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CTTN Research Grants Program 2024

Progress and Challenges to Implement Emission Trading Mechanisms in CAREC Nations: Insights from Kazakhstan and China

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Abstract

Emissions trading mechanisms (ETMs) are pivotal for reducing greenhouse gas emissions by setting caps on emissions and allowing the trading of emission allowances, incentivizing reductions where they are most cost-effective. However, ETM implementation in CAREC countries faces significant challenges, primarily due to the suboptimal financial architecture and nascent state of carbon markets. This study aims to systematically identify and analyze these challenges and barriers, propose an optimized financial architecture, and assess the green finance potential to support effective ETM implementation. Recognizing the diverse economic conditions across CAREC countries, this study conducted a comparative analysis to achieve this objective. The methodology was designed to identify the primary barriers related to success factors, financial incentives, stakeholder engagement, regulatory support, and technological infrastructure, which are essential to financial architecture. The findings of this study revealed that existing ETMs in CAREC countries face significant legalization gaps, which impact their efficiency through limited compliance and integration challenges. Low carbon pricing and insufficient financial incentives are key obstacles to green technology adoption. Low stakeholder engagement and outdated technological infrastructure are other concerns that do not support the transparency and effectiveness of ETMs. A comprehensive scenario analysis was conducted to assess the impact of carbon pricing strategies, emission reduction targets, and the EU's carbon border adjustment mechanism on the energy sectors of China and Kazakhstan. By evaluating baseline conditions against policy implementation, carbon sensitivity, and climate target achievement, the analysis revealed the financial and operational challenges faced by these economies in transitioning to low-carbon models. The findings suggest targeted policies to overcome these impediments and lay out a path for ETMs to contribute effectively to climate action efforts in CAREC countries.

Keywords: Emission trading mechanisms, financial architecture, green finance, carbon market, scenario analysis, CAREC

1. Introduction

1.1. Background

Climate change is a crucial issue that requires immediate attention and inventive solutions (Rogelj et al., 2016). Conference of the Parties (COP) meetings have implemented diverse approaches to bolster the sustainable development goal (SDG) 13, which addresses climate change and its consequences. An essential approach is the adoption of an emissions trading mechanism (ETM), a cornerstone of green finance that reduces greenhouse gas (GHG) emissions (Lin & Jia, 2017). The ETM, or cap-and-trade system, is a market-based strategy that limits GHG emissions, enabling entities to trade emission allowances to comply with these limits (X. Zhang et al., 2020). The cap-and-trade approach received official support at the COP26 in 2021, which focused on creating a global carbon-trading market. This economic and commercial transformative mechanism supports revenue generation from GHG emission measures (W. Cai & Ye, 2022). By setting a cap on emissions and allowing the trading of emission permits, ETM allows countries and companies to economically benefit from their efforts to lower emissions, incentivizing further reductions and promoting global climate goals.

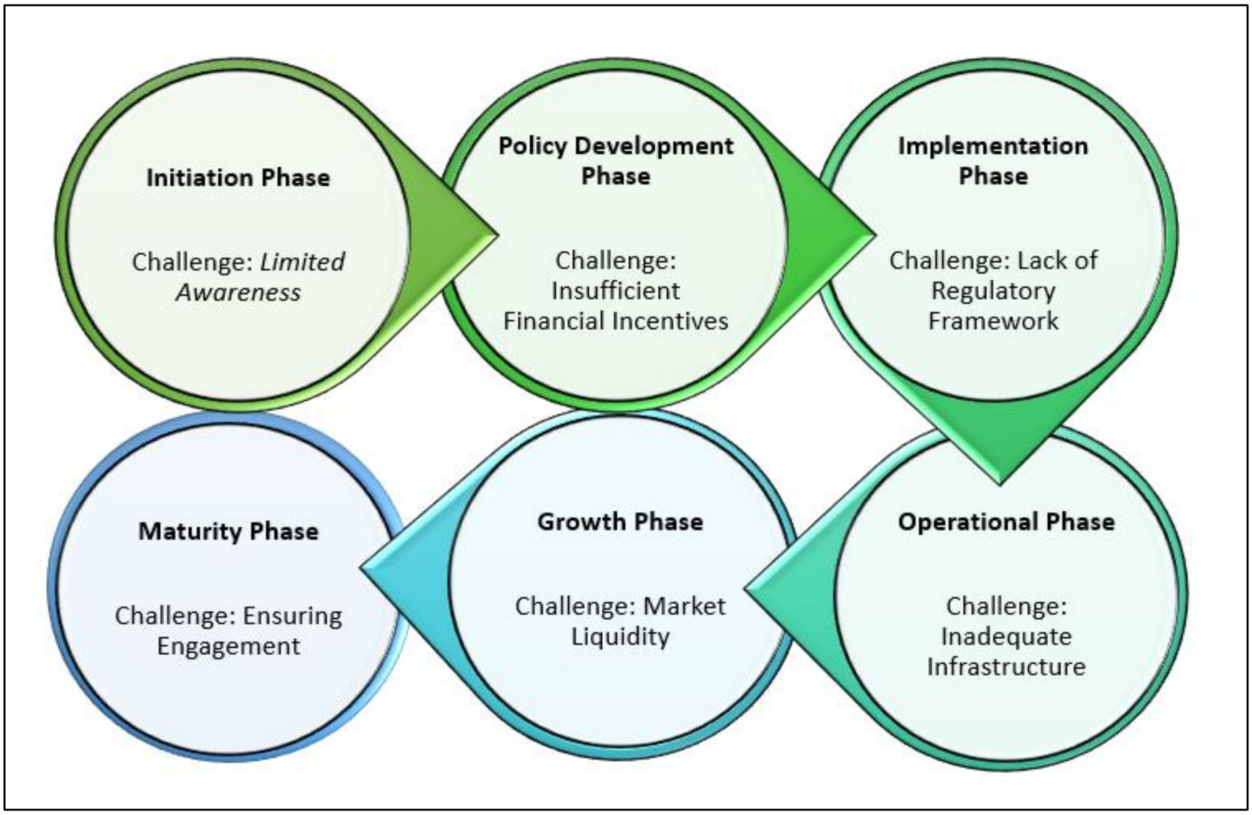
Well-developed and implemented ETM mitigates emissions cost-effectively and foster low-carbon technological innovation in high-emission sectors such as power generation, manufacturing, and transportation (Z. Rui Chen & Nie, 2020). According to the International Carbon Action Partnership (ICAP, 2023), approximately 40 national dominions (cities, states, and regions), accounting for nearly a quarter of the global GHG emissions, are implementing carbon pricing as a key ETM strategy to achieve sustainable growth targets. In terms of carbon pricing, ETM reduces seven GtCO2e, or 12% of global emissions (Jung & Song, 2023). The most reliable ETM is the European Union's emission trading system (EU ETS)—the world's largest GHG ETS. The EU ETS has demonstrated a tangible impact on reducing global emissions, contributing to the ambitious climate goals of the EU (Koumpli, 2023).

Moreover, globally, ETSs generate significant revenue, reinvest in green transition projects, and create socio-economic impacts toward green economies. For instance, among the developing countries, China, South Korea, and Mexico's ETS, and Columbia's carbon tax and offset system allow the auction of a portion of allowances to generate revenue to support green technologies and energy efficiency improvements through environmental reinvestment (Kim & Yu, 2018; Naegele, 2018; Sandoff & Schaad, 2009). However, in many developing economies, ETSs face various challenges, such as cap stringency, market liquidity, allowance allocation, and integration with environmental policies (Oke et al., 2024). Figure 1 illustrates the challenges faced at each stage of ETM implementation and strategic intervention.

The Central Asia Regional Economic Cooperation (CAREC) countries are important for achieving global environmental sustainability goals owing to unique geographical, economic, and environmental characteristics. They are rich in natural resources, including significant fossil fuel reserves and vast potential for renewable energy (solar, wind, and hydroelectric power). This is crucial for balanced global energy strategies (CAREC Energy Outlook, 2022). In addition, CAREC countries are at various stages of economic transition to sustainable and market-driven economies, offering opportunities to integrate sustainable practices and green technologies as part of their development. Moreover, owing to their renewable energy resource endowment, the countries have significant emission reduction potential. Most importantly, these countries are highly vulnerable to climate change, emphasizing the need for proactive environmental stewardship (Tsevegjav, 2023).

Figure 1

Challenges during the ETM lifecycle



Source: Author's creation. Notes: ETM, emission trading mechanism.

Table 1 presents the sustainability commitments of the CAREC countries in terms of economic indicators, GHG emissions, key emission sectors, and nationally determined contributions (NDCs). This explains each country's unique environmental challenges that drive its sustainability strategies. These CAREC countries embraced ETMs that are critical for achieving environmental sustainability goals and adhering to international climate commitments.

Table 1

An overview of the sustainability commitments of CAREC countries

Country	GDP (USD, 2022)	Total GHG emissions in 2022 MtCO2e (% of the world)	Key emitting sectors	NDC targets	Other key environmental indicators	Environmental significance
Afghanistan	$14.26B	29.12 (0.05%)	Agriculture, energy	13% reduction compared to 2015 levels by 2030	20% renewable energy by 2030	Rich in solar and hydro potential, it is crucial for rural electrification.
Azerbaijan	$78.72B	68.88 (0.13%)	Oil and gas, transport	35% reduction compared to 1990 levels by 2030	30% improvement in energy efficiency by 2030	Major oil exporter; renewable shift critical for energy diversification.
China	$1,7963B	15684.63 (29.16%)	Industry, energy	Peak emissions by 2030, carbon neutrality by 2060	Increase forest cover by 4,500 km^2 annually until 2030	The world's largest CO2 emitter and leading in renewable energy investment.
Georgia	$24.78B	18.05 (0.03%)	Transport, energy	25% reduction compared to 2005 levels by 2030	40% of electricity from renewables by 2030	Significant hydro resources are vulnerable to climate change impacts.
Kazakhstan	$225.49B	331.53 (0.62%)	Oil and gas, mining	15% reduction compared to 1990 levels by 2030	50% increase in energy efficiency in industry by 2030	Largest landlocked country; major coal and oil producer.
Kyrgyz Republic	$11.54B	21.94 (0.04%)	Agriculture, heating	20% reduction compared to 2010 levels by 2030	100% renewable electricity by 2050	Relies heavily on hydropower, potential for solar and wind.

Mongolia	$17.14B	62.79 (0.12%)	Mining, livestock	14% reduction compared to 2010 levels by 2030	30% reduction in air pollution in Ulaanbaatar by 2025	Extreme temperatures; wind and solar power potential.
Pakistan	$374.69B	546.10 (1.02%)	Energy, agriculture	20% reduction by 2030 with international support	60% cleaner production methods in industry by 2030	High vulnerability to climate change; energy demand growing rapidly.
Tajikistan	$10.49B	22.82 (0.04%)	Hydropower, agriculture	10-20% reduction compared to 2010 levels by 2030	Increase hydropower share to 90% of electricity generation	Rich in hydropower; water resource management critical.
Turkmenistan	$56.54B	128.92 (0.24%)	Gas flaring, oil extraction	10% reduction compared to 2000 levels by 2030	20% increase in gas flaring reduction technologies by 2030	Substantial gas reserves: addressing gas flaring is a priority.
Uzbekistan	$80.39B	227.21 (0.42%)	Energy, agriculture	10% reduction compared to 2010 levels by 2030	25% improvement in water use efficiency in agriculture by 2030	Strategic location for solar power; water scarcity issues.

Abbreviations: GDP, gross domestic product; NDC, nationally determined contributions; Sources: GHG Emissions Data: Emissions Database for Global Atmospheric Research (EDGAR); GDP Data: World Bank Indicators (WDI).
NDC Targets: NDC Registry (https://www4.unfccc.int/); key emitting tors and environmental indicators: International Energy Agency (IEA) reports.

Figure 2 presents the geographical spread and developmental stages of ETM in Asian countries, indicating that in the CAREC alliance, Kazakhstan and China have operational ETS. Kazakhstan's in-force status could serve as a model or benchmark for other CAREC countries seeking to develop their ETS. Meanwhile, Pakistan is in under development or consideration stage. Figure 2 reflects the regional trend toward adopting market-based carbon pricing and emission reduction mechanisms.

Figure 2

Status of emission trading in CAREC and neighbor countries

Abbreviations: ETS, emission trading scheme. Source: International Carbon Action Partnership (ICAP) https://icapcarbonaction.com/en/ets

1.2. Problem Statement

The adaptability of ETM to diverse economic contexts and capacity to spur innovation make it an essential topic in research and policy development. As the global community strives to meet the Paris Agreement goals, understanding the nuances of ETMs and their implementation challenges is imperative. The CAREC counties are characterized by diverse economic and regulatory contexts, leading to different progress stages in carbon market adoption. Of the CAREC countries, China's national ETS primarily covers the power sector; Kazakhstan's ETS includes the energy and industrial sectors, but is in an early developmental stage. Both systems face challenges related to cap stringency, market liquidity, allowance allocation, regulatory and policy gaps, inadequate market infrastructure, limited stakeholder awareness and capacity, and lack of robust monitoring, reporting, and verification (MRV) systems to ensure transparency and trust (B. Chen & Wu, 2023; Koumpli, 2023; Peng et al., 2023; Z. J. Wang & Zhao, 2021). Moreover, the EU's carbon border adjustment mechanism (CBAM) could significantly impact countries in the Central Asian region as it prevents carbon leakage by imposing tariffs on imports from countries with less stringent carbon pricing mechanisms (Park et al., 2023). CBAM exposure is an economic risk that directly affects trade competitiveness and market dynamics of ETS. Countries with higher exposure to CBAM penalties (owing to carbon-intensive exports and weak carbon pricing) face barriers to ETM performance, particularly in economic costs and market participation (Shi, 2024). These challenges impede their ability to engage fully with and benefit from ETMs, thus affecting the CAREC countries' collective climate action efforts. In addition, the intricacies of the energy sector, which heavily depends on fossil fuels, further complicate the transition toward a green economy. Therefore, identifying and addressing these challenges is imperative for unlocking the potential of the CAREC alliances to establish robust and effective carbon markets that contribute to global emission reduction goals.

1.3. Research Aims and Objectives

This research aimed to:

1. Identify primary barriers hindering effective implementation of ETMs in the CAREC countries. This involves examining the existing regulatory, financial, and market structures and their alignment with ETM requirements and assessing gaps in current operational ETS frameworks (China and Kazakhstan).

