade liberalization, and global market integration. While these shifts boosted production and exports, they also increased energy use and carbon emissions. This section examines key trends in industry, trade, and energy to contextualize the link between economic activity and environmental outcomes from 1989 to 2022.

1.1.Industrial Development

Turkiye is the world's 17th largest economy with a GDP of USD 1.024 trillion as of 2023 and is among the developing countries that have risen to the upper-middle-income group due to the comprehensive reforms and high growth rates achieved between 2006 and 2017 (World Bank, 2024a). Although the country has faced economic resilience, inclusiveness, and sustainability challenges in recent years, state-led development strategies, an export-led growth model, and efforts to integrate into global supply chains are shaping industrialization and trade policies (Altay, 2024). While economic growth is a critical factor in the face of challenging post-COVID macroeconomic conditions and declining productivity shaping the country's economic outlook, dependence on high-carbon footprint processes in industry and transportation poses a significant challenge to environmental sustainability (World Bank, 2024b).

Economic growth in a country is driven by industrialization through improvements in productivity, the creation of economies of scale, and the generation of positive externalities, as posited by Kaldor's Law (Arısoy, 2013). In this regard, Figure 1 illustrates the development of the industry sector in Turkiye, measured as a percentage of GDP, for the period from 1989 to 2022.

Figure 1. Industry Value Added as a Percentage of GDP in Turkiye (1989–2022)



Source: World Bank (2025e)

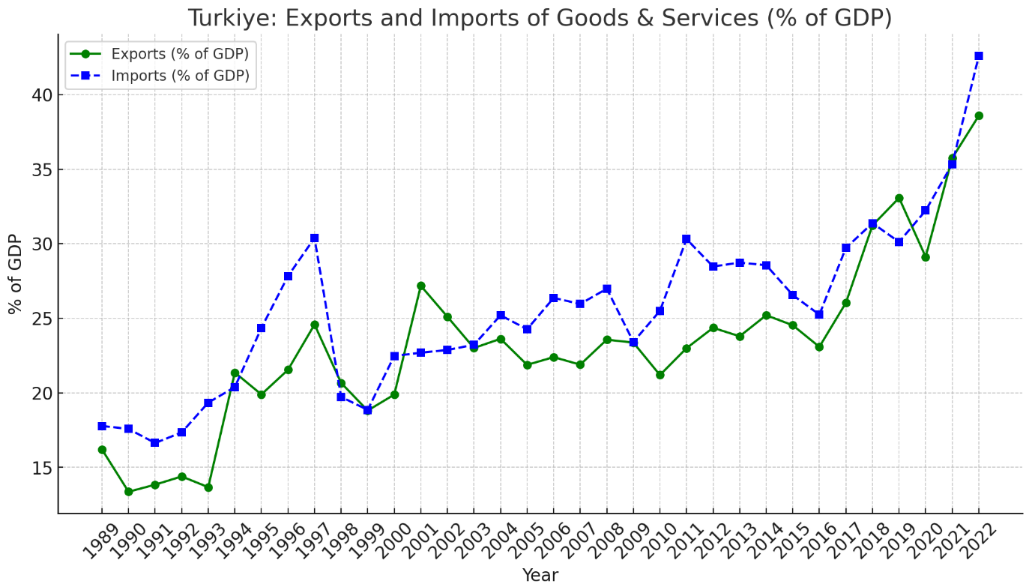
As shown in the figure, the fluctuations across the years demonstrate the Turkish economy's sensitivity to external shocks, particularly during major crises such as those in 2001 and 2009 (Ari, 2008; Uçan & Aktakas, 2012). Industrial performance in Turkiye is closely tied to foreign trade dynamics due to the sector's high dependency on imported raw materials and intermediate goods (Varlık et al., 2024). Moreover, export markets remain vulnerable to global and regional downturns, which further amplifies the volatility of industrial output (Gokturk et al., 2013; Lo Turco & Maggioni, 2014).

Moreover, Figure 1 illustrates the structural significance of the industrial sector, with its share in GDP consistently exceeding 24% even during periods of economic contraction. In absolute terms, the industrial value added reached USD 319.47 billion in 2023 (World Bank, 2025c), reflecting a substantial increase since 1989. This upward trajectory aligns with Turkiye's broader industrial and trade-oriented development strategies. However, it also raises growing concerns regarding environmental sustainability. Notably, carbon emissions from industrial processes reached 53.1 Mt CO_2e, placing Turkiye among the highest-emitting countries in its income group (World Bank, 2025a). Against this backdrop, the present study seeks to explore the linkage between industrial development, foreign trade patterns, and carbon emissions, offering an empirical assessment of their interdependence from 1989 to 2022.

1.2.Exports and Imports

In response to the macroeconomic imbalances and external vulnerabilities that intensified during the 1970s, Turkiye transitioned to a more liberal, export-oriented economic model after 1980 to stabilize the economy and promote sustainable growth. The new policy framework contributed to financial stabilization and fostered export-led growth (Celasun, 1994). While trade openness helped increase export volumes, it also led to a growing dependence on imported intermediate and capital goods, particularly in the industrial sector. Figure 2 shows both exports and imports of goods and services as a percentage of GDP in Turkiye from 1989 to 2022, highlighting fluctuations over time.

