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EVALUATION NOTE

TURKİYE'S CARBON INTENSITY ATLAS: REGIONAL VULNERABILITIES IN THE GREEN TRANSITION

Industrial production remains a central pillar of the global economy. As global value chains deepen, industrialization continues to drive output, trade, and productivity, forming the core of growth strategies in many developing nations. As of 2024, industry value added accounts for 26% of global GDP; the corresponding shares are 27% in low-income economies, 32% in lower-middle-income economies, 34% in upper--middle-income economies, and 22% in high-income economies.[3] Industry also represents a substantial share of employment. According to International Labour Organization (ILO), the share of industry in total employment in 2023 stands at 11% in low-income economies, 23% in lower-middle- and high-income economies, 28% in upper-middle-income economies, and 27.6% in Türkiye.[4] These figures underscore that in upper-middle-income economies, industry occupies a more central role in both value creation and employment than in other income groups.

Given its central position in economic structures, rising energy demand, and associated carbon emissions, industry has become a primary focus of global climate policy. According to the IPCC's 2019 assessment, 34% of global greenhouse gas (GHG) emissions originate from energy, 24% from industry, and 22% from agriculture.[5] When total emissions are examined by country groups, patterns broadly mirror differences in industrial intensity. Low-income economies account for 1.75% of global emissions (898

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[3] World Bank, Industry (including construction), value added (% of GDP)
[4] World Bank, Employment in industry (% of total employment) (modeled ILO estimate)
[5] https://www.ipcc.ch/report/ar6/wg3/chapter/technical-summary/

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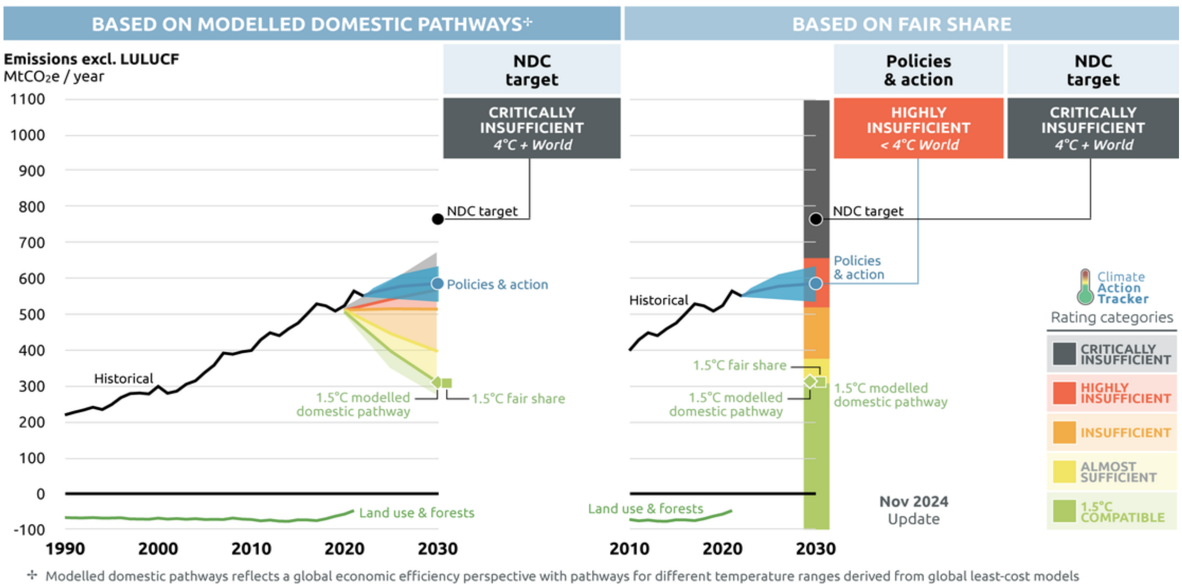
million tons CO_2e[6]), lower-middle-income economies 15.5% (7,928 million tons CO_2e), high-income economies 34.2% (17,509 million tons CO_2e), and upper-middle-income economies 48.4% (24,735 million tons CO_2e)[7].

Türkiye's Industry and the Current State of the Green Transition

Türkiye has emerged as a prominent industrial economy both in its region and among upper-middle-income peers, supported by a rapidly expanding industrial base. In the early 2000s, manufacturing's share in GDP averaged around 15%; during 2021–2023, this share increased to 21%, representing an approximately six-percentage-point rise over two decades. However, this industrial expansion has coincided with rising GHG emissions, thereby intensifying environmental pressures.

