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Green Transition in the CAREC Region: Enabling Environmental Standards Compliance

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List of Abbreviations

Acronym	Full Form
ADB	Asian Development Bank
CAREC	Central Asia Regional Economic Cooperation
CCUS	Carbon capture, utilization, and storage
CEPII	Centre for Prospective and International Information Studies
CO_2	Carbon dioxide
EIA	Energy Information Administration
EGDI	E-government development index
EDGAR	Emissions Database for Global Atmospheric Research
EU	European Union
GDP	Gross domestic product
GHGs	Greenhouse gases
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
OECD	Organization for Economic Co-operation and Development
PPP	Purchasing power parity
PRC	People's Republic of China
SMEs	Small and medium enterprises
STIRPAT	Stochastic impacts by regression on population, affluence, and technology
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
WDI	World Development Indicators

Abstract

Despite the Paris Agreement and Sustainable Development Goals commitments, the intensity of emissions in the Central Asia Regional Economic Cooperation (CAREC) region remains high. As of 2023, CAREC countries collectively emitted over 14 billion tonnes of carbon dioxide (CO_2). At an average of 7.79 tonnes per capita and 0.41 kg per dollar of GDP, these levels exceed the global average for emissions per unit of output. These figures underscore the urgent need for targeted climate action to accelerate the region's green transition.

This study adopts a regional perspective to assess CO_2 emission trends and identify sectoral disparities across CAREC economies. A suite of fiscal, monetary, and financial instruments has been deployed to support the global green transition. Within this landscape, we focus on environmental standards and eco-labels, which operate as demand-side market-shaping tools that guide producers and consumers toward low-carbon choices. Given the high emission-levels of CAREC countries' energy-intensive sectors, we empirically analyze the effectiveness of energy management standards using panel data.

Notably, such standards promote compliance with low-carbon production processes and product attributes and present a bottom-up approach that complements broader policy frameworks. Therefore, to scale their impact, it is vital to allocate financial resources that enable firms to meet mandatory standards and encourage the adoption of voluntary ones. Hence, this study proposes a three-pronged policy agenda: prioritizing high-emission sectors for certification, streamlining and harmonizing environmental standards, and strengthening institutional and financial support for firm-level compliance. These measures are key to ensuring that firms avoid superficial compliance or greenwashing and adopt and implement the standards sincerely.

Keywords: carbon emissions, CAREC region, green transition, ISO 50001 certification, firm compliance

1. Introduction

The atmospheric concentration of carbon dioxide (CO_2) has surged from approximately 278 ppm in 1750 to a prevailing level of 420 ppm—a staggering 51% increase (World Meteorological Organization, 2024). Driven by rapid industrialization, trade expansion, and unsustainable resource consumption, climate change poses a critical threat to human civilization and economic development in the 21st century. The integration of environmental and economic agendas is now rendered critical. Nevertheless, despite recurrent warnings and adverse events, the climate crisis remains unabated as the global community shies away from the full commitments necessary for its reversal (United Nations, 2020, 20). The consequences are already severe, with climate change causing irreversible damage to terrestrial, freshwater, cryospheric, coastal, and ocean ecosystems. While some progress has been made, gaps in adaptation persist across sectors and regions, primarily affecting lower-income populations (Intergovernmental Panel on Climate Change, 2023). These challenges are compounded by their technical complexity, the presence of economic winners and losers, and the need to balance mitigation and adaptation efforts at the local, national, and global levels.

The 2015 Paris Agreement marked a pivotal global commitment to climate mitigation, requiring countries to adopt progressively ambitious Nationally Determined Contributions to curb emissions and transition toward sustainable economies (UNFCCC, 2023). The Central Asia Regional Economic Cooperation (CAREC) region faces some of the most severe climate challenges. Recent climate-related disasters, such as the catastrophic floods in Pakistan, prolonged droughts in Afghanistan and the People's Republic of China (PRC), extreme heatwaves, and cross-border conflicts over dwindling water resources in Central Asia, are examples of their intensification over time (Asian Development Bank, 2023). These escalating crises underscore the urgency of climate action within the CAREC 2030 Strategy. As signatories to the Paris Agreement, CAREC countries have pledged to reduce carbon emissions. Under the 2030 Sustainable Development Agenda, they have set targets to reduce greenhouse gas (GHG) emissions by 10–20% by 2030 (Asian Development Bank, 2019). While all CAREC countries have submitted Nationally Determined Contributions, and many have developed climate change strategies and adaptation plans, effective implementation remains a major challenge.

Among other factors, CO_2 and other GHGs generated by human activity lie at the core of the climate-change challenge: trapping heat in the atmosphere and disrupting global climate systems (United States Environmental Protection Agency, 2023). As the primary contributor to GHG accumulation, CO_2 emissions have increased more than ninefold over the past century due to industrialization and expanding trade. In this context, the CAREC region presents a concerning situation: total CO_2 emissions exceed 14 billion tonnes, translating to 7.79 tonnes per capita and 0.41 kg per dollar of GDP. Although the CAREC region's per capita emissions surpass the global average of 4.68 tonnes, they remain below the 9.94 tonnes in high-income countries. However, emissions per unit of economic output in the CAREC (0.41 kg/$) are significantly higher than the global average of 0.23 kg/$ and exceed those of high-, middle-, and low-income country groups. This situation warrants urgent and targeted action to accelerate the region's green transition.

To achieve a green transition, a diverse mix of policy instruments has been adopted globally. These include fiscal, monetary, and financial approaches. Fiscal policies include carbon taxes, cap-and-trade systems, and emissions trading schemes that directly address carbon pricing. Monetary instruments such as green quantitative easing and climate-aligned collateral frameworks enable central banks to contribute to climate-related goals. Similarly, financial policies such as green bonds and other climate-linked securities are employed to promote sustainable finance. Furthermore, policymakers pursue market-fixing approaches, including fossil fuel divestments and carbon taxes, alongside market-shaping approaches, including tradable permits, quotas, and investment incentives. Within this varied policy landscape, environmental standards and eco-labels—the focus of this study—function as demand-side market shaping tools that guide producer and consumer behavior toward low-carbon choices. To address these challenges, well-coordinated efforts are necessary at the national and regional levels. This study adopts a CAREC region-wide perspective to assess carbon emissions, analyze intra-regional disparities, and position the region within a global context. Furthermore, in recognizing the private sector as a critical driver of climate action, we emphasize firm-level environmental compliance as a bottom-up strategy that complements broader fiscal, monetary, and regulatory initiatives for achieving carbon neutrality.

This study primarily assesses the effectiveness of environmental standards in reducing emissions and supporting the green transition. By generating empirical evidence on their impact, we aim to make a compelling case for governments to invest in facilitating firm-level compliance. Strengthening regulatory support for environmental standards can serve as a strategic policy lever to promote sustainable industrial practices and reinforce long-term decarbonization in the CAREC region.

The following objectives are pursued:

a) Examine CO_2 emission trends in the CAREC region, including long-term patterns, intra-regional variation, and comparisons with global benchmarks to inform decarbonization strategies.
b) Assess the impact of ISO 50001 energy management certification on carbon emissions using a macroeconomic, country-level framework while accounting for heterogeneity across geographic regions and industrial sectors.
c) Discuss key policy and institutional mechanisms for facilitating firm-level compliance with low-carbon standards.

The remainder of this paper is structured as follows. Section 2 presents an overview of CO_2 emissions in the CAREC region, highlighting regional variations and global comparisons. It also outlines alternative policy approaches to managing carbon emissions. Section 3 describes the methodology and data sources used in the empirical analysis, and Section 4 discusses the findings of the study. Finally, Section 5 presents the conclusions and offers policy recommendations.