Figure 2. Trends in Turkiye's Exports and Imports of Goods & Services as a Percentage of GDP (1989-2022)



Source: (World Bank, 2025d, 2025b)

As shown in the figure, after the trade liberalization in the Turkish economy, exports gradually increased with some fluctuations, reaching 24% of GDP in 1997, and imports were more volatile and fluctuating between 17% and 30% of GDP. Following the 1996 Customs Union Agreement with the EU, trade volumes expanded markedly, but the impact on exports remained limited (Akkemik, 2011; Gullu, 2015). The country continued to experience significant trade deficits, particularly during crisis periods such as 1994–2001. Economic instability in the late 1990s negatively affected both exports and imports, as domestic currency depreciation substantially increased the overall import rate as a result of export-driven policies and a strong reliance on imported inputs (Ketenci, 2017).

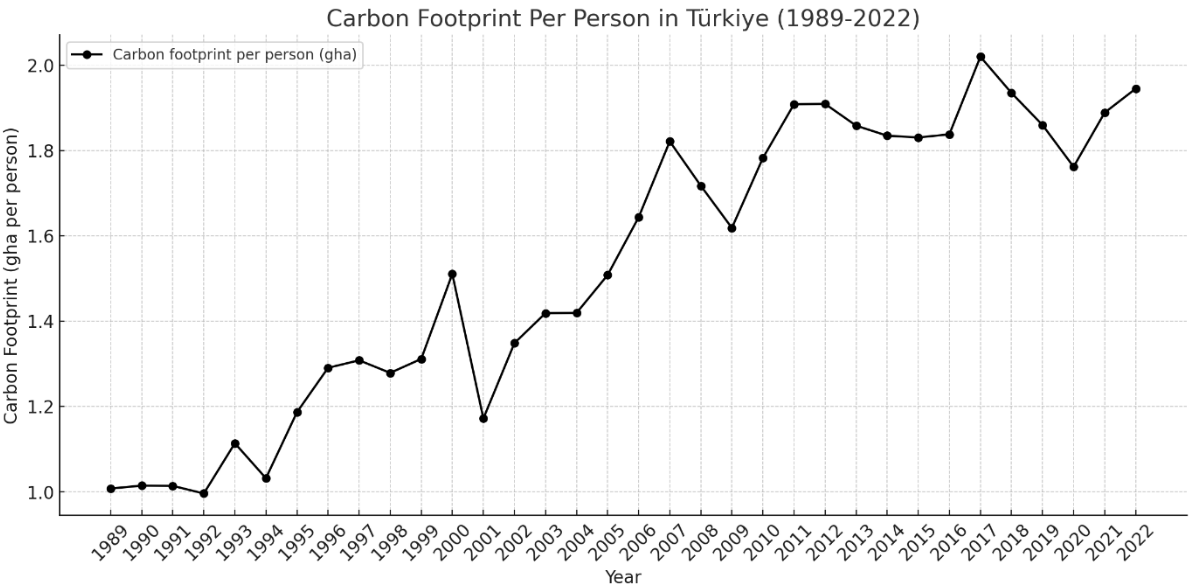
Between 2010 and 2022, Turkiye's foreign trade recovered strongly, aided by global liquidity conditions and domestic monetary expansion. However, imports consistently outpaced exports, culminating in record-high trade-to-GDP ratios in 2021 and 2022. After 2019, the share of exports and imports in GDP rose rapidly—despite a short-term decline in 2020 due to the pandemic—and reached unprecedented levels in the following years. This trend, while reflecting Turkiye's deeper integration into global markets, has also been driven by the government's expansionary monetary policies and export-oriented growth strategies (Çetin, 2022; Louis-Jacques & Ay, 2023). However, due to the country's import-dependent export structure, particularly in manufacturing, rising exports have been accompanied by a parallel surge in imports, exacerbating the structural current account deficit (Engin & Konuk, 2022; Erkök, 2023). Additionally, a significant share of imports consists of energy inputs, which further deepens the trade imbalance. Turkiye's dependence on imported fossil fuels—especially natural gas and oil—places additional pressure on the current account and exposes the economy to external energy price shocks.

1.3. Energy Use and Carbon Emissions

Turkiye's rapid industrialization and urban expansion since the 1990s have significantly increased energy demand, particularly in manufacturing and transportation sectors (Kaygusuz & Sari, 2011; Kuyuk et al., 2010). This growing demand has largely been met through fossil fuel consumption, as domestic energy production—especially from renewables—has lagged behind industrial needs. As of 2023, fossil fuels accounted for 60.6% of final energy consumption in the industrial sector, underscoring the country's dependence on non-renewable energy sources (Turkish Statistical Institute, 2024a).

This reliance on fossil fuels has led to notable environmental consequences. Carbon emissions from industrial activity and energy use have steadily increased, placing Turkiye among the 15 highest carbon-emitting countries globally (World Bank, 2025a). This situation has underscored the need to balance economic growth with environmental sustainability (Demirtaş & Baş, 2023), as industrial expansion and trade integration have often advanced without sufficient environmental safeguards. Figure 3 shows the annual carbon emissions rates for the years between 1989 to 2022.

