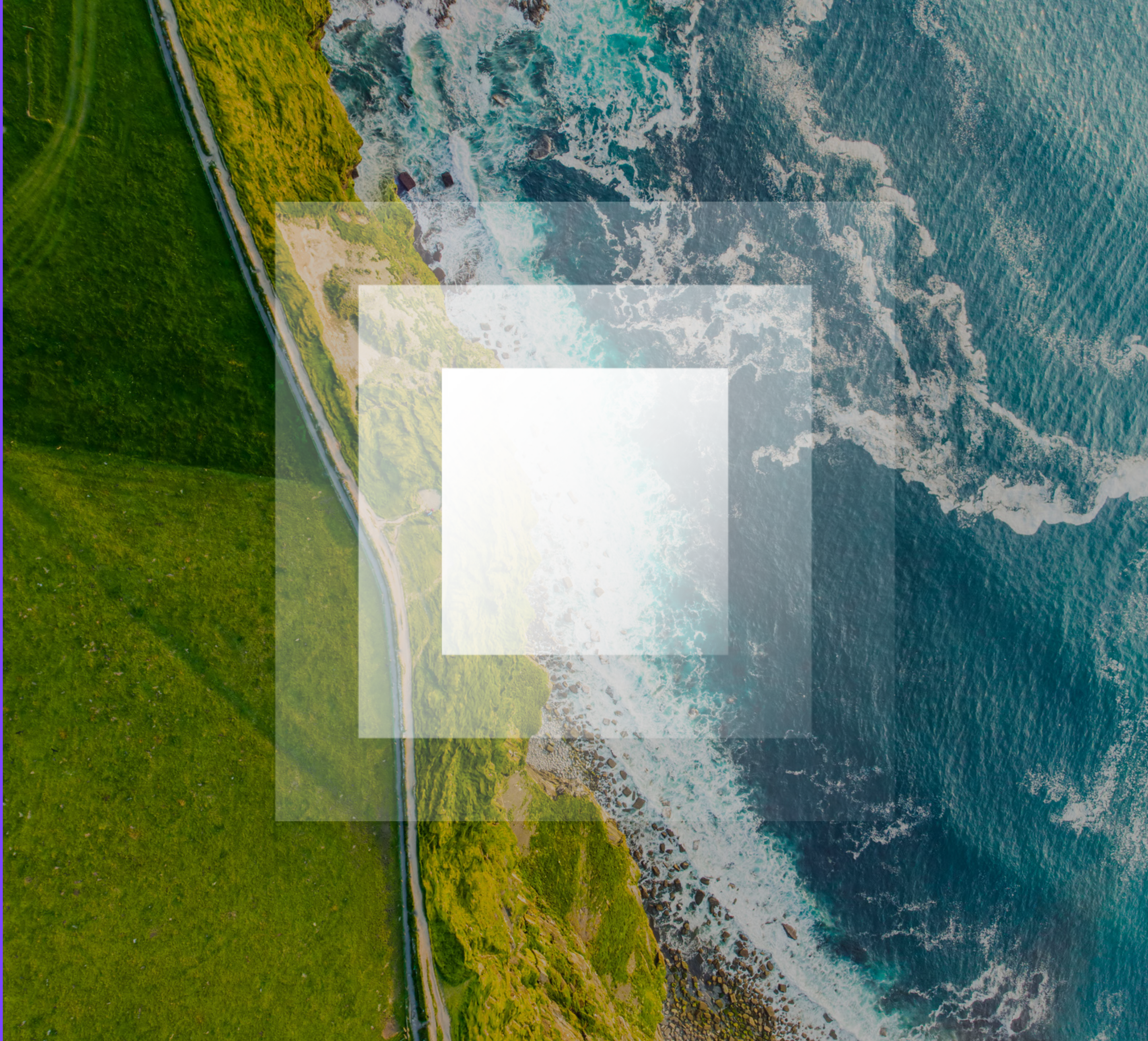
SUSTAINABILITY



An Effective Tool for Net Zero

A Foundational Overview of Global Carbon Markets

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EXECUTIVE SUMMARY

The Paris Agreement and the widely adopted goal to reach net-zero greenhouse gas emissions have unified global consensus on tackling climate change, with carbon pricing playing a crucial role. As a market-driven carbon pricing method, global carbon markets (GCMs) are an effective tool to determine carbon pricing and support the net-zero goal. This report provides a detailed overview of GCM mechanisms, their role in advancing net-zero objectives, their current issues, and a comparison with carbon taxes.

Climate change can significantly impact the investment industry, making it crucial for investors to understand GCMs. On one hand, investment professionals can use GCMs to engage in impact investing—for example, to foster and achieve net-zero goals where an investment strategy specifically incorporates net zero. On the other hand, as a rapidly growing and promising market globally, GCMs offer potential investment and trading opportunities. This report provides investors with a comprehensive introduction to the mechanisms, advantages, and disadvantages of GCMs, addressing gaps in current research.

The report consists of five main chapters:

- The first chapter introduces the background of the Paris Agreement and net zero, along with their relevance to the investment industry.
- The second chapter details the mechanisms of compliance carbon markets (CCMs), including carbon allowances and offsets, the cap-and-trade system, sector coverage, allowance distribution, trading, and price stability. It then takes three well-known CCMs as examples—the EU Emissions Trading System (EU ETS; highest total traded value), the California Cap-and-Trade Program (highest covered percentage), and the China National Emissions Trading Scheme (China National ETS; highest covered absolute emissions)—and provides detailed discussions of governance, coverage, stages of development, allowances, pricing, and market activity for each. In addition, we introduce the mechanisms of voluntary carbon markets (VCMs).
- The third chapter highlights the advantages of GCMs as an effective tool for achieving net zero. Specifically, GCMs contribute to the gradual reduction of carbon emissions. They also price carbon emissions and provide emitters (both covered and not covered) and individuals with opportunities to participate in the global carbon reduction process—advancing the growth of other green technologies and green/transition finance.
- The fourth chapter analyzes the issues and challenges GCMs face. These include (1) unreasonable caps; (2) price fluctuations; (3) disparities in the development of different markets; (4) severe market fragmentation, leading to carbon leakage and carbon arbitrage; (5) the high uncertainty and rapid changes in market and policy developments that impose additional costs on businesses; and (6) limited access for direct investor participation.

- The fifth chapter introduces carbon taxes and compares their method of implementing carbon pricing with that used for GCMs. GCMs are driven by market mechanisms, whereas carbon taxes are influenced by fiscal policy. Each has advantages and disadvantages.

We conclude this report with several findings on GCMs:

1. **GCMs are still evolving.** Although they all use cap-and-trade mechanisms at their core, they are geographically fragmented and vary in scope and design, including different emission reduction targets, timelines, coverage percentages, covered sectors, auction proportions, auction revenue use, and offset acceptance. These variations mainly arise from their respective emission baselines, economic development conditions, and individual goals.
2. **CCMs do not offer a complete solution to carbon pricing.** VCMs fill some gaps in CCMs, particularly in providing carbon offsets and encouraging investor participation, and can play a crucial role in achieving cost-effective emission reductions. Outside the covered emitters, participation in CCMs is limited. In particular, investors have limited involvement in CCMs, and their primary approach to engage in GCMs is through VCMs.
3. **GCMs presently face many challenges.** Tighter integration of GCMs would help expand these markets and could lead to less volatility in carbon prices, further supporting global coordination toward net-zero goals.
4. **GCMs currently generate more revenue than carbon taxes.** Carbon taxes offer simplicity and price stability, though tax revenues may or may not be directed toward emission reduction activities. GCMs have the advantage of clear and transparent carbon reduction targets and typically allocate a high proportion of their revenue to green spending.

This report contributes to the literature by helping investors understand GCMs. Related companies can also use this report to deepen their understanding of GCMs and to inform production decisions and corporate transition planning. In addition, policymakers can use this report to understand the existing issues in GCMs and make targeted policy adjustments.

1. INTRODUCTION

This chapter introduces the background of the Paris Agreement and net zero, along with their relevance to the investment industry.

1.1. Background on Net Zero and Global Carbon Markets

On 12 December 2015, 196 parties signed the Paris Agreement at the UN Climate Change Conference (COP21) in Paris. This legally binding international treaty on climate change took effect on 4 November 2016. Its primary goal is to limit the rise in global average temperature to below 2 degrees Celsius above preindustrial levels while striving to keep it under 1.5 degrees Celsius. Each signatory must submit its nationally determined contributions (NDCs) that outline the emission reduction measures it plans to implement.[1,2] To achieve this goal, it is essential to reduce global carbon emissions by 45% by 2030 and reach net zero by 2050. According to UN Climate Action, achieving net zero involves reducing carbon emissions to minimal residual emissions, which natural and other carbon dioxide removal measures can absorb and store permanently.[3]

Carbon dioxide (CO_2) is the primary greenhouse gas (GHG) driving global climate change due to its high human-driven emissions and long atmospheric lifetime (Fankhauser, Smith, Allen, Axelsson, Hale, Hepburn, Kendall, Khosla, Lezaun, Mitchell-Larson, Obersteiner, Rajamani, Rickaby, Seddon, and Wetzer 2022). Consequently, both the Paris Agreement and the net-zero target focus on reducing CO_2 emissions. Industrial production results in significant carbon emissions, incurring potentially substantial social costs that producers do not bear. Therefore, pricing carbon emissions is crucial to incentivize companies to internalize the negative externalities their operations impose on society, playing a vital role in achieving the net-zero target. Carbon pricing can be implemented in two ways: by directly levying a carbon tax or by utilizing carbon markets through market mechanisms. This report focuses on carbon markets and compares these two approaches in Chapter 5.

As a market-based solution, global carbon markets (GCMs) are an effective tool to determine carbon pricing and support the net-zero goal. GCMs refer to the market mechanism that achieves carbon reduction targets by capping the total number of carbon emission allowances/permits. As a continuously evolving market mechanism, GCMs have seen rapid growth worldwide. According to the International Carbon Action Partnership (ICAP), GCMs expanded from only the European Union Emissions Trading System (EU ETS) in 2005 to cover

[1]https://unfccc.int/process-and-meetings/the-paris-agreement.

[2]According to UN Climate Action, all parties to the Paris Agreement have issued at least a first NDC. In addition, 151 parties submitted a new/updated NDC as of 2021. See www.un.org/en/climatechange/all-about-ndcs.

[3]www.un.org/en/climatechange/net-zero-coalition.