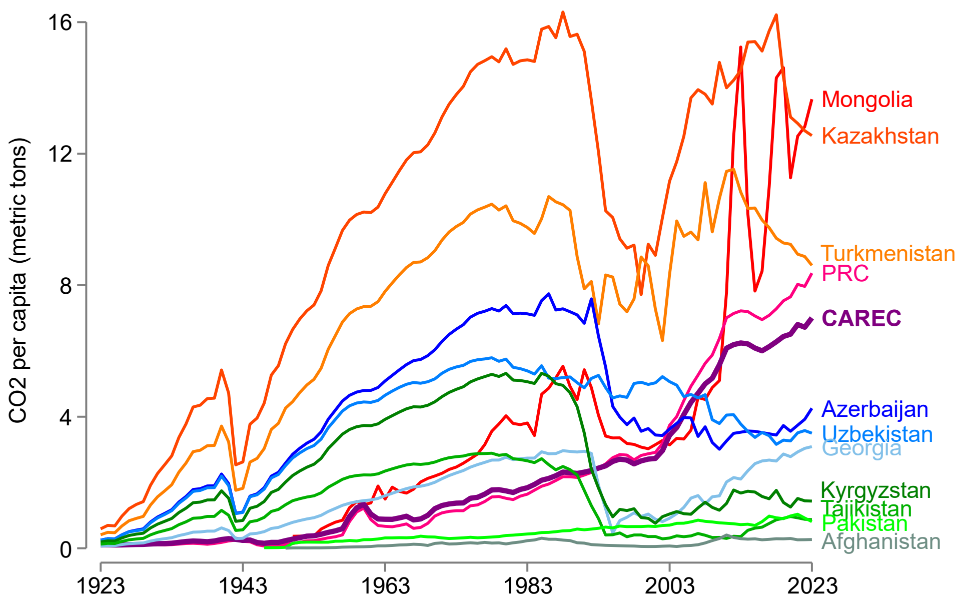
2. CO_2 Emissions and their Mitigation

2.1. CO2 Emissions in the CAREC Region

For a clear perspective on the CAREC region's decarbonization goals, it is important to understand its carbonization trends. This includes analyzing the growth of carbon emissions and their intra-regional variations over time and comparing global patterns.

Figure 1 presents the per capita carbon emissions of CAREC countries over the past century, highlighting two key findings. First, CO_2 emissions in the CAREC region have been steadily rising over the past two decades. Second, the regional average closely mirrors the PRC's emissions trajectory, largely due to the PRC's dominance of the region's economic activity and industrial output. The PRC has experienced the most dramatic increase in emissions over the last 20 years, which reflects its rapid industrialization and economic growth. Kazakhstan, Mongolia, and Turkmenistan also report emissions that are consistently above the regional average, while Afghanistan, Pakistan, and Tajikistan have some of the lowest per capita emissions within the region.

Figure 1: CO2 emissions in CAREC countries, 1923–2023



Notes: The values for the CAREC countries are calculated based on the aggregated carbon emissions and population data of its member countries. Carbon emissions data are sourced from *Our World in Data (Ritchie et al., 2023)*.

The long-term series shows periods of decline, particularly in the early 1990s, which can be associated with the dissolution of the Soviet Union and the resulting contraction of heavy industry and energy use. Subsequent restructuring has shifted several CAREC economies toward less carbon-intensive activities, with some efficiency gains in the energy system further contributing to these reductions.

In addition to examining long-term trends, we analyze a cross-sectional view for 2023. Table 1 presents the total volume per capita, and CO_2 emissions per dollar of GDP, and reveals significant disparities in emissions levels, both in absolute terms and relative to population and economic output.

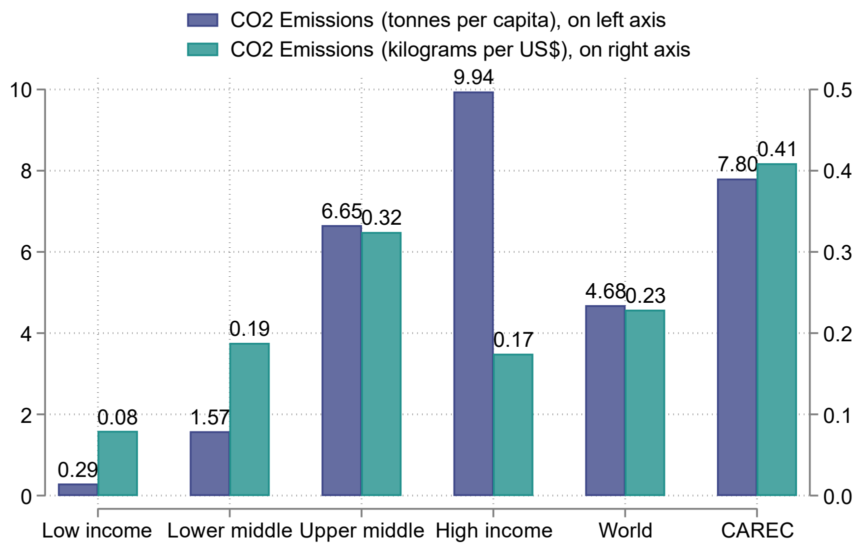
Table 1: CO2 Emissions by CAREC Countries, 2023

Countries	CO_2 (Million tonnes, Mt)	CO_2 (tonnes per person)	CO_2 (kilogram per US$)
Afghanistan	8.71	0.21	0.11
Azerbaijan	42.77	4.21	0.20
People's Republic of China	13259.64	9.40	0.42
Georgia	12.86	3.46	0.15
Kazakhstan	239.87	11.80	0.34
Kyrgyz Republic	10.46	1.47	0.23
Mongolia	28.12	8.08	0.50
Pakistan	200.51	0.81	0.15
Tajikistan	9.31	0.90	0.20
Turkmenistan	65.99	8.96	0.50
Uzbekistan	137.90	3.87	0.39
CAREC Region	14016.13	7.80	0.41

Notes: GDP is expressed in 2021 PPP US$. The values for the CAREC region are calculated based on CO_2 emissions, population, and GDP aggregated at the regional level. Emissions data are taken from the Emissions Database for Global Atmospheric Research; European Commission JRC & PBL, 2023).

The PRC dominates regional emissions, contributing 13,259.64 million tonnes of CO_2, which accounts for most of the CAREC region's total emissions of 14,01,6.13 Mt. However, in terms of CO2 emissions per dollar of GDP, the PRC's figure stands at 0.42 kg, partly reflecting better technologies and energy efficiency. Kazakhstan and Turkmenistan emit the highest CO_2 per capita, at 11.8 and 8.96 tonnes, respectively, driven mainly by their high fossil fuel dependence and energy-intensive industries. Mongolia also records elevated per capita emissions at 8.08 tonnes, while Uzbekistan, Azerbaijan, and Georgia have relatively lower levels, at 3.87, 4.21, and 3.46 tonnes, respectively. On the lower end, Afghanistan, Pakistan, and Tajikistan have some of the smallest emissions per capita, with Afghanistan at 0.21 tonnes, Pakistan at 0.81 tonnes, and Tajikistan at 0.90 tonnes, reflecting lower industrial activity and energy consumption. The data highlights the wide range of emissions patterns in the CAREC region, shaped by variations in industrial development, energy mix, and economic structures.

Figure 2: Comparison of CO2 emissions across country groups, 2023

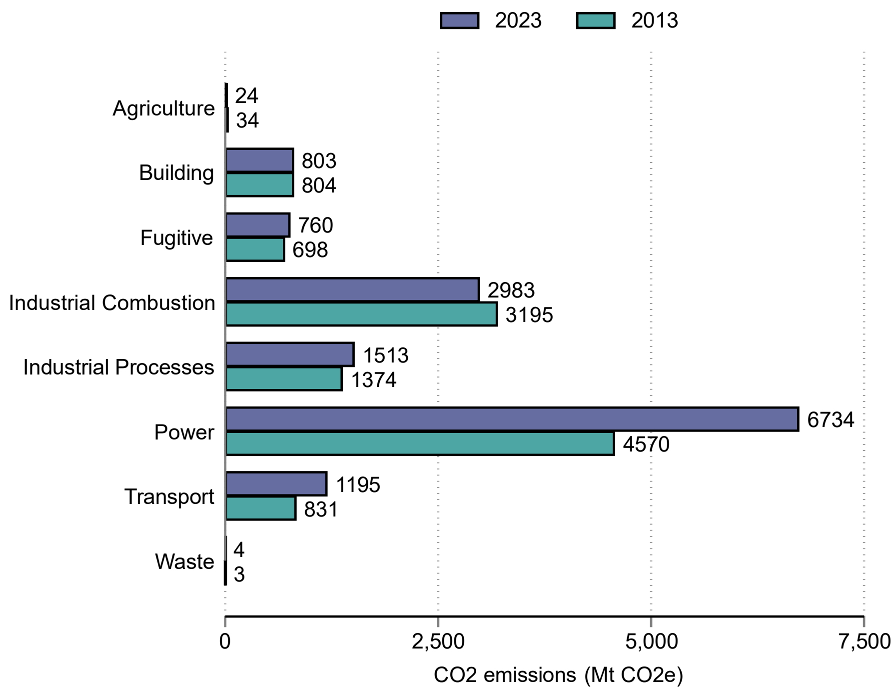


Notes: The values for the CAREC region are calculated based on CO_2 emissions, population, and GDP aggregated at the regional level. Emissions data are taken from the Emissions Database for Global Atmospheric Research; European Commission JRC & PBL, 2023).