Figure 3. Trends in Carbon Footprint Per Person in Turkiye (1989-2022)



Kaynak: (Footprintnetwork, 2025)

The data reveal a clear upward trend over the period, with temporary declines in 2001 and 2009 corresponding to economic slowdowns and contractions in industrial output. Overall, per capita carbon emissions rose in parallel with GDP growth, which expanded by approximately 8.47 times during the same period (World Bank, 2025c). These trends indicate a strong correlation between economic activity and environmental degradation. The simultaneous increase in exports, imports, and industrial production (as shown in Figures 1 and 2) suggests that Turkiye's integration into global supply chains has intensified energy use and increased carbon emissions, as illustrated in Figure 3. These trends indicate a strong correlation between economic activity and environmental degradation through urbanization, tourism, industrialization, and foreign trade—key drivers of environmental pollution in developing economies (Doğanlar et al., 2021; Karaaslan & Çamkaya, 2022; Malik, 2021; Raihan & Tuspekova, 2022).

Although Turkiye has invested in diversifying its energy mix—particularly through renewables—the transition from fossil fuels remains gradual due to high investment costs, regulatory delays, and technological dependence. As a result, the environmental benefits of renewables have yet to significantly offset emissions from industrial activity.

These dynamics highlight a persistent policy dilemma: how to sustain industrial growth and export competitiveness while minimizing environmental harm. Addressing this challenge requires a more comprehensive understanding of industrialization, foreign trade (exports and imports), and carbon emissions. This study seeks to inform such efforts by empirically examining the evolving relationships among these variables over time."

2. LITERATURE REVIEW

Building on the contextual developments outlined in the previous section, this part reviews the existing literature on the linkages between industrialization, foreign trade, and environmental sustainability, with a focus on carbon emissions. While many studies have addressed these relationships individually, fewer have examined their combined impact—particularly in the case of developing economies such as Turkiye.

A broad strand of the literature confirms that in developing economies, industrial development is one of the main contributors to rising emissions due to its fossil fuel intensity and infrastructure-related inertia. While analyzing 23 developing nations in a panel study, Sikder et al. (2022) found that a 1% increase in industrialization leads to a 0.54% increase in CO_2 emissions, highlighting the prominent role of industrial activity compared to other factors such as GDP growth and energy use. Similarly, a panel study of 50 developing countries reports a statistically significant and positive relationship between CO_2 emissions and energy consumption, largely driven by industrialization and fossil fuel use (X. Zhang et al., 2019). In the case of Turkiye, a time series study (1970–2014) finds a strong positive relationship between energy consumption and industrialization, with bidirectional causality between energy use, industrial activity, and environmental outcomes (Malik, 2021). In parallel, Raihan & Tuspekova (2022) emphasize that a 1% increase in industrialization leads to a 0.24% rise in carbon emissions in Turkiye, largely due to the fossil fuel-based energy demand, pollutant-intensive production structures, and limited adoption of clean technologies.

Research on the environmental impact of trade dynamics in developing countries presents mixed findings regarding the effects of exports and imports on carbon emissions. While examining seven ASEAN countries from 1990 to 2017, exports are found to increase CO_2 emissions across most quantiles due to pollution-intensive industries, whereas imports show mixed effects—raising emissions at lower levels but slightly reducing them at higher levels (Salman et al., 2019). Hasanov et al. (2021) demonstrate that in the case of BRICS countries, a 1% increase in exports reduces consumption-based CO_2 emissions by 0.22%, while a 1% increase in imports raises emissions by 0.23%, primarily as a result of increased domestic consumption of carbon-intensive imports and the relocation of emission responsibilities through exports. Similarly, studies conducted in the context of Turkiye reveal that while exports tend to mitigate carbon emissions, imports are associated with an increase in emissions, highlighting the dual role of trade in shaping the country's environmental outcomes. Haug & Ucal (2019) analyze the asymmetric effects of trade on CO_2 emissions per capita in Turkiye and find that reductions in exports are associated with increased emissions, whereas increases in imports significantly exacerbate them. Topcu (2021) finds that exports and renewable energy consumption reduce the ecological footprint, whereas imports increase it, likely due to the country's dependence on imported resources and the environmental burden embedded in traded goods. While analyzing the impact of trade, on consumption-based CO_2 emissions in Turkiye from 1990 to 2019, it has been found that a 1% increase in exports reduces emissions by 0.84%, whereas a 1% increase in imports raises emissions by 0.43% (Mukhtarov, 2024). In this regard, studies focusing on trade openness, typically defined as the sum of exports and imports relative to GDP, reveal contrasting findings regarding its environmental impact in the context of Turkiye. Onifade et al. (2021), focusing on Turkiye and Caspian region countries, find that a 1% increase in trade openness leads to a 0.32% rise in carbon emissions, thereby negatively affecting environmental quality. Akhayere et al. (2022) further emphasize that trade openness in Turkiye—particularly driven by increased imports—has adverse environmental impacts. However Kılavuz & Doğan (2021) report no meaningful long-term relationship between trade openness and CO_2 emissions.