58 countries and regions by 2024.[4] The World Bank reports that GCMs covered about 19% of emissions by 2024, up from approximately 7.9% in 2020.[5] The implementation of carbon reduction measures by various countries has led to a significant increase in carbon prices. According to LSEG, the EU allowance (EUA) price reached a historic high of €100.34 per metric ton of CO_2 equivalent (tCO_2e) in February 2023, compared with just €2.75 in April 2013.[6] The development of GCMs has also driven the rapid growth of related financial products, such as carbon credits. By setting a price on emissions, GCMs also incentivize covered emitters to invest in low-carbon technologies and projects that require capital, indirectly supporting the development of green finance more generally. A BloombergNEF report suggests that the global sustainable finance market size was over $4 trillion in 2021 (BloombergNEF 2022).

GCMs have become a powerful tool for supporting net-zero targets. For example, the total verified carbon emissions from covered emitters under the EU ETS decreased by 41% in 2020 compared with 2005 when the system began (European Environment Agency 2022). California's carbon market, the largest state-level carbon trading system in the United States, expects to reduce the state's emissions by more than 40% below 1990 levels by 2030 (California Air Resources Board 2022). However, according to the International Energy Agency, the existing climate commitments are still insufficient to achieve net zero by 2050 (IEA 2022). Therefore, GCMs must play a greater role. Additionally, under the global cooperation envisioned by the Paris Agreement, countries are continuously strengthening their communication and collaboration, which will further promote the sustained development of GCMs.

1.2. Relevance to the Investment Industry

From a broad perspective, climate change can have a substantial and lasting impact on the investment industry and the practice of investment management. It creates new investment opportunities as innovative new decarbonization and clean energy technologies in need of capital are developed. At the same time, the operational risks, policy risks, cost increases, profit fluctuations, and physical and transition risks to existing industries caused by climate change directly affect companies' profits and, thus, investors' returns. Investors should be fully aware of and understand these potential risks.[7]

Therefore, understanding how GCMs play a part in mitigating climate change is crucial for the investment industry. On one hand, as an effective tool to reduce carbon emissions, investment professionals with climate-related goals can use GCMs to engage in impact investing to foster and achieve net-zero objectives. According to PwC (2023), the proportion of private market investments

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[4]See the ICAP ETS map at https://icapcarbonaction.com/en/ets.

[5]https://carbonpricingdashboard.worldbank.org/compliance/coverage.

[6]In October 2007, London Stock Exchange and Italian Stock Exchange in Milan (Borsa Italiana) merged, creating London Stock Exchange Group (LSEG).

[7]A working paper by Pang and Shrimali (2024) develops climate stress testing focused on transition risk.

(including both private equity and venture capital) allocated to climate tech rose to 11.4% in Q3 2023 and was on track to maintain an annual rate of 10% for the year. This continued a decade-long trend of increasing investment in this sector, suggesting investors seek capital gains while aiming to combat climate change (PwC 2023). On the other hand, as a rapidly growing and promising market globally, GCMs offer new potential investment and trading opportunities.

Specifically, the investment industry may use GCMs in the following ways:

- *Supporting global climate goals:* Investors can contribute to the development of GCMs through participation and related investments, thereby advancing global climate objectives.
- *New investment opportunities:* Carbon trading offers investors new investment strategies and products that are less correlated with traditional investment options, such as equities, bonds, and real estate.
- *Financial analysis and company valuation:* As the compliance carbon market expands to cover more industries, it forces companies to internalize the cost of carbon emissions into production costs, thereby affecting financial performance, market valuations, and investor returns.

Therefore, a comprehensive and accurate understanding of GCMs helps investors respond to global emission reduction initiatives and explore new investment opportunities.

1.3. Gaps in the Current Literature

In this section, we discuss the current literature on GCMs and the gaps in the literature.

Carbon Market Overview

Newell, Pizer, and Raimi (2014) introduce the origin, development, and prospects of the early GCMs based on the Kyoto Protocol. Schmalensee and Stavins (2017) provide an overview of the design and performance of seven major emissions trading programs, summarizing their experiences. Udara Willhelm Abeydeera, Wadu Mesthrige, and Samarasinghalage (2019) review the current literature on carbon emissions and offer references for carbon emission control policies and future carbon reduction targets. Pollitt (2019) discusses the successes of the EU ETS, the Australian carbon tax, and carbon market initiatives in the United States and China, emphasizing the importance of global collaboration. Shen, Zhao, and Deng (2020) summarize the existing research and development trends in carbon trading. Reports by the World Bank (2023), JPMorgan Chase & Co. (2023), McKinsey (2021), and BCG (Porsborg-Smith, Nielsen, Owolabi, and Clayton 2023) focus on the specific aspects of the carbon market mechanism, such as pricing mechanisms, voluntary carbon market projects, and regional regulations. Ji, Hu, and Tang (2018) focus on the price determination mechanism and analyze the theoretical basis of carbon price formation and the carbon price transmission mechanism from the perspective of market participants. Song (2024) uses China's carbon market to investigate carbon price changes and the development of international carbon credits. The article explores models that can effectively predict carbon prices.

Effectiveness of Carbon Markets

Hu, Li, and Tang (2017) use the Beijing pilot carbon market as a case study to assess the operational performance and maturity of the carbon trading program, offering improvement suggestions regarding quota management, carbon trading activity, market liquidity, technology innovation, and carbon trading disclosure. Cui, Zhang, and Zheng (2018) evaluate the effect of ETS on low-carbon innovation at the firm level and find that the ETS facilitates innovation in low-carbon technologies. Zhou, Xin, and Li (2022) reveal that carbon markets help reduce energy intensity but have an unstable impact on improving carbon efficiency. Liu, Qiu, Jia, and Zhou (2022) show that the carbon emissions trading policy can significantly promote green technology innovation but with a lagged effect.

Challenges for Carbon Markets

Tuerk, Mehling, Flachsland, and Sterk (2009) study the feasibility of different forms of linking between carbon markets and the time frames for their implementation. The paper finds that only a few direct bilateral links are viable in the short term because of the divergent policy priorities of different nations and regions, calling for global cooperation. Newell, Pizer, and Raimi (2013) outline the challenges for GCMs and suggest that there should be fewer free allowances, better management of market-sensitive information, and an integrated global trading architecture. Betz, Michaelowa, Castro, Kotsch, Mehling, Michaelowa, and Baranzini (2022) also focus on the challenges for GCMs and offer policy and governance solutions to the risks and abuses to environmental integrity.

Carbon Pricing

Känzig and Konradt (2023) use the EU ETS to analyze the impact of carbon pricing on the economy. The paper finds that while both policies (carbon taxes and carbon markets) are effective in reducing carbon emissions, the economic costs with the carbon market are higher than those with carbon taxes due to such factors as fiscal policy and revenue recycling, pass-through and sectoral coverage, spillovers and leakage, and monetary policy. Millischer, Evdokimova, and Fernandez (2023) study whether European stock markets incorporate carbon prices in company valuations and how they discriminate between firms with different carbon intensities. The paper shows that stock markets can play a key role in the low-carbon transition, especially with clear carbon pricing and disclosure systems. The financial market's response can encourage high-emission firms to reduce emissions and invest more in low-carbon and clean energy projects. Macaluso, Tuladhar, Woollacott, Mcfarland, Creason, and Cole (2018) discuss the implications of carbon tax scenarios on sectoral output changes, energy production and consumption, and the competitiveness of the US economy. The paper suggests that variations in carbon tax trajectories and different options for using the tax revenue lead to varying levels of impact.

Research on carbon markets published by CFA Institute, such as Azlen, Child, and Gostlow (2020), offers a high-level introduction to emissions trading systems (ETSs) and emphasizes carbon's potential as an asset class.[8] Moreover, research studies published by CFA Institute in the *Financial Analysts Journal* (Andersson, Bolton, and Samama 2016; Bolton, Kacperczyk, and Samama 2022; Furdak and Wee 2020) mention carbon markets, but they focus primarily on portfolio management from a technical perspective. Compared to the study by Azlen et al. (2020), this report broadens the research scope and topic coverage, provides a detailed analysis of GCMs, and highlights the function of GCMs as an effective tool for net zero.

Gaps in the Literature

The rapid expansion and highly fragmented nature of GCMs have led to three major gaps in current research:

- *Research scope:* Most research focuses on a given regional carbon market, such as those in the EU, California, or China, and presents case studies. Investment professionals should understand the differences among GCMs so they can determine the extent to which these markets contribute to emission reductions in a given region and the issues that impede greater market integration toward more unified carbon pricing.
- *Issues of GCMs:* There is a lack of an in-depth discussion of GCM issues concerning market structure and functioning, but these issues are essential to understand before investment professionals can effectively participate in these markets.
- *Comparison between carbon taxes and carbon markets:* A comparison of the two methods of carbon pricing is essential to understanding them so investment professionals, policymakers, and other stakeholders can evaluate and weigh their pros and cons.

Through three major examples, this report fills these gaps and will help the investment industry better understand GCMs by comprehensively reviewing their mechanisms, analyzing their advantages and disadvantages, and comparing them with carbon taxes.

[8]The case study by Azlen et al. (2020) originally appeared in the CFA Institute report "Climate Change Analysis in the Investment Process" (Orsagh 2020). CFA Institute complemented the report with an episode of *The Sustainability Story* podcast (CFA Institute 2021) and in a blog post by Voss (2021). Azlen also provided a short discussion on carbon pricing in a webinar hosted by CFA Society Philadelphia (Azlen 2020).

2. OVERVIEW OF GLOBAL CARBON MARKETS

This chapter details the mechanisms of compliance carbon markets (CCMs) and takes three well-known CCMs as examples—the EU ETS, the California Cap-and-Trade Program, and the China National ETS. In addition, this chapter introduces the mechanisms of voluntary carbon markets (VCMs).

2.1. Compliance Carbon Markets

CCMs are the predominant form of GCMs, significantly surpassing their counterpart, the VCMs, in scale. In 2023, the traded value of global CCMs reached a record €881 billion ($948.75 billion), showing a 2% increase from 2022, as reported by LSEG (Twidale 2024).[9] CCMs operate with regulatory force with the goal of controlling and reducing carbon emissions from covered emitters by setting a jurisdictional limit on carbon emissions.

Exhibit 1 shows the list of CCMs. According to ICAP, there are currently 58 CCMs globally, with 36 in force, 14 under development, and 8 under consideration. Notable examples include the EU ETS (highest total traded value), the California Cap-and-Trade Program (highest covered percentage), and the China National ETS (highest covered absolute emissions).[10]

2.1.1. The Mechanisms

This section introduces the mechanisms of CCMs, including carbon allowances and offsets, the cap-and-trade system, sector coverage, allowance distribution, trading, and price stability.