2. Assess the economic impacts of carbon pricing and ETS implementation on the energy and industrial sectors in the CAREC countries, with a focus on the role of CBAM in shaping regional emission reduction strategies.
3. Evaluate the feasibility and economic trade-offs of emission reduction scenarios to understand the impacts of different carbon pricing strategies and policy interventions on emissions and economic output in the CAREC countries.
4. Explore strategic approaches to overcome the identified challenges. These approaches include policy recommendations, capacity-building initiatives, and development of a conducive market environment for ETMs.

2. Literature Review

2.1. Theoretical Framework

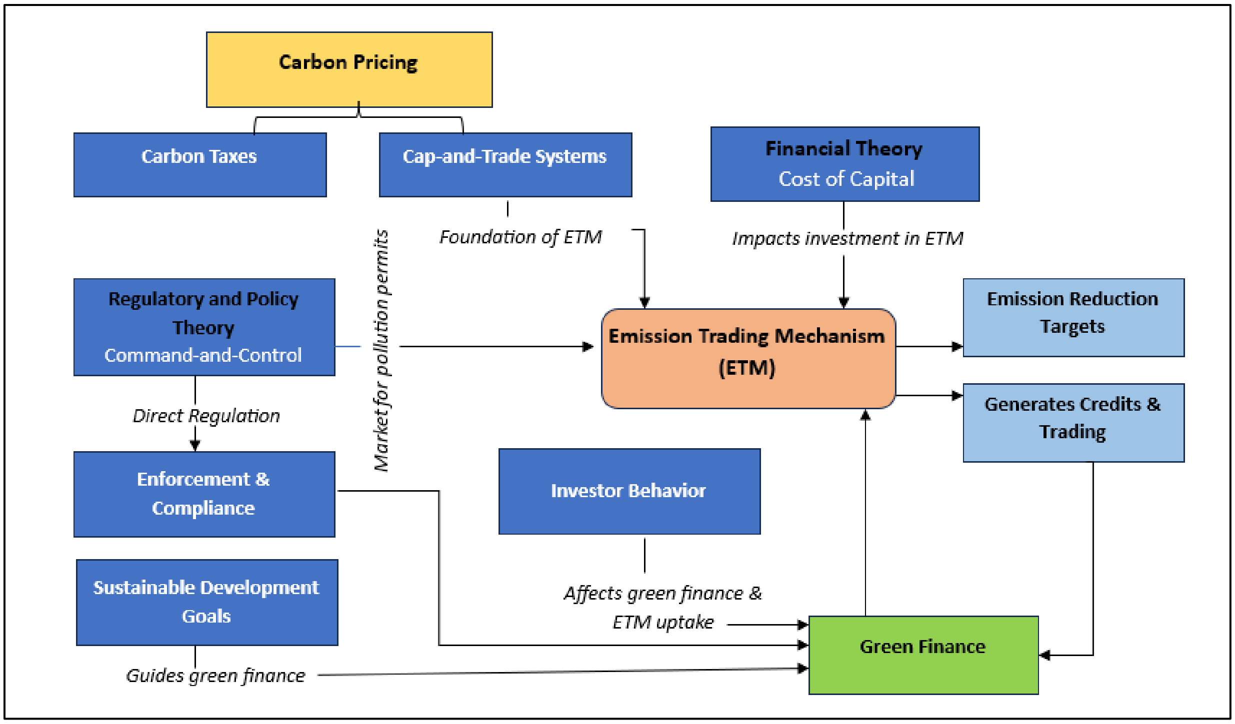
The ETM controls pollution by providing economic incentives to reduce pollutant emissions (Chevallier, 2009). Its underlying principle is that the total emission level should be capped to achieve environmental goals. ETMs have significant theoretical relevance in promoting sustainable environmental practices and tackling climate change challenges. The theoretical framework (Figure 3) of the intersection of green finance and ETM encapsulates the principles of market-based instruments, financial theory, and regulatory policy theory (Alberola et al., 2008; W. Cai & Ye, 2022; Cumming et al., 2024; Mehling & Haites, 2009). Market-based instruments such as cap-and-trade systems are based on the concept that creating a market for pollution permits can provide an economic incentive to reduce emissions. This aligns with financial theory of influencing the cost of capital and guiding investment decisions toward ETMs (Yang et al., 2018).

Consequently, ETMs were developed based on the idea that setting a cap on emissions and allowing the market to determine the price of trading permits can lead to cost-effective ways to mitigate emissions and achieve targets (Rogelj et al., 2016). According to Lin and Jia (2017), enabling credit trading at a market price for emissions efficiently allocates emission reductions to entities that can achieve them most cost-effectively. This flexibility has substantial advantages over command-and-control policies, which may fail to consider different emission reduction costs across sources (W. Cai & Ye, 2022). This market-based approach is complemented by direct regulations that ensure compliance, refining market mechanisms (Kim & Yu, 2018).

Simultaneously, the framework acknowledges the role of SDGs as a pivotal guide for green finance, ensuring that investments align with broader environmental and social objectives. Investor behavior, influenced by these aligned goals, affects the uptake of green finance and ETMs as investments are channeled toward achieving climate action and sustainable cities (Smith & Swierzbinski, 2007). The generation of credits and facilitation of trading stimulate a cycle that reinforces the application of green finance, ultimately financing SDGs and contributing to emission reductions. The integration of these components within the framework suggests a cyclical relationship in which regulations, market mechanisms, and sustainable development interact to create a robust system for green finance and effective emissions trading.

Figure 3

Theoretical framework



Abbreviation: ETM, emission trading mechanism. Source: Author's creation

2.2. Empirical Review

ETM has garnered substantial scholarly attention, yielding several studies that illuminate its multifaceted impacts on environmental sustainability. A recent study by Jang et al. (2024) highlights the success of ETMs in the EU and South Korea, where ETMs incentivize significant reductions in emissions through the cap-and-trade principle. The mechanism is praised for its flexibility, which allows companies to innovate and reduce emissions while adhering to an overall emissions cap. However, critics question the efficacy of ETMs, stating the challenges of setting appropriate caps, leakage concerns, and potential for market manipulation. For instance, X. Q. Chen et al. (2023) highlighted instances in which overly generous allocations of carbon credits led to surplus emissions, undermining the effectiveness of the scheme. Additionally, concerns persist about the environmental integrity of carbon offsets and the risk of "hot air" credits that do not correspond to actual emission reductions (Chevallier et al., 2011).

Studies have also highlighted the challenges faced by developing countries in implementing ETM. ETM emphasizes the potential for financial inflows from carbon credit sales, technology transfers, and sustainable development benefits in developing countries. The clean development mechanism under the Kyoto Protocol is frequently mentioned for providing access to green technologies and additional financing to developing countries (Abadie & Chamorro, 2008; W. Li & Jia, 2017). However, ETM implementation in developing countries faces significant obstacles. These include limited institutional capacity, lack of clear legal frameworks, and insufficient technical expertise. Oke et al. (2024) explored carbon trading practices in the construction industry, and found that the most significant barriers to its adoption are difficulties in obtaining financing, lack of cost-effective abatement options and methods, attitude toward environmental sustainability and climate change, lack of awareness of carbon market opportunities, and risk of changes in the rules governing participation and credit.

Hameed et al. (2023) criticized the application of ETMs in Pakistan, noting the challenges posed by the country's decentralized governance structure and varied interests of provincial governments. Furthermore, reliance on foreign carbon credit buyers raises concerns about the long-term sustainability and autonomy of such initiatives. Based on the importance of regional integration, interest in overcoming individual limitations and leveraging ETMs to meet climate targets and promote sustainable development is growing. Regional integration shares resources and technological advancements, harmonizes policies, enhances market liquidity, and strengthens collective bargaining power, regional cooperation, and resilience against market volatility.

Peng et al. (2023) stated that regional cooperation on ETMs could facilitate the sharing of best practices, harmonize standards, and establish a regional carbon market, offering a promising avenue for climate action. Ranson and Stavins (2016) revealed significant growth in the connection between countries cap-and-trade programs for GHGs. These connections are direct or through shared credit systems such as clean development mechanisms. Although linking these systems can make it harder for a country to control its carbon policies, the move towards linking suggests that political and economic advantages generally outweigh these challenges. The growing ties between these systems, which are often influenced by the closeness between countries, are an important part of how the world approaches climate policy. However, skepticism remains regarding the feasibility of regional ETM frameworks. The challenges include disparate economic and environmental priorities among regional countries, risk of carbon leakage between countries with and without ETMs, and complexity of integrating national systems into a cohesive regional market (Antoci et al., 2021; X. Wang et al., 2018).

In addition, existing studies have increasingly focused on the intersections and interdependencies between green finance and ETM. For instance, Y. F. Zhang and Umair (2023) revealed that green finance products could be more effective in countries with active carbon pricing, as the pricing mechanisms enhance the risk-return profile of green investments. Moreover, Leitao et al. (2021) stated that green bonds consistently and positively affect the EU ETS, enhancing its performance during high- and low-volatility periods. By contrast, conventional bonds and energy commodities have high volatility and negatively impact the carbon market.

Conversely, robust green finance markets support the stability and effectiveness of ETS by providing liquidity and reducing volatility. For instance, Jin et al. (2020) revealed that among volatility, commodity, energy, and green bond indices, green bond is the best hedge for carbon futures and performs well even in crisis.

Case studies on the Chinese national ETM such as those by S. Chen & Wang (2023) and Jiang et al. (2023) have explored the complexities of implementing ETM in developing countries. They found that while ETM can drive emission reductions, their success depends on the broader financial and regulatory environment, including access to green finance. Empirical research highlights the difficulties while confirming the promise of green financing and ETS in mitigating climate change. These studies have focused mostly on the need for worldwide coordination, possible effects on trade and competition, and social consequences of carbon pricing. Leitao et al. (2021) stated that a more integrated strategy for climate finance may combine green financing instruments with carbon pricing systems to provide synergistic benefits.

3. Conceptual Framework

Emission trading limits allowable emissions and enables emission allowance trading. Furthermore, it promotes technological innovation and cost-effective and adaptive emission control methods (Chevallier, 2009). ETM has gained popularity due to its ability to ensure precise emission limits and facilitate political agreements by strategically allocating allowances. Additionally, it can engage with similar systems to amplify its impact on larger, interconnected carbon markets. Implementing a limit on emissions and assigning a cost to emission allowances enables ETM to create a powerful economic motivation for reducing emissions. Consequently, it encourages investments in more environmentally friendly alternatives and ensures a standardized method for valuing emissions in the market (Alsaifi et al., 2020). This highlights the need to enhance its effectiveness and scope in CAREC countries.

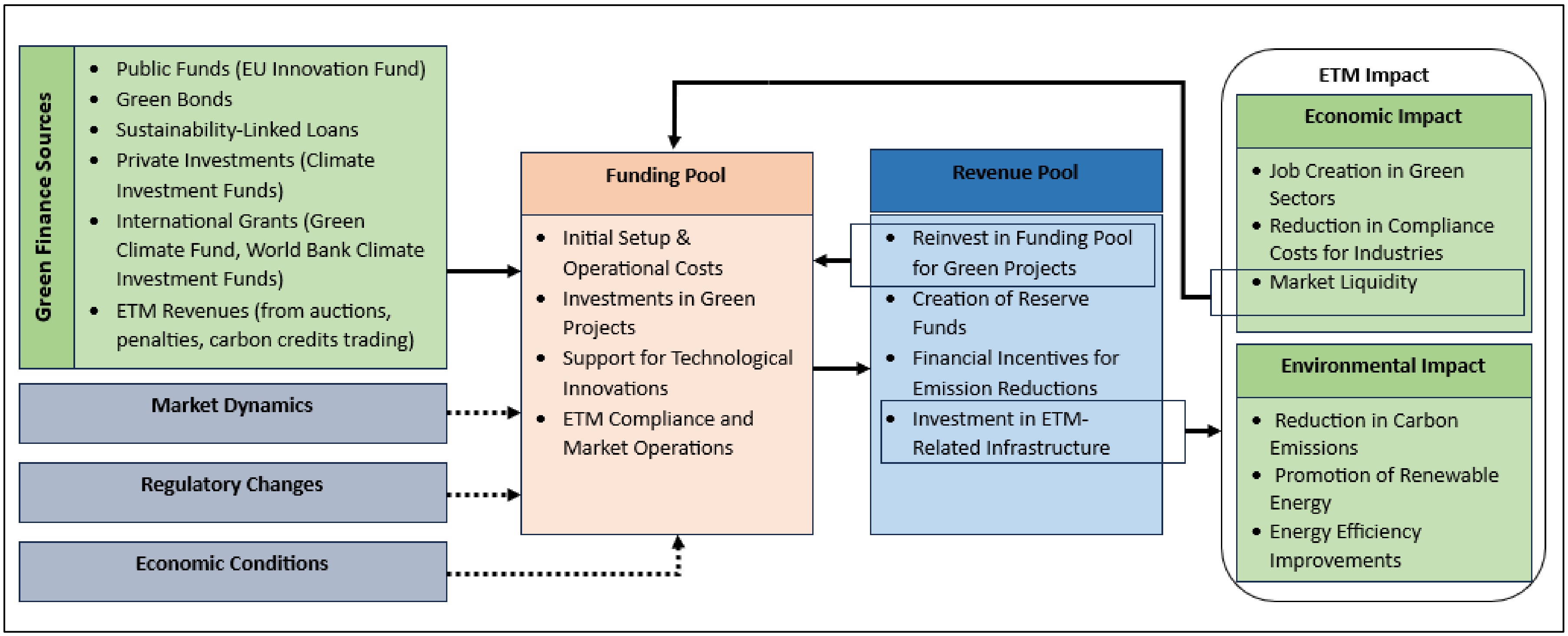
Green finance is based on various financial tools, regulations, and markets that promote environmental sustainability and address climate change. Fund raising for investments in environmentally friendly projects, such as renewable energy, energy efficiency, and pollution control measures, is crucial. Support is provided for the transition to a low-carbon economy by ensuring that financial resources are directed toward reducing GHG emissions and developing resilience to climate change (Lin & Jia, 2017). Green financing is crucial for supporting the development of infrastructure and technologies necessary for a strong low-carbon economy by providing the required investment funds (Leitao et al., 2021). It assists enterprises and governments in adopting sustainable practices by covering the upfront expenses of emission reduction (Agliardi & Agliardi, 2019).

Furthermore, green financing can enhance the liquidity of carbon markets, guaranteeing seamless and effective functioning of emission-authorized buying and selling mechanisms. This improves the system of rewards and punishments established by ETMs, allowing for a faster and more efficient reaction to the urgent need to decrease GHG emissions (Pan & Dong, 2023). Thus, combining the principles of green finance with ETMs can be an effective approach for CAREC alliances to attain their environmental and sustainability objectives, facilitating both market-driven emission reduction and funding for sustainable economic trajectories.