Although the existing literature on trade, industrialization, and carbon emissions is extensive, many studies examine these relationships separately or over limited periods. This study addresses this gap by offering an integrated analysis of the short- and long-term effects of industrial output, exports, and imports on carbon emissions in Turkiye from 1989 to 2022. By combining these interrelated economic drivers within a single empirical framework, the study provides a clearer understanding of how growth strategies shape environmental outcomes in developing countries.

3. DATA AND METHODOLOGY

3.1. Data

This study analyzes the relationship between carbon emissions, exports, imports, and industry variables in Turkiye from 1989 to 2022. The variables used in the study and their corresponding references are presented in Table 1.

Table 1. Definitions and Sources of Variables

Variable Name	Source
Carbon Emissions	Global Footprint Network
Exports	WorldBank
Imports	WorldBank
Industry	WorldBank

3.2.Method

In this study, unit root tests were first conducted for carbon emissions, exports, imports, and industry variables to determine their stationarity levels. Since no long-run relationship was detected among the variables, a VAR model was established. In the VAR model, variance instability and autocorrelation issues were examined. Finally, the residuals of the VAR model were analyzed to determine whether they conform to a normal distribution. After reviewing the variance decomposition table, the ordering of the variables was determined. The causal relationships between the variables were then examined using the Granger causality test, followed by an impulse-response analysis to assess the direction of causality among the variables.

3.3. Empirical Findings

3.3.1. Unit Root Tests

The stationarity properties of the variables are examined using the Augmented Dickey-Fuller (ADF) and Ng-Perron tests, which are widely used unit root tests in time series analysis. The ADF test, introduced by Dickey & Fuller, 1981 assesses the presence of a unit root in a given time series, with the following null and alternative hypotheses:

H_0: The series is non-stationary.

H_1: The series is stationary.

The results of the ADF unit root test, presented in Table 2, indicate that the variables are non-stationary at their level values, as the null hypothesis (H_0) cannot be rejected at the 5%

significance level, confirming the presence of a unit root. However, after taking the first differences and reapplying the unit root tests, the null hypothesis (H_0) is rejected, indicating that the series become stationary at their first differences.

Ng & Perron (2001) stated that when the moving average roots of errors converge to -1, a higher-order lag length should be employed, whereas Bayesian and Akaike criteria tend to favor shorter lag lengths. As part of the Ng-Perron unit root test, new information criteria were developed, leading to the calculation of four different test statistics (Sarıkovanlık et al., 2019, p. 22). While the MZa and MZt tests adopt the same null hypothesis as the ADF test, the null hypothesis in the MSB and MPT tests is formulated as follows:

H_2: The series is stationary.

H_3: The series is non-stationary.

Accordingly, if the calculated MZa and MZt test statistics are smaller than the critical values, the null hypothesis of a unit root cannot be rejected (Ng & Perron, 2001). Similarly, if the MSB and MPT test statistics are smaller than the critical values, the null hypothesis of no unit root cannot be rejected (Göktaş, 2011, p. 54). As shown in Table 2, the results of the Ng-Perron unit root test indicate that the MZa and MZt test statistics are smaller than the critical values, leading to the failure to reject the null hypothesis (H_0), confirming the presence of a unit root in the series. Additionally, since the MSB and MPT test statistics are greater than the critical values, the H_3 hypothesis is rejected, further supporting the conclusion that the series contain a unit root.

Table 2. ADF and Ng-Perron Unit Root Tests

Variables	Lag Length	Critical Value	t-Statistics	Probability Value
		ADF Test		
carbon	0	Test Critical Value	-3.184371	0.1049
		5% level	-3.552973	
carbon	1	Test Critical Value	-6.784618	0.0000
		5% level	-1.951687	
export	0	Test Critical Value	-2.280650	0.4322
		5% level	-3.552973	
export	1	Test Critical Value	-4.873408	0.0000
		5% level	-1.952066	
import	0	Test Critical Value	-2.193670	0.4773
		5% level	-3.552973	
import	1	Test Critical Value	-4.654216	0.0000
		5% level	-1.951687	
industry	0	Test Critical Value	-1.821507	0.3640
		5% level	-2.954021	
industry	1	Test Critical Value	-5.338016	0.0000
		5% level	-1.951687	
		Ng-Perron Test		
Carbon	**MZ_a**	**MZ_t**	**MSB**	**MPT**
Asymptotic critical value*:	-12.7334	-2.48329	0.19502	7.37362
5% level	-17.3000	-2.91000	0.16800	5.48000
Export	**MZ_a**	**MZ_t**	**MSB**	**MPT**
Asymptotic critical value*:	-10.3186	-2.05689	0.19934	9.77459
5% level	-17.3000	-2.91000	0.16800	5.48000
İmport	**MZ_a**	**MZ_t**	**MSB**	**MPT**
Asymptotic critical value*:	-10.9388	-2.02324	0.18496	9.77519
5% level	-17.3000	-2.91000	0.16800	5.48000

İndustry	MZ_a	MZ_t	MSB	MPT
Asymptotic critical value*:	-2.48165	-1.09684	0.44198	9.77879
5% level	-8.10000	-1.98000	0.23300	3.17000

3.3.2. Cointegration Test

In the VAR model, all variables must be stationary. If a variable is non-stationary, it is transformed into a stationary series by taking its differences. Since all variables in this study are non-stationary at their level values, they are made stationary by taking their first differences.