Carbon Allowances and Offsets

The two fundamental elements of CCMs are carbon allowances and carbon offsets. A carbon allowance, or carbon permit, legally permits the emission of one tCO_2e within a calendar year under the CCM framework. A carbon offset, or carbon credit, in contrast, represents the reduction of one tCO_2e by either decreasing CO_2 emissions or removing previously emitted CO_2, such

[9]For reference, the NYSE daily trading volume of US securities was $103 billion (Cboe Global Markets, five-day average for the week of 12 August 2024; www.cboe.com/). The global crude oil market's size in 2023 was $1,450 billion (MMR; www.maximizemarketresearch.com/market-report/global-crude-oil-market/72016/).

[10]There are three metrics to evaluate the market size of CCMs: total traded value, covered percentage, and covered absolute emissions. Total traded value refers to the total financial value of all transactions within a given carbon market. The EU ETS had a total traded value of €770 billion in 2023, representing 87% of the global total for that year, representing the highest total traded value worldwide (Twidale 2024). The covered percentage indicates the proportion of total carbon emissions within a jurisdiction regulated by the carbon market. The California Cap-and-Trade Program covered around 80% of the state's carbon emissions in 2023, representing the highest covered percentage worldwide. The covered absolute emissions refer to the actual amount of carbon emissions regulated by the carbon market, measured in metric tons of CO_2 equivalent (tCO_2e). China's national carbon market covered around 5.1 billion tCO_2e in 2023, about 14% of the world's total carbon emissions for that year (37.4 billion tCO_2e; IEA 2024), representing the highest covered absolute emissions worldwide (Lv and Stanway 2024).

Exhibit 1. List of Global Compliance Carbon Markets

In Force (36)			Under Development (14)		Under Consideration (8)
Australia	Germany	Mexico	Brazil	Russia: Sakhalin	Argentina
Austria	Indonesia	Montenegro	Canada national (Oil & Gas)	Turkey	Chile
Canada regional (8)[a]	Japan: Saitama	New Zealand	Colombia	Ukraine	Malaysia
Canada federal	Japan: Tokyo	Switzerland	EU ETS 2[d]	USA regional (4)[e]	Pakistan
Mainland China regional (8)[b]	Kazakhstan	United Kingdom	India	Vietnam	Philippines
China national	South Korea	USA regional (4)[c]	Japan		Taiwan, China
EU					Thailand
					USA: Maryland

[a]Canada has eight regional carbon markets in force: Alberta (2020), British Columbia (2024), New Brunswick (2021), Newfoundland and Labrador (2019), Nova Scotia (2023), Ontario (2022), Quebec (2013), and Saskatchewan (2023). [b]Mainland China has eight regional pilot carbon markets in force: Beijing (2013), Chongqing (2014), Fujian (2016), Guangdong (2013), Hubei (2014), Shanghai (2013), Shenzhen (2013), and Tianjin (2013). [c]The United States has four regional carbon markets in force: California (2012), Massachusetts (2018), Regional Greenhouse Gas Initiative (RGGI, 2009), and Washington State (2023). [d]The EU ETS 2 is a new and separate ETS specifically targeting emissions from fuels used for combustion in buildings, road transport, and other smaller sectors not covered under the current EU ETS. It is designed to complement the existing EU ETS. [e]The United States has four regional carbon markets under development: Colorado, New York, Oregon, and Pennsylvania.

Source: ICAP (2024).

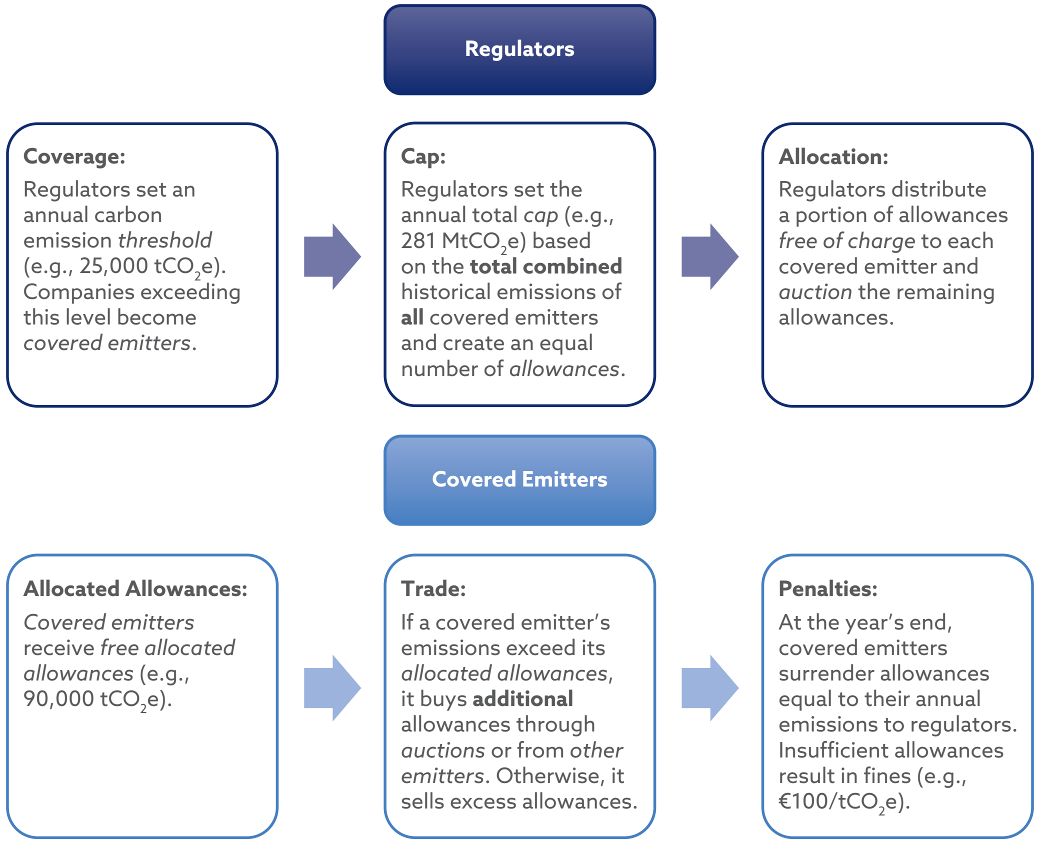
as through land restoration or tree planting. CCMs issue carbon allowances to covered entities as emission permits. Covered entities must submit carbon allowances annually to match their carbon emissions. Conversely, VCMs issue carbon offsets only. Some CCMs, however, such as the California Cap-and-Trade Program and the Regional Greenhouse Gas Initiative (RGGI), allow entities to submit carbon offsets to match their carbon emissions. Others, such as the EU ETS, do not accept carbon offsets. Even in markets where offsets can be used to match emissions, there are often many restrictions. As a result, the use of carbon offsets in CCMs is currently quite limited.

Cap-and-Trade System

At its core, a CCM operates a cap-and-trade system based on carbon allowances and, possibly, offsets. **Exhibit 2** illustrates the structure of the cap-and-trade system and key concepts. Regulators overseeing the CCM must first set a threshold for companies' annual carbon emissions (e.g., 25,000 tCO_2e), typically based on Scope 1 emissions.[11] Companies exceeding this threshold become

[11]The GHG Protocol categorizes corporate carbon emissions into three scopes. Scope 1 includes direct emissions from sources that a company owns or controls. Scope 2 consists of indirect emissions from the generation of purchased energy consumed by the company. Scope 3 covers all other indirect emissions resulting from the company's activities, occurring in the value chain both upstream and downstream. See https://ghgprotocol.org/.

Exhibit 2. Key Terms for the Cap-and-Trade System



covered emitters and fall under the CCM's regulation. Some carbon markets, such as China's national carbon market, apply a uniform threshold across all sectors; other carbon markets, such as the EU ETS and the California Cap-and-Trade Program, calculate different thresholds for different industrial sectors. After identifying covered emitters, regulators set a cap—for example, 281 million tCO_2e or 281 $MtCO_2e$ (million tCO_2e)—based on emitters' historical total combined emissions, representing the annual total emission target of the CCM. The cap is usually lower than the historical total emissions to achieve emission reduction. The cap aims to decrease annually, ideally approaching zero over a given time frame. Regulators then issue an equivalent number of emission allowances.[12]

The threshold and the "cap" are not the same. The threshold determines whether a company falls under CCM regulation, corresponding to the emission level of a single emitter. In contrast, the cap sets a collective limit for all covered emitters, often matching the emissions of hundreds or thousands of emitters. Regulators distribute a portion of the allowances for free to each

[12]Currently, in all major carbon markets, a carbon allowance corresponds to 1 tCO_2e. Similarly, one carbon offset typically corresponds to 1 tCO_2e in VCMs.

covered emitter. The number of free allocated allowances each emitter receives depends on such factors as historical emissions, reduction difficulty, production levels, and industry competitiveness but not on the threshold. The regulators distribute the remaining allowances via auctions.

From a company's perspective, those with annual emissions exceeding the threshold become covered emitters and receive a certain number of free allocated allowances. If a company's annual emissions surpass its allocated allowances, it must purchase additional allowances either through auctions or by trading with other covered emitters in the CCM. Conversely, companies with emissions below their allocated allowances can sell the surplus allowances for profit. Companies must match their annual emissions with allowances by the year's end, as covered emitters must surrender allowances equal to their annual emissions to regulators. Failure to submit sufficient allowances results in fines (e.g., €100/tCO_2e) or more severe penalties. Once submitted, the regulators cancel the allowances, effectively removing them from circulation to ensure they cannot be reused. Allowances are typically valid for multiple years. Many CCMs, such as the EU ETS, allow "banking" of unused allowances for future use or "borrowing" of future allowances in case of current shortfalls.

At the company level, the CCM does not set a hard cap on a single company's emissions. While companies receive a limited number of free allocated allowances initially, they can obtain additional allowances through auctions or trading with other companies. Even if emissions exceed their allowances, companies can opt to pay fines or accept penalties. However, the CCM's regulations increase the cost of emissions, incentivizing companies to reduce their carbon footprint. At the overall carbon market level, the cap sets the total annual emissions goal. The cap is not absolute, since some companies may exceed their allowances, leading to total emissions above the cap. These companies, however, will face fines or other penalties, so collective emissions rarely exceed the cap.