Türkiye's updated interim target is to reach net 695 million tons of total emissions (CO_2e) by 2030[8] (including LULUCF[9]). Similarly, within the scope of NDC 3.0, Türkiye announced an interim target for 2035 last month, aiming to reduce emissions by 466 Mt CO_2e and bring total emissions down to 643 Mt CO_2e. Both the 2030 and 2035 interim targets indicate that-despite the 2053 net-zero pledge-Türkiye is unlikely to enter a phase of meaningful emission reductions over roughly the next five years. In parallel, Climate Action Tracker—an independent initiative that assesses countries' alignment with the Paris Agreement—rates Türkiye's current policies and actions as "highly insufficient."

Figure 1. Türkiye's net-zero pathway



Note: Modelled national pathways span trajectories across different warming levels derived from globally least-cost scenarios, reflecting them from a global economic efficiency perspective.
Source: Climate Action Tracker

[6] CO_2e is the expression of different greenhouse gases in terms of carbon dioxide equivalent, taking into account their 100-year Global Warming Potential (GWP) coefficients.
[7] World Bank, Total greenhouse gas emissions excluding LULUCF (Mt CO_2e)
[8] Republic of Türkiye Updated First Nationally Determined Contribution
[9] Land Use, Land-Use Change and Forestry

A significant portion of Türkiye's GHG emissions is concentrated in specific industrial clusters. This concentration has direct implications for both the effectiveness of climate policy and regional development dynamics. Accordingly, analyzing regional carbon intensity by jointly considering industrial and energy policies provides a critical evidence base for Türkiye's progress toward its 2053 net-zero target. This consideration defines the purpose and scope of the present study.

Purpose and Scope

The primary objective of this study is twofold: (i) to assess Türkiye's decoupling performance by comparing its economic growth and GHG emissions dynamics with those of other countries; and (ii) to identify regional differences in emission intensity within Türkiye by calculating **province-level GHG emissions per PPP-adjusted dollar of GDP (CO_2e/USD).**

The emission-intensity indicator is computed by converting total GHG emissions into CO_2-equivalent (CO_2e) and dividing by GDP. In the context of climate policy assessment, economic growth remains a central objective for countries; therefore, it is not sufficient to focus solely on total emissions. Equally important is the emission intensity with which growth is achieved.

National-level decoupling analyses suggest that, relative to peers, Türkiye has not yet entered a phase of **absolute decoupling**. However, national-level assessments often overlook structural heterogeneity within countries. This can lead to overly centralized roadmaps that ignore regional differences and vulnerabilities. In Türkiye's case, provinces differ substantially in production structures, energy intensity, and technological capacity. The province-level calculations presented here aim to support the design of green transition policies tailored to regional needs and to identify which provinces are more vulnerable—or comparatively advantaged—on the pathway to the 2053 net-zero target. In doing so, the study extends the decoupling discussion from cross-country comparisons to a within-country spatial perspective, offering an integrated framework that jointly evaluates global trends and regional heterogeneity.

To generate province-level estimates, this study draws on the subnational emissions data provided by Climate TRACE. It is a global coalition established in 2020 by civil society organizations, technology firms, and research institutions. Its objective is to track GHG emissions worldwide in a transparent and accessible manner using satellite-based observations, AI-enabled estimation methods, and big-data analytics—without relying exclusively on official reporting or delayed statistics. Through high-resolution datasets, Climate TRACE enables emissions monitoring not only at the national level but also at subnational scales. The emissions data used in this study are provided by Climate TRACE in CO_2e terms, accounting for the global warming potential (GWP) coefficients of different gases. GDP data representing provinces' economic activity are sourced from Turkish Statistical Institute's (TURKSTAT) current-price GDP series. To ensure international comparability, these values are converted into **PPP-adjusted international dollars** using World Bank PPP conversion factors.[10] Each province's total GHG emissions are divided by PPP GDP to compute **CO_2e/USD**. The resulting ratios enable quantitative comparison of carbon intensity across provinces and identify spatial vulnerabilities relevant to Türkiye's green transition agenda. This approach aims to support both the prioritization of policy focus areas and the strategic direction of investments.