By diversifying funding sources, green finance may become more resilient, ensuring that the financial structure remains flexible and supports long-term sustainability and climate action objectives. Public-private partnerships facilitate collaboration between government entities and the business sector by combining resources to promote green financing. Diversification can help reduce risks that depend on a single source of financing (Mirza et al., 2023). Furthermore, combining financial instruments allows public money to facilitate private investment in climate projects to reduce investment risks. Another approach is to increase the availability of green and climate bonds to obtain funds for climate change-related projects. This helps diversify sources of investment (Liu et al., 2021). This study proposes an optimal financial structure for ETMs, as shown in Figure 4.

Figure 4

Optimized comprehensive financial architecture for emission trading mechanisms



Abbreviations: ETM, emission trading mechanism; EU, the European Union.

The framework includes a complex system for managing financial inflows and outflows, strategic reinvestment, and income utilization, to promote sustainability and growth. The first stage depicts securing financing from diverse sources, including public funds, green bonds, international grants, and private investments. These sources direct funds to a centralized funding pool. The pool is the central hub for financial operations, allocating resources to crucial ETM components, including the initial setup, operational expenses, green project investments, and support for technical advancements. As the ETM becomes operational, a revenue pool is created through the sale of carbon credits, penalties for failing to comply, and profits from green investments. This revenue pool is an active and essential source of cash that sustains the long-term viability of the mechanism. It facilitates essential reinvestment in the funding pool, allocation of new environmentally friendly projects, and establishment of reserve money to stabilize carbon credit markets. It offers monetary rewards for meeting and exceeding emission reduction goals.

In addition, this framework acknowledges the impact of external variables such as market dynamics, regulatory changes, and economic circumstances. These factors impact the movement of funds and the overall effectiveness of ETM. Moreover, they highlight the need for a robust and adaptable financial framework that can withstand external pressures while preserving the integrity and goals of ETM (H. Cai et al., 2023; Pang & Duan, 2016). This model enables the development of a strong and flexible financial structure for ETMs, which promotes environmental sustainability and effectively addresses economic and regulatory difficulties and uncertainties.

4. Methodology

4.1. Data and Sampling

This study aimed to compare ETMs of different countries to gain insights into successful ETM among the CAREC countries. For this, data from various sources were used. In addition, purposive sampling was used to select countries within and outside the CAREC alliance with operational ETM. Countries from various economic contexts and ETM statuses were selected to facilitate a comparative analysis. For instance, the EU ETS is often regarded as the most mature and well-established carbon market globally, with extensive regulatory frameworks, significant market size, and high stakeholder engagement. This makes it a benchmark for best practice and long-term effectiveness.

ETMs of other countries, such as New Zealand, stand out for their inclusion of non-energy sectors, such as forestry, demonstrating how sectoral integration can enhance emission coverage. South Korea's ETS, with its high emission coverage (89%) and market-oriented design, offers an advanced framework relevant to industrialized economies. In the CAREC alliances, China and Kazakhstan represent emerging systems, with narrower sectoral scopes focused on energy and industrial sectors. By comparing these systems, this study captured a spectrum of ETS designs from nascent to mature and comprehensive frameworks. This helped identify transferable lessons, highlight gaps, and tailor recommendations to improve ETS performance and regulatory alignment in the CAREC countries.

This selection provides actionable insights into how varying regulatory, economic, and market contexts influence ETS effectiveness, aligning with the study's objective of informing strategic approaches for the CAREC alliances.

4.2. Data Analysis Techniques

4.2.1. Comparative Analysis

To identify the challenges faced by CAREC countries in implementing and developing ETM, existing ETMs were evaluated based on their status, such as operational, under development, and under consideration. Of the two operational ETMs in CAREC countries—China's national ETS exclusively covers the energy sector and Kazakhstan's ETS, the energy and industrial sectors. These frameworks represent early stages of ETS development, with significant gaps in data availability for other sectors. Therefore, this study focused on the sectors currently covered by these ETMs to ensure a realistic and data-driven analysis. Given the limited scope of ETS coverage and absence of detailed sectoral data, the comparative analysis methodology in this study followed that used by B. Chen and Wu (2023).

Comparative analysis has significant value as the cornerstone methodology because it facilitates comparison of ETM structure across different economic contexts, within and outside CAREC nations, in terms of adaptability, performance, and challenges. It helps reveal insights that cannot be obtained through isolated analysis, identifying the patterns of practices and policies that support or limit the success of ETMs (B. Chen & Wu, 2023). This comparative lens enables the investigation of how specific regional, financial, economic, and regulatory conditions influence the design, implementation, and outcomes of ETMs. This analysis is critical in the CAREC nations, where economic and environmental contexts vary widely, necessitating tailored approaches to climate policy and carbon trading. Furthermore, the comparative analysis methodology offers evidence-based policy recommendations. By identifying the best practices and common challenges across different contexts, this study suggests strategic interventions that are both effective in and adaptable to local conditions. This is particularly pertinent for policymakers seeking to enhance the functionality and impact of ETMs in their countries.

The study objectives were designed to align with this approach, focusing on identifying barriers, assessing economic impacts, evaluating emission reduction scenarios, and proposing strategic solutions to improve ETM performance. While this methodology does not encompass a broader sectoral analysis, it is the most appropriate choice given the scope and data limitations of CAREC countries' current ETS framework. This methodology contributes to the academic discourse on ETMs by providing a nuanced understanding of their operation and effectiveness. From a practical perspective, it equips stakeholders with the knowledge to refine existing mechanisms, design more efficient ones, and pursue collaborative regional strategies for climate action, bolstering collective efforts to mitigate climate change. Table 2 lists the factors that should be compared to identify challenges and solutions in ETMs in CAREC countries.

Table 2

Factors for comparative analysis of emission trading mechanisms (ETMs)

Main points	Sub-points	Definition and measure
Success factors	Total emissions covered	The total amount of GHG emissions regulated by the ETS each year (in MtCO2e).
	Allowance allocation efficiency	Mechanism and frequency of emission allowances issued by the ETS to cover the total.
	Compliance rate	Percentage of participants who comply with the ETS requirements by providing sufficient allowances.
	Total revenue generated	Total revenue generated from emission allowance auctioning under the ETS (in $ million)
Financial architecture optimization	Pricing mechanisms	The structure of carbon pricing within ETMs is measured by the diversity and adaptability of pricing strategies (fixed, auction, and market-based).
	Funding and subsidies	Financial support level is measured by the amount and types of subsidies available.
	Access to green Finance	The availability and ease of access to green financial products for stakeholders within the ETM are measured by the number of available green financial instruments and their uptake.
	Investment in renewable and low-carbon technologies	Total investment in renewable energy and low-carbon technologies, including those funded by ETS revenues or other incentives (in $ million).
Stakeholder engagement	Awareness and capacity building	Educational initiatives such as workshops, seminars, and informational resources distributed measure the efforts to educate and empower stakeholders.
	Participation rates	The number and diversity of participants measure the degree of involvement of various sectors in the ETM.
	Feedback mechanisms	The availability and efficacy of stakeholder feedback platforms are measured by the number of feedback channels and responsiveness to suggestions.
Regulatory support	Legal framework	The robustness of legal structures supporting ETMs is measured by the legislation's comprehensiveness and clarity (IPRI).

	Legal framework for CBAM readiness	The preparedness of a country's legal system to adopt and implement CBAM regulations.
	Alignment with CBAM requirements	The extent to which national policies conform to CBAM standards and practices.
	Aggregate Relative CBAM Exposure Index (product and relative exposure)	A measure of the vulnerability of industries and products to CBAM based on their carbon intensity and export levels.
	Alignment with national policies	The degree to which ETMs are integrated with national environmental policies is measured by policy coherence and synergy indicators.
	International cooperation	The involvement in international carbon markets and agreements is measured by the participation in global carbon trading and environmental initiatives.
Technological infrastructure	MRV systems	The sophistication of monitoring, reporting, and verification systems is measured by accuracy, transparency, and ease of use.
	Trading platforms	The quality and accessibility of carbon trading platforms are measured by user-friendliness, reliability, and security.
	Innovation support	The support for technological advancements is measured by investment in research and development for new emission-reduction technologies.

Notes: GHG, greenhouse gas; CBAM, carbon border adjustment mechanism; ETM, emission trading mechanism; ETS, emission trading system; MRV, monitoring, reporting, and verification.

4.2.1.1. Success Factors. This study evaluated the success of existing ETMs by comprehensively considering their environmental, economic, and regulatory aspects. For instance, total emissions covered and total allowance exhibits the government's scope and commitment to capping emissions (M. Jiang et al., 2018). Likewise, compliance rate directly indicates the integrity and effectiveness in participant engagement and enforcement. A high compliance rate suggests the seriousness and good management of emission reduction obligations (ADB, 2016). In addition, the total revenue generated from the auction of carbon allowances specifies the economic impact of the ETM in terms of the financial scale of the system and capital used to bolster the low-carbon transition (M. Li et al., 2019). These measures are important for understanding the real-world effectiveness and alignment of ETM policies with global and national climate change objectives.

4.2.1.2. Financial Architecture Optimization. Financial architecture optimization refers to a refined financial framework and mechanism that supports the market efficiency and economic output of ETMs. It ensures market liquidity and establishes an accurate pricing mechanism for the allocation of emission allowances. In addition to attracting more investment and leveraging financial innovations, the linkage of ETM with broader financial markets promotes economic and environmental sustainability goals.

To compare financial architecture optimization, this study examined pricing mechanisms, funding and subsidies, access to green finance, and green-technology investments. The carbon pricing structure of an ETM is essential for determining market behavior. Of the various pricing mechanisms, fixed pricing provides stability and predictability but lacks the flexibility to efficiently adapt to environmental targets and economic shifts (Howie & Akmetov, 2024). Conversely, auction-based pricing mechanisms are advantageous for determining accurate prices with higher economic efficiency by regularly adjusting for market demand and supply (Lin & Jia, 2017). Market-based pricing is a more dynamic form set by demand and supply forces that encourage investments and innovations to mitigate emissions. However, it poses a risk without adequate regulation in high-volatility situations (Peng et al., 2023).

A strong financial architecture also requires adequate funding and appropriate subsidies to support ETM, particularly in sectors with excessively high initial costs of green technologies. Subsidies can lower the financial barriers to entry, enabling more companies to participate and invest in emission-reduction strategies. However, poorly designed subsidies may distort the market or encourage reliance on financial support, reducing the ETM's cost-effectiveness (Lin & Jia, 2020). Access to green financing provides the capital necessary to support large-scale green transitions. A robust green finance framework attracts external investment and boosts economic sustainability (Leitao et al., 2021).

Additionally, a key factor in the effectiveness of ETM is investment in renewable and low-carbon technologies. Therefore, to foster sustainable development, high investment levels provide robust market responsiveness and a strong regulatory environment. In mature ETMs, revenue and incentives often support these investments (Lin & Jia, 2020).

4.2.1.3. Stakeholder Engagement. Stakeholder engagement is a crucial factor for effective ETMs. It ensures that the policies are well informed and broadly accepted, supporting compliance and operational progress. ETM has various stakeholders, ranging from industry leaders to community representatives. Furthermore, various potential stakeholders are associated during lifecycle of an ETM and follow essential engagement principles, such as transparency, inclusiveness, and responsiveness, to implement ETS policies successfully.

The success of an ETM depends on raising awareness and capacity, increasing participation rates, and establishing feedback systems. The awareness and capacity can be created through educational initiatives such as workshops and seminars, enabling more effective engagement and compliance (Vasilijević et al., 2015). Moreover, the direct integration of ETMs and acceptance is reflected in stakeholder participation rates across industrial, government, and public sectors. Low participation signifies challenges such as complex compliance requirements or poor engagement strategies served by ETMs. Feedback mechanisms are essential factors that swiftly implement and address stakeholder inputs. Subsequently, changes are implemented to meet real-world demands and enhance the transparency of ETMs (Oke et al., 2024).

4.2.1.4. Regulatory Support. Regulatory support for ETM covers three critical aspects: legal framework, alignment with national policies, and international cooperation. A strong legal framework is important, as it provides clear rules, establishes responsibilities, and outlines penalties, ensuring that all market participants understand their obligations and the consequences of noncompliance. Such legal structures are strengthened by alignment with national policies, ensuring that ETMs are integrated with broader environmental and energy policies without flow (Tao et al., 2024). This integration enhances the effectiveness of ETMs and avoids policy conflicts. Additionally, international cooperation expands the scope and impact of ETMs by integrating them into global carbon markets, facilitating the exchange of best practices and supporting coordinated global responses to climate challenges (B. Chen & Wu, 2023). A regulatory framework with these components promotes the legitimacy, effectiveness, and global accessibility of ETMs.

4.2.1.5. Technological Infrastructure. Technology infrastructure supports ETM's functionality and impact and comprises three factors—MRV systems, trading platforms, and innovation support—that are important to a system's effectiveness and efficiency. MRV systems ensure the ETM's integrity through accurate monitoring, reporting, and verification of emissions, with their performance gauged by accuracy, transparency, and user-friendliness (Usapein & Chavalparit, 2017). Trading platforms are crucial for the execution of emission allowance transactions. They are evaluated based on their robustness, user-friendliness, reliability, and security to prevent fraud and maintain market integrity (Y. Zhang et al., 2022). Furthermore, innovation support fosters continuous technological advancements in emission reduction. Its effectiveness is measured by the level of investment in research and development, which drives innovation and signifies commitment to long-term emission mitigation.

4.2.2. Scenario Analysis

The comparative analysis in this study provides a snapshot of the existing economic structures, emission profiles, and regulatory frameworks across countries to identify the barriers to and challenges in implementing ETM. Assessing the feasibility, effectiveness, and economic impact of ETMs in CAREC nations required a forward-looking approach to scenario analysis that explore how changes in policy, market conditions, and green finance instruments could affect outcomes. This allowed the study to model different pathways, such as increasing carbon prices, expanding ETS coverage, introducing financial incentives, and assessing their impacts on emission reduction, economic growth, and trade competitiveness. The integration of scenario analysis ensured that the study not only diagnoses the challenges, but also actively finds viable solutions to optimize the financial and regulatory framework for successful ETM implementation.