As a hypothetical example, suppose the regulator in Country A sets a 25,000 tCO_2e threshold, bringing companies with annual emissions above this level under CCM regulation. Based on this threshold, it identifies 400 covered emitters, with a historical total combined annual emission of 400 MtCO_2e. The regulator then sets a cap at 350 MtCO_2e and issues an equivalent number of allowances. It distributes 70% (245 MtCO_2e) of the allowances for free to the covered emitters while auctioning the remaining 30% (105 MtCO_2e) gradually throughout the year. Company B, operating in Country A, with annual emissions of 50,000 tCO_2e, falls under the CCM regulation and receives 40,000 tCO_2e of allowances based on past emissions and other factors. Near the year's end, anticipating total annual emissions of 45,000 tCO_2e, Company B purchases 2,000 tCO_2e of allowances via auction and buys 3,000 tCO_2e of allowances from other, lower-emission companies to meet the regulator's requirements.

When emitters need to buy additional allowances or wish to sell unused ones, the "trade" system comes into play. Demand and supply determine the allowance prices, compelling emitters to internalize the externalities of carbon emissions into their production costs. CCMs use annually decreasing carbon caps and market-driven carbon pricing mechanisms to encourage emitters to reduce emissions and explore green energy transitions.

Some CCMs also permit covered emitters to purchase and submit carbon offsets to match their emissions. Like carbon allowances, entities surrender carbon offsets to the regulatory authority, which then removes these offsets from circulation once submitted. Since some regions, such as Africa and South America, have lower costs for emission reductions, emitters may purchase carbon offsets backed by carbon-reduction projects in these regions at lower prices than those for carbon allowances in the emitter's local CCM jurisdiction. This use of carbon offsets and allowances (and the combination thereof) aligns with the goal of reducing emissions at the lowest costs possible for the covered entity.

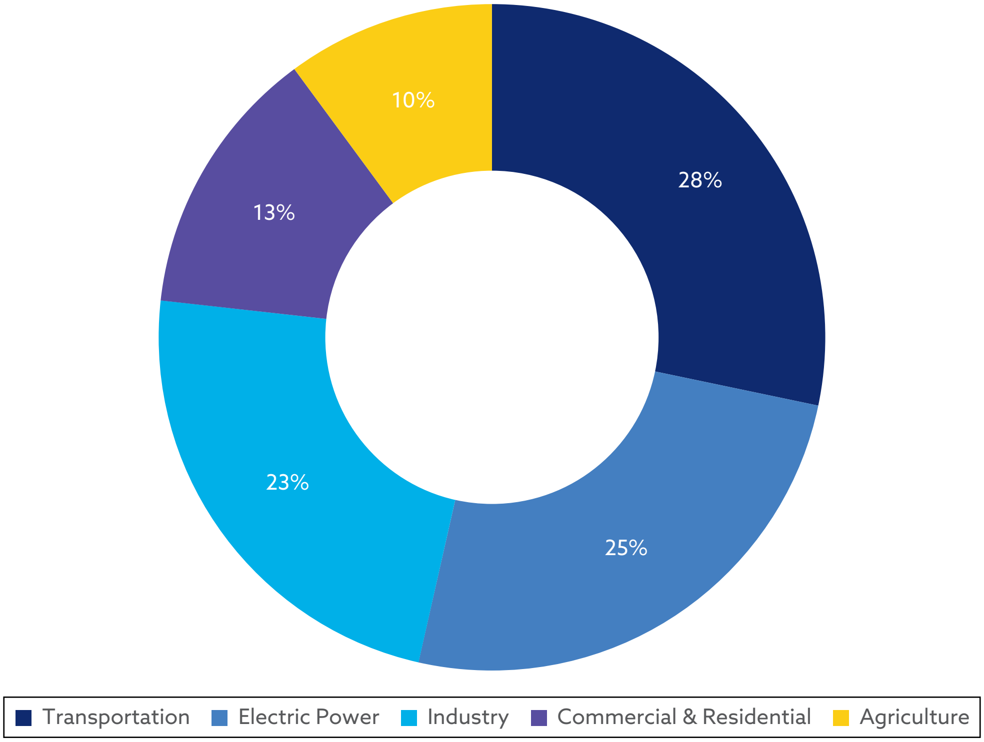
However, as global efforts to reduce carbon emissions expand, the cost of carbon offsets is expected to gradually increase. While emitters can reduce their emission costs by participating in these projects in the short term, this practice is not sustainable in the long term. Additionally, carbon offsets are a vital element of VCMs; their role in achieving net-zero targets over the long term is potentially significant. As caps and allowances in CCMs decrease over the long term, carbon offsets will likely be the only way to balance some unavoidable GHG emissions, such as those from livestock or agriculture. Independent standard-setting entities are typically responsible for certifying projects related to carbon offsets, and the requirements for using carbon offsets vary among different CCMs.

Sector Coverage

Exhibit 3 presents the total US GHG emissions by economic sector in 2022. According to the US Environmental Protection Agency (EPA), the primary sectors for GHG emissions in 2022 were transportation (28%), electric power (25%), and industry (23%). Transportation has surpassed electric power as the main source of emissions in recent years. Most CCMs cover these three sectors to varying degrees.

CCMs generally cover medium and large emitters but typically allow small emitters to join voluntarily. In addition, as the cap decreases, the emission threshold is typically lowered so that, eventually, most emitters will be covered. This mechanism provides small emitters with time to transition to clean energy. Once the authorities determine the covered sectors and entities subject to the emission threshold and set the overall cap, they assign individual quotas to each sector and entity based on certain rules.

Exhibit 3. Total US GHG Emissions by Economic Sector in 2022



Note: According to the EPA (2024), the industry economic sector includes CO_2 emissions from the combustion of fossil fuels that are included in the Energy Information Administration's industrial fuel-consuming sector, minus the agricultural use of fuel. Examples include coal mining, the mineral industry, the chemical industry, and the metal industry.

Source: EPA (www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks).

Allowance Distribution

The two main methods of allowance distribution are free allocation and auction. Some CCMs, such as the EU ETS, have historically relied on free allocation to distribute most allowances, typically to energy-intensive industries—though a significant proportion of allowances are distributed via auction. The purpose is to prevent overaggressive cost increases that could reduce the international competitiveness of covered emitters. This allocation method offers the advantage of achieving emission reduction targets in a more gradual manner. As reduction goals progress, the proportion of free allocation in these CCMs will gradually decrease, shifting toward auctions.

US CCMs primarily use auctions to distribute allowances. The frequency of auctions ranges from daily to several times a week. Covered emitters obtain allowances by submitting bids to the issuing authority. This method has the benefit of distributing allowances to the most efficient emitters at the lowest economic costs through the market mechanism. Additionally, the clearing prices from auctions provide emitters with crucial information for cost planning. It is important to note that some CCMs, such as the EU ETS, may cancel an auction if there are only limited bids or if bid prices are too low to ensure reasonable pricing.

A potential downside of this method is that, like taxes, auction revenues do not necessarily apply to initiatives related to climate change. The use of auction revenue varies among carbon markets, either as general government revenue or specifically for green finance projects. The EU ETS primarily directs auction revenue to member states' budgets. However, according to the European Environment Agency (2023), member states must allocate 50% of the auction revenue generated by mid-2023 and all auction revenue thereafter to support climate and energy objectives; 76% of the auction revenue was used for these purposes in 2021 and 2022. Member states must disclose their use of auction revenue annually to the European Commission. The EU ETS also auctions a portion of allowances to specifically fund the Innovation and Modernization Funds, which support decarbonization in the covered sectors.[13] In California, most auction revenue (63% in Q2 2024) is allocated to the Greenhouse Gas Reduction Fund (California Climate Investments 2024), while the reminder (37% in Q2 2024) goes to California Climate Credits provided to utilities for ratepayer protection (California Air Resources Board 2024). California Climate Investments, solely funded by the allowance auction revenue, aims to aid disadvantaged and low-income communities.[14] According to California Climate Investments (2024), by December 2023, the California Cap-and-Trade Program had invested $11 billion of the auction revenue in approximately 578,500 projects, reducing emissions by 109 $MtCO_2e$. In contrast, China's national carbon market currently lacks specific regulations for the use of auction revenue. Overall, the distribution of auction revenue across carbon markets reflects different priorities and regulatory frameworks.

Trading

Allowance trading occurs through both over-the-counter (OTC) transactions and organized exchanges. The balance between these methods varies significantly among carbon markets. In OTC transactions, parties directly negotiate and execute trades without an exchange intermediary, allowing customized contracts and flexible settlement dates. This method offers privacy and the ability to tailor agreements to meet specific needs, though it generally lacks transparency. In contrast, allowance trading on organized exchanges, such as the European Energy Exchange (EEX) and the Intercontinental Exchange (ICE), follows strict regulations. These exchanges ensure greater transparency, liquidity, and a clear price discovery process through standardized contracts. Prominent platforms (such as ICE and EEX) handle a substantial volume of carbon allowance trades and offer various carbon products, including futures and options contracts. Covered emitters can use these products to meet immediate compliance needs or hedge against future emission cost risks.

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[13]https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/auctioning_en#auctioning-revenues-and-their-use.

[14]www.caclimateinvestments.ca.gov/.

The proportion of OTC versus exchange trading can differ, but exchange trading usually dominates in markets with stricter transparency and regulatory requirements, such as the EU ETS and the California Cap-and-Trade Program. However, market participants continue to use OTC trading due to its flexibility and privacy benefits. Financial institutions are increasingly participating in trading, either acting as market makers or providing related services to large emitters.

Price Stability

As a developing market mechanism, high price volatility is a characteristic of CCMs. Similar to how central banks stabilize financial markets through open market operations, regulatory bodies typically stabilize allowance prices by setting up allowance reserves. When market prices exceed the predefined price range, it triggers the release or withholding of allowances to bring prices back into the normal range. The price ceiling protects covered emitters from significant price shocks. In addition, carbon allowance auctions typically set an auction reserve price as a price floor. Fines levied on firms resulting from insufficient allowances also implicitly establish a price floor for carbon emissions.

2.1.2. EU Emissions Trading System

The European Union launched the EU ETS in 2005 as the world's first major carbon trading market. As a critical component of the EU's strategy to combat climate change under the European Green Deal, the EU ETS aims to reduce GHG emissions economically and effectively. The system originated from the EU's commitments under the Kyoto Protocol, which set binding emission reduction targets for participating countries. The origin of the EU ETS traces back to the late 1990s when the EU began to explore cost-effective ways to reduce GHG emissions across its member states. The goal was to establish a market-driven approach to managing carbon emissions by setting an overall emission cap and allowing entities to trade allowances to meet their specific targets.