Before conducting the cointegration test, the optimal lag length of the variables must be determined. The lag length with the smallest information criterion is selected as the optimal value. The statistical software used in this study marks the most suitable lag length with stars. However, there is an ongoing debate in the literature regarding whether the Akaike Information Criterion (AIC) or the Schwarz Criterion (SC) should be preferred, as the criterion with the most assigned stars is generally considered the best choice. As shown in Table 3, these criteria suggest a lag length of 0. However, since the minimum required lag length must be at least 1, the appropriate lag length for this study is determined as:

Table 3. Common Lag Length of the Variables

Lag	LR	FPE	AIC	SC	HQ
0	NA*	1.046725*	11.39708*	11.58212*	11.45740*
1	23.45321	1.205814	11.52730	12.45245	11.82887
2	16.95019	1.659225	11.78909	13.45437	12.33193
***The optimal lag length that minimizes the information criterion**					

The Pantula Principle is applied to determine the appropriate model for Johansen cointegration analysis. According to this principle, inferences are made based on the stage at which the null hypothesis (H_0) of no cointegration is accepted (Yavuz & Zhalelkanova, 2018, p. 57). When examining the summary table of cointegration test specifications based on the Pantula Principle (Table 4), the numbers indicate the number of cointegrated vectors for each case. Since the trace statistic is smaller than the critical value at all stages, or the probability value does not allow for rejecting the null hypothesis (H_0) at any stage, it is concluded that there is no cointegration relationship between the variables.

Table 4. Pantula Principle

Hypothesis	Eigenvalue	Trace Statistics	Critical Value (0.05)	Probability Value
0	0.462629	43.70008	54.07904	0.3000
1	0.334949	23.82595	35.19275	0.4740
2	0.234678	10.77341	20.26184	0.5640
3	0.066870	2.214732	9.164546	0.7347

3.3.3. VAR Analysis

The VAR model must be free from autocorrelation and variance instability issues, and its residuals are expected to follow a normal distribution. Additionally, the estimated autoregressive roots must lie within the unit circle to ensure the stationarity and stability of the VAR model. Autocorrelation tests are conducted for variables that have been made stationary by taking their differences, as determined by the unit root test. For the second-lag autocorrelation test, the hypotheses are formulated as follows (Kakacak et al., 2020, p. 3095):

H_4: There is no autocorrelation.

H_5: There is autocorrelation.

According to the probability values in Table 5, the null hypothesis (H_4) cannot be rejected, indicating the absence of an autocorrelation problem.

Table 5. Autocorrelation Test for the VAR Model

Lag	LM Value	Probability Value
1	15.76187	0.4697
2	42.01494	0.1108

The model is analyzed for heteroskedasticity (variance instability), and the hypotheses are formulated as follows:

H_6: There is no heteroskedasticity.

H_7: There is variance instability.

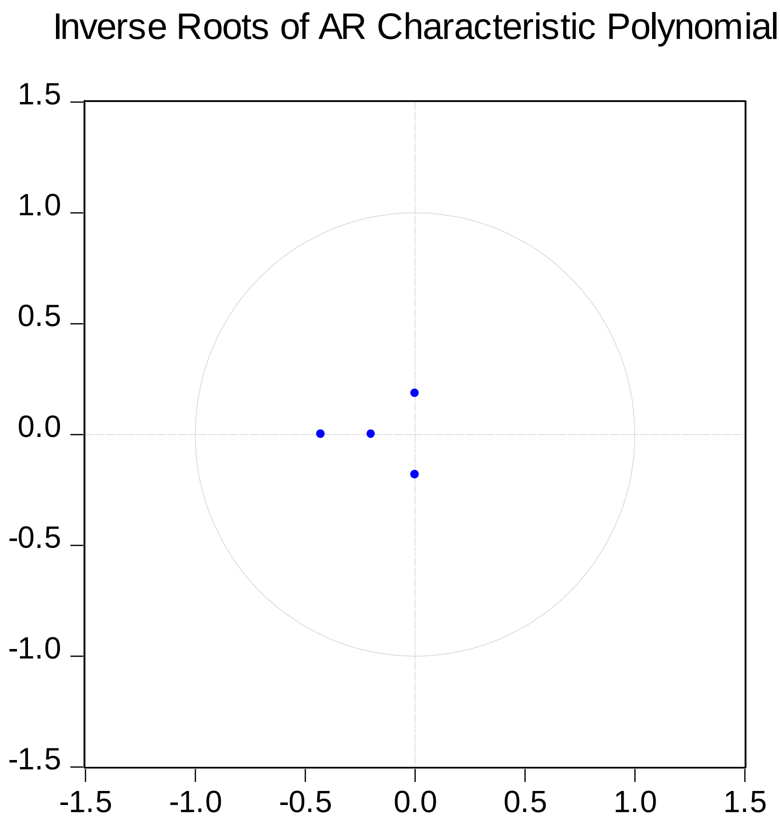
According to the probability value from the heteroskedasticity test in Table 6, the null hypothesis (H_6) cannot be rejected, indicating the absence of variance instability in the model. In other words, the assumption of constant variance holds.