The computable general equilibrium (CGE) model is a well-established tool for analyzing the impact of ETM across economies, capturing interactions between sectors, households, firms, and government policies (Tang et al., 2016). CAREC countries such as China and Kazakhstan have implemented national ETSs, whereas other countries are exploring or developing their own systems. The CGE model incorporates structural components such as the production function, which suggests that the output of each sector is determined by a constant elasticity of substitution (CES) production function that combines capital (K), labor (L), and energy (E) inputs (Huang et al., 2019):

$$Y_i = TFP_i \left[\beta_i K_i^{\theta_i} + (1-\beta_i)(L_i \, . \, E_i)^{\theta_i}\right]^{\frac{1}{\theta_i}}$$

Where, Y_i is the output of sector i; TFP_i, total factor productivity; and β_i is the elasticity parameteras a share of capital in total inputs (how much of the sector's production depends on capital versus labor and energy); and θ_i, elasticity of substitution. Furthermore, carbon emissions based on energy consumption are calculated using sector-specific carbon intensity as follows:

$$C_i = \omega_i . E_i$$

Where, C_i is the carbon emission in sector i, ω_i is the carbon intensity, and E_i, energy consumption. For carbon pricing, the total cost of emission permits is calculated as follows:

$$P_i = \tau . C_i$$

Where, P_i is the total permit cost, τ is the carbon price, and C_i is the emission of the energy sector.

By applying the CGE model, this study aimed to evaluate the potential effects of ETM implementation under various scenarios considering trade competitiveness, carbon pricing sensitivity, and climate target achievement. The following scenarios were analyzed:

Scenario 1: Baseline vs. policy implementation (CAREC nations)

ETM cases in Kazakhstan and China rely heavily on fossil fuels for energy production, making these countries high-emission economies. The baseline scenario reflects the current economic practices without additional climate policies, where emissions increase as economies grow. By contrast, a policy implementation scenario introduces carbon pricing or ETM, which aims to reduce emissions by making carbon-intensive industries more expensive. For instance, in Kazakhstan, increasing the carbon price from $1/ton to $30/ton CO2 significantly reduced emissions by approximately 10%, although it also increased carbon permit costs. For CAREC countries, implementing these policies could reduce energy consumption and emissions but result in substantial financial and operational costs. The challenge is to balance emission reductions and economic impacts, especially in regions where energy production is a major economic driver. Countries must focus on financial mechanisms to absorb the costs of transitioning to low-carbon economies.

Scenario 2: Carbon pricing sensitivity

This scenario explores the effects of different levels of carbon pricing on emissions and costs. In CAREC countries, the energy sector is the largest source of emissions, and changes in carbon pricing can have significant economic impacts. Where many economies are developing or transitioning, higher carbon prices can reduce emissions, but increase the financial burden on industries. Governments in these countries must carefully evaluate carbon-pricing mechanisms, balance emission reductions with economic stability, and consider how carbon revenues can be recycled to support green technologies and industries.

Scenario 3: Climate target achievement

This scenario analyzes CAREC countries' achievement of climate targets, such as those outlined in their NDCs under the Paris Agreement. For instance, Kazakhstan's current policy aims for a 7% reduction in emissions from the level in 1990 by 2030; however, more ambitious targets, such as a 15% reduction, require deeper cuts in energy consumption and higher abatement costs. Achieving these targets requires CAREC countries to transition from fossil fuel, invest in renewable energy, and improve energy efficiency. For CAREC nations, achieving climate targets could significantly reduce emissions but would require substantial investments. Their reliance on fossil fuel and energy-intensive industries means that they face economic and social challenges when transitioning to green economies. Collaboration between regional climate finance mechanisms and renewable energy projects will help meet these targets while maintaining economic growth.

Scenario 4: EU CBAM impact on CAREC exports

The EU's CBAM is designed to impose tariffs on carbon-intensive imports, which could significantly impact CAREC countries that export energy-intensive products to the EU, such as steel, aluminum, and cement. It presents a challenge to industries that rely on exports to the EU, as they may become less competitive due to carbon tariffs. CAREC countries need to reduce the carbon intensity of their exports to mitigate the impact of CBAM, which could involve significant investments in cleaner production technologies and renewable energy sources. Additionally, there may be opportunities for CAREC countries to align with EU carbon standards to maintain market access.

5. Findings and Discussion

The economic and environmental variabilities in the study regions are highlighted through their different economic structures, levels of industrial development, and regulatory frameworks that shape the functionality and effectiveness of ETMs (Table 3). This data-driven comparison enabled a clearer understanding of how each country's unique economic and regulatory contexts influence its approach to emissions reduction and environmental performance. This type of comparative data is critical to ensure that the analysis considers diverse economic and environmental structures and avoids oversimplified comparisons.

Table 3

Economic and emission profile of the sample

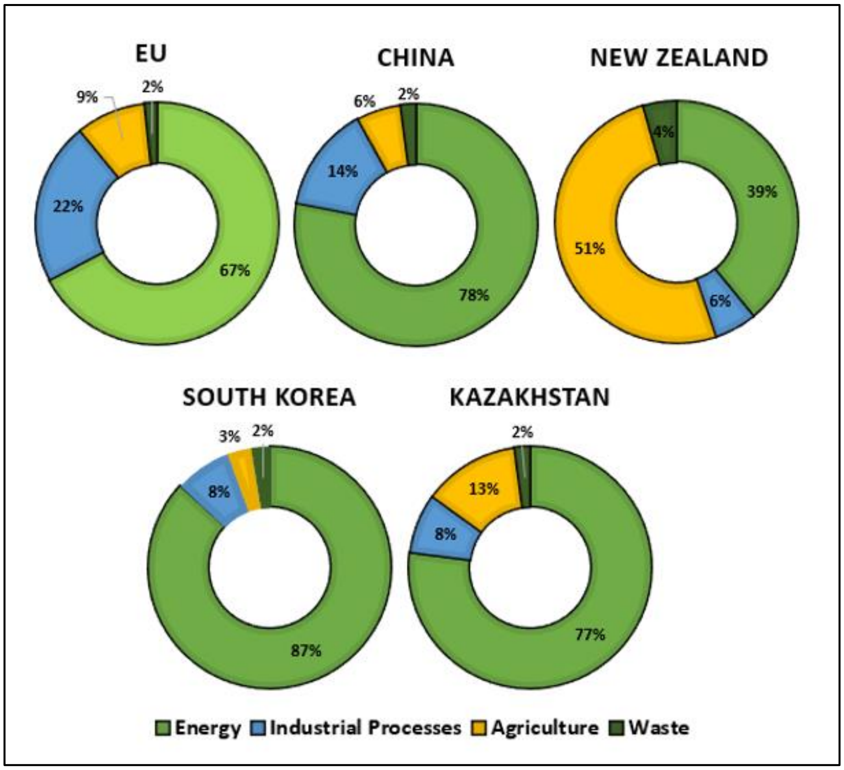
Metrics	EU	South Korea	New Zealand	China	Kazakhstan
Economic size (GDP)	$16.76 trillion	$1.67 trillion	$246.73 billion	$17.88 trillion	$225.5 billion
GDP per capita (Current US$)	$37,466.7	$32,394.7	$48,216.5	$12,662.6	$11484.4
Industrial value added (Current US$)	$3078.02 billion	$493.32 billion	$31.34 billion	$5503.05 billion	$67.02 billion
Carbon emissions (MtCO2e)	3587.80	725.74	82.72	15667.42	331.53
Carbon emission per capita (t CO2eq/cap)	8.09	14.01	16.83	10.95	17.33
Carbon emission per GDP (t CO2/1k$)	0.14	0.27	0.14	0.49	0.48
Stringency of environmental regulations (2019)	1 to 76	50	15	47	96
Emissions reductions targets (%)	30% from 1990	20% from 2000	30% from 1990	18% from 2005	15% from 2010
Environmental performance index	-	46.90	56.70	28.40	40.90

GDP: gross domestic product; EU: the European Union; WDI: World Development Indicators; UNIDO: United Nations Industrial Development Organization; WEF: World Economic Forum; UNFCCC: UN Framework Convention on Climate Change; EPI: Yale Environmental Performance Index; EDGAR: Emissions Database for Global Atmospheric Research. Data obtained for 2022.

The economic size and industrial output of the EU and China are significantly larger than those of New Zealand and Kazakhstan, which directly influences the scale of their carbon emissions and ETM implementation. For instance, while China emits 15,684.63 MtCO2e, the EU emits 3,587.80 MtCO2e. Carbon emissions per capita also differ significantly, with Kazakhstan emitting 17.33 tCO2e due to its reliance on fossil fuels. Regulatory stringency and emission reduction targets vary, with the EU being more aggressive in both. The environmental performance index highlights these disparities, with South Korea ranking much higher than China in environmental health. The inclusion of New Zealand and South Korea in the analysis enabled this study to capture a broader range of economic and environmental contexts, further supporting the argument that cross-country comparisons of ETMs need to be contextualized. These samples, other than the EU, emphasize that factors such as regulatory stringency, industrial output, carbon intensity, and environmental performance vary widely, even among advanced economies. Therefore, the analysis is more robust, highlighting the diversity of policy approaches and reinforcing the importance of adjusting comparative frameworks. The pie charts in Figure 5 depict the sector-wise emissions across the five regions. Energy is the dominant source of emissions in all regions except New Zealand, where agriculture is a notable contributor. However, the contribution from industrial processes and waste varies, reflecting different economic and industrial structures.

Figure 5

Sector wise Emission in the Sample (2022)



Authors Creation. Source: ICAP(2023)

Table 4 presents a comparative analysis of the impact and overall performance of different ETMs.

Table 4

Comparative Analysis of Impact and Effectiveness of ETM

Country/Region	EU	New Zealand	South Korea	China	Kazakhstan
Start of operation (year)	2005	2008	2015	2021	2013
GHGs covered	CO2, HFCs, N2O, PFCs, SF6	CO2, CH4, N2O, SF6, HFCs, and PFCs	CO2, CH4, N2O, HFCs, PFCs, SF6	CO2	CO2
Sectoral coverage	Maritime, domestic aviation, industry, power	Forestry, maritime, waste, domestic aviation, transport, buildings, industry, power	Maritime, waste, domestic aviation, transport, buildings, industry, power	Power	Industry (extractive iand processing), power
Total emissions covered in MtCO2e (% of total CO2e) 2021*	1,386 (38%)	27.9 (48%)	547.9 (89%)	5024.2 (40%)	161.2 (47%)
Allocation efficiency	High [a,b]	Moderate [a,b]	Moderate [a,b,c,d]	Moderate [b,c,d]	Low [b]
Cap formation process	Top-down, centralized cap[1]	Bottom-up, sector-wide caps[2]	Bottom-up, sector-specific caps[3]	Top-down, intensity-based[4]	Bottom-up, production-based[5]
Cost per ton CO2e ($)	90.25	38.3	7.66	9.65	1.04
Compliance rate (% in 2021)	97.15	99	98	99.5	95
Revenue generated ($ million 2022)	42,838	1,406	262	0.0[d]	0.0

[1] The cap is set top-down at the EU level, with a linear reduction factor applied annually to achieve climate goals. Emission allowances are distributed through auctioning and some free allocations.

[2] Cap formation is bottom-up, with sector-wide caps based on emissions from sectors such as forestry and agriculture, adjusted to meet national targets.

[3] Caps are set bottom-up for sector-specific emissions, with allowances allocated based on historical emissions, combining auctioning and free allocation.

[4] Focusing on reducing carbon intensity per unit of GDP, currently covering the power sector.

[5] Cap formation is bottom-up and production-based, with free allocations based on historical emissions intensity for industries such as power and oil.

a: Auctioning; b: Free Allocation (benchmarking[6]); c: Free Allocation (grandparenting[7]); d: Auction to be introduced. Source: International Carbon Action Partnership (ICAP), World Development Indicators (WDI), ERCST EXPLANATORY NOTE: EU ETS Compliance 2022, Environmental Protection Authority Newzeland, Climatelinks *: The percentage coverage data for total emissions covered is sourced from the ICAP website, while total emissions figures are obtained from the World Development Indicators (WDI). The emissions covered by each country were calculated based on the total emission values.

The EU ETS is the oldest and covers a broad range of GHGs, such as CO2, HFCs, N2O, PFCs, and SF6. This extensive coverage indicates a comprehensive approach toward reducing GHG emissions. The most recent ETM in China focuses only on carbon emissions, signifying its implementation phase, which displays its strategic moves toward the abatement of massive-scale emissions in the power sector. Table 3 shows the sectoral coverage by the ETMS; for instance, the EU and South Korea cover a wide range of sectors, from power to maritime, demonstrating the holistic integration of domestic carbon mitigation policies. Kazakhstan emphasizes its power and industrial sectors, while China focuses only on the power sector and highlights targeted economic structure strategies. South Korea's ETM covers 89% of total emissions, indicating strong commitment to comprehensive emission mitigation initiatives. In contrast, Kazakhstan covers 47%, highlighting the need for expansion of potential coverage areas.

Regarding emission allowance allocation, the EU ETS displays high efficiency, with the highest carbon price (USD 90.25) and 97% compliance rate. This indicates the ETM's robustness and maturity. Kazakhstan exhibits low efficiency in this, with a carbon price of only USD 1.04 per ton of CO2e and 95% compliance rate. This underscores the country's challenges in establishing a robust carbon market during the early stages of the ETM. Another significant indicator of an ETM's success is its revenue-generating capacity, which indicates the financial impact, sustainability, effectiveness, and scale of its respective

[6] Benchmarking typically set based on the average emissions of a sector or the best available technology (BAT) emissions rate. Facilities performing at or below the benchmark might receive all the allowances they need for free, while less efficient facilities receive fewer allowances, incentivizing them to improve.

[7] Grandparenting is a method of free allocation where allowances are distributed based on historical emissions levels of each participating entity. This method considers a certain baseline period to determine how many emissions an entity was responsible for and allocates allowances accordingly.

systems. Of the sample ETMs, the EU generated the highest revenue (USD 42 million) in 2022. Of the CAREC countries, China and Kazakhstan, under benchmarking and grandparenting, allocated free allowances in 2022 but did not generate revenue from ETM.

Figure 6 shows the comparison on more matrices, such as coverage, carbon price, auction share, and maximum allowed offset limits of the ETMs to represent their market dynamics, pricing, and regulatory approaches.

Figure 6

Comparison of Different Dimensions of ETM, Carbon Markets Key Metrics

Abbreviation: ETM, emission trading mechanism; ETS, emission trading system. Source: ICAP (Emissions Trading Worldwide: Status Report 2024)

South Korea’s emission coverage of 89% indicates the regulation of a broad scope of emissions within its ETM that potentially enhances ETM’s impact on carbon emission mitigation targets. In contrast, Kazakhstan’s emission coverage is the lowest, signifying that a smaller proportion of total emissions is regulated and that the ETM has a limited impact on carbon footprint. The comparison of carbon prices shows that the EU has a strong demand for carbon credit, which exhibits the effectiveness of the ETM and market maturity. In contrast, the low carbon price in Kazakhstan demonstrates the lack of demand or an oversupply of allowances, which causes insufficient financial incentives for companies to implement their emission reduction initiatives.