[10] World Bank, PPP conversion factor, GDP (LCU per international $)

Economic Growth and Carbon Decoupling: Conceptual Framework and Country Experiences

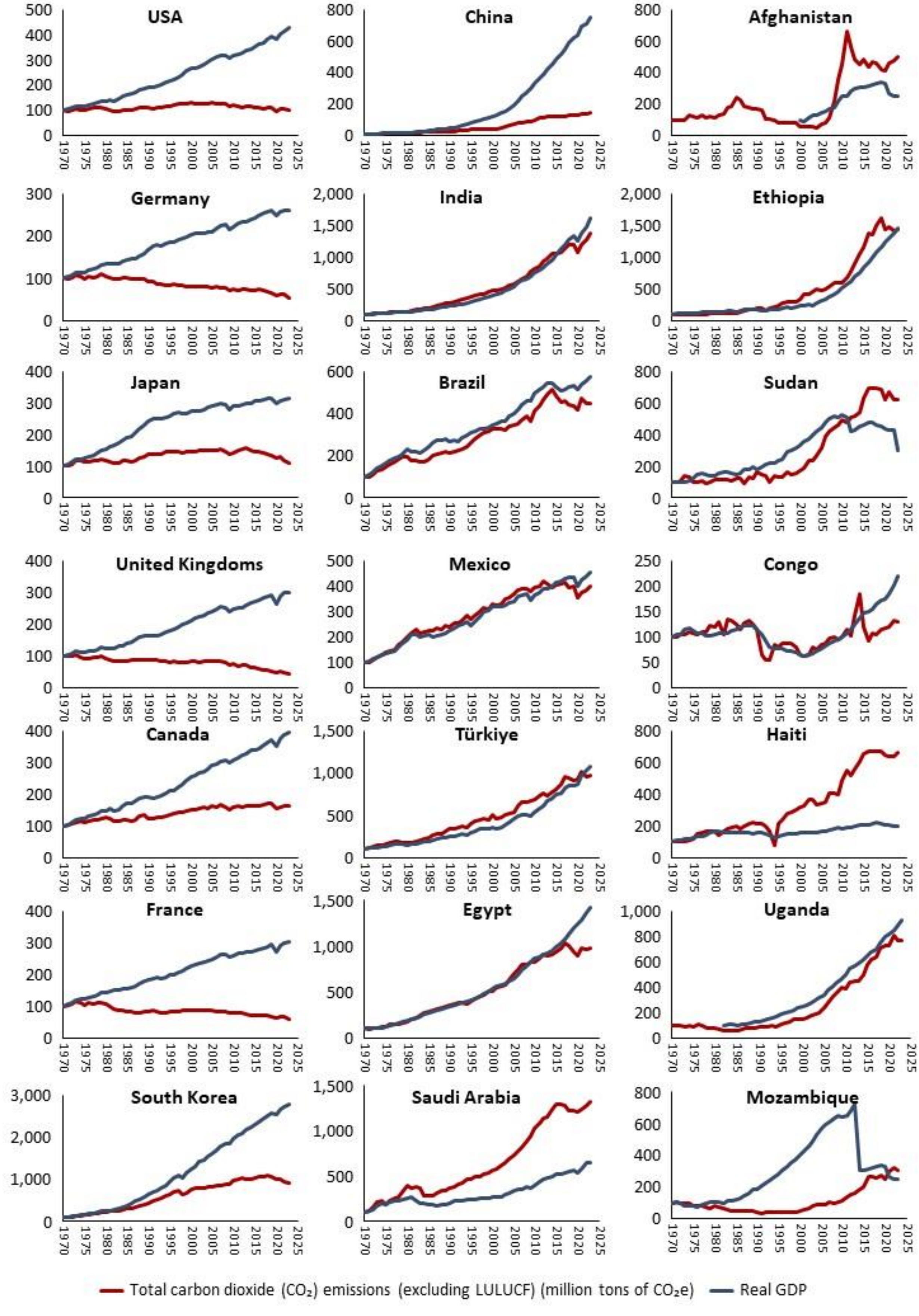
The relationship between economic growth and environmental pressures is commonly discussed through the concept of carbon decoupling, defined as the weakening—or breaking—of the link between GDP growth and environmental indicators (e.g., carbon emissions, energy consumption, natural resource use). Two forms of decoupling are typically distinguished:

- **Relative decoupling:** GDP grows and emissions also grow, but emissions increase more slowly than GDP. Environmental pressure does not decline; it merely rises at a reduced pace.
- **Absolute decoupling:** GDP continues to grow while total emissions decline in absolute terms. This reflects a structural separation between growth and environmental pressure.

As illustrated in Figure 2, advanced economies have increasingly decoupled growth from emissions. The United States has expanded its GDP roughly fourfold since 1970, while keeping emissions broadly around 1970 levels. Similarly, Germany, France, and the United Kingdom have grown by around threefold since 1970, while their total CO_2 emissions have fallen—entering an absolute decoupling trajectory. Japan and the Republic of Korea are among high-income economies that transitioned from relative to absolute decoupling after 2010.