The EU ETS aims to reduce net emissions to at least 55% below 1990 levels by 2030 and achieve climate neutrality by 2050, aligning with the European Climate Law.[15] According to ICAP, the EU ETS covered 38% of the EU's emissions in 2021, and the cap for 2024 is 1,386 $MtCO_2e$.[16] The EU ETS permits the banking of allowances starting from 2008 but does not allow borrowing between periods. The average auction price of an EU allowance was €83.24 ($90) in 2023.

[15]https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/our-ambition-2030_en.

[16]https://icapcarbonaction.com/en/ets/eu-emissions-trading-system-eu-ets.

Governance

The governance of the EU ETS is a complex multilevel framework includes the European Commission, member states, and various regulatory bodies. The European Commission manages the overall system and its reform. It determines the emission caps for participants and is responsible for legislative initiatives to enhance the system. Member states focus on the daily management of the EU ETS, translating EU directives into national laws, managing allowance allocations, and ensuring the compliance of covered emitters.

Coverage

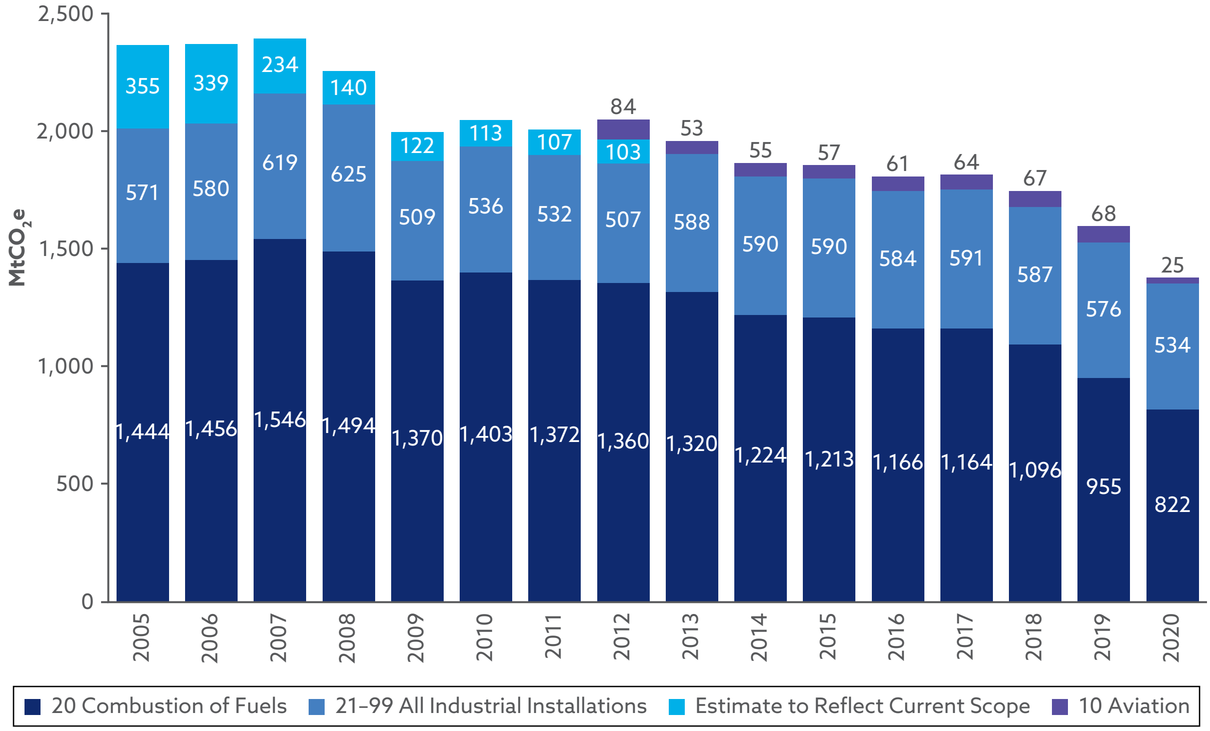
The EU ETS extends beyond the 27 EU member states to include Iceland, Liechtenstein, and Norway through the European Economic Area agreement, thus covering 30 countries in total. It integrates these three countries into the EU's climate policy and establishes a collective strategy to reduce emissions across Europe. According to ICAP, the EU ETS covers over 11,000 energy-intensive installations, such as power stations, industrial plants, and airlines, operating in these countries. It covers the major sources of GHGs in Europe, including electricity and heat generation, energy-intensive industries (such as oil refineries and those involved in the production of steel, iron, and aluminum), and aviation.

Exhibit 4 displays the breakdown of CO_2 emissions from various sectors in the EU ETS from 2005 to 2020 (end of Phase III), with each color representing a different sector. The combustion of fuels consistently contributes the majority of emissions over this period. This sector showed a slight decline over time, suggesting improvements in fuel combustion efficiency, a shift toward less carbon-intensive fuels, or both. Industrial installations initially maintained a relatively stable emission level but exhibited a noticeable decrease after 2017. This decrease may result from regulatory measures, technological advancements, or structural changes within the industrial sectors. Aviation emissions increased until around 2019 and then experienced a sharp decline in 2020. The significant drop in 2020 likely stemmed from the global reduction in air travel due to the COVID-19 pandemic. Over this period, total emissions demonstrated a downward trend, reflecting the EU ETS's overall success in reducing emissions in the covered sectors. The year 2020 stands out with a substantial decrease in emissions in all sectors, especially in aviation, influenced by the COVID-19 pandemic's impact on economic and social activities.

Development

The development of the EU ETS has occurred in four phases since 2005. Each phase had its own unique focuses, goals, and lessons learned. Phase I aimed to establish a functional carbon market. Phase II focused on optimizing emission reduction targets. Phase III started significant reforms. The current phase, Phase IV, further expands the scope and coverage of the EU ETS.

Exhibit 4. Carbon Emissions by Activity Type for the EU ETS Member States, 2005–2020



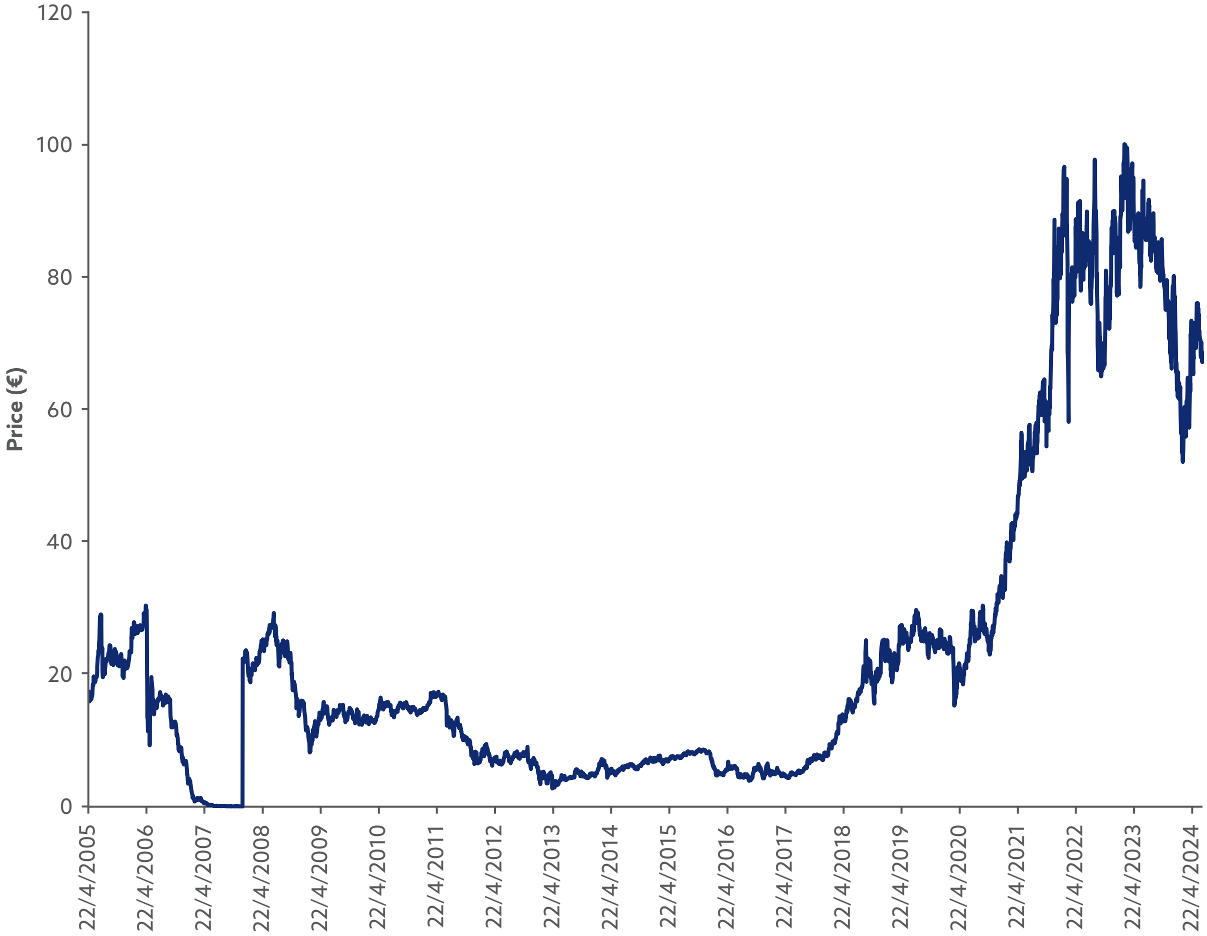
Notes: "Estimate to reflect current scope" in 2005–2012 means the exhibit adjusts emission data in Phase I (2005–2007) and Phase II (2008–2012) to match the industry coverage of the EU ETS in Phase III (2013–2020), ensuring consistent year-over-year comparisons. For example, because the EU ETS initially covered only certain sectors and later expanded to include more sectors, the emission data for earlier years were adjusted to reflect what they would have been under the expanded scope.

Source: European Environment Agency (www.eea.europa.eu/data-and-maps/daviz/eu-ets-emissions-by-activity-type-2#tab-googlechartid_chart_31).