The auction of shares refers to the percentage of total emission allowances sold through public bids for revenue generation and market efficiency, instead of allocating them free to entities. The EU, New Zealand, and South Korea auctioned 57%, 54%, and 3% shares of total emission allowances, respectively. The maximum allowed offset limit refers to the upper limit on the number of offset credits that can be used to meet emission reduction obligations in the ETM. Kazakhstan has a 100% maximum allowed offset limit, which means that it uses them (external projects) alone to meet all emission mitigation obligations and may not drive an actual emission reduction directly, revealing the low effectiveness of its ETS. The insights of these matrices reflect the current state of the ETM of each country and provide a direction for how these ETMs can be optimized by influencing strategic decisions to achieve their economic and environmental objectives.

Table 5 provides an overview of the financial architecture optimization of the ETMs.

Table 5

Comparison of Financial Architecture Optimization in the Sample

ETM System	EU	New Zealand	South Korea	China	Kazakhstan
Pricing mechanisms	Fixed and market-based auction	Fixed and market-based	Auction and market-based	Fixed	Fixed
Funding and subsidies ($ billion) in 2022[a]	128.88	1.321	3.130	2.260	0.028
Access to green finance (Liquidity)	High	Moderate	High	Moderate	Low
Investments in green technologies ($ billion) in 2022[B]	180.00	0.300	0.321	546.00	0.337
Revenue efficiency	High	Moderate	High	Moderate	Low

a: Overall green funding and subsidies, b: overall investments in green technologies Source: ICAP, IRENA, WDI, CIF climate investment funds, Statista, European Investment Bank, and Pons and Varin (2023). BloomsburgNEF,

The EU ETM holds considerable financial architecture optimization, employing hybrid pricing mechanisms that combine fixed and market-based regulations, and uses auctions to allocate emission allowances to exploit market flexibility for promoting efficiency. Market flexibility influences efficiency in several ways. This provides a clear market incentive for firms to make cost-effective decisions. Moreover, it fosters a competitive environment in which firms are incentivized to innovate and adopt cleaner technologies. Flexible markets can dynamically adjust to changes in economic conditions, regulatory environments, and technological advancements while maintaining the efficiency and effectiveness of ETM. In addition, a flexible market reduces the cost of compliance and ensures liquidity through active trading.

Similarly, New Zealand and China have also applied fixed and fixed and market-based mechanisms, respectively, tailored to their specific environmental and economic frameworks with the help of market-driven decision-making. South Korea has a dynamic market-oriented approach, and its ETM employs auctions to set allowance prices.

Meanwhile, Kazakhstan's ETM has a fixed-priced mechanism, suggesting a more traditional regulatory approach with less emphasis on market mechanisms. However, this approach lacks dynamic price adjustments in response to changes in demand and supply. Moreover, it leads to high costs and inefficient resource allocation to achieve carbon mitigation targets. The traditional approach cannot attract investment or technological innovation, hindering Kazakhstan's competitiveness in the global energy market.

Financial architecture outcomes, funding, and subsidies show the EU's strong commitment and aggressive climate policies to support emission reduction goals. The comparatively low subsidies and funding for green projects in New Zealand, South Korea, and China indicate their different scales of operation, strategic priorities, and economic capacities. In contrast, Kazakhstan's lower green funding and subsidies illustrate limited financial resources and nascent stages of ETM development. Adequate funding and subsidies support the development and implementation of ETM. They provide the necessary capital to support infrastructure development, technology adoption, and capacity building, which are essential for establishing and operating an ETM. Additionally, subsidies encourage participation in ETM by offsetting the initial costs and risks associated with transitioning to greener practices. Table 5 depicts that liquidity, referred by access to green finance, is high in the EU and South Korea, which enhances their ability to meet environmental targets by investing in sustainability projects. Whereas, New Zealand and China's moderate accessibility suggests a developing green finance market, reflecting room for growth and investment inflow. In contrast, low accessibility in Kazakhstan could hinder significant advances in green technology adoption.

China leads in technology investments, with $546 billion total investments in 2022 in solar and wind energy, electric vehicles, and batteries. It is followed by the EU, with a significant contribution to green technologies, indicating China and the EU's strong focus on investments in clean technology to directly support their ETS goals. These investments enhance the ability to reduce emissions, meet carbon caps, and foster compliance with the ETS framework. Revenue efficiency refers to funds generated from the sale of carbon permits within the trading system. This demonstrates the effective use of these revenues in financing green investments such as renewable energy and climate mitigation projects, ensuring a lucrative return on green investments. The high revenue efficiency observed in the EU and South Korea indicates that their ETMs are well-structured and generate significant financial resources. Although not the sole drivers of green investments, these resources provide crucial financial support for initiatives such as renewable energy, electric vehicles, and other low-carbon technologies, aligning with broader climate policy goals.

In summary, Kazakhstan's limited green finance resources restrict its ability to invest in low-carbon technologies and infrastructure compared to countries such as China, which has a more mature green-bond market. This finding identifies a financial barrier (objective 1) by highlighting the inadequate market liquidity and access to green finance. It also partially addresses the second objective of this study by illustrating the economic constraints that prevent effective ETS implementation and limit investments in green technology.

Figure 7 and Table 6 demonstrate distinct patterns and priorities in stakeholder engagement in various ETMs.

Table 6

Stakeholder Engagement in the Sample ETMs

Countries	**Awareness programs**	**Participation rates**	**Feedback mechanism efficiency**	**Key phases**	**Engagement principles**
EU	Extensive	Very high	High	Especially policy development and operational	Openness, responsiveness
New Zealand	Moderate	Moderate	Moderate	Initiation, growth	Communication, transparency
South Korea	Substantial	High	High	Policy development, implementation	Responsiveness, communication

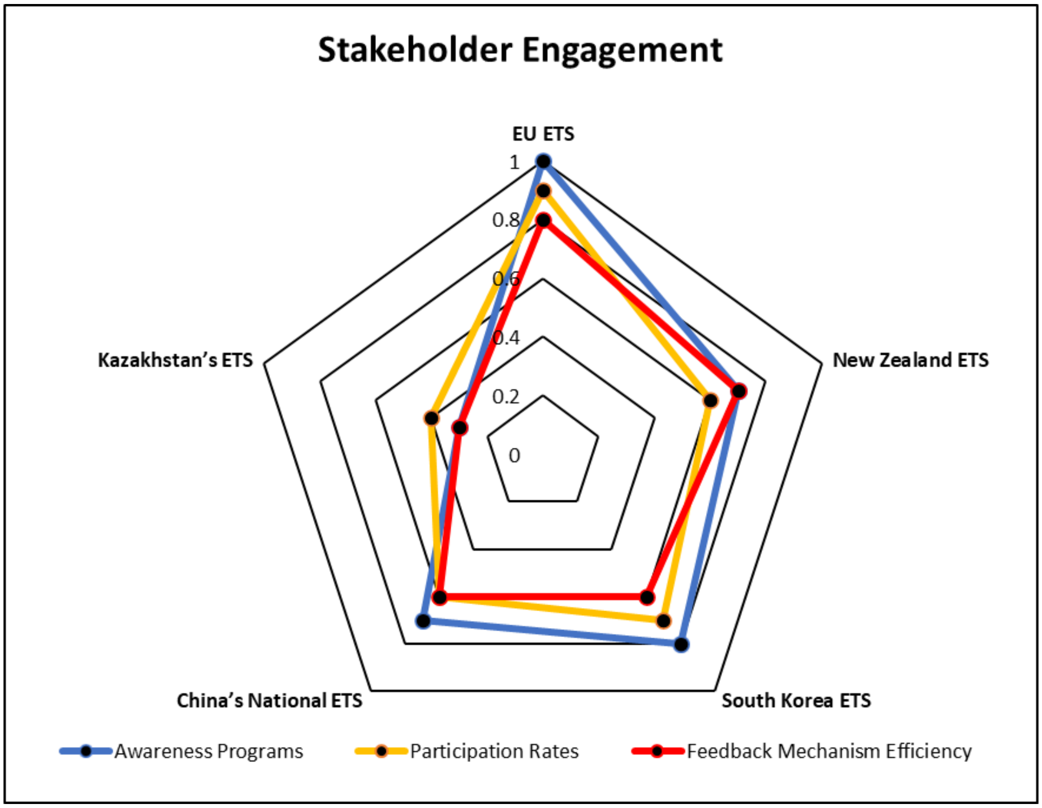
China	Considerable	Moderate	Moderate	Growth, operational	Inclusiveness, responsiveness
Kazakhstan	Limited	Low	Low	Initiation, policy development	Needs improvement in all areas

Source: International Emissions Trading Association (IETA), United Nations Framework Convention on Climate Change (UNFCCC), International Carbon Action Partnership (ICAP), and International Union for the Conservation of Nature (IUCN)

The awareness programs, participation rates, and efficiency of feedback mechanisms measure stakeholder engagement. The findings suggest that the EU has a highly developed framework for raising stakeholder awareness, likely through diverse and frequent educational and informational initiatives, followed by South Korea. China and New Zealand have exhibited significant and average efforts, respectively, in stakeholder engagement (Pacher, 2019). Kazakhstan could benefit from enhanced stakeholder engagement to ensure a broader understanding of the ETS and its advantages and effective participation. Expanding awareness initiatives would make stakeholders more informed and actively involved in the system, fostering a greater alignment with the country's climate goals. The EU ETS's high participation rate reflects effective communication and stakeholder involvement strategies. This indicates the successful implementation of the ETS, in which market players are actively involved in carbon trading, supporting the system in achieving emission mitigation goals. With low participation rates, Kazakhstan faces barriers to full engagement, owing to the shortage of adequate incentives, insufficient information dissemination, and compliance complexities.

Figure 7

Stakeholder Engagement in the Sample ETMs



Source: Authors creation based on information from International Carbon Action Partnership (ICAP)

Effective feedback mechanisms ensure that ETSs remain transparent, relevant, and adaptive to environmental conditions and market changes. The EU and South Korea have high feedback mechanism efficiency, which suggests that they are well structured and appreciate stakeholder input for the continuous improvement and adaptation. They have matured and developed ETMs, leading them to engage stakeholders and ensure effective management of their participation and feedback. The feedback process in Kazakhstan is less effective, potentially hindering the system's ability to evolve and better address stakeholder concerns.

Table 7 compares the regulatory support in the sample ETMs' legal environmental measures.

Table 7

Regulatory Support for the Sample ETMs

ETM system	EU	New Zealand	South Korea	China	Kazakhstan
Legal framework score IPRI (legal and political environment**)**	4.2-8.2 (4.8-8.7)	7.79 (8.8)	6.38 (6.2)	5.59 (5.1)	4.63 (4.5)
Legal framework for CBAM readiness	Fully implemented	Under development	Low	Under development	Weak
Alignment with CBAM requirements	High	Moderate	Low	Low	Very Low
Aggregate relative CBAM exposure index **(**Product and relative Exposure**)**	-	0.00046 (Fertilizer: 0.0005)	0.00017 (Iron and steel: 0.0002)	0.00282 (Cement: 0.003)	0.01579 (Aluminum: 0.040)
Carbon emission intensity of exports (KG/USD)	-	0.18	0.66	8.15	1.02
Impact on export-Intensive sectors (% of GDP)*****	-	0.18%	0.02%	0.05%	0.18%
Alignment with national policies	Very High	High	High	Moderate	Low
International cooperation	Extensive	Moderate	High	Moderate	Limited

Abbreviation: CBAM, carbon border adjustment mechanism. Source: International Property Rights Index (IPRI) European Commission, International Carbon Action Partnership (ICAP). World Bank CBAM Exposure * Vulnerability to CBAM.

This comparative analysis assessed various aspects of regulatory support, such as the legal framework score related to the international property rights index and the legal and political environment. High scores of the EU and New Zealand indicate that the legal environment is conducive to the enforcement and sustenance of ETMs. Kazakhstan needs to strengthen its legal and political framework and develop a legal structure to effectively enforce and comply with ETMs. Figure 8 illustrates the legal and political environmental scores of the sample.

The interaction between domestic carbon markets and international mechanisms, such as the EU CBAM, is a critical factor in shaping ETS performance in CAREC countries. The domestic carbon markets in

Kazakhstan and China are relatively nascent compared to those in the EU. For instance, while Kazakhstan's ETS focuses on energy and industrial sectors, it has limited alignment with CBAM requirements, exposing the country to trade risks owing to its reliance on carbon-intensive exports. Similarly, China's ETS, which is limited to power sector, faces challenges in integrating with global carbon markets, owing to regulatory gaps and limited sectoral coverage. These interactions highlight the need for stronger policy alignments and capacity-building initiatives to enhance the integration of domestic markets with international ETMs.

Table 7 exhibits the key metrices related to the readiness of the CBAM and its exposure across different countries. The aggregate relative CBAM exposure index shows that China and Kazakhstan face higher exposure risks, particularly in carbon-intensive industries, such as cement and aluminum, respectively. The high vulnerability of these countries to CBAM in terms of both exposure and carbon intensity could have substantial implications for their export-driven economies. Their limited alignment with CBAM requirements indicates the pressing need for policy reforms to mitigate future economic impacts. Conversely, New Zealand and South Korea are less exposed and better positioned to adapt. Figure 9 demonstrates that Kazakhstan has the highest CBAM exposure index and exports 14% of its products to the EU, indicating its significant vulnerability to the CBAM. In contrast, New Zealand and South Korea have much lower CBAM exposure and reliance on EU, with exports at 5% and 10%, respectively.