By contrast, in many middle-income economies GDP and CO_2 emissions continue to rise in tandem, albeit at varying rates. China is a prominent case of relative decoupling: GDP increased around 80-fold since 1970, while emissions rose around 20-fold. Yet, in absolute terms, this still implies a substantial increase; China now accounts for roughly 30% of global emissions (IEA, 2023). India exhibits a similar relative decoupling trend particularly after 2016, while remaining the third-largest emitter. Other middle-income countries such as Brazil, Mexico, Indonesia, and Egypt joined this process later; after 2010 the sensitivity of emissions to growth began to decline. Türkiye, in this context, reflects typical dynamics of a rising economy: as GDP grows rapidly, GHG emissions also continue to rise. Hence, it is not yet possible to identify a decoupling phase for Türkiye. Finally, in low-income economies, a clear decoupling pattern is harder to detect, making classical decoupling approaches more difficult to apply.

Figure 2. Countries' carbon decoupling performance (1970=100), 1970–2024



Source: World Bank; TEPAV calculations.

Methodology

Measuring Decoupling via Elasticity

A widely used approach to measuring decoupling is the **elasticity** of emissions with respect to GDP growth, based on comparing growth rates:

$$\varepsilon = \frac{\%\Delta \mathrm{C}}{\%\Delta \mathrm{GDP}}$$

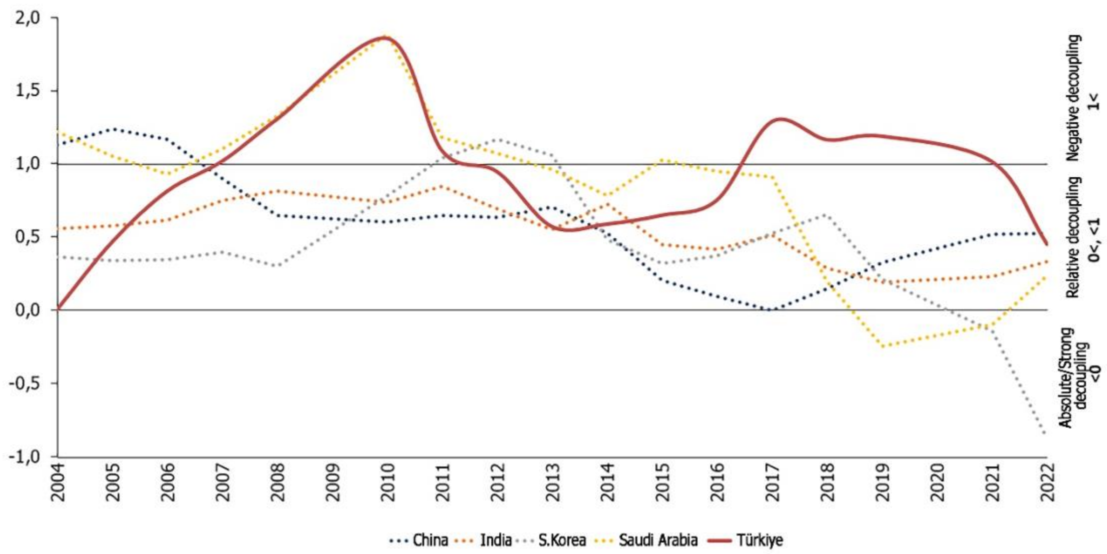
where **ε** denotes decoupling elasticity, **%ΔC** the percentage change in GHG emissions, and **%ΔGDP** the percentage change in GDP.

Following Tapio (2005), the coefficient characterizes the growth–emissions relationship:

- **ε > 1:** emissions grow faster than GDP (**negative decoupling / "reverse decoupling"**)
- **0 < ε < 1:** GDP grows faster than emissions (**relative decoupling**)
- **ε < 0:** GDP grows while emissions fall (**absolute/strong decoupling**)

Figure 3 presents decoupling elasticities for selected countries. China reduced its elasticity clearly below 1 after 2010, fluctuating around 0.5—indicating that it restrained emission growth despite high GDP growth. India similarly maintained an elasticity in the 0.5–1 range, sustaining relative decoupling. S. Korea provides an example of strong decoupling, with elasticity turning negative from the mid-2010s onward. Saudi Arabia long maintained elasticity above 1, implying faster emission growth than GDP; more recently, values closer to zero suggest limited relative decoupling. Türkiye, by contrast, exhibits elasticity above 1 over much of the period, indicating a tendency toward negative decoupling. While Türkiye occasionally moved into relative decoupling in the 2010s, it has not yet transitioned to absolute decoupling, where total emissions decline.