Phase I (2005–2007)

The first phase was a pilot program from 2005 to 2007, covering over 10,000 large industrial emitters and power plants. The primary goal was to establish a functional carbon market and test the mechanisms. Authorities distributed nearly all allowances through free allocation and set the noncompliance penalty at €40/tCO_2e. Phase I successfully established a market price for carbon by allowing free trade of allowances and built a comprehensive infrastructure for monitoring, reporting, and verifying emissions. However, it faced significant challenges, particularly the overallocation of allowances, leading to a price collapse (see **Exhibit 5**). This situation occurred because member states overestimated emissions in their national allocation plans, resulting in an oversupply of allowances.

Exhibit 5. EU ETS Carbon Price, April 2005–April 2024



Note: The exhibit shows the trade price for the ICE ECX Front December EUA Futures contract.

Source: LSEG.

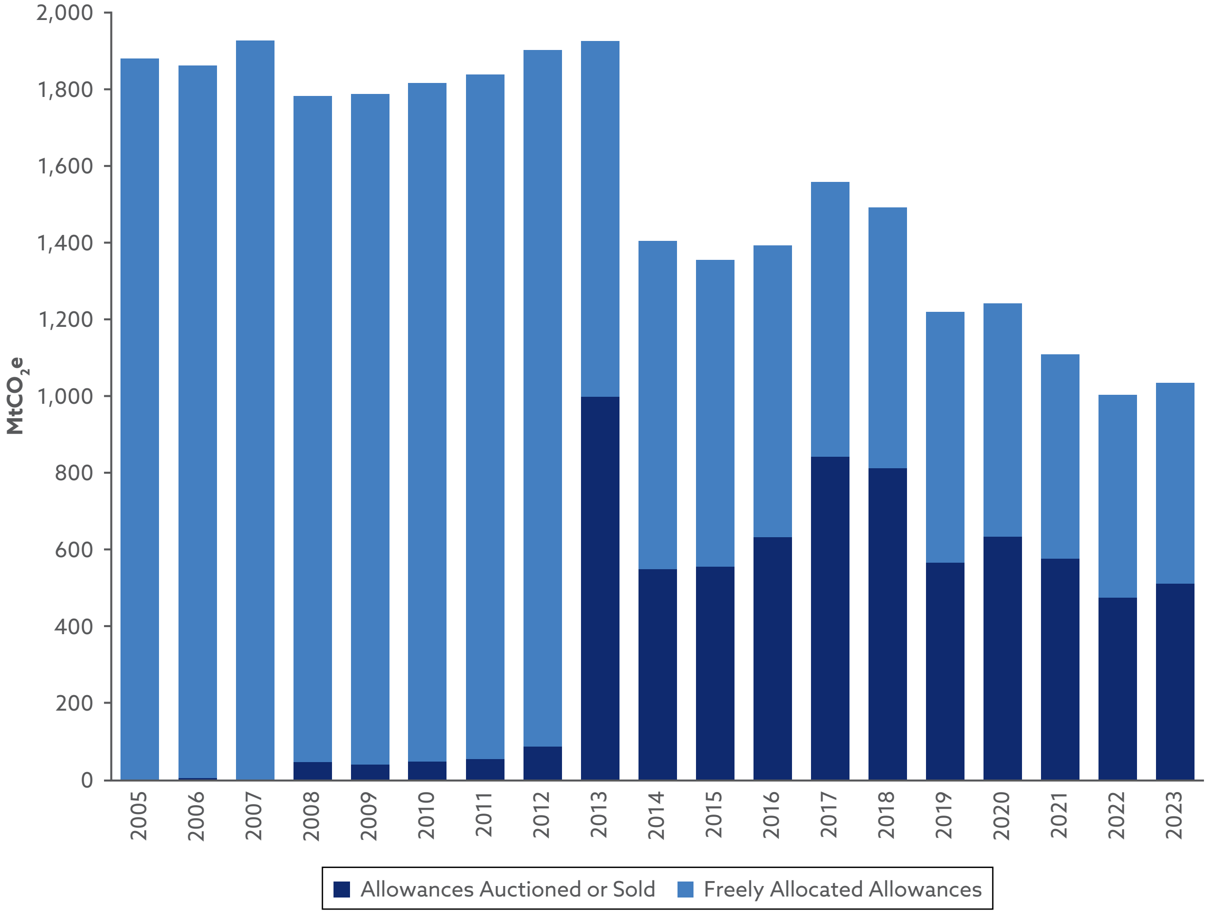
Phase II (2008–2012)

Phase II coincided with the first commitment period of the Kyoto Protocol, seeking to solve the issues of Phase I by tightening the allowance cap and enhancing the emission data accuracy for allocations. This phase expanded the coverage of the EU ETS to include three new countries—Iceland, Liechtenstein, and Norway. The cap for this phase was approximately 6.5% lower compared to 2005 levels, representing a significant step toward actual emission reductions. During this period, the carbon price was more stable (as shown in Exhibit 5), although it still fluctuated due to economic variables and industrial activities across the EU.

Phase III (2013–2020)

Phase III brought several significant reforms to enhance the EU ETS. It replaced the individual national caps from earlier phases with a single EU-wide emission cap, promoting a fairer and more consistent regulatory framework across all member states. Authorities auctioned a significant proportion of allowances instead of free allocation (see **Exhibit 6**), enhancing economic efficiency and reducing the risk of carbon leakage.[17] A key innovation in Phase III was the establishment of the Market Stability Reserve (MSR) in 2019. The MSR aimed to manage the market's allowance surplus and enhance the system's resilience against significant shocks by automatically adjusting allowance supply based on a predefined price range.

Exhibit 6. Total Allocated EU Allowances, 2005–2023



Source: European Environment Agency, EU ETS data viewer (www.eea.europa.eu/data-and-maps/dashboards/emissions-trading-viewer-1).

[17]Carbon leakage occurs when a company that is facing increased costs due to the carbon emission regulations in its original market moves its operations to another market without such regulations. Chapter 4 discusses this issue.

Phase IV (2021–2030)

Phase IV aligns with the EU's heightened climate goals outlined in the European Green Deal. The cap continues to decrease annually by 2.2%, and the system expands to cover emissions from maritime transport. Furthermore, Phase IV tightens the free allocation regulations to incentivize covered emitters to innovate and reduce emissions. The management of carbon market adjustments, including the MSR, is also under review to improve market stability and price predictability. Since the beginning of 2020, the market has seen a significant increase in carbon prices, partly reflecting the scope expansion and continued cap reductions.

Carbon Offsets

According to ICAP, in Phase I, the EU ETS permitted the unlimited use of Clean Development Mechanism (CDM) and joint implementation (JI) credits.[18] However, due to an oversupply of allowances and low prices, covered entities did not use any offset credits during this period. In Phase II, the EU ETS allowed most CDM/JI credits to cover only a certain proportion of emissions. Covered entities used 1,058 $MtCO_2e$ of international credits in this phase. In Phase III, the EU ETS strictly limited the use of offset credits. Since March 2015, the EU ETS no longer permits carbon credits from the first commitment period of the Kyoto Protocol. International credits generated after 2012 must come from projects in least developed countries. Additionally, the EU ETS excluded projects involving industrial gas credits (HFC-23 and N_2O), regardless of the host country. The authority capped the total use of credits for Phase II and Phase III at 50% of the overall reduction target, around 1.6 $GtCO_2e$. By Phase IV, the EU ETS completely stopped accepting carbon offsets.

Allowances

Exhibit 6 shows the total allocated EUAs from 2005 to 2023. It divides them into two groups: freely allocated allowances (in light blue) and auctioned or sold allowances (in dark blue). This chart demonstrates that there has been a significant shift in policy from freely allocated allowances to a system that increasingly relies on auctioned or sold allowances. From 2005 to about 2012, authorities freely allocated the majority of emission allowances, a common practice in the early stages of ETSs. This strategy aimed to introduce industries to the trading system gradually without imposing a sudden financial burden. However, a notable transition began with the evolution of the cap-and-trade mechanism, when starting in 2013 (the beginning of Phase III) the proportion of auctioned or sold allowances significantly increased. This change reflects policy reforms that strengthen the carbon market by distributing allowances through

[18]According to UN Climate Change, the CDM and JI are two flexible mechanisms under the Kyoto Protocol. The CDM allows industrialized countries to earn tradable certified emission reductions (CERs) by implementing projects in developing countries, which they can use to offset their own emissions. JI enables industrialized countries to earn emission reduction units (ERUs) by implementing projects in other industrialized countries or transition economies. See https://unfccc.int/process/the-kyoto-protocol/mechanisms.

more competitive market processes rather than direct and free allocations. This shift also encourages industries to engage more actively in carbon management and emissions reductions, as buying allowances becomes a more significant operational cost.

The total volume of emission allowances also has been decreasing, especially after 2013. The latest years shown in Exhibit 6, 2022 and 2023, have the lowest allowance levels in the dataset. This ongoing decline could result from various factors, including improvements in energy efficiency, shifts to renewable energy sources, economic factors affecting production and energy use, and the overall tightening of emission caps in line with the EU's climate targets.