Table 6. Heteroskedasticity Test for the VAR Model

Chi-Square	df	Probability Value
86.19866	36	0.2979

Applying a normality test is essential for a VAR model that is free from autocorrelation and variance instability issues. Under the normality assumption, all estimated roots are expected to lie within the unit circle to ensure stationarity. If even one root is located on or outside the unit circle, the VAR model would be deemed non-stationary (Kakacak et al., 2020, p. 3097). As shown in Figure 4, since all roots of the model lie within the unit circle, the series are considered stationary.

Figure 4. Unit Root Graph for the VAR Model



Variance decomposition analysis is a useful tool for identifying the most influential variable on a given variable within a VAR model. Therefore, this analysis should be performed in the VAR model to determine which variable has a greater impact on another variable (Özgen & Güloğlu, 2004, p. 97).

Table 7 presents the explanatory power of each variable for itself and other variables in the first period. The ranking is based on the values observed in this period. The self-explanatory power of the carbon emissions variable in the first period is 100%, making it the most endogenous variable. The second most endogenous variable is exports, with a self-explanatory power of 91.24%, followed by imports at 50.52%, and industry at 92.88%.

Accordingly, the variable ordering is determined as follows: **carbon emissions, industry, exports, and imports.**

Table 7. Variance Decomposition for the VAR Model

Period	carbonperson S.E.	dcarbonperson	dexport	dımport	dındustry
1	0.114644	100.0000	0.000000	0.000000	0.000000
2	0.124285	92.02179	3.502807	0.335104	4.140300
3	0.124856	91.23474	3.580691	0.697269	4.487302
4	0.124895	91.17778	3.578975	0.749118	4.494125
5	0.124901	91.17030	3.578891	0.756089	4.494717
6	0.124902	91.16882	3.578898	0.757407	4.494873
7	0.124902	91.16855	3.578896	0.757659	4.494897
8	0.124902	91.16850	3.578895	0.757705	4.494900
9	0.124902	91.16849	3.578895	0.757713	4.494900
10	0.124902	91.16849	3.578895	0.757714	4.494901
Period	export S.E.	dcarbonperson	dexport	dımport	dındustry

1	2.553969	8.756755	91.24324	0.000000	0.000000
2	3.139895	25.08236	60.70733	14.10519	0.105118
3	3.177161	25.09283	59.64664	14.88237	0.378158
4	3.179030	25.06351	59.57653	14.98183	0.378131
5	3.179545	25.05559	59.55839	15.00505	0.380976
6	3.179647	25.05399	59.55467	15.00980	0.381542
7	3.179665	25.05372	59.55402	15.01063	0.381635
8	3.179668	25.05367	59.55390	15.01078	0.381654
9	3.179669	25.05366	59.55388	15.01080	0.381658
10	3.179669	25.05366	59.55388	15.01081	0.381658
	import				
Period	S.E.	dcarbonperson	dexport	dımport	dındustry
1	3.270822	19.77274	29.70515	50.52210	0.000000
2	3.319457	21.66285	28.89483	49.14177	0.300556
3	3.330835	21.74026	28.86303	48.91415	0.482564
4	3.332123	21.72418	28.84575	48.92699	0.503072
5	3.332268	21.72235	28.84331	48.93049	0.503852
6	3.332291	21.72209	28.84294	48.93100	0.503978
7	3.332296	21.72204	28.84287	48.93109	0.504009
8	3.332296	21.72203	28.84285	48.93111	0.504014
9	3.332297	21.72203	28.84285	48.93111	0.504015
10	3.332297	21.72203	28.84285	48.93111	0.504015
	industry				
Period	S.E.	dcarbonperson	dexport	dımport	dındustry
1	1.213811	2.721287	2.574535	1.820400	92.88378
2	1.347910	5.424712	3.413389	13.97456	77.18734
3	1.368718	5.731144	3.362607	16.04261	74.86364
4	1.370816	5.713860	3.352450	16.29722	74.63647
5	1.371244	5.711110	3.351865	16.34228	74.59474
6	1.371331	5.710491	3.351742	16.35120	74.58657
7	1.371347	5.710382	3.351710	16.35283	74.58508
8	1.371350	5.710364	3.351705	16.35312	74.58481
9	1.371350	5.710360	3.351704	16.35317	74.58476
10	1.371350	5.710360	3.351704	16.35318	74.58475

Once the time series used in the causality test for the VAR model become stationary, the causal relationships between them can be examined (Kakacak et al., 2020, p. 3098). If a causal relationship exists among the series, the impulse response analysis can be interpreted based on the direction of causality.

In Table 8, the Granger causality test results indicate statistical significance at the 10% level for the relationship between the industry and export variables. Accordingly, a causal relationship is identified **from exports and imports to industry** and **from imports to exports**. One of the most notable findings of the Granger causality analysis is the absence of any statistically significant causal relationship between the carbon footprint variable and other macroeconomic indicators. This result may be attributable to the use of carbon footprint per capita instead of the more conventional CO_2 emissions variable. The carbon footprint variable captures a broader set of consumption-based emissions, which may exhibit weaker short-term dynamics with trade and industrial activity compared to production-based emissions. The use of this indicator was a deliberate methodological choice, reflecting its growing adoption in the recent environmental economics literature and its ability to capture cross-border emission responsibilities. Although this may have limited the detection of direct causality, it allowed the study to incorporate a more holistic measure of environmental impact.