Figure 3. CO_2 emission elasticity in selected countries, 4-year moving average, 2004–2022



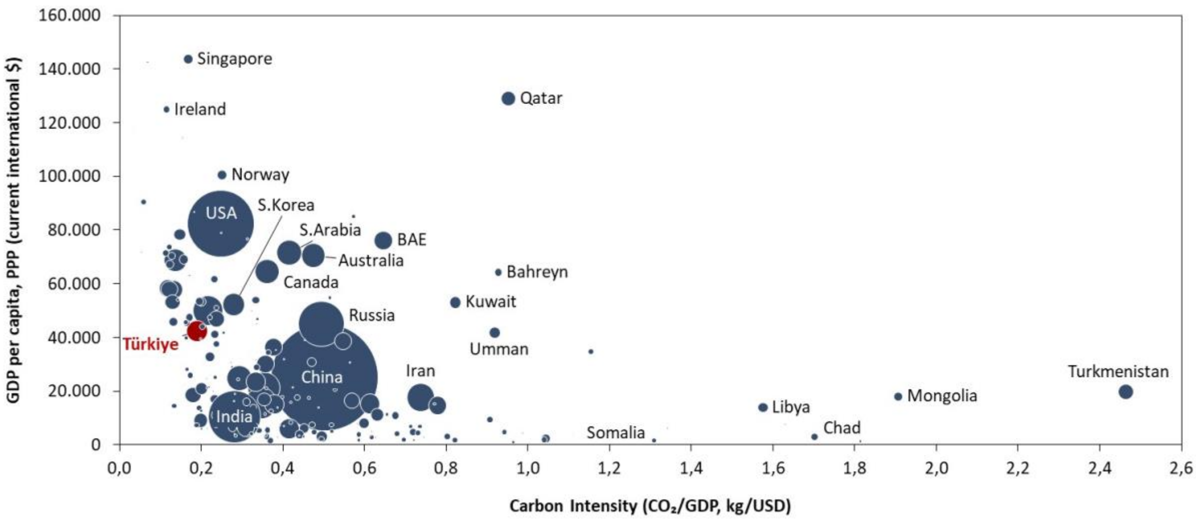
Source: World Bank; TEPAV calculations.

Emissions Intensity, Income, and Türkiye's "Carbon Geography"

Figure 4 shows the relationship between per-capita income and GHG emissions intensity. The overall pattern indicates that higher-income economies tend to have lower carbon intensity, whereas lower-income economies generate higher emissions per unit of income—highlighting the role of sectoral structure of economy, energy efficiency and access to clean production technologies in development trajectories. Türkiye appears below the global average with a carbon intensity of approximately **0.2 kg CO_2/USD**. However, the national average masks substantial subnational variation. When provinces are included in the same global ranking using the same method, **Zonguldak** ranks 6th globally with **1.5 kg CO_2/USD**, while **Karabük (1.3)**, **Çanakkale (1.2)**, and **Kütahya (1.0)** enter the top 15. In contrast, major metropolitan provinces such as **İstanbul, Ankara, İzmir, and Bursa** remain below **0.1 kg CO_2/USD**, close to European averages.

This confirms that although Türkiye's overall carbon intensity may look relatively low, the country's **carbon geography is highly fragmented**. Provinces with concentrated industrial and power generation capacity are strongly carbon-dependent, whereas service-oriented metropolitan economies are comparatively less carbon-dependent. Türkiye's carbon profile is therefore not balanced nationally; it is **regionally polarized**. As such, green transition policies should not be designed solely around national averages, but rather around provinces' production structures, energy profiles, and sectoral concentrations. The next section examines these spatial differences in detail and analyzes the structural characteristics of high-intensity provinces.