Furthermore, having examined emissions within CAREC countries, it is useful to compare the region with global income groups. Figure 2 shows that per capita CO_2 emissions in the CAREC region stand at 7.80 tonnes: this is higher than the global and upper-middle-income averages of 4.68 and 6.65, respectively, but lower than the high-income average of 9.94. Lower-income groups have much smaller per capita emissions, with low-income countries at just 0.29 tonnes and lower-middle-income countries at 1.57 tonnes. In terms of CO_2 intensity per dollar of GDP, the CAREC region's 0.41 kg far exceeds the global average of 0.23 and even upper-middle-income economies at 0.32, indicating a more carbon-intensive economy. Conversely, high-income countries have lower emissions intensity at 0.17, reflecting better energy efficiency. This highlights the urgent need for stringent policies in the CAREC to reduce emissions, including stricter environmental regulations, clean energy incentives, and investments in low-carbon technologies. Without decisive action, high carbon intensity could hinder further sustainable economic growth and environmental resilience.

Finally, examining emissions by sector provides valuable insight for prioritizing targeted mitigation efforts. As shown in Figure 3, between 2013 and 2023, CO_2 emissions in the CAREC region reveal clear shifts in sectoral contributions. Emissions in the agricultural sector decreased from 34.33 Mt to 24.17 Mt, and declined from 3195.07 Mt to 2983.12 Mt in industrial combustion, suggesting efficiency improvements or structural shifts in these sectors. The building sector remained nearly unchanged.

Figure 3: Sectoral CO2 emissions in CAREC Region, 2023



Notes: The values for the CAREC region are calculated based on CO_2 emissions, population, and GDP aggregated at the regional level. Emissions data are taken from the Emissions Database for Global Atmospheric Research; European Commission JRC & PBL, 2023).

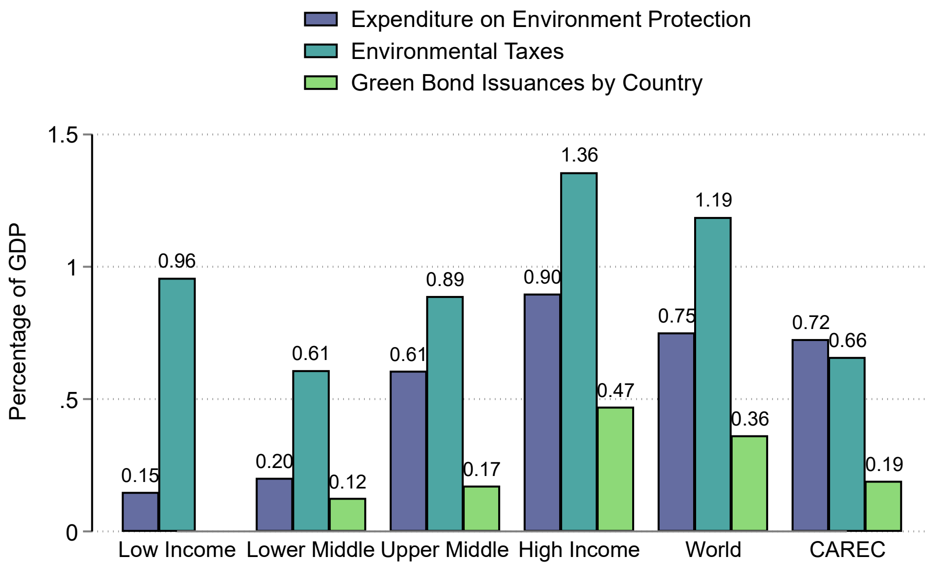
Conversely, emissions increased in several areas: power generation saw the most dramatic rise from 4569.86 Mt to 6733.92 Mt, making it the highest-emitting sector in 2023. Transport emissions also rose sharply, from 831.20 Mt to 1194.75 Mt, reflecting growing mobility or vehicle dependence. Industrial processes showed a moderate increase from 1373.58 Mt to 1513.15 Mt, possibly indicating increased manufacturing activity. Fugitive emissions rose slightly, while waste-related emissions, although low in absolute terms, increased modestly.

2.2.Policy Instruments for Decarbonization

Governments employ various policy instruments to advance the green transition, including public environmental expenditure, environmental taxation, green finance mechanisms, such as green bonds, and firm-level initiatives, such as voluntary environmental standards. Figure 4 presents an overview of environmental financial indicators: environmental taxes, environmental protection expenditure, and green bonds expressed as a percentage of GDP across different income groups, the CAREC region, and the global average. The CAREC region allocates 0.72% of its total GDP to environmental protection, which is close to the global average. This indicates a relatively strong public sector commitment. However, environmental tax revenue is low at 0.66% of GDP, suggesting a limited use of fiscal instruments to influence environmental behavior. Green bond issuance remains modest at 0.19%, well below the global average, reflecting underdeveloped market-based financing mechanisms.

Green bonds are an important policy instrument for promoting sustainability and achieving carbon neutrality. In collaboration with Swedish investors, The World Bank pioneered this initiative by issuing the first green bond in 2008. These bonds were intended to finance climate-friendly projects such as renewable energy, energy efficiency, and sustainable agriculture. Since then, the green bond market has grown significantly, with the World Bank and the International Finance Corporation issuing billions globally to support environmental objectives.

Figure 4: Comparison of green finance across country groups

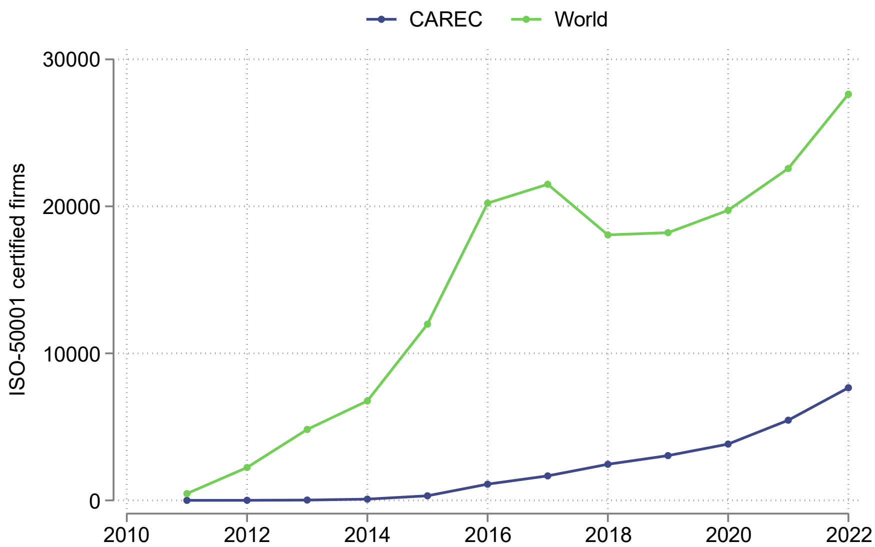


Notes: The values for CAREC are calculated based on the indicator values and GDPs of its member countries. Data are sourced from IMF Climate Dashboard.

Green finance, particularly through green bonds, is increasingly used to fund environmentally sustainable projects. Fatica and Panzica (2021) find that green bonds reduce firms' carbon intensity when the proceeds are used for new investments and reviewed externally. Cross-country analyses by Chang, Taghizadeh-Hesary, Chen, and Mohsin (2022), and Meo and Abd Karim (2022) confirm their positive effect on environmental quality, despite varying results. Bhutta, Tariq, Farrukh, Raza, and Iqbal (2022) highlight the importance of regulatory frameworks and disclosure practices in enabling the growth and impact of green bonds.