Figure 8

Legal and Political Environment in the Sample

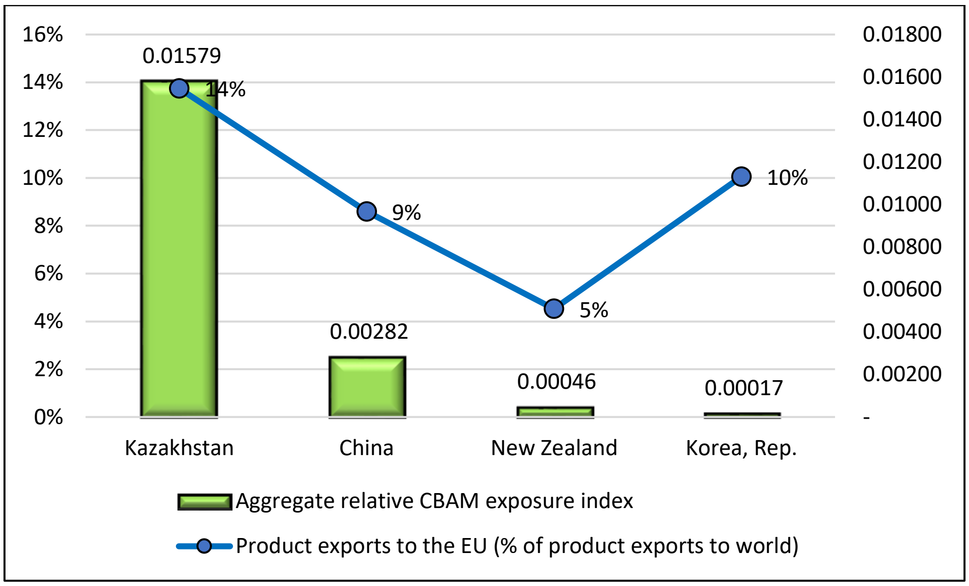
The concentration and height of the dots indicate each country's performance in terms of legal and political environment components. Source: Adapted from the International Property Rights Index of the European Commission.
https://composite-indicators.jrc.ec.europa.eu/explorer/explorer/indices/ipri/international-property-rights-index

The EU has the highest integration of ETM with national climate and energy policies, illustrating its strong coherence with government initiatives, market mechanisms, and environmental objectives to address climate change. Kazakhstan's low integration of ETS with national climate and energy policies suggests challenges in effectively utilizing the ETS to meet its climate goals, owing to less supportive legislation, insufficient alignment with other environmental or energy initiatives, or limited stakeholder engagement in the ETS process. These factors hinder the effectiveness of GHG emission mitigation.

The EU has extensive international cooperation that facilitates capacity building, knowledge sharing, and potential market connectedness. International cooperation enhances market liquidity and stability through the effectiveness of ETMs. South Korea exhibits high levels of international cooperation, whereas China and New Zealand exhibit moderate cooperation. The limited international cooperation in Kazakhstan's ETM restricts access to global carbon markets and reduces opportunities to learn technical and strategic skills from well-established ETMs.

Figure 9

Aggregate Relative CBAM Exposure Index



Abbreviations: CBAM, carbon border adjustment mechanism; EU, the European Union. Source: World Bank. 2023. https://www.worldbank.org/en/data/interactive/2023/06/15/relative-cbam-exposure-index#4.

Table 8 presents the regulatory framework matrix, which assesses how the legal structure supports the compliance mechanism, penalties for non-compliance, and degree of integration with the international market in the various ETMs. These regulatory dimensions are important as they influence the effectiveness and credibility of ETMs.

Table 8

Regulatory framework matrix

Country	Legal robustness	Compliance mechanisms	Penalties for non-compliance	Integration with international markets
EU				
New Zealand				
South Korea				
China				
Kazakhstan				

Note: **Dark Blue** indicates a robust and well-defined regulatory framework, **Green** indicates moderate robustness and some areas of concern, and **Blue** indicates significant areas requiring improvement. Source: Energy Policy Tracker, United Nations Framework Convention on Climate Change (UNFCCC) and International Carbon Action Partnership (ICAP). Compiled by the authors.

The matrix depicts that the EU has a robust and well-defined legal framework for ETM, providing clarity and certainty to market participants, and fostering confidence and compliance. However, Kazakhstan must improve its legal framework. The EU and New Zealand have strong and highly effective compliance mechanisms. Other ETMs must improve to ensure complete adherence to these mechanisms. EU ETMs impose strong penalties for noncompliance, which helps prevent regulation volatility and is necessary for the integrity of ETMs. The legal frameworks of the ETMs in the EU and South Korea are sufficiently strong to integrate extensively with other carbon markets, enhancing the market's efficiency, accessibility (liquidity), and flexibility.

In contrast, the penalties are either insufficiently stringent or ineffective in China and Kazakhstan's ETMs, destabilizing the entire mechanism. Their legal regulatory frameworks face several challenges that affect their effectiveness. For instance, Kazakhstan's ETM is part of its environmental code (2007). Despite this legislative foundation, enforcement mechanisms and regulatory clarity needs improvement. The country's regulatory standards are still developing as relatively recent adopters of the ETS with gaps in MRV practices. Limited institutional capacity and expertise hinder enforcement and compliance (ICAP, 2024). Additionally, Kazakhstan's economic reliance on fossil fuels creates policy conflicts as the government is cautious about imposing strict carbon reduction measures that might affect industrial growth. Political considerations further contribute to a less ambitious framework as policymakers balance environmental goals with economic stability.

China's national ETM is limited to power sector, excluding high-emission industries such as steel and cement. Expanding the sectoral coverage requires complex regulatory adjustments and industry-specific guidelines that are lacking. Additionally, regional inconsistencies in policy enforcement are a significant challenge; while the national government sets emission benchmarks, provincial authorities have considerable autonomy, resulting in varied interpretations and application of regulations. This uniformity gap weakens compliance and creates disparities in enforcement across provinces. Another critical issue is the development of more robust MRV systems. Inaccurate data and inconsistent verification procedures make it difficult to ensure compliance and measure the true impact of emission reduction efforts. In addition, China's ETS is largely isolated from global carbon markets, with limited integration and alignment with international standards.

These regulatory gaps highlight the primary barriers to effective ETM implementation by showing how limited legal robustness and sectoral coverage hinder the scalability and impact of carbon trading mechanisms in CAREC countries. Understanding these gaps would help develop tailored strategies to strengthen the regulatory frameworks.

Table 9 depicts the comparative analysis of the technological infrastructure of various ETMs.

Table 9

Technological Infrastructure of the Sample ETMs

ETM	**MRV systems**	**Trading platforms**	**Innovation support ($ million)**

EU	Advanced	User-friendly	180,000
New Zealand	Moderate	Reliable	300
South Korea	Advanced	Highly secure	321
China	Basic	Developing	546,000
Kazakhstan	Basic	Basic	337

Source: International Carbon Action Partnership (ICAP), Bloomsburg NEF

MRV enhances accuracy and transparency, improves compliance and enforcement, facilitates policy adjustments, and supports international commitments; therefore, investments in advanced MRV are essential. The MRV system in the EU and South Korea are “advanced” as their ETMs employ highly sophisticated and robust systems for MRV of emissions data. New Zealand has “moderate” MRV, indicating functional but less advanced systems compared to those of the EU and South Korea, which impact the precision and effectiveness of emission tracking and compliance enforcement. In contrast, China and Kazakhstan have “basic” MRV systems, suggesting minimal functionality or underdeveloped systems, leading to challenges in the efficiency and accuracy of emission data management and compliance.

Developing user-friendly trading platforms is essential, as they enhance market participation, increase engagement and compliance, reduce administrative burden, and support small and medium enterprises (SMEs). MRV and trading platforms form the backbone of a dynamic and robust carbon trading market, which is crucial for achieving economic and environmental sustainability. Table 8 illustrates that the EU platforms are accessible and easy to use, facilitating active trading and participation by various entities. New Zealand has “reliable” platforms, which are not cutting-edge, but are stable and dependable for trading activities. South Korea has “highly secure” trading platforms that emphasize cybersecurity, ensuring that trading activities are protected from unauthorized disruptions or access. The trading platforms in China and Kazakhstan can be rated as “developing” and “basic,” respectively, indicating ongoing efforts to enhance trading infrastructure and developmental stages of the platforms, limiting market participation and the effectiveness of the ETMs. Investments in innovation are essential for helping countries develop and deploy cutting-edge technologies to improve the effectiveness of ETMs. The EU and China show massive financial commitments to innovation, signaling future-focused strategies.

Another challenge related to effective implementation of ETMs is the integration of a robust carbon accounting mechanism. Carbon accounting is typically divided into three categories: scope 1 (direct emissions from owned or controlled sources), scope 2 (indirect emissions from purchased electricity, steam, or heating), and scope 3 (all other indirect emissions across the value chain, including raw-material production and transportation). Each scope poses unique challenges in terms of data availability, measurement accuracy, and verification (Bebbington & Larrinaga-Gonzaléz, 2008).

Accurate carbon accounting is challenging in many regions because of limited data infrastructure and inconsistent reporting standards. For scope 1 emissions, industries often face difficulties capturing real-time emission data owing to outdated monitoring technology. Scope 2 accounting requires collaboration with energy providers who may have limited capabilities or incentives to provide precise emission factors for purchased energy. Scope 3 is the most complex, involving the entire supply chain, and necessitates cooperation with suppliers, logistics partners, and end users who may lack the resources or expertise for detailed emission reporting (Uddin & Holtedahl, 2013).

Without reliable carbon accounting for all three scopes, establishing baselines, setting reduction targets, and verifying compliance are challenging, which undermines the effectiveness of ETMs. Addressing these challenges requires standardized methodologies, robust verification frameworks, and capacity-building initiatives to improve industry data collection and reporting capabilities (McDonald, 2024).

The limitations of carbon accounting and MRV systems represent a significant barrier as they prevent accurate tracking and verification of emissions. This analysis addresses objective 1 by identifying the technical and data-driven challenges that undermine the effectiveness of ETMs in CAREC countries.

5.1. Scenario Analysis

5.1.1. China Case Study

Table 10 shows the scenario analysis for China to compare the baseline with policy implementation. In the baseline scenario, China's carbon permit cost is USD 106.49 billion at the current USD 10/ton carbon price. Under the policy implementation scenario (carbon price of USD 30/ton), emissions are reduced by 10%; however, the carbon permit cost increased significantly to USD 287.51 billion due to the higher carbon price. This indicates that the energy sector can effectively reduce emissions through improved efficiency and that the financial cost of compliance escalates sharply under more stringent carbon pricing regimes. This cost increase could significantly challenge China's industrial competitiveness, particularly in energy-intensive sectors. However, the scenario emphasizes the potential for significant emission reductions without sacrificing the overall economic output, suggesting that China can balance economic growth and climate goals with proper regulatory support and investment in cleaner technologies.

Table 10

Scenario 1: Baseline vs. Policy Implementation in China

Metric	Baseline	Policy implementation
Energy output (million USD)	3,384,006[8]	3,384,006
Energy consumption (1000 toe)	742,782	668,503.80
Carbon emissions (MtCO2)	10,648.54	9,583.69
Carbon price (USD/ton)	10	30
Carbon permit cost (million USD)	106,485.40	287,510.70

Source: ADB People's Republic of China Input-Output tables, Chinese National Emissions Trading System (ETS), International Energy Agency (IEA)

Table 11 presents Scenario 2 for carbon pricing sensitivity. This analysis demonstrates a clear trade-off between environmental benefits and economic costs with increase in carbon prices in China. At USD 20/ton, emissions are reduced by 5%, with a manageable carbon permit cost of USD 202.32 billion. However, at USD 50/ton, while emissions decreases by 20%, the carbon permit cost surges to USD 425.94 billion, representing a significant financial pressure on China's energy sector. It highlights China's challenges in balancing ambitious climate goals with economic sustainability. As a heavily-industrialized and energy-intensive economy, the higher carbon pricing needed to achieve substantial emission reductions will disproportionately impact key sectors such as steel, cement, and aluminum, which are critical to its export-driven economy. Therefore, a combination of gradual carbon pricing increase, investment in renewable energy, and technological innovation are needed to mitigate the financial impact

[8] Energy output is the aggregated value of mining and quarrying (c2) that provides raw energy inputs such as coal, oil, and natural gas, coke, refined petroleum, and nuclear fuel (c8) transforms crude oil and other raw materials into usable petroleum products and nuclear fuel, and electricity, gas, and water supply (c17) represents the core energy services that deliver electricity and gas to end consumers (industries, households, etc.). Each of these sectors is essential to the energy value chain, so combining them will give you the overall output for the energy sector Sourced from Table 1.17: China Input-Output for the year 2022, ADB.

while advancing toward climate targets. Without such strategic measures, steep economic costs may hinder economic growth and the capacity to meet climate commitments.

Table 11

Scenario 2: Carbon Pricing Sensitivity in China

Carbon price (USD/ton)	Energy consumption (1000 toe)	Carbon emissions (MtCO2)	Carbon permit cost (USD million)
20	705,642.90	10,116.11	202,322.20
30	668,503.80	9,583.69	287,510.70
50	594,225.60	8,518.83	425,941.50

Assumption: Emission reductions of 5%, 10%, and 20% were observed at 20, 30, and 50 USD/ton, respectively. Source: International Energy Agency (IEA)

The climate target achievement scenario presented in Table 12 shows that China achieved a 14% reduction in emissions, from the level in 2005, to 10,657.54 MtCO2 at an abatement cost of USD 43.23 billion. However, to meet its 2030 climate target of 65% reduction, emissions must reduce to 4,335.33 MtCO2, an additional reduction of 6,313.21 MtCO2. This demands significant energy consumption reductions and an estimated USD 157.83 billion abatement costs. The comparison reveals that, while China has made notable progress, the next phase will require much deeper cuts and substantially higher investments. Transitioning to a low-carbon economy will necessitate stronger financial mechanisms, renewable energy investments, and international cooperation to balance emission reduction with economic growth.

Table 12

Scenario 3: Climate Target Achievement in China

Metric	Current reduction (since 2005)	Target (climate policy)
Emission reduction in %	**-14%**	**-65%***

Emissions (MtCO2)	10,657.54	4,335.33
Energy consumption (1000 toe)	638,793.48	302,442.40
Emissions reduction (MtCO2)	1,729.13	6,313.21
Abatement cost (USD million)	43,228.25	157,830.25

As per the NDC, reduction by 2030, Source: Global Carbon Project, 2022; historical data based on China's NDC submission (UNFCCC, 2015), International Energy Agency (IEA), McKinsey & Company's global carbon abatement costs.

Table 13 demonstrates the impact of EU CBAM on China's exports. CBAM has introduced a carbon price of USD 55/ton CO2, resulting in an additional cost of USD 113.33 million to China for exports to the EU. This increase would raise the price of Chinese exports by 1.73%, potentially leading to a 1.04% reduction in export volumes. China exports highly carbon-intensive goods to the EU, including steel, cement, aluminum, and chemical products. These industries are particularly vulnerable to CBAM because of their high carbon footprints. This scenario highlights the financial pressure that China may face in its trade relations with the EU, as the carbon pricing of these carbon-intensive products could diminish their competitiveness in the European market.