Figure 4. Countries' GHG emissions intensity and GDP per capita, 2023

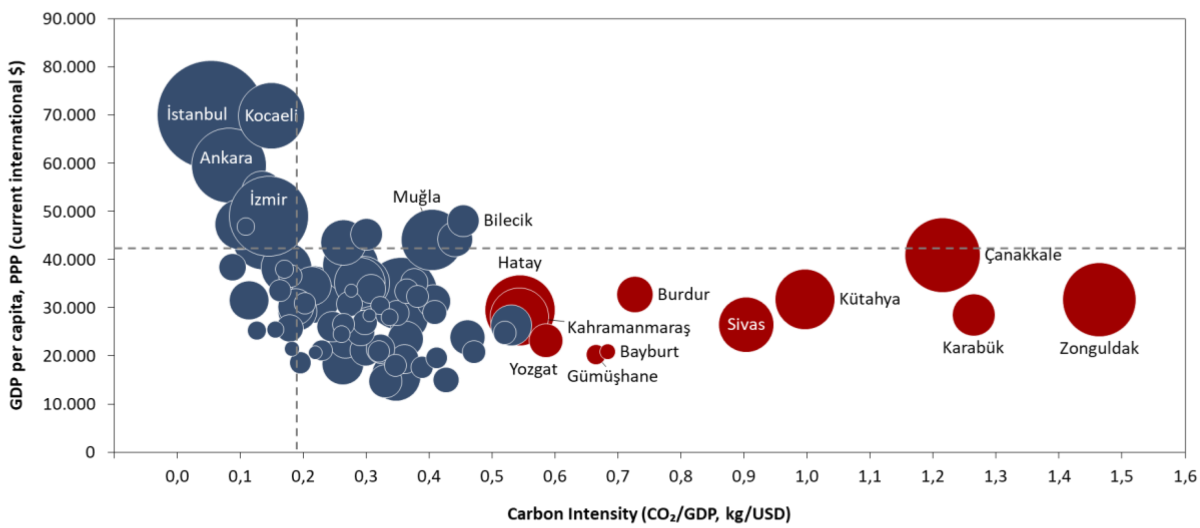


Note: Circle sizes represent CO_2e in million tonnes ($MtCO_2e$).
Source: Climate TRACE; TEPAV calculations.

Province-Level Carbon Intensity and Spatial Findings in Türkiye

Figure 5 presents differences across provinces in PPP-adjusted GDP per capita and production-based carbon intensity as of 2023. The horizontal axis shows GDP per capita and the vertical axis shows emissions intensity. Circle sizes indicate total emissions. The visualization highlights that provinces such as **Zonguldak (1.46)**, **Karabük (1.26)**, **Çanakkale (1.21)**, and **Kütahya (0.99)** exhibit high carbon intensity despite comparatively low income levels. By contrast, **İstanbul (0.05)**, **Ankara (0.08)**, **İzmir (0.14)**, and **Kocaeli (0.14)** combine higher income levels with lower carbon intensity. These differences help inform regional prioritization in Türkiye's green transition. Provinces with heavy industry and fossil-fuel-based production—such as Zonguldak, Karabük, Kütahya, and Çanakkale—emerge as among the most vulnerable areas in the transition.

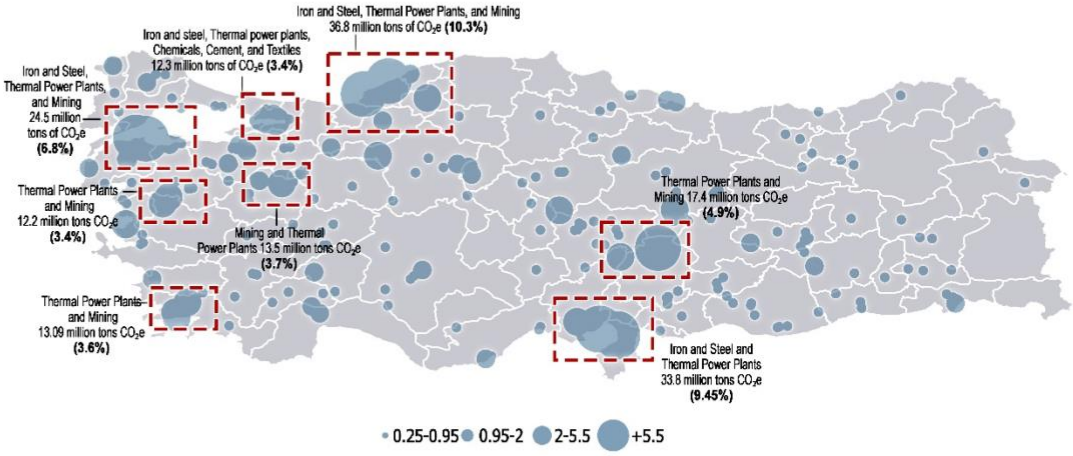
Figure 5. Provinces' GHG emissions intensity and GDP per capita, 2023



Note: Circle sizes represent total greenhouse gas emissions (million tonnes CO_2e), and dashed lines indicate the Türkiye average.
Source: Climate TRACE, TÜİK, TEPAV calculations.