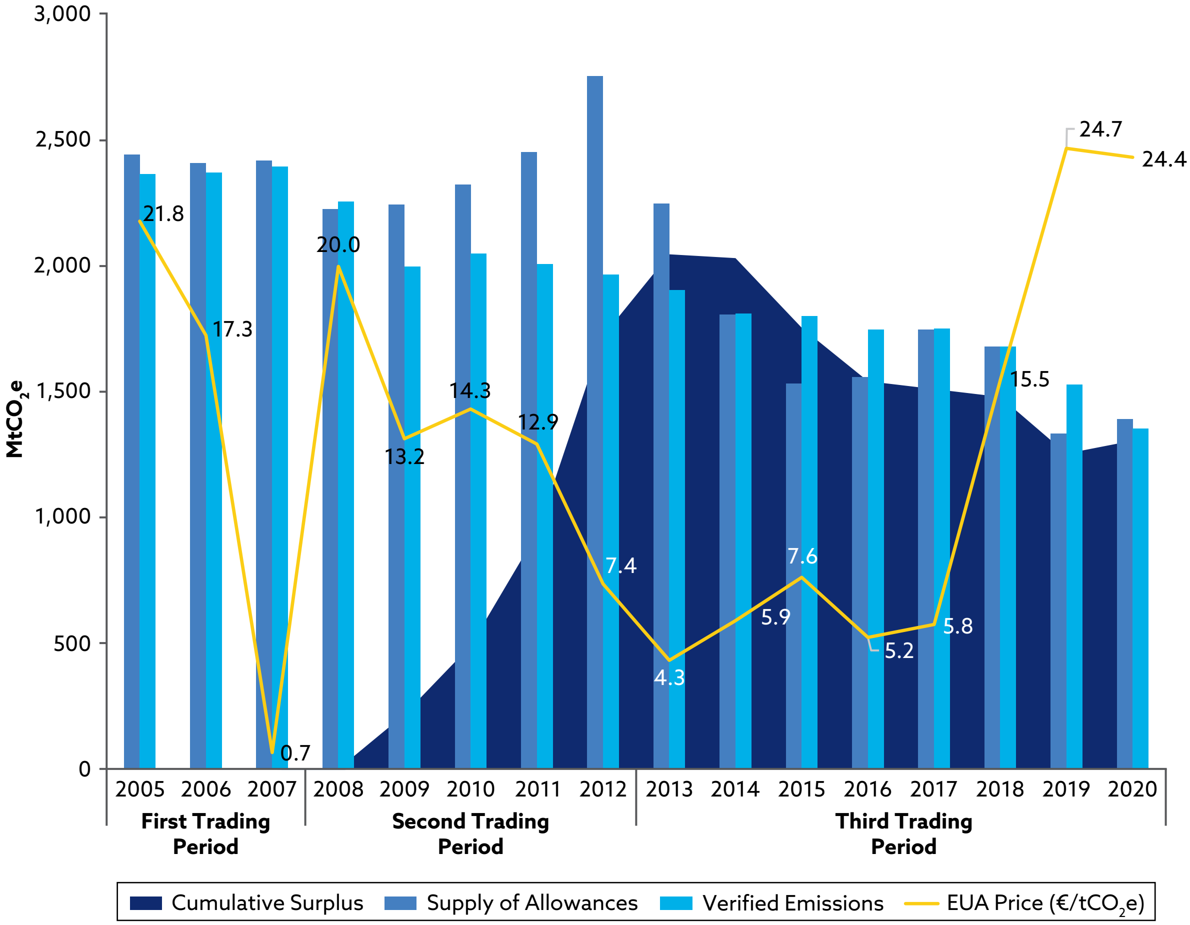
Overall, the trend toward more auctioned allowances and the general decrease in total emissions and allowances indicate the EU ETS's effectiveness as a tool for reducing GHG emissions in the region. The increasing use of market mechanisms to distribute allowances shows a matured system designed to promote cost-effective emission reductions across covered sectors.

Supply and Demand

Exhibit 7 outlines the dynamics between the supply of allowances, verified emissions, the cumulative surplus of allowances, and EUA prices in the EU ETS from 2005 to 2020 (covering the first three phases). From 2005 to 2012, the supply of allowances often exceeded verified emissions, indicating an oversupply in the market, which is typical for a new cap-and-trade system as it finds equilibrium. Notably, in the first two years, the surplus was minimal, but from 2008 onward, there was a visible surplus each year until 2013. This surplus contributed to the initial decrease in allowance prices. The supply of allowances dropped sharply in 2013 with the start of the third trading period, which aligns with the EU's strategy to incrementally reduce the cap over time. This reduction in allowance supply led to a stabilization and then a rise in the price of allowances.

The cumulative surplus grew significantly starting in 2008 and peaked around 2013, indicating underutilization of allowances, possibly due to inaccurate emission forecasts, reductions in industrial activity, and/or increased efficiency. The MSR, introduced in 2019, contributed to reducing this surplus as it aimed to adjust the supply of allowances to stabilize the market. EUA prices fluctuated considerably over the period. After the initial collapse in 2006, prices recovered slightly but remained relatively low through 2013, which could reflect the overallocation of allowances and the economic downturn during this period. Since 2018, prices have risen steeply due to regulatory measures to reduce the allowance surplus and the anticipation of stricter emission reduction targets (see also Exhibit 5).

Exhibit 7. Emissions, Allowances, Surplus, and Prices in the EU ETS, 2005–2020



Source: European Environment Agency (www.eea.europa.eu/data-and-maps/figures/emissions-allowances-surplus-and-prices).

2.1.3. California Cap-and-Trade Program

The California Cap-and-Trade Program launched in 2013 and is among the world's most comprehensive carbon pricing programs. California is a key member of the Western Climate Initiative (WCI), a nonprofit corporation supporting shared emissions trading to multiple US states and Quebec, Canada.

A notable feature of California's program is its linkage with similar programs in other jurisdictions, such as Quebec's carbon market, through the WCI.[19] This connection allows for mutual recognition of carbon allowances and offsets, enabling covered emitters in the respective jurisdictions to trade them across

[19]https://ww2.arb.ca.gov/our-work/programs/cap-and-trade-program/program-linkage.

borders. This collaboration broadens the regional carbon market and enhances the liquidity of allowances.

The California Cap-and-Trade Program aims to achieve a 40% reduction below 1990 levels by 2030 and reach an 85% reduction below 1990 levels and carbon neutrality by 2045. The program forms a key part of the state's broader climate policy, originated with the Global Warming Solutions Act of 2006 (Assembly Bill 32, or AB 32), and serves as a leading example of how states can address climate change.

The program covers 85% of California's emissions and includes around 450 facilities. According to ICAP, the cap for 2024 is 281 $MtCO_2e$.[20] The program allows the banking of allowances within certain limits, which decrease annually, but does not permit borrowing.

Governance

The California Air Resources Board (CARB), under the California Environmental Protection Agency, primarily manages the California Cap-and-Trade Program. CARB's responsibilities include monitoring GHG emissions, formulating regulations, and overseeing the allowance distribution. CARB evaluates various mechanisms and market-based approaches to enhance the system's efficiency and equity. It determines the state's emission cap and the total number of emission allowances that decrease annually. CARB distributes a small portion of allowances for free to mitigate economic disruption and auctions the majority (70% in 2023) to improve market efficiencies. The program conducts quarterly auctions where emitters purchase allowances. CARB uses auction revenues to fund state programs that further reduce GHG emissions and support communities influenced by pollution.

CARB rigorously monitors compliance to maintain program rules and market integrity. California has established an extensive market surveillance system to oversee the trading and holding of allowances and to enforce strict noncompliance penalties. Despite the legal challenges contesting CARB's authority to auction allowances, California courts have upheld the program, confirming the state's authority to price carbon and use auction proceeds to advance environmental goals (Carroll 2013).

Carbon Offsets

The program allows the use of carbon offsets with qualitative and quantitative limits. According to the ICAP, qualitatively, the program only permits compliance offset credits issued by CARB or linked cap-and-trade programs, and these must originate from projects under six specific compliance offset protocols.

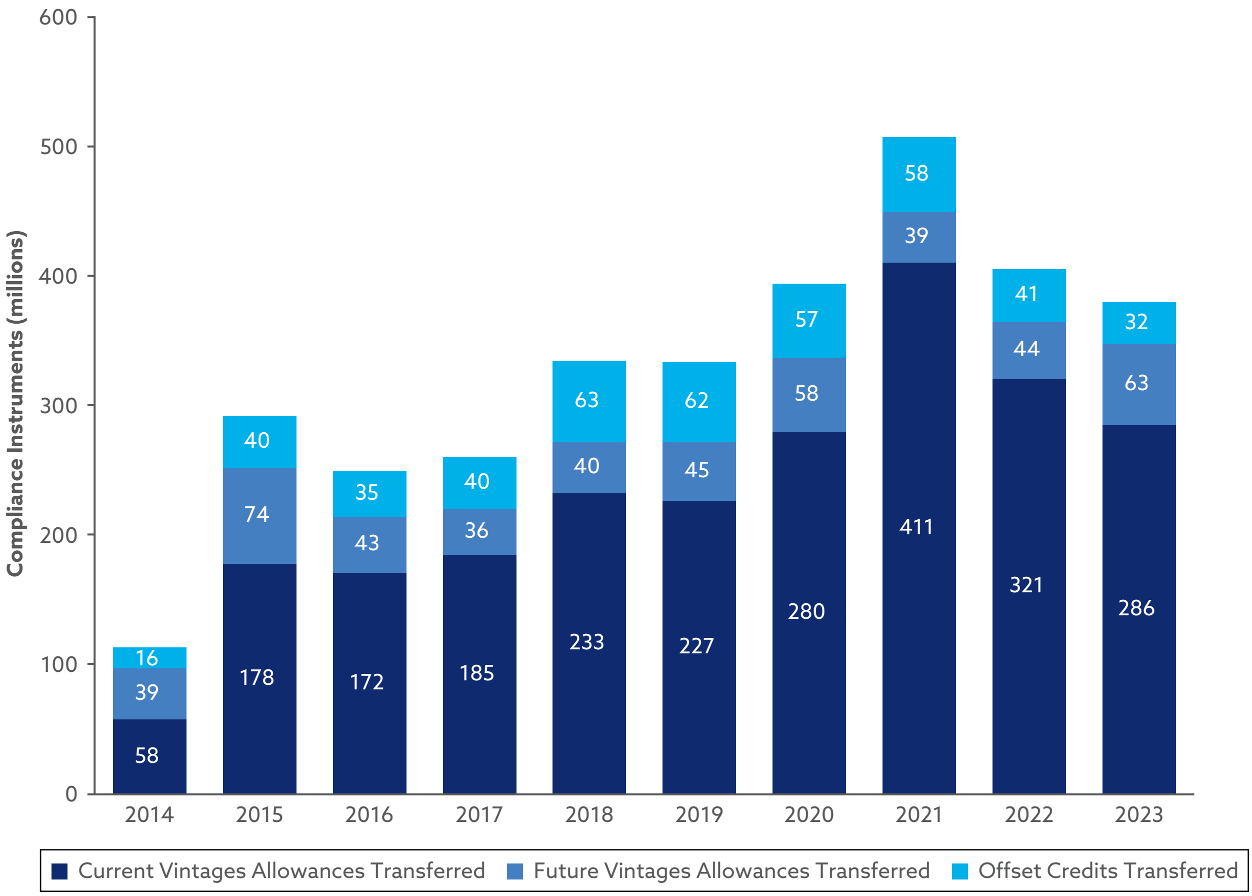
[20]https://icapcarbonaction.com/en/ets/usa-california-cap-and-trade-program.

Quantitatively, according to AB 398, covered entities could use offset credits to meet up to 8% of their 2013–20 emissions, 4% for 2021–25 emissions, and 6% for 2026–30 emissions. In addition, starting in 2021, no more than 50% of an entity's offset usage can come from projects without direct environmental benefits in the state (DEBS). Projects in California automatically qualify as providing DEBS, while projects outside California must demonstrate benefits through scientific evidence and project data.