Unlike top-down fiscal or market-based policies, voluntary environmental standards such as ISO 14001 and ISO 50001, represent firm-led, process-focused approaches to environmental improvement. Voluntary environmental standards such as ISO 14001 and ISO 50001 have demonstrated significant potential in reducing industrial emissions and improving performance. Sam and Song (2022) show that ISO 14001 certification significantly lowers carbon emissions among Korean manufacturing firms, while Arocena, Orcos, and Zouaghi (2021) find that ISO 14001 enhances environmental and economic performance, with the effects moderated by firm size and national environmental awareness.

Figure 5: ISO 50001 certified firms, 2011–2022



Notes: The sharp shift around 2017 reflects a change in survey methodology. ISO clarified that from 2018 onwards, data was adjusted to correct earlier overreporting based on the number of sites instead of the actual number of certificates. Data source: ISO Survey (2023).

On the energy management front, Fitzgerald, Therkelsen, Sheaffer, and Rao (2023) report that ISO 50001 leads to sustained energy efficiency improvements in manufacturing facilities, supporting its role in industrial decarbonization. Expanding this to a global scale, McKane et al. (2017) estimate that widespread ISO 50001 adoption could result in substantial energy savings, emission reductions, and cost benefits, making it a valuable climate policy tool. The ISO 50001 standard supports improved energy performance, cost reduction, and lower CO_2 emissions, offering substantial global potential for energy and emission savings. Since its launch in 2011, the number of ISO 50001-certified firms has grown significantly. Figure 5 presents the number of certified firms in the CAREC region and globally from 2011 to 2022.

3. Methodology

3.1.Estimation Approach

Notably, 1945–46 was a pivotal period when new manufacturing technologies were introduced after World War II. These new technologies led to the large-scale manufacture of varied products, such as human-made radioisotopes, detergents, plastics, and synthetic pesticides, which drove up the rate of release of pollutants, a trend that has continued unabated since then. The IPAT equation, pioneered by Ehrlich and Holdren (1971), emerged alongside the modern environmental movement; it mathematically expressed environmental impact (I) as the product of three key factors: population (P), affluence (A), and technology (T), mathematically I = P×A×T.

Since its inception, the IPAT equation has remained highly popular. Several variants of the equation have been developed over time. However, Dietz and Rosa (1998) and later York, Rosa, and Dietz (2003) criticized the IPAT equation for its simplistic disaggregation of environmental change factors, arguing that it fails to account for the interactions among population, affluence, and technology. To address this limitation, they referenced studies that expanded on the IPAT to incorporate greater complexity. Their key contribution is Stochastic Impacts by Regression on Population, Affluence, and Technology (STIRPAT): this is a reformulation that enables the disaggregation of P, A, and T, and subsequent hypotheses-testing throughs statistical regression analysis. Addressing the limitations of the IPAT model, Aziz, Hossain, and Lamb (2024), Rokhmawati, Sarasi, and Berampu (2024), Wu, Wang, Wang, and Feng (2021), and Yu et al. (2023) have employed the STIRPAT model to estimate environmental impact.

In the following steps we outline the empirical model, developed within the STIRPAT framework. Similar to recent studies (e.g., Aziz et al., 2024; Li, Wang, Liu, and Jiang, 2021), we adopt a per capita emissions approach. First, using the panel structure and rearranging the IPAT equation, we derive equation (1), where μ represents the intercept, and e_{it} denotes the error term. The parameters β and γ capture the partial effects of affluence and technology on the environment, respectively. Next, equation (2) is logarithm-transformed to obtain equation (3), where $\alpha = \ln(\mu)$, and $\varepsilon_{it} = \ln(e_{it})$.

$$\left(\frac{I}{P}\right)_{it} = \mu\, A_{it}^{\beta}\, T_{it}^{\gamma}\, e_{it} \tag{1}$$

$$\ln\left(\frac{I}{P}\right)_{it} = \alpha + \beta \ln A_{it} + \gamma \ln T_{it} + \varepsilon_{it} \tag{2}$$

Environmental impact may be influenced by a country's adherence to the Kyoto Protocol and the Paris Agreement, as well as compliance with environmental standards. Together, these policies are used as a proxy for T_{it} in a typical STIRPAT model, as empirically specified in equation (3).

$$\ln\left(\frac{I}{P}\right)_{it} = \alpha + \beta \ln A_{it} + \rho\, Policy_{it} + \delta\, Control_{it} + \varepsilon_{it} \quad (3)$$

Extending equation (3) above, we specify the empirical model by including the main policy variable of interest (ISO50pc), and control variables, in order to capture other macroeconomic factors at the country level.

$$\ln CO2pc_{it} = \alpha + \rho \ln ISO50pc_{it} + \delta_1 \ln GBONDgdp_{it} + \delta_2 EPI_{it} + \delta_3 \ln CO2proxim_{it} + \delta_4 \ln ENERGYpc_{it} + \delta_5 \ln FOSSILshr_{it} + \delta_6 \ln GDPpc_{it} + \delta_7 \ln INDVA_{it} + \delta_8 \ln TRADEgdp_{it} + \varphi_i + \lambda_t + \varepsilon_{it} \quad (4)$$

Specifically, in addition to other explanatory variables, we include country fixed effects (φ_i) and time fixed effects (λ_t). We estimate the model using a panel econometric approach. To address endogeneity, we also re-estimate the model using the lagged certification variable.

The variable (GBONDgdp) represents green bond issuance as a percentage of GDP. The electronic participation index is denoted by (EPI). Carbon emissions of other countries, weighted by the inverse of their bilateral distance (CO_2proxim), are a constructed variable that reflects the influence of neighboring countries' emissions due to similar production and consumption patterns. In other words, these variable captures spatial dependence based on geographic proximity. It is constructed as a weighted average of other countries' emissions, where the weights are the inverse of the geographic distance (D_{ij}) between countries I and j, as specified in equation (5) below.

$$CO2proxim_{it} = \sum_j \frac{1}{D_{ij}} CO2pc_j \text{, where j is other than i} \quad (5)$$

Among other control variables, primary energy consumption per capita (ENERGYpc) measures average energy use per person, while the share of energy from fossil fuels in total energy consumption is denoted by (FOSSILshr). GDP per capita (GDPpc), expressed in constant 2015 US dollars, is included to capture the level of economic development. Additional variables include industry value added as a percentage of GDP (INDVA) and trade as a percentage of GDP (TRADEgdp).

All the variables (except EPI) were log-transformed for the regression. Two measures were constructed for ISO 50001: a population-normalized variable (ISO50pc), calculated as the number of certificates per population, and a GDP-normalized variable (ISO50gdp), calculated as the number of certificates per GDP (in million USD). In cases where no certificates were reported, the zeros were replaced with ones in order to allow log transformation before normalization. The empirical estimations examine the relationship between ISO 50001 energy management certification and carbon emissions. In addition to the baseline specification, the analysis incorporates regional heterogeneity, sector-specific effects, and alternative lag structures to assess the robustness of the estimated relationship.

3.2.Data Sources

Data on ISO certification counts were obtained from the ISO Survey, while information on green bond issuance was sourced from the IMF Climate Dashboard. The Electronic Participation Index (EPI) was retrieved from United Nations databases. Bilateral distance data were drawn from the Centre for Prospective and International Information studies. All other variables were compiled from the World Bank's World Development Indicators. The data set was initially compiled for 173 countries; however, missing observations reduced the final sample to 106 countries covering the period 2011–2023. Table 2 presents the descriptive statistics for the variables used in this study.

Table 2: Descriptive Statistics

	(1)	**(2)**	**(3)**	**(4)**
Variables	**Mean**	**Std. Dev.**	**Min**	**Max**
ISO50	154.51	711.80	0.00	9,024.00
EPI	0.62	0.25	0.00	1.00
CO2pc	6.09	5.36	0.10	28.69
CO2gdp	0.50	0.40	0.04	2.98
CO2proxim	5.36	1.35	2.60	13.38
GBONDgdp	0.43	1.67	0.00	28.61
ENGYpc	2,673.28	2,376.53	150.20	17,478.89
GDPpc	19,825.94	21,617.60	523.26	110,425.89
FOSLegy	72.62	22.51	8.56	100.00
INDVA	27.13	9.42	2.39	74.81
TRDgdp	93.37	58.53	22.49	393.14

Note: N=1082

4. Results and Discussion

4.1. Baseline Effects of Energy Management Certification on Carbon Emissions

Based on the IPAT framework, the regression results in Table 3 provide strong evidence that ISO 50001 certification is associated with reductions in carbon emissions. Columns (1) and (3) use per capita normalization for CO_2 emissions and certification counts, while columns (2) and (4) normalize these variables using GDP or economic size. In all specifications, the ISO certification coefficient, whether current or lagged, is negative and statistically significant—an increase in the number of ISO-certified firms corresponds to lower carbon emissions. This supports the hypothesis that energy management practices promoted by ISO 50001 contribute to emission reductions.