Table 8. Granger Causality Analysis

Carbon Person	Chi-Square	Probability Value
Industry	1.546041	0.2137
Export	1.803482	0.1793
Import	0.029467	0.8637
All	2.657821	0.4474
Industry	Chi-Square	Probability Value
Carbonperson	0.716149	0.3974
Export	4.958638	0.0260
Import	3.999516	0.0455
All	6.757152	0.0801
Import	Chi-Square	Probability Value
Carbonperson	0.562420	0.4533
Industry	0.098356	0.7538
Export	0.000329	0.9855
All	0.995859	0.8023
Export	Chi-Square	Probability Value
Carbonperson	0.480858	0.4880
Industry	0.050481	0.8222
Import	6.034626	0.0140
All	12.55945	0.0057

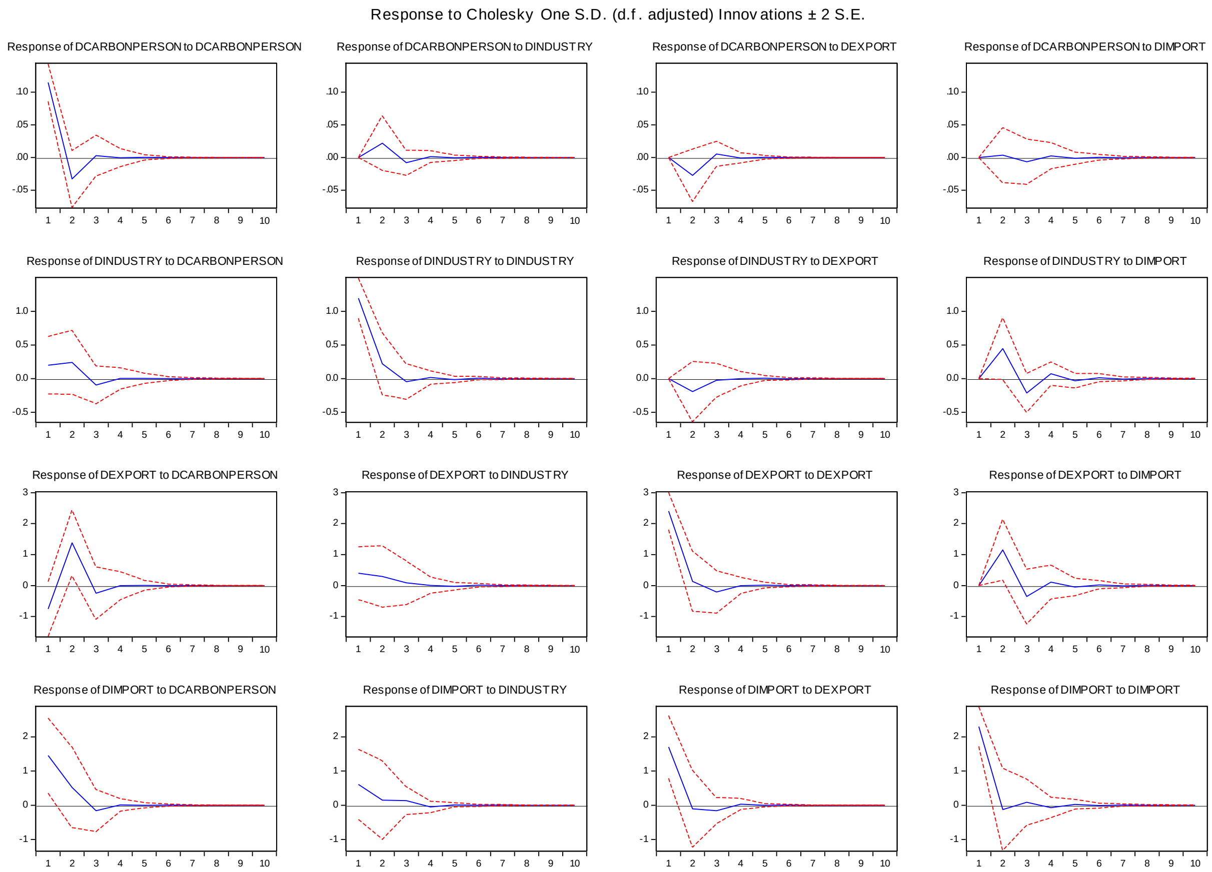
According to the causality test results, a causal relationship is identified between exports and imports and between industry and exports. Therefore, the impulse response analysis should be interpreted in this context.

As shown in Figure 5, industry's response to a one-unit shock in imports initially increases until the middle of the second period, then decreases until the middle of the third period, rises again until the middle of the fourth period, and finally dissipates. The response starts off positive, turns negative in the intermediate periods, and displays a fluctuating pattern over time. The observed fluctuations may indicate that industrial performance is sensitive to external trade shocks, with the direction and persistence of these effects possibly influenced by factors such as global demand conditions, exchange rate volatility, and the timing of input usage. These patterns could reflect the inherent vulnerability of an import-dependent industrial structure, where responses to trade shocks vary depending on production cycles, supply chain flexibility, or temporary adjustments in inventory and procurement strategies.