Figure 6 maps the locations with the highest emissions from energy and manufacturing facilities in Türkiye. Derived from satellite-based observations, these data render spatially visible the emissions of manufacturing and power generation sites, reflecting the geographic concentration of carbon-intensive activities such as iron and steel, thermal power generation, mining, chemicals, and cement. Key hotspots include **Zonguldak–Karabük–Bartın (36.8 Mt CO_2e; 10.3% of total manufacturing & energy emissions)**, **İskenderun–Yumurtalık (33.8 Mt; 9.45%)**, **Çanakkale (24.5 Mt; 6.8%)**, and **Afşin–Elbistan (17.4 Mt; 4.9%)**. The picture indicates that emissions are concentrated in specific industrial centers, suggesting that regional transformation policies should focus particularly on these areas.

Figure 6. Emissions map of manufacturing and power generation facilities, Mt CO_2e, 2024



Note: Circle sizes represent CO_2e in million tonnes (MtCO_2e).
Source: Climate TRACE; TEPAV visualizations.

Figure 7 presents the sectoral composition of employment in districts with the highest emissions in energy and manufacturing. In locations such as **Zonguldak (21.1%)**, **Soma (37.8%)**, **Afşin (40%)**, **Yatağan (28.3%)**, **Çanakkale–Biga (23.8%)**, **İskenderun (18.7%)**, and **Adana–Yumurtalık (43%)**, leading employment sectors closely overlap with high-emission activities. For example, Zonguldak and Soma have employment strongly anchored in coal and lignite extraction; **Zonguldak–Ereğli (21.6%)**, **İskenderun (18.7%)**, and **Çanakkale (16.2%)** are dominated by basic metals and iron–steel. In **Afşin (25.9%)** and **Yumurtalık (29.3%)**, energy generation—particularly thermal power—forms the core of local employment.

Figure 7. Employment distribution in the highest-emitting districts, 2024

Source: SGK TEPAV calculations.

Key Insights: Provincial Carbon Intensity and Spatial Vulnerabilities

This study measures the carbon intensity of economic activity across Türkiye's provinces and identifies where spatial vulnerabilities concentrate in the green transition. The findings point to three core messages:

- First, although Türkiye's overall carbon dependence appears relatively low in cross-country comparisons, substantial **within-country heterogeneity** exists. Provinces differ markedly in the carbon dependence of their economies. **Zonguldak, Karabük, Çanakkale, and Kütahya** stand out with high emissions intensity due to production structures reliant on coal, iron–steel, and other energy-intensive industries, despite comparatively low income levels. Conversely, **İstanbul, Ankara, İzmir, Kocaeli, and Antalya** combine high GDP per capita with lower carbon intensity—indicating that the income–emissions relationship varies at the provincial level.
- Second, spatial analysis demonstrates that carbon-intensive sectors are **highly clustered** in particular regions. Provinces such as **Zonguldak, Karabük, Afşin–Elbistan, İskenderun, and Çanakkale** concentrate mining, iron–steel, and thermal power generation. Even if these provinces are not the largest centers of total industrial production, their strong dependence on carbon-intensive activities makes them among the most vulnerable regions for achieving the 2053 net-zero target. In contrast, service-oriented provinces such as İstanbul may contribute more emissions in absolute terms, yet their economic structures are not as carbon-dependent and therefore not vulnerable to the same extent.
- Third, employment data deepen the vulnerability assessment. In districts such as **Zonguldak, Soma, Karabük, İskenderun, Çanakkale–Biga, Afşin–Elbistan, and Adana–Yumurtalık**, employment is concentrated in coal mining, basic metals, and thermal power generation. This underscores the central role of carbon-intensive employment in local economies and signals a critical risk area for **just transition** debates.

Overall, provincial carbon intensity is not merely an environmental metric; it is also a strategic policy instrument that directly shapes Türkiye's economic competitiveness, social equity balance, and position in international trade. Systematically integrating this indicator into policymaking is critical for accelerating Türkiye's green transition, reducing regional disparities, and safeguarding global competitiveness through a sustainable pathway.