The use of lagged certification variables in columns (3) and (4) addresses potential endogeneity concerns, recognizing that higher emissions could trigger policy responses, including increased certifications. The consistency of the results across contemporaneous and lagged models reinforces the robustness of the findings.

Among the control variables, green bond issuance and the electronic participation index show significant negative associations with emissions—financial and digital governance mechanisms also play a role in emission mitigation. Conversely, primary energy consumption and fossil fuel share expectedly have strong positive effects. Other controls such as GDP per capita, industrial value added, and trade share vary in significance and direction, but are secondary to the main focus on ISO certification. Spatial dependence in emissions, reflected by CO_2proxim, highlights the need for regional cooperation, with policies addressing cross-border spillover effects through shared clean technology initiatives and harmonized energy efficiency standards.

Table 3: Effect of Energy Management Certification on Carbon Emissions

	Contemporaneous		**Lagged**	
	(1)	**(2)**	**(3)**	**(4)**
Variables	**ln_CO2pc**	**ln_CO2gdp**	**ln_CO2pc**	**ln_CO2gdp**
ln_ISO50pc	-0.014***			
	(0.004)			
ln_ISO50gdp		-0.014***		

		(0.004)		
lag_ln_ISO50pc			-0.017***	
			(0.004)	
lag_ln_ISO50gdp				-0.017***
				(0.004)
ln_GBONDgdp	-0.061***	-0.062***	-0.060***	-0.061***
	(0.017)	(0.017)	(0.017)	(0.017)
EPI	-0.086***	-0.080***	-0.093***	-0.086***
	(0.028)	(0.028)	(0.030)	(0.030)
ln_CO2proxim	0.679***	0.680***	0.742***	0.743***
	(0.127)	(0.127)	(0.131)	(0.131)
ln_ENGYpc	1.132***	1.101***	1.165***	1.138***
	(0.095)	(0.095)	(0.120)	(0.120)
ln_FOSLegy	0.990***	0.994***	0.963***	0.963***
	(0.099)	(0.099)	(0.126)	(0.126)
ln_GDPpc	0.537***	-0.480***	0.593***	-0.426***
	(0.048)	(0.048)	(0.054)	(0.053)
ln_INDVA	0.096***	0.095***	0.086***	0.087***
	(0.031)	(0.031)	(0.032)	(0.032)
ln_TRDgdp	0.030	0.033	-0.000	0.003
	(0.032)	(0.032)	(0.035)	(0.035)
Constant	-17.782***	-10.642***	-18.384***	-11.271***
	(0.804)	(0.804)	(1.014)	(1.014)
Observations	1,082	1,082	976	976
R-squared	0.466	0.547	0.422	0.509
Countries	106	106	106	106

Notes: All variables, except EPI, are log-transformed. Robust standard errors are provided in parentheses. Country and time fixed effects are not reported for brevity.

The results indicate that ISO 50001 certification is linked to meaningful emission reductions. A 10% increase in certifications is associated with a 0.15 to 0.17% approximate decline in CO_2 emissions, which remains robust when lagged values are used. Green bond issuance also contributes to emissions reductions: a 10% rise in issuance roughly corresponds to a 0.6% reduction in emissions. Improvements in digital governance matter do so as well: each one-point increase in the EPI reduces emissions by approximately 8 to 9%. Conversely, higher energy use per person and greater reliance on fossil fuels drive emissions upward, with a 1% increase each leading to approximately 1% rise in emissions. Economic development shows mixed effects, with income growth measured per capita raising emissions, but lowering them when expressed relative to GDP; while industry expansion raises emissions slightly, and trade openness shows no clear relationship. These findings suggest that when supported by green finance and digital governance, environmental standards such as ISO 50001 can play a complementary role in broader energy and industrial policies. They also highlight the importance of prioritizing energy efficiency and clean energy transitions while ensuring that financial and regulatory mechanisms are instituted to help firms adopt and comply with standards effectively, especially in energy-intensive sectors.

Next, we examine whether the effect varies across regions by exploring regional heterogeneity. Table 4 examines the regional heterogeneity in the relationship between ISO 50001 certification and carbon emissions by disaggregating the certification variable across continents. Data from the CAREC region are reported separately from the rest of Eurasia to highlight its specific contribution. The results indicate that ISO certifications are generally associated with reductions in emissions, although the magnitude and significance vary by region. In both columns, where emissions are measured either per capita or relative to GDP, the coefficients for the Americas are the largest and statistically most significant, suggesting a strong negative relationship between certification and emissions in that region. For the CAREC region, the effect is also negative and significant—ISO-certified firms in CAREC countries contribute meaningfully to emission reductions.

As shown in the empirical analysis, compliance with standards leads firms to adopt cleaner production processes and modify product attributes, improving efficiency and reducing CO_2 emissions. Therefore, it is important to allocate financial resources for accelerating the standard adoption process. For an effective approach to carbon neutrality, it is also pertinent to identify areas for prioritized action by understanding the sectoral composition of emissions in each country.

Table 4: Effect of Energy Management Certification - Regional Heterogeneity

		(1)	(2)
Variables		**ln_CO2pc**	**ln_CO2gdp**
ln_ISO50pc/ln_ISO50gdp:			
	Africa	-0.020	-0.023*
		(0.013)	(0.013)
	Americas	-0.031***	-0.032***
		(0.008)	(0.008)
	CAREC Region	-0.015**	-0.015**
		(0.007)	(0.007)
	Eurasia (except CAREC)	-0.010**	-0.010**
		(0.005)	(0.005)
	Oceania	0.003	0.004
		(0.021)	(0.022)
Constant		-18.164***	-11.054***
		(0.816)	(0.817)
Observations		1,082	1,082
R-squared		0.471	0.551
Countries		106	106

Notes: Robust standard errors are provided in parentheses. Other control variables listed in Table 3, country and time fixed effects are not reported for brevity.

4.2.Sectoral Analysis

Table 5 presents the percentage share of CO_2 emissions by sector for each CAREC country, offering insight into the primary sources of national emissions. The power sector emerges as the dominant contributor in most countries, particularly in Mongolia (58.4%), the PRC (48.8%), and Kazakhstan (46.1%), highlighting its central role in national emission profiles. In some countries, other sectors also play a significant role: the building sector contributes notably in the Kyrgyz

Republic (40.8%), Turkmenistan (39.4%), and Georgia (26.2%). Transport emissions are relatively high in Georgia (34.5%) and Afghanistan (26.9%), while industrial combustion is a major source in Afghanistan (38.0%) and Pakistan (26.8%). Industrial processes also contribute substantially in Tajikistan (20.8%) and Pakistan (12.6%). These variations suggest that emission reduction strategies should be tailored to the dominant sectors driving emissions in each country.

Table 5: Sectoral Shares of CO2 Emissions in CAREC Countries, 2023

Countries	Agri.	Building	Fugitive	IndComb	IndProc	Power	Transport
Afghanistan	0.2	7.2	2.2	38	1	24.5	26.9
Azerbaijan	0.3	26.4	8.2	5.8	3.9	35.9	19.5
People's Republic of China	0.1	4.9	5.3	21.7	11	48.8	8.1
Georgia	0.7	26.2	1.1	13.4	15.6	8.6	34.5
Kazakhstan	0.2	17	8.6	12.3	6	46.1	9.8
Kyrgyz Republic	1.2	40.8	0.7	5	10.6	25.2	16.4
Mongolia	0	12.5	8.3	8.6	1.9	58.4	10.3
Pakistan	2.8	9.5	2.9	26.8	12.6	23.8	21.6
Tajikistan	0.5	24.9	0.3	14.3	20.8	18.1	21.1
Turkmenistan	1.3	39.4	13	1	3	24	18.3
Uzbekistan	1.3	26.7	8.6	9.7	7.3	34.6	11.8

Notes: IndComb = Industrial Combustion; IndProc = Industrial Processes. The waste sector is excluded due to its negligible contribution. Emissions data are taken from the Emissions Database for Global Atmospheric Research; European Commission JRC & PBL, 2023). Legend: values: 0–10 = white; 10–20 = yellow; 20–30 = orange; above 30 = red.