Table 13

Scenario 4: The Impact of CBAM on China's Exports

Metric	**Value**
Total export value to EU (USD million)	654,861.78
Emission intensity of exports (tCO2e/USD million)	3.147
Total emissions from exports (tCO2e)	2,060,502.77
Proposed carbon price under CBAM (USD/ton)	55
Total CBAM cost (USD)	113,327,652.35
Percentage increase in export prices	1.73%
Estimated export reduction (%)	-1.04%

Abbreviations: CBAM, carbon border adjustment mechanism; EU, the European Union. Source: World Bank, IEA, European Commission CBAM

5.1.2. Kazakhstan Case Study

Table 14 compares Kazakhstan's energy sector under baseline and policy implementation scenarios. The energy output remained constant at USD 66,578 million in both cases. Under the policy scenario, energy consumption was reduced by 10% (from 69,868.3 to 62,881.47 thousand toe), reducing carbon emissions from 224 MtCO2 to 201.6 MtCO2. The carbon price increased from USD 1 to USD 30, resulting in a significant increase in carbon permit costs from USD 224 million to USD 6,048 million. The analysis revealed that implementing a carbon pricing policy in Kazakhstan's energy sector significantly reduced energy consumption and carbon emissions (by approximately 10%). However, it imposed significant financial costs on the energy sector, highlighting the trade-off between environmental and economic benefits.

Table 14

Scenario 1: Baseline vs. Policy Implementation

Metric	**Baseline**	**Policy implementation**
Energy output (Million USD)	66,578[9]	66,578
Energy consumption (1000 toe)	69,868.30	62,881.47
Carbon emissions (MtCO2)	224	201.6
Carbon price (USD/ton)	1	30

[9] Energy output is the aggregated value of mining and quarrying (c2) that provides raw energy inputs like coal, oil, and natural gas, Coke, refined petroleum, and nuclear fuel (c8)) transforms crude oil and other raw materials into usable petroleum products and nuclear fuel, and electricity, gas, and water supply (c17) represents the core energy services that deliver electricity and gas to end consumers (industries, households, etc.). Each of these sectors is essential to the energy value chain, so combining them will give you the overall output for the energy sector Sourced from Table 1.17: Kazakhstan Input-Output for the year 2022, ADB.

Carbon permit cost (USD million)	224	6048

Source: Kazakhstan Input-Output Tables, Kazakhstan Emissions Trading System (ETS), International Energy Agency (IEA)

Table 15 shows the impact of different carbon prices on Kazakhstan's energy consumption, emissions, and permit costs. As the carbon price increases from USD 20/ton to USD 50/ton, energy consumption decreases from 64,976.52 to 59,387.06 thousand toe, and carbon emissions fall from 208.32 MtCO2 to 190.4 MtCO2. However, the cost of carbon permits has increased significantly. Higher carbon pricing effectively reduces energy consumption and emissions but imposes a steep financial pressure on the energy sector. The results highlight the balance between achieving emission reductions and managing the economic costs of carbon regulations.

Table 15

Scenario 2: Carbon Pricing Sensitivity

Carbon price (USD/ton)	Energy consumption (1000 toe)	Carbon emissions (MtCO2)	Carbon permit cost (USD million)
20	64,976.52	208.32	4,166
30	62,881.47	201.6	60,480
50	59,387.06	190.4	9,520

Assumption: Emission reductions of 5%, 10%, and 20% were observed at 20, 30, and 50 USD/ton, respectively. Source: International Energy Agency (IEA)

Table 16 compares Kazakhstan's current policy with a more ambitious climate target of achieving 15% emission reduction by 2030. Under the current policy, emissions have been reduced by 7% since 1990, resulting in 224 Mt CO2 emissions at an abatement cost of USD 840 million. However, the ambitious climate policy aims to reduce emissions to 156.8 MtCO2 by 2030, requiring significant cuts in energy consumption and doubling the abatement cost to USD 1.68 billion. This assumption is modelled for a single policy implementation year, assuming immediate price adjustment. The analysis highlights that achieving a more aggressive 15% emission reduction will significantly increase costs and necessitate greater energy reductions than the current 7%. This highlights the trade-off between ambition and financial consequences, with the climate target requiring larger investments to meet deeper emission cuts.

Table 16

Scenario 3: Climate Target Achievement

Metric	**Baseline (current policy)**	**Target (climate policy)**
Emission reduction in %	**-7%**	**-15%***
Emissions (MtCO2)	224	156.8
Energy Consumption (1000 toe)	69,868.30	59,387.06
Abatement Cost (USD millions)	840	1,680

As per the NDC, conditional reduction by 2030, Source: Global Carbon Project, 2022; historical data based on China's NDC submission (UNFCCC, 2015), International Energy Agency (IEA), and McKinsey & Company's global carbon abatement costs.

Table 17 illustrates the potential impact of the CBAM on Kazakhstan's exports to the EU. With a total export of USD 4.2 billion and an emission intensity of 615 MtCO2e per million USD, the total emissions associated with Kazakhstan's exports amounted to 2.583 million tons of CO2e. Under the proposed CBAM carbon price of USD 55/ton, Kazakhstan's exports would incur a total CBAM cost of USD 142.065 million, leading to a 3.38% increase in export prices. Consequently, Kazakhstan's exports to the EU could potentially decrease by 2.03% due to increased costs. The cost of the CBAM significantly increases the price of Kazakhstan's exports to the EU, potentially making it less competitive. This could result in a noticeable reduction in export volume, highlighting the financial challenges that carbon-pricing mechanisms pose to emission-intensive exports.

Table 17

Scenario 4: CBAM's Impact on Kazakhstan's Exports

Metric	**Value**

Total export to the EU (USD million)	4,200
Emission intensity of exports (tCO2e/million USD)	615
Total emissions from exports (tCO2e)	2,583,000
Proposed carbon price under CBAM (USD/ton)	55
Total CBAM cost (USD)	142,065,000
Percentage increase in export prices	3.38%
Estimated export reduction (%)	-2.03%

Abbreviations: CBAM, carbon border adjustment mechanism; EU, the European Union. Source: World Bank, IEA, European Commission CBAM

The scenario analyses for China and Kazakhstan show that while carbon pricing drives emission reductions, it also imposes substantial economic costs on key sectors. For instance, China's energy sector faces rising costs owing to increased carbon prices, which challenges its competitiveness. This finding addresses objective 2 by assessing the economic impact of carbon pricing and revealing a critical trade-off between environmental objectives and economic sustainability. The high costs underscore the need for carefully-phased carbon pricing policies to minimize negative impacts on competitiveness. Likewise, CBAM creates additional economic risks for CAREC countries, particularly Kazakhstan, which has high exposure due to its carbon-intensive exports. This barrier highlights how external carbon pricing mechanisms, such as CBAM, impact the economic performance of CAREC countries. By analyzing CBAM exposure risks, this study expanded the understanding of the economic implications of international carbon pricing for local industries.

5.2. **Feasibility Assessment of Green Finance Instruments**

Feasibility assessment of green finance instruments helps optimize the green financial architecture by ensuring that the right financial mechanisms are in place to support the transition to a low-carbon economy. It helps evaluate the effectiveness of instruments, such as green bonds, carbon credits, and sustainability-linked loans, which mobilize capital towards sustainable projects. It also provides insights into the regulatory and market conditions required to effectively scale these instruments. Without assessing this, financial incentives may be misaligned, slowing the deployment of clean technologies and undermining emission-reduction efforts. Therefore, the feasibility of these instruments drives climate goals while maintaining economic stability. This study only assessed the feasibility of green bonds owing to easily accessible data. Green bonds can directly finance projects that help countries meet ETS targets, such as renewable energy, energy-efficient projects, and sustainable infrastructure.

In 2023, China's green bond market was valued at USD 371.95 billion, demonstrating significant capital generation potential for environmental and low-carbon projects. The proceeds were primarily directed towards mixed projects (72%), with smaller allocations for renewable energy (20%) and energy efficiency (16%). This allocation strategy focuses on large-scale, integrated projects that align with China's long-term sustainability and ETM goals (Table 18 and Figure 10).

Table 18

Green Bonds Feasibility Analysis

Country	**Market value (USD)** in 2023	**Capital utilization**	**Regulatory framework**	**Challenges**	**Investor demand**
China	371.95 billion	Investment directed towards solar, wind, electric vehicles, and green infrastructure	Well-developed green bond market	Limited transparency in tracking bond use	High – strong interest from domestic and international investors

Kazakhstan	235.25 million	Funds are primarily used for energy efficiency and renewable projects in the public sector	Developing regulatory framework for green bonds	Lack of green bond standards and clear reporting	Moderate – growing but limited institutional demand

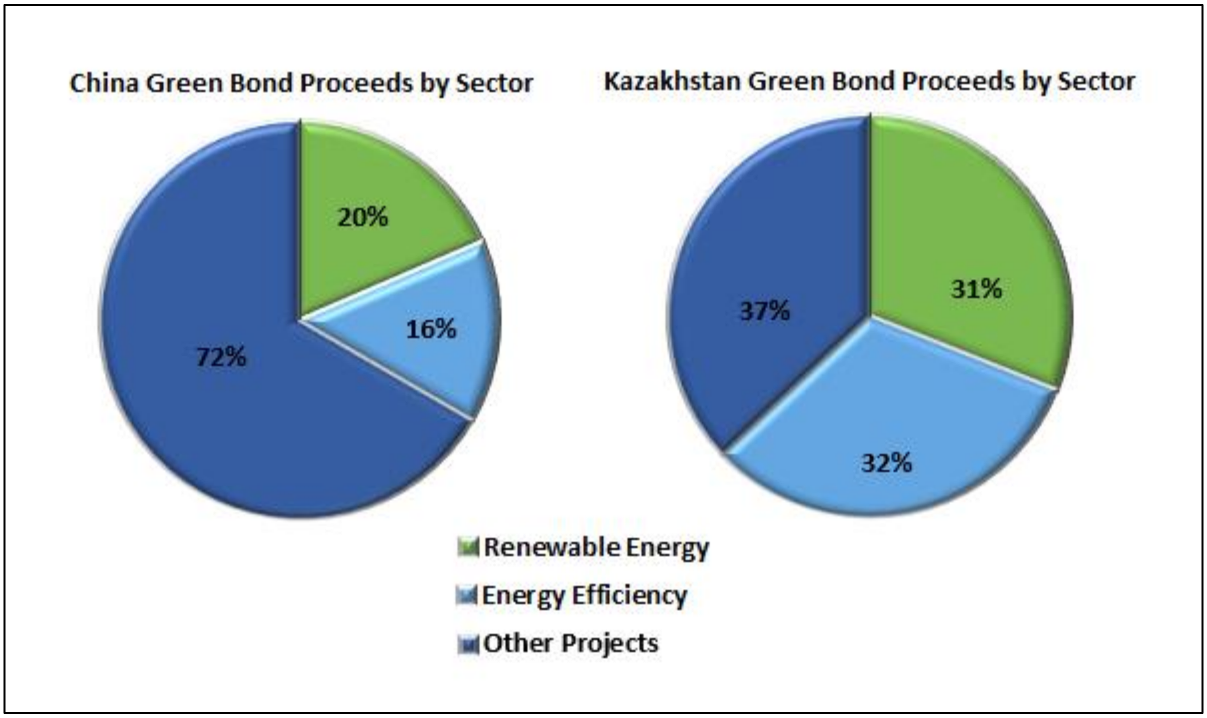
Source: Astana International Financial Centre (AIFC) and Climate Bonds Initiative, and CIB Economic Research and Consulting (CIB Research)

Despite a well-developed regulatory framework, the key challenge is ensuring transparency in tracking fund utilization. High investor demand indicates strong market confidence, positioning China's green bonds as a viable instrument for capital mobilization and financial architecture optimization to support its ETM and climate objectives.

Kazakhstan's green bond market, although smaller at USD 235.25 million, is gaining traction and is crucial in financing the country's transition to a low-carbon economy. The proceeds were evenly distributed across renewable energy (31%), energy efficiency (32%), and mixed projects (37%), indicating a balanced approach to green investments. The regulatory framework is still in the developmental stage and faces challenges related to a lack of green-bond standards and clear reporting mechanisms. However, the growing investor demand reflects a positive outlook for future market expansion. Green bonds hold substantial promise for Kazakhstan's ETM by providing the much-needed capital for clean energy projects and energy efficiency improvements, contributing to optimizing its financial architecture to support national emission reduction goals.

Figure 10

Green Bonds Proceed by Sectors



Source: Created by the author, based on information extracted from the Astana International Financial Centre (AIFC) and Climate Bonds Initiative 2023 reports.

In summary, China's well-developed green bond market demonstrates high feasibility for supporting ETM and optimizing the financial architecture; although it needs to improve transparency. With a balanced sectoral allocation strategy, Kazakhstan's green bond market is emerging and offers growing potential for green finance, despite regulatory challenges. Both countries illustrate the essential role of green bonds in raising and utilizing capital to support ETM goals and optimize financial systems for a low-carbon future.

6. Conclusion

This study mainly aimed to identify and delineate the barriers hindering the effective implementation of ETMs in CAREC countries. It was motivated by the growing imperative of regions to adopt sustainable and effective mechanisms to reduce carbon emissions and combat climate change. Various ETMs outside the CAREC, such as those in the EU, New Zealand, and South Korea, and within the CAREC in China and Kazakhstan were compared. The strength and enforcement capabilities of the legal structure to promote ETMs were assessed, revealing Kazakhstan's significant gap in legal robustness. The inadequacy of legal and regulatory frameworks indicates a lack of comprehensive and enforceable legislation specific to emissions trading. This creates challenges such as poor compliance, lack of stakeholder trust, and integration with international carbon markets.

Additionally, the analysis suggests that insufficient funding, inadequate subsidies, and unattractive carbon pricing significantly reduce the efficacy of ETMs in CAREC countries. The carbon pricing set by the market is significantly lower for encouraging businesses to reduce emissions because the expense of emission would not be economically prohibitive considering the investment needed to mitigate them. In addition, owing to the low accessibility of green funds and insufficient subsidies, technologies with the potential to reduce emissions may not reach their potential. Encouraging investment in green technology and practices requires addressing these financial and market-related constraints by creating a stable and financially appealing market.

Stakeholder engagement is important for the success of any environmental program, particularly carbon trading. Stakeholder resistance is a significant barrier due to the lack of understanding of the advantages and functioning of ETMs, concerns about the expenses associated with compliance, or doubts about the influence of such mechanisms on company operations. The results of the comparative analysis highlight the importance of enhancing stakeholder engagement in regions such as Kazakhstan. Effective participation from enterprises, government entities, and the public is crucial for ensuring feedback collection and informed decision-making. Without active involvement of all stakeholders, comprehensive insights cannot be obtained.