Industry's response to a one-unit shock in exports initially decreases until the middle of the second period, then increases, with the shock's effect dissipating in the third period. This fluctuating response may suggest that the industrial sector does not immediately benefit from export shocks, potentially due to temporary production rigidities or adjustment lags. The delayed positive reaction could indicate a gradual alignment with external demand conditions. However, since the effect dissipates without becoming strongly positive, it is possible that such shocks generate only short-lived or uneven impacts on industrial output.

Exports' response to a one-unit shock in imports initially rises, followed by a decline until the middle of the second period, then exhibits another cycle of increase and decrease, with the shock effect dissipating in the fourth period. This oscillating pattern may point to the dual role of imports in export performance. While an initial boost could be related to improved access to intermediate inputs, the subsequent decline might reflect exchange rate fluctuations or rising import costs. The partial recovery that follows suggests a possible short-term adjustment by export-oriented firms. Overall, the effect appears temporary and may vary depending on the nature of imported goods, production cycles, and external market conditions.

Figure 5. Impulse-Response Functions of the VAR Model



CONCLUSION

This study examined the relationship between carbon footprint, industrial activity, exports, and imports in Turkiye between 1989 and 2022, using a VAR model framework supported by unit root tests, cointegration analysis, variance decomposition, and Granger causality tests. While Turkiye has pursued an export-led industrialization strategy in recent decades, its heavy reliance on imported intermediate goods and fossil fuels has posed challenges not only for economic resilience but also for environmental sustainability. Global and regional crises, such as COVID-19 and the Ukraine-Russia war, have caused fluctuations in commodity prices, increasing Turkiye's economic vulnerability, while its reliance on fossil fuels exacerbates carbon emissions, posing further challenges with the EU's CBAM. Without a shift to sustainable energy and production, Turkiye risks not only challenges in sustaining its export-driven growth but also the potential loss of its most important trade partner, the EU, as this transition failure could lead to increased trade restrictions and costs.

The findings reveal that carbon footprint is the most dominant variable in the system, preceding industrial production, exports, and imports in terms of influence. However, contrary to expectations and much of the existing literature, no direct causal relationship was found between trade or industrial activity and the carbon footprint variable. This divergence may be attributed to the methodological choice of using carbon footprint per capita—a broader, consumption-based environmental indicator—rather than conventional production-based CO_2 emissions data commonly used in previous studies. Unlike CO_2 emissions, which measure emissions at the point of production, carbon footprint accounts for both direct and indirect emissions that occur across various stages of the supply chain, including embedded emissions in imported goods. This broader scope introduces temporal dispersion, as the environmental impact of trade activities—particularly imports—may materialize with a delay and in geographically dispersed contexts. Therefore, short-term causality tests such as the Granger analysis may not capture these lagged and diffuse effects effectively. Furthermore, although Turkiye's industrial and export structures are known to be carbon-intensive, the relatively stable pattern of emissions over the period may have limited the statistical variability required to detect causality. This methodological shift provides a meaningful contribution by challenging traditional measures and offering new insights into the environmental consequences of trade and industrial activity in emerging economies. In this context, the study contributes to the literature by adopting an alternative environmental metric that allows for a more comprehensive evaluation of the trade–environment nexus.

The Granger causality analysis shows significant causal links from exports and imports to industry and from imports to exports, confirming that foreign trade remains a key driver of industrial performance in Turkiye. These results suggest that the industrial sector responds dynamically to changes in external demand and the availability of imported inputs, reflecting the country's reliance on global supply chains and imported intermediate goods. Complementing this finding, the impulse response functions indicate that industrial output reacts to trade shocks in a delayed and fluctuating manner, underlining the sector's sensitivity to external economic conditions.

In line with the empirical findings of this study, the following policy recommendations are proposed to support Turkiye's efforts to align industrial growth with environmental sustainability and enhance trade resilience. For Turkiye and other developing countries with similar economic structures, enhancing trade resilience requires reducing reliance on imported raw materials and intermediate goods by diversifying trade partners and strengthening local supply chains. Reducing this dependency is crucial to minimize vulnerability to external shocks and ensure more stable industrial performance. Export-oriented industries should be supported through technology-driven efficiency improvements and strategic investment in high-value-added manufacturing. Promoting environmentally friendly supply chain practices, carbon-conscious logistics, and sustainable industrial zones will be essential to mitigate the environmental impact of trade-driven industrialization and to comply with evolving global regulations. Moreover, environmental inspections should be strengthened in industrial production, particularly regarding the use of high-emission raw materials. Exporting firms that adopt low-emission technologies and cleaner production processes should be rewarded through targeted incentives such as tax reductions, subsidies, and access to green financing.

Finally, policymakers should consider developing mechanisms to monitor indirect emissions—such as those embedded in imported goods—that may not be captured in short-term economic analyses but are reflected in broader environmental indicators like carbon footprint. Establishing reliable emissions tracking systems and promoting environmental certification schemes can support more comprehensive sustainability monitoring. Additionally, strong coordination between public institutions, industry representatives, and research organizations will be essential to ensure the effective implementation and long-term adaptability of industrial and environmental policies.

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