The estimates for ln_ISO50pc (energy management certifications per capita) suggest that certification has a negative and significant association with CO_2 emissions in several energy-intensive sectors (Table 6). Greater certification is linked to lower emissions in buildings, industrial combustion, industrial processes, power, and waste sectors, with the largest effects observed in power and industrial activities. Conversely, the relationship is small and insignificant in agriculture and transport, while it even shows a weak positive (although insignificant) sign in fugitive emissions. Overall, these results indicate that energy certification is most effective in reducing emissions where energy use and process efficiency play a central role.

Table 6: Effect of Energy Management Certification on Carbon Emissions at Sectoral Level

	(1) agri	(2) building	(3) fugitive	(4) indcomb	(5) indproc	(6) power	(7) transport	(8) waste
ln_ISO50pc	-0.02	-0.01**	0.01	-0.03***	-0.04***	-0.04***	-0.00	-0.03*
	(0.01)	(0.01)	(0.02)	(0.01)	(0.01)	(0.02)	(0.00)	(0.02)
ln_GBONDgdp	0.01	-0.07***	0.12	0.00	0.00	-0.09	-0.10***	-0.11
	(0.05)	(0.03)	(0.10)	(0.03)	(0.03)	(0.07)	(0.02)	(0.07)
EPI	-0.13	-0.15***	0.41***	0.03	-0.00	-0.17	-0.02	0.24**
	(0.08)	(0.04)	(0.15)	(0.05)	(0.05)	(0.12)	(0.03)	(0.12)
ln_CO2proxim	0.34	0.27	-1.60**	0.85***	0.78***	0.37	0.45***	1.19**
	(0.40)	(0.19)	(0.69)	(0.23)	(0.22)	(0.51)	(0.13)	(0.52)
ln_ENGYpc	0.78***	1.04***	1.50***	0.31*	0.41**	1.25***	0.68***	0.62
	(0.28)	(0.14)	(0.54)	(0.17)	(0.16)	(0.39)	(0.10)	(0.41)
ln_FOSLegy	-0.58**	0.79***	-0.80	0.93***	1.06***	2.30***	0.36***	0.53
	(0.29)	(0.15)	(0.52)	(0.18)	(0.17)	(0.41)	(0.10)	(0.40)
ln_GDPpc	0.16	0.41***	0.20	0.84***	0.64***	0.03	0.67***	-0.10
	(0.15)	(0.07)	(0.27)	(0.09)	(0.08)	(0.20)	(0.05)	(0.20)
ln_INDVA	0.60***	0.01	-0.15	-0.04	0.37***	0.49***	-0.10***	-0.30
	(0.09)	(0.05)	(0.24)	(0.05)	(0.05)	(0.12)	(0.03)	(0.19)
ln_TRDgdp	-0.17*	0.10**	-	0.01	0.10*	-0.16	0.06*	0.09

			0.54***					
	(0.10)	(0.05)	(0.18)	(0.06)	(0.06)	(0.13)	(0.03)	(0.15)
Constant	-10.78***	-16.80***	-6.75	-16.14***	-17.57***	-20.86***	-13.45***	-14.71***
	(2.47)	(1.20)	(4.54)	(1.43)	(1.38)	(3.35)	(0.80)	(3.71)
Observations	921	1,082	989	1,082	1,082	1,063	1,082	703
R-squared	0.12	0.20	0.10	0.19	0.26	0.15	0.42	0.07
Number of c	85	106	97	106	106	106	106	69

Notes: agri = Agriculture; IndComb = Industrial Combustion; IndProc = Industrial Processes. All variables, except EPI, are log-transformed. Robust standard errors are provided in parentheses. Country and time fixed effects are not reported for brevity. Estimates are presented with 2 decimal places to save space.

A sector-specific approach is essential for effective decarbonization, particularly in hard-to-abate, carbon- and energy-intensive industries, such as iron and steel, cement, chemicals, pulp, and paper. The iron and steel industry alone accounted for approximately 25% of global industrial CO_2 emissions in 2019, making it a key target for climate mitigation efforts (International Energy Agency (IEA), 2020). Lei et al. (2023) propose a techno-specific decarbonization roadmap by aligning emission-reduction technologies with specific production routes for each plant. Similarly, the cement industry, responsible for around 7% of global CO2 emissions (Chaudhury, Sharma, Thapliyal, Singh, et al., 2023), faces major challenges in reducing its carbon footprint due to growing demand driven by urbanization and infrastructure development. Strategies such as alternative fuels, lowering the clinker-to-cement ratio, enhancing energy efficiency, and implementing carbon capture, utilization, and storage, are being explored to achieve net-zero targets in the sector.

4.3.Robustness Checks

To assess the stability of the baseline findings, a set of robustness checks is conducted. These tests examine whether the estimated impact of ISO 50001 energy management certification on carbon emissions is sensitive to alternative dynamic specifications and to the definition of the CAREC regional grouping. These ensure that the main results are not driven by modeling choices or the influence of a single large economy.

The first robustness exercise evaluates the persistence of the estimated effects on emissions when certification adoption is delayed. ISO 50001 certification variables are lagged by one and two years to capture adjustment dynamics in energy management practices. As reported in Table 7, ISO 50001 certifications continue to exhibit negative and statistically significant effects on carbon emissions under population-normalized (ISO50pc) and GDP-normalized (ISO50gdp) measures, indicating lower emissions per capita and relative to economic output. The stability of the estimates across lag structures and normalizations reinforces the evidence that ISO 50001 adoption contributes to emission reductions over time.

Table 7: Robustness Check with Alternative Lags

	(1)	**(2)**	**(3)**	**(4)**
VARIABLES	**ln_CO2pc**	**ln_CO2gdp**	**ln_CO2pc**	**ln_CO2gdp**
L1_ln_ISO50pc	-0.017***			
	(0.004)			
L1_ln_ISO50gdp		-0.017***		
		(0.004)		
L2_ln_ISO50pc			-0.013***	
			(0.004)	
L2_ln_ISO50gdp				-0.013***
				(0.004)
ln_GBONDgdp	-0.060***	-0.061***	-0.039**	-0.039**
	(0.017)	(0.017)	(0.017)	(0.017)
EPI	-0.093***	-0.086***	-0.126***	-0.120***

	(0.030)	(0.030)	(0.034)	(0.034)
ln_CO2proxim	0.742***	0.743***	1.362***	1.360***
	(0.131)	(0.131)	(0.159)	(0.158)
ln_ENGYpc	1.165***	1.138***	0.830***	0.815***
	(0.120)	(0.120)	(0.203)	(0.203)
ln_FOSLegy	0.963***	0.963***	1.084***	1.081***
	(0.126)	(0.126)	(0.178)	(0.178)
ln_GDPpc	0.593***	-0.426***	0.619***	-0.394***
	(0.054)	(0.053)	(0.059)	(0.058)
ln_INDVA	0.086***	0.087***	0.080**	0.082**
	(0.032)	(0.032)	(0.032)	(0.032)
ln_TRDgdp	-0.000	0.003	-0.035	-0.033
	(0.035)	(0.035)	(0.037)	(0.037)
Constant	-18.384***	-11.271***	-17.444***	-10.414***
	(1.014)	(1.014)	(1.479)	(1.476)
Observations	976	976	867	867
R-squared	0.422	0.509	0.411	0.493
Number of c	106	106	106	106

Notes: All variables, except EPI, are log-transformed. Robust standard errors are provided in parentheses. Country and time fixed effects are not reported for brevity.

A second robustness check addresses concerns that the PRC's economic size and emission profile may disproportionately influence the baseline regional results. To examine this possibility, the PRC is excluded from the CAREC grouping, and the remaining ten member countries are analyzed separately under the label CARECnoPRC (CAREC without PRC). The revised estimates in Table 8 show that the negative effect of ISO 50001 certification on emissions for CARECnoPRC countries remains strong and statistically significant—the baseline CARECnoPRC results are not driven solely by the PRC's weight in the region. Rather, certification adoption across the remaining CAREC countries independently contributes to lower emissions. Simultaneously, the Americas continue to exhibit the strongest overall effect, while

Africa and Eurasia show smaller but statistically significant reductions, and no meaningful relationship is observed for Oceania.