The effectiveness of an ETM relies heavily on the existing technology infrastructure, particularly MRV systems and trading platforms. The basic and underdeveloped status of these technologies in the CAREC countries is a significant barrier. Advanced MRV systems are essential for precise monitoring and documentation of emissions. This is fundamental to maintain the integrity and credibility of an ETM. Efficient and user-friendly trading platforms are crucial to allow the actual trading of carbon allowances. Inconvenient or vulnerable platforms discourage participation and undermine market effectiveness. Therefore, investing in advanced technologies to create strong MRV systems and reliable trading platforms is crucial. This will help overcome technological obstacles and improve the transparency and efficiency of ETMs in CAREC countries.

The scenario analysis in this study offers a comprehensive understanding of the financial and environmental implications of carbon pricing strategies, policy implementations, and impact of CBAM. Analysis of baseline versus policy implementation, carbon pricing sensitivity, climate target achievement, and CBAM impact on exports shows that China and Kazakhstan face significant challenges in aligning their economic and energy-intensive sectors with global climate goals. The analysis indicates that while policy-driven interventions can achieve moderate emission reductions, the financial pressure is significant, particularly from increased carbon permit prices. Higher carbon prices lead to greater emission cuts, but strain industries, especially in carbon-intensive economies. Achieving ambitious climate goals, such as China's target of 65% emission reduction by 2030, require massive investments in cleaner technologies and energy efficiency, with abatement costs reaching hundreds of billions. Additionally, the impact of CBAM highlights the vulnerability of carbon-intensive exports, potentially undermining the trade competitiveness of countries heavily reliant on energy-intensive industries.

6.1. Policy recommendations

The results suggest the following targeted policy recommendations: overcoming the identified barriers, supporting capacity-building initiatives, and creating a conducive market environment in CAREC countries.

6.1.1. Expand Sectoral Coverage

The existing performance analysis shows that the EU and South Korea's broad sectoral integration and extended coverage promote holistic environmental improvements. Kazakhstan, which currently follows global best practices in sectoral coverage and focuses mainly on power and industry, has established a solid foundation for its ETMs. Consequently, Kazakhstan has the potential to expand its ETM to include other high-emissions sectors. The baseline versus policy implementation scenario reveals that while moderate emissions reductions can be achieved by focusing on energy and industry, broader sectoral coverage is necessary to meet long-term climate goals. Policymakers should consider expanding ETMs to include sectors such as transportation, agriculture, and construction, which are currently underregulated, but contribute significantly to national GHG emissions. Sectors can be prioritized based on their GHG emission magnitude using criteria such as total emissions, emission reduction potential, and feasibility of accurately monitoring and reporting emissions. Aligning these expansions with international best practices, such as those employed by the EU and South Korea, would ensure an effective extended coverage that is well-integrated into the existing framework.

Next, the emission reduction potential and economic impact of including sectors in the ETM must be evaluated, as policymakers should consider sector-specific growth trends and projections that may affect future emissions. Moreover, CAREC countries must establish a baseline for current emissions in each sector, which would serve as a reference point for measuring the impact of the ETM. Carbon footprint analyses and life cycle assessments can be used to obtain detailed insights into sector-specific emissions. Identifying existing technologies, practices, and innovations helps assess the technical feasibility of reducing emissions in each sector. This sectoral expansion will ensure a more comprehensive approach to emission reduction across all major sources.

6.1.2. Emission Allowance Allocation Efficiency

The performance analysis shows that Kazakhstan and China can improve the efficiency, transparency, and credibility of their ETMs by switching from free allocation (grandfathering) to auctioning. This transformation would be beneficial for discovering accurate prices, as allocation by auction leads to more efficient carbon pricing by reflecting the true picture of the market and demand for allowances. Moreover, it supports emission mitigation and encourages investment in carbon reduction initiatives. In addition, the transformation reduces windfall profit, where entities benefit from free allowances more than they need, selling excess allowances for profit rather than using them to cover actual emissions.

To effectively implement this transformation strategy, CAREC countries can introduce a phased approach to increase the percentage of allowances auctioned each year, coupled with mechanisms to stabilize the market in cases of price volatility, such as a market stability reserve. The first step is to understand how the involved sectors distributes the allowances, influence of free allocation on low-carbon technologies, and operational changes in investment behavior. Countries must then develop a multiyear plan that gradually increases the proportion of auctioned allowances. For instance, they could start by auctioning 20% of the allowances and increasing them by 10% annually. This phased approach helps the market and participating entities adjust gradually and prevents economic shocks. Next, they must develop a transition plan targeting different sectors based on their current technological advancements and economic sensitivities. Power sector can be targeted as it can make rapid adjustments and move quickly to auctions for allowance allocations compared with the manufacturing sector in CAREC countries. In subsequent phases, transparent stakeholder communication, implementation of market stability measures, and price controls are crucial.

6.1.3. Carbon Pricing Transformation

Carbon pricing is important for enhancing financial incentives for emissions reduction. Among CAREC countries, Kazakhstan has low carbon prices, which should be gradually increased to reflect the true carbon emission costs. This study recommends design and implementation of effective policies to facilitate controlled and sustainable increases in carbon prices. These policies should establish an initial floor price that is sufficiently low to be economically and politically feasible, yet high to meaningfully influence emission-reduction decisions. The carbon-pricing sensitivity scenario highlights the direct relationship between carbon-pricing levels and emission reductions. To incentivize meaningful emission cuts, it is recommended that countries gradually increase their carbon prices, starting with moderate levels (e.g., US$20-30/ton) and scaling up to more stringent prices (e.g., US$50/ton). This approach would allow industries to adjust progressively while reducing their financial pressure in the short term. Moreover, adopting pricing structures that consider sectoral differences, such as higher carbon prices in high-emission sectors, could maximize the effectiveness of the pricing mechanism.

In addition, for an effective carbon pricing mechanism, countries also need to focus on economic adjustment factors, such as linked carbon prices with inflation and adjusting them according to GDP growth (this is not yet a widely established practice). This approach would provide flexibility, allowing carbon pricing to adapt to economic fluctuations during downturns and alleviating undue economic pressure. Furthermore, for carbon price policy measures, a strong regulatory mechanism is needed to enforce decisive floor prices and economic diversification initiatives.

6.1.4. Strengthening Legislative Framework

This study found a significant gap in the legal foundation necessary for effective ETMs in CAREC countries. A comprehensive legislative change is required to develop clear and enforceable rules and regulations tailored to ETMs. Drawing on the EU's robust legal framework, policymakers in CAREC countries may draft new laws or amend existing ones to provide precise definitions, compliance requirements, and penalties for failure to comply. New laws should enact a strong emissions trading act.

This comprehensive statute should establish a legal framework for ETM operation, including the creation, trading, and retirement of emission allowances.

Moreover, regarding carbon market regulation laws, legal authorities should set rules for trading platforms, including requirements for transparency, market access, and anti-fraud measures. In addition, they need to enact a climate change adaptation act, which should be broader, integrating ETMs within a wider climate-policy framework and addressing adaptation and mitigation strategies and the roles of various stakeholders. Moreover, authorities can enact green investment facilitation and cross-border emission trading laws. Policymakers must ensure that these laws and regulations align with the international best practices. Legislation should be sufficiently flexible to adapt to market changes and technological advancements. It should facilitate cross-border carbon trading and attract worldwide investment. Inspired by the successes of the EU and New Zealand, CAREC countries should establish stringent and transparent compliance mechanisms. Regular audits, real-time emission monitoring, and public reporting enhance transparency and trust in ETMs.

The impact of CBAM on export scenarios shows that countries heavily reliant on carbon-intensive exports, such as Kazakhstan and China, face significant economic challenges. To mitigate this, governments should engage in diplomatic dialogue with trading partners, seek flexibility in CBAM regulations (transitional periods or exemptions), and explore domestic carbon pricing adjustments that align with international standards. In addition, supporting carbon-intensive industries in decarbonizing their production processes can help maintain competitiveness in global markets.

6.1.5. Enhance Financial Incentives and Support

CAREC countries face extensive financial barriers, with inadequate funding and uncompetitive carbon pricing being the most significant. Analyzing the success of high carbon prices in the EU, CAREC countries should implement a dynamic pricing strategy, starting with a price floor and ceiling, to stabilize market prices and encourage investments in low-carbon technologies. As observed in the EU and South Korea, generous subsidies and funding can catalyze significant investments in green technologies. Currently, support for innovation in Kazakhstan is much lower than that in China and other countries. Therefore, to overcome financial barriers, policymakers and governments should provide and strengthen subsidies for companies investing in green technologies and develop research and development strategies to reduce emissions. Subsidies can be provided for solar and wind projects in countries with high solar and wind potential such as Kazakhstan and Uzbekistan. These subsidies include tax reductions, direct grants, or low-interest loans to promote investment in renewable energy infrastructure.

Moreover, the government should offer subsidies for adopting water-saving irrigation technologies in agrarian economies, such as Tajikistan and Kyrgyzstan. These could include direct subsidies for equipment purchases or tax credits for investments in water-efficient systems. Likewise, governments could also introduce performance-based subsidies in industrial sectors, particularly in countries with heavy industries, such as Kazakhstan. The CAREC should consider establishing green investment funds specifically targeted at industries with high emissions or those transitioning to greener alternatives. In urbanized areas with significant air pollution, such as major cities in Azerbaijan and Georgia, governments should provide subsidies for electric vehicle purchases and charging infrastructure development. They should also offer tax rebates, toll exemptions, or direct purchase subsidies. In addition, to enhance access to green finance, government and private sectors should be encouraged to issue green bonds, establish green banks, promote international partnerships, develop capacity-building plans, and launch public awareness campaigns.

6.1.6. Technology Infrastructure Investments

This study revealed technological limitations, especially in basic MRV systems and underdeveloped trading platforms in Kazakhstan and China. Drawing on South Korea’s approach of setting up and implementing effective ETM, governments must invest in advanced MRV technologies. For instance, investments in high-precision sensors can provide accurate data on emissions. In addition, they can implement automated data management systems that automatically integrate emissions data into reporting frameworks to minimize human error and improve reliability. In addition, frequent training sessions for personnel on the latest MRV technologies and data handling practices are imperative. The improved MRV system would ensure precise monitoring and reporting of emissions.

Moreover, user-friendly and secure digital trading platforms should be developed to facilitate efficient and transparent trading of emission allowances. Countries can collaborate with technology companies to design blockchain-based platforms that ensure data security and integrity. Additionally, CAREC countries should create intuitive user interfaces to help traders with varying technical knowledge and expertise. Moreover, real-time feed data is required for dynamic pricing and trading market sensitivity. A strong technological infrastructure also enhances market liquidity. This ensures broad participation for which authorities should implement regulatory reforms to reduce the cost and complexity of entering the emission trading market.

6.1.7. Fostering Stakeholder Engagement

The study revealed that in CAREC countries, less stakeholder engagement indicates low awareness and participation, which are key barriers to establishing effective ETMs. To increase stakeholder engagement, governments should implement a comprehensive engagement program to educate and inform all stakeholders about ETM life cycle. They could organize monthly workshops and seminars to educate stakeholders on the benefits and operations of ETM. Moreover, the involvement of industry experts and policymakers as expert speakers would provide authoritative insights and updates during interactive sessions to enhance understanding. In addition, information materials tailored for different stakeholder groups should be shared on various media platforms for comprehensive information campaigns.

Furthermore, countries should establish a regular schedule of consultation forums where stakeholders can provide feedback and express their concerns. A robust online feedback mechanism would help obtain suggestions regarding ETM operations and policies. Other initiatives, such as regular ETM progress report publication, collaboration and partnership with NGOs and academia, and industry alliances would foster a cooperative approach toward ETM advocacy and implementation.

6.1.8. Promoting Market Readiness and International Integration

The findings of this study underline the lack of readiness for integration into international carbon markets, particularly in Kazakhstan and China, where limited alignment with global market standards has been observed. Therefore, concerted efforts should be made to harmonize domestic ETM regulations with international standards to enhance market readiness. This includes the adoption of verification and compliance practices that meet global benchmarks. Establishing bilateral or multilateral agreements with ETMs in other nations could facilitate streamlined integration and provide broader market access to carbon trading.

This study focused on Kazakhstan and China, which are the only CAREC countries with operational ETMs. While broader policy recommendations were briefly mentioned for Uzbekistan, Tajikistan, Kyrgyzstan, Azerbaijan, and Georgia, they are general suggestions for regional ETM development and not the primary focus of the analysis. The scope of this research is limited to countries with active ETS frameworks, ensuring that the findings and recommendations are grounded on the available data and operational realities.

6.2. Limitations

This study comprehensively analyzed ETMs within and outside CAREC countries; however, data availability and quality were significant limitations. In some CAREC countries, comprehensive and reliable data on carbon emissions, trading volumes, and market performance are limited or not publicly available. This lack of data transparency could impede the accuracy of comparative analyses, potentially leading to conclusions that do not entirely reflect ground realities. Additionally, the dynamic nature of policy environments and market mechanisms challenges the long-term relevance of this study. As ETM evolves and new policies are introduced, some findings may be outdated, necessitating ongoing research to align with the developments in the field. Moreover, external factors such as global economic conditions and geopolitical developments could influence the effectiveness of ETMs and carbon-pricing strategies, which were not fully explored in this study.

6.3. Future Research Direction

Although this study provides a comparative analysis of ETMs across different regions, several areas require further research to enrich the discourse on climate policies and carbon markets. For instance, long-term socioeconomic impacts of ETMs on various industries and communities, particularly in carbon-intensive economies, such as China and Kazakhstan, should be investigated. It would provide insights into how ETMs influence employment, income distribution, and industrial competitiveness over time. Future studies should focus on the impact of stakeholder engagement in improving ETM compliance and effectiveness. Understanding the perspectives of local businesses, communities, and environmental organizations could reveal the potential barriers to successful ETM adoption and suggest ways to enhance stakeholder buy-ins. This is relevant in regions where public- and private-sector alignments on climate goals are critical for policy success.

Furthermore, a valuable research direction would be to analyze the integration of ETMs with other climate policies, such as renewable energy incentives and carbon taxes. Exploring how these policies interact could provide a more holistic understanding of the optimal policy combinations for emission reduction. Additionally, expanding the scope of research to cover emerging green finance instruments such as carbon-linked bonds and sustainability-linked loans would be beneficial. These instruments can potentially enhance ETM financing. However, further investigation is needed to assess their feasibility and impact in diverse economic contexts.

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