Policy Assessment: The Green Transition and Technological Restructuring

Türkiye's carbon intensity patterns indicate that the economic structure is constrained not only environmentally, but also technologically. While Türkiye's carbon dependence appears low partly due to the scale of the services sector, a vulnerability emerges in the EU market—the main destination for Türkiye's manufacturing exports. The EU's Carbon Border Adjustment Mechanism (CBAM) is no longer a purely technical preparation agenda; it is an operational policy reality. Under CBAM, Türkiye's key export market is entering a new era in which products compete not only on price and quality, but also on carbon footprint and production technology. Maintaining the current production structure is therefore no longer economically sustainable.

Türkiye's fundamental challenge today is that production structures reliant on carbon-intensive sectors are increasingly becoming technologically obsolete and trapped in a low-productivity equilibrium. Many high-emission sectors are simultaneously characterized by low digitization and low R&D intensity. For this reason, the success of the green transition depends not only on emissions reduction, but also on strengthening technological transformation capacity. Technology is decisive along three dimensions:

1. **Productivity:** New production technologies reduce carbon intensity by lowering energy use and resource waste.
2. **Competitiveness:** Low-emission production is now a core condition for competitiveness in the EU market; without technological upgrading, Türkiye's industrial export capacity will erode.
3. **New value chains:** Clean energy, battery technologies, green hydrogen, and circular economy based solutions will determine Türkiye's ability to attract investment and create jobs in new industrial ecosystems.

Accordingly, developing a comprehensive, green-transition-aligned technological restructuring strategy is no longer optional for Türkiye; it is a necessity. Key pillars should include:

- **Technology upgrading programs in energy-intensive sectors:** Scaling low-emission production technologies (e.g., carbon capture, green hydrogen, electric arc furnaces) in iron–steel, cement, chemicals, and energy. In line with Türkiye's updated NDC, a rapid and clear coal phase-out timeline—given coal's outsized role in emissions growth-is critical, alongside a comprehensive just transition strategy for the vulnerable regions, provinces, and clusters identified in this study.
- **Designing post–Climate Law instruments with regional differentiation:** Ensuring that emerging Emission Trading System (ETS), just transition, and local government regulations reflect regional and provincial heterogeneity.
- **Digitization and data-driven industry:** Making production processes traceable via AI, and sensor technologies, enabling real-time measurement of both carbon footprints and productivity performance.
- **Regional smart specialization:** Integrating technology-led transformation in carbon-intensive provinces with regional development policies, creating new job areas and re-skilling existing workforces.
- **Public–private financing instruments:** Supporting green transition investments with long-term finance and directing public banks, development agencies, and private funds toward this transformation.

Finally, CBAM offers Türkiye less an external constraint than an opportunity for internal strategic reorientation. In this new industrial paradigm, technology is not merely an input to production; it is the key to environmental sustainability and economic competitiveness. Achieving net-zero targets will depend on pairing the green transition with social policy and regional development tools, while decisively advancing technology-based restructuring across the economy.

Conclusion

This paper set out to move the green transition discussion in Türkiye beyond national averages by combining a decoupling perspective with a province-level "carbon intensity atlas." The national picture remains clear: Türkiye has not yet entered an absolute decoupling phase in which economic growth is sustained while emissions fall. Instead, the growth–emissions link largely persists, signalling that the 2053 net-zero pledge will require a deliberate break from the current emissions-intensive growth pattern rather than incremental efficiency gains alone.

The core contribution of the analysis is to show that Türkiye's carbon dependence is not uniform; it is spatially concentrated and structurally uneven. The national average masks a fragmented "carbon geography" where a small set of provinces and industrial clusters carry disproportionately high emissions intensity due to coal, thermal power, iron–steel, cement, chemicals, and other energy-intensive activities. These hotspots are also labour-anchored: in several high-emitting districts, employment is tightly linked to carbon-intensive sectors, making the transition not only an environmental and technological challenge but also a regional development and social equity issue. In this context, one-size-fits-all roadmaps risk missing where vulnerabilities—and therefore policy leverage—actually sit.

Policy implications follow directly. Provincial carbon intensity should be treated as a strategic planning variable that guides sequencing, investment prioritization, and the design of transition instruments. As the EU market increasingly prices carbon through CBAM and related regulatory architecture, maintaining competitiveness will depend on accelerating technological upgrading in energy-intensive sectors, strengthening traceability and data infrastructure, and mobilizing long-term finance for low-carbon investments. Equally important, climate instruments—such as an emerging ETS and post–Climate Law regulations—need regional differentiation so that the transition is both feasible and fair. Ultimately, CBAM should be understood less as an external constraint than as a catalyst for internal strategic reorientation: Türkiye can safeguard export competitiveness and reduce regional disparities by pairing technology-led decarbonization with just transition measures and place-based development policies.

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