Table 8: Robustness Check on Regional Heterogeneity - CAREC Region Excluding China

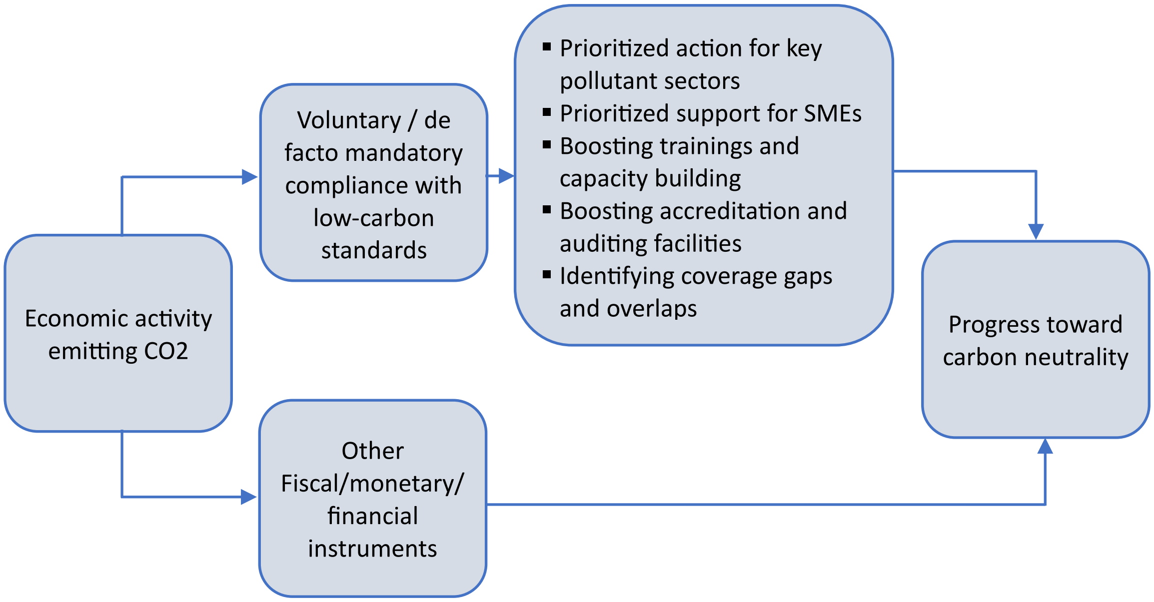
		(1)	(2)
		ln_CO2pc	**ln_CO2gdp**
ln_ISO50pc/ln_ISO50gdp:			
	Africa	-0.021	-0.023*
		(0.013)	(0.013)
	Americas	-0.032***	-0.032***
		(0.008)	(0.008)
	CARECnoPRC	-0.030***	-0.031**
		(0.011)	(0.012)
	Eurasia (Except CARECnoPRC)	-0.010**	-0.009**
		(0.004)	(0.004)
	Oceania	0.003	0.004
		(0.021)	(0.022)
	Constant	-18.217***	-11.098***
		(0.813)	(0.814)
Observations		1,082	1,082
R-squared		0.472	0.552
Countries		106	106

Notes: Robust standard errors are provided in parentheses. Other control variables listed in Table 3, country and time fixed effects are not reported for brevity.

While a wide range of policy instruments are used to support green transitions, including public expenditure on environmental protection, carbon taxation, emissions trading, and green finance, environmental management standards such as ISO 50001 provide a complementary, market-based and bottom-up pathway to emissions reduction. By encouraging firms to internalize energy efficiency and carbon management practices, such standards can operate alongside fiscal and regulatory measures without relying solely on command-and-control approaches. However, their effectiveness depends critically on the surrounding institutional and policy environment. As shown in Figure 6, progress toward carbon neutrality through certification-based mechanisms requires the addressal of coverage gaps and overlaps across standards, strengthening of accreditation and auditing capacities, expansion of training and firm-level capability building, prioritizing support for small and medium-sized enterprises (SMEs), and targeting key pollutant sectors where mitigation gains are largest. The discussion that follows elaborates on these complementary mechanisms and their implications for designing effective and scalable low-carbon transition strategies.

Building on this framework, several challenges arise in the practical implementation of environmental standards. Despite their recognized importance, regulatory coverage may remain incomplete, with certain activities insufficiently regulated or subject to weak enforcement, limiting overall effectiveness. Additionally, regulatory overlap, in which multiple instruments such as emissions trading, subsidies, and efficiency standards are applied simultaneously, can lead to excessive compliance costs. Colmer, Martin, Muûls, and Wagner (2023) highlight how such overlaps in the EU's Climate and Energy Package can undermine policy efficiency, despite good intentions.

Figure 6:A Framework to Facilitate Firm-Level Compliance with Low-Carbon Standards



Another major concern is the high cost of compliance, which presents a significant barrier to firms adopting environmental standards. These costs include certification fees, increased paperwork, time delays, bureaucratic burdens (Camilleri, 2022), and particularly high auditing costs for initiatives such as eco-labeling (Yenipazarli, 2015). Compliance obligations may include reporting, planning, consultancy, impact assessments, and cognitive costs associated with understanding new regulations (Harju, 2019). Costs related to meeting specific legislative content requirements are often burdensome for the products and/or their manufacturing processes.

These compliance costs disproportionately impact SMEs, which lack the economies of scale enjoyed by larger firms. Fauziati and Kassim (2018), Kotnik, Klun, and Slabe-Erker (2020), Ropret et al. (2018), and Solilova et al. (2019) indicate that while larger companies face lower relative compliance costs, SMEs typically encounter financial pressures that can significantly reduce profitability. In some cases, compliance costs for small firms can exceed 10% of their turnovers, which directly affects business performance (Eichfelder & Schorn, 2012).

Regarding compliance costs, overlapping requirements across environmental standards can further exacerbate compliance burdens. For example, ISO 50001 and ISO 14001 require energy use monitoring and reporting; ISO 14064 and the GHG Protocol Corporate Standard demand comprehensive GHG inventories; and product-level standards such as PAS 2050 and ISO 14067 rely on nearly identical life cycle methodologies. Such duplications may result in repeated audits and redundant documentation, which can disproportionately affect SMEs already facing high compliance costs. An instructive case comes from GLOBALG.A.P., which employs a benchmarking mechanism to recognize equivalent national schemes (such as KenyaG.A.P. and ChinaG.A.P.), avoiding duplicative audits and reducing costs. Adopting similar harmonization practices in the context of energy and carbon standards could help firms in the CAREC region meet environmental requirements more effectively and with fewer resource constraints.

To ease the adoption process, domestic facilities must be strengthened for accreditation and auditing. Improving the accessibility and affordability of such services can help reduce adoption-related costs and facilitate compliance. Nevertheless, enforcement remains a challenge, with the existing literature identifying barriers in auditing and institutional support. Gunningham (2011) and Kwasniak (2009) explore these enforcement challenges and propose remedies, but implementation gaps remain. Institutional voids in areas such as waste management and recycling further limit regulatory effectiveness, particularly when infrastructure is lacking or fragmented (Daou, Salamoun, & Abdallah, 2024). Broader governance weaknesses are also evident when voluntary and statutory frameworks are poorly integrated or lack accountability (Bergeson, 2016). Inconsistencies in the stringency of environmental regulations also hinder their impact. While stricter regulations are generally linked to better environmental outcomes (Wang, Yan, Wang, & Chang, 2020), uneven implementation can dilute their effectiveness. The differences between regulation on paper and their practical enforcement can affect economic and environmental results. Therefore, Galeotti, Salini, and Verdolini (2020) highlight the importance of accurately measuring the stringency of any environmental policy. Based on the incremental cost of compliance with these stringent environmental measures, it is necessary to prioritize support for SMEs to facilitate their meeting of environmental standards. Capacity-building and training programs can play an important role, as evidenced by previous studies (Aggarwal & Agarwala, 2023; Molina-Azorin et al., 2021; Saeed et al., 2019). To avoid the risk of compliance becoming superficial and unsustainable in the long term, a culture of compliance and continuous improvement must be promoted to equip firms with the skills and awareness needed for meeting evolving standards.

The European Union's Carbon Border Adjustment Mechanism was introduced in 2021 and is intended for full implementation by 2026; it will initially cover carbon-intensive goods such as steel, cement, aluminum, fertilizers, electricity, and hydrogen. As these sectors are considerably relevant to several CAREC economies, compliance with environmental standards will increasingly shape their access to EU markets. Therefore, it is pertinent for the region to adopt low-emission policies and strengthen certification systems so that firms can achieve climate goals and safeguard their competitiveness in global trade.

5. Conclusion and Policy Recommendations

This study adopts an empirical analysis to demonstrate that firms' compliance with environmental standards significantly contributes to carbon emission reductions. The findings highlight the significance of an integrated approach that balances policy enforcement with mechanisms that encourage firms to voluntarily adopt low-carbon practices in the CAREC region. To support the wider adoption of environmental standards, we outline the following policy actions:

a) **Prioritizing Policy Action:** A sector-specific strategy can ensure that compliance measures are effective and feasible, leading to meaningful reductions in carbon emissions without undermining economic competitiveness. As shown in Table 5, emissions are concentrated in the power sector in countries such as the People's Republic of China, Kazakhstan, and Mongolia, while industrial combustion and processes dominate in Pakistan, Tajikistan, and Georgia. This heterogeneity suggests that targeted ISO 50001 certification programs should focus on high-emission sectors within each country, alongside practical regulatory measures that encourage the firm-level adoption of energy-efficient and low-carbon technologies.

b) **Streamlining Certification Guidelines:** Numerous environmental standards exist, with each addressing different aspects of sustainability. To enhance coherence and efficiency, there is a need for a comprehensive mapping of existing standards to identify gaps—especially those related to carbon emissions—and assess where stricter criteria are required. Harmonizing certification guidelines will help avoid overlapping requirements, enabling firms to comply with streamlined protocols that reduce redundancy and administrative costs. To improve regulatory clarity and ease the compliance burden for businesses, a unified and transparent certification system must be designed.

c) **Facilitating Firm Compliance:** SMEs, in particular, face significant barriers due to limited technical expertise and the high compliance costs associated with environmental measures. Therefore, financial support is crucial to help these firms meet the requirements of low-carbon certification. To promote inclusive participation in the green transition across the CAREC region, governments should establish domestic accreditation bodies and local auditing facilities to reduce reliance on costly international certification services. Moreover, government-sponsored training programs aimed at capacity building could equip firms with the necessary knowledge and skills to comply with environmental standards. Similarly, initiatives promoting knowledge sharing and peer learning could empower firms to learn from successful case studies and adopt best practices. In this context, the PRC's experience in rapidly scaling up the adoption of environmental standards can provide valuable guidance for other CAREC countries.

Several CAREC members have only a few ISO 50001 certifications. For example, in 2023, Afghanistan, Pakistan, and Uzbekistan had 22, 41, and 44 certificates, respectively, while countries such as the Kyrgyz Republic and Tajikistan reported none. Conversely, the PRC has experienced a rapid surge in certification over the past decade. To maintain competitiveness, especially under emerging measures such as the EU's Carbon Border Adjustment Mechanism, the PRC has instituted strong incentives to improve compliance with emission reduction standards. Other CAREC economies with carbon-intensive export portfolios, such as Kazakhstan (11.8 tonnes of CO_2 per capita in 2023), Turkmenistan (8.96), and Mongolia (8.08), should also adopt certification strategies to decarbonize energy and metals production. The sectoral distribution of emissions points to different priorities across the CAREC countries. In Afghanistan and Pakistan, industrial combustion and transport dominate, calling for stricter efficiency and cleaner fuel policies. In Kazakhstan and Mongolia, the power sector alone contributes nearly half or more of the emissions, highlighting the need for renewable energy and cleaner grids. Building-related emissions are high in Turkmenistan and the Kyrgyz Republic, suggesting retrofitting and energy management measures. These patterns show that sector-specific certification and targeted interventions are more effective than uniform approaches.

Improving on other aspects such as digital governance can further complement certification. The EPI, which is part of the UN's e-government framework, shows strong negative coefficients in the regressions: a one-point increase is associated with an 8–9% reduction in emissions. For CAREC members with relatively low digital participation, strengthening e-government platforms, expanding online procedures for licensing and compliance, and enabling paperless trade could accelerate emission reductions and regulatory efficiency.

In reflecting on the scope and contribution of this study, certain limitations warrant acknowledgment and highlight important directions for future research. The analysis centers on ISO 50001 certifications as a proxy for environmental standards and their impact on CO_2 emissions, excluding other climate policy instruments. ISO 50001 was chosen because it is the leading international energy management standard with globally comparable data. While the use of global panel data for 106 countries during 2011–2023 provides broad macro-level insights, more detailed evidence could be gained from sectoral or firm-level studies. Another limitation lies in the reliance on certification counts, as the ISO Survey does not report audit rigor, compliance quality, or enforcement information. Future research should seek to capture these dimensions more directly. Finally, although this study discusses overlaps among environmental standards and their cost implications, the systematic mapping of certification gaps and their financial burden on SMEs remains an important topic for further investigation.

Appendices

Appendix 1: Variables and Sample

Variable	Definition, Transformation, and Source
ln_CO2pc	CO_2 emissions per capita (t CO_2e per capita), excluding land use, land-use change, and forestry (LULUCF); log-transformed. Source: World Bank

ln_CO2gdp	CO_2 intensity of GDP, measured as kilograms of CO_2 emissions per constant 2015 US$ of GDP; log-transformed. Source: World Bank, WDI.
ln_CO2proxim	Spatially weighted average of other countries' CO_2 emissions, where weights are the inverse of bilateral geographic distance; log-transformed. Source: Author's calculations using CEPII distance dataset.
ln_ISO50pc; ln_ISO50gdp; L1_ln_ISO50pc; L2_ln_ISO50pc; L1_ln_ISO50gdp; L2_ln_ISO50gdp	ISO 50001 energy management certifications per capita (population-normalized, ln_ISO50pc) and normalized by GDP (ln_ISO50gdp); log-transformed. L1_ and L2_ denote the respective first and second lags of these variables. Source: ISO Survey of Management System Standard Certifications.
ln_GBONDgdp	Green bond issuance as a percentage of GDP; log-transformed. Source: Climate Bonds Initiative.
EPI	E-Participation Index based on content analysis of national government websites; scores normalized on a 0–1 scale (higher = better). Source: United Nations E-Government Development Index.
ln_ENGYpc	Energy use per capita (kg of oil equivalent per person); log-transformed. Source: World Bank, WDI.
ln_GDPpc	GDP per capita (constant 2015 US$); log-transformed. Source: World Bank, WDI.
ln_FOSLegy	Fossil fuel energy consumption (% of total energy use); log-transformed. Source: World Bank, WDI.
ln_INDVA	Industry (including construction) value added as % of GDP; log-transformed. Source: World Bank, WDI.
ln_TRDgdp	Trade openness, measured as trade (% of GDP); log-transformed. Source: World Bank, WDI.

Appendix 2: List of Countries

Angola, Albania, United Arab Emirates, Argentina, Australia, Austria, Azerbaijan, Belgium, Bangladesh, Bulgaria, Bahrain, Belarus, Bolivia, Brazil, Botswana, Canada, Switzerland, Chile, The People's Republic of China, Cameroon, Congo, Colombia, Costa Rica, Cyprus, Czechia, Germany, Denmark, Dominican Republic, Algeria, Ecuador, Egypt, Spain, Estonia, Finland, France, United Kingdom, Georgia, Ghana, Greece, Guatemala, Honduras, Croatia, Hungary, Indonesia, India, Ireland, Iran, Iceland, Israel, Italy, Jamaica, Jordan, Japan, Kazakhstan, Kenya, The Kyrgyz Republic, Cambodia, South Korea, Kuwait, Lebanon, Lithuania, Luxembourg, Latvia, Morocco, Moldova, Mexico, North Macedonia, Malta, Mongolia, Mauritius, Malaysia, Namibia, Niger, Nicaragua, Netherlands, Norway, Nepal, New Zealand, Oman, Pakistan, Panama, Peru, Philippines, Poland, Portugal, Paraguay, Romania, Russia, Senegal, Singapore, El Salvador, Slovakia, Slovenia, Sweden, Togo, Thailand, Tunisia, Tanzania, Ukraine, Uruguay, United States, Uzbekistan, Vietnam, Yemen, South Africa, Zambia.

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