Market Activity

Exhibit 8 summarizes the annual transfer volumes of compliance instruments (allowances and offset credits) from 2014 to 2023 in California's carbon market. Each year, the majority of the market transfers were current vintages, reflecting

Exhibit 8. Market Transfers of Compliance Instruments by Year in California's Carbon Market, 2014–2023



Source: California Air Resources Board (2024).

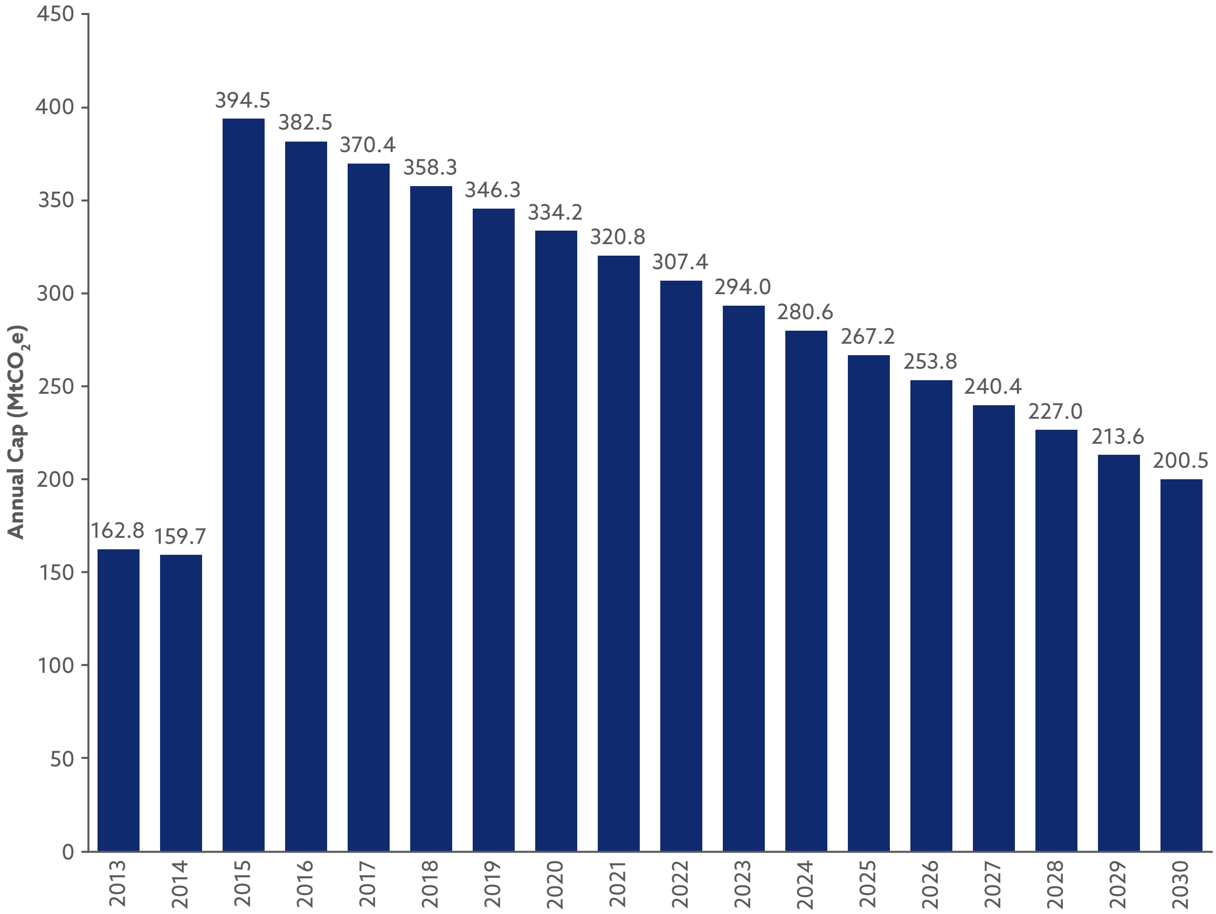
an active trading environment where entities actively align their allowance with the current year's emissions. Transfers of offset credits represented a smaller fraction of market activity relative to allowances, aligning with the program's design that limits the use of offsets to a specific percentage of compliance obligations. As noted earlier, prominent platforms, such as ICE and EEX, also offer futures and options contracts for future vintage allowances, which covered emitters can use to hedge future emission cost risks. Transfers involving future vintages indicate that entities are preparing for future compliance needs, demonstrating proactive participation in the carbon market. The active market for future vintage allowances indicates confidence in the program's long-term viability since entities are investing in allowances for use in upcoming compliance periods.

The trend from 2014 to 2023 is a growing market with increasing volumes of transferred allowances, indicating a robust and active carbon market. This market includes a blend of trading in current and future allowances and using offset credits. The ongoing trade in future vintages and the relatively consistent role of offset credits indicate the program's well-rounded design and effectiveness in providing participants with diverse compliance options.

Unlike Exhibit 7, which shows the trends in allowance supply and verified emissions in the EU ETS, Exhibit 8 provides insights into the market trading activities behind the cap, including the volumes of different compliance instruments. This perspective offers a fuller understanding of the carbon market's operation and how emitters respond to the mechanism. The overall upward trend indicates an increasing demand for carbon allowances and offsets among market participants as the cap constantly decreases. The rise in future vintage allowances traded suggests that companies anticipate tightening future emission caps and are preparing early to lower future compliance costs. The smaller share of offsets reflects California's approach to allowing the use of offsets while also limiting their proportion.

The cap of the California Cap-and-Trade Program has shown a continuous downward trend, as shown in **Exhibit 9**. The program began in 2013 with a 2% reduction in the 2014 cap. In 2015, the cap increased with the inclusion of fuel distribution in the program. During the second compliance period (2015–2017), the cap declined by 3.1% per year. In the third compliance period (2018–2020), the cap continued to decrease at an average annual rate of 3.3%. In the fourth compliance period (2021–2030), the cap declines by around 4% per year. Overall, the trend in the cap shows an increasing rate of decline.

Exhibit 9. California Cap-and-Trade Program's Annual Cap, 2013–2030

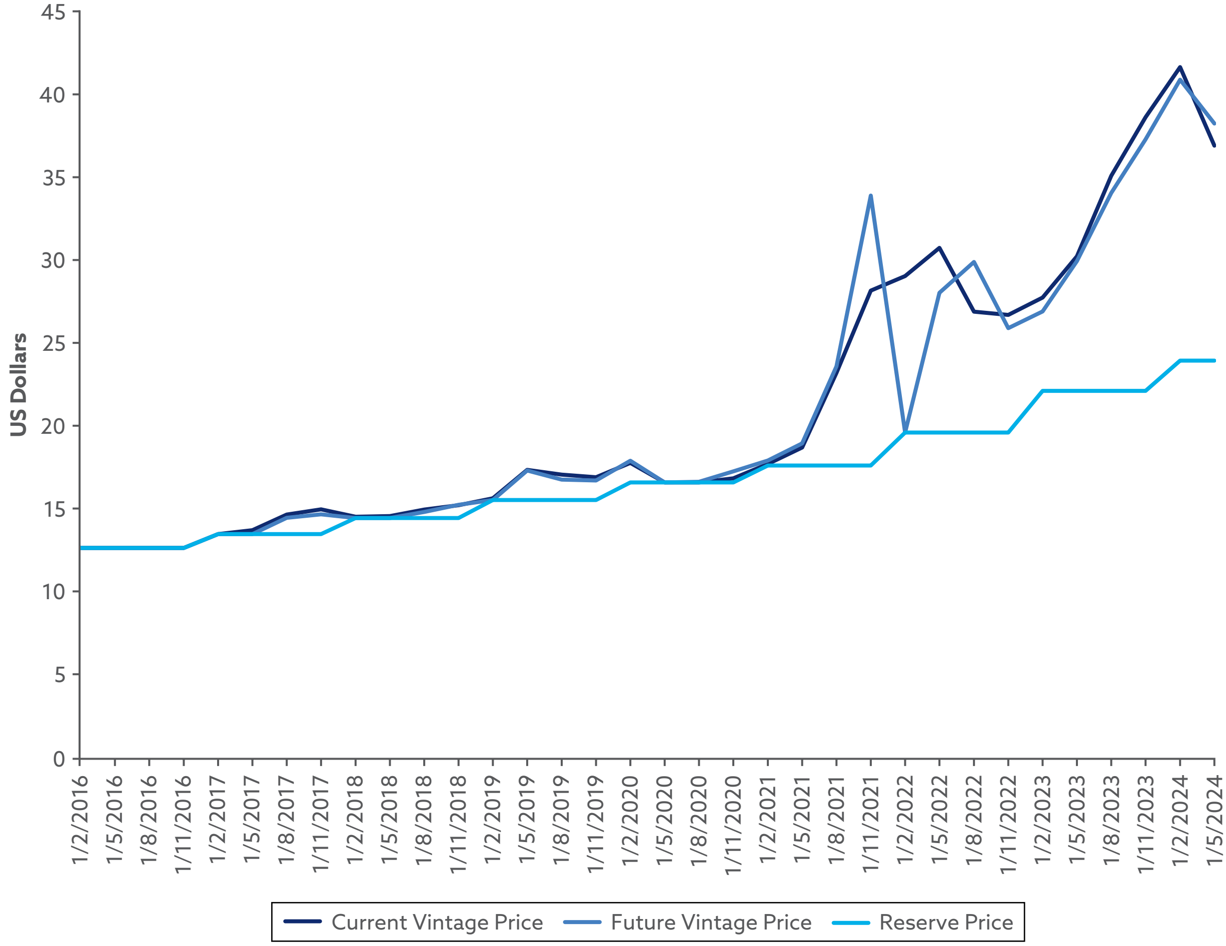


Source: ICAP (https://icapcarbonaction.com/en/ets/usa-california-cap-and-trade-program).

Price

As of May 2024, the auction price for an allowance was $37.02 (see **Exhibit 10**), indicating an approximate trebling of auction prices over the eight-year period shown. Exhibit 10 also shows the auction price of future vintages, which allows emitters to manage expected higher compliance costs. Future vintage prices have tracked close to the current vintage price for most of the period shown.

Exhibit 10. WCI Auction Price, February 2016–May 2024



Source: LSEG.

2.1.4. China National Emissions Trading Scheme

The China National ETS was initiated in 2021 and is now the world's largest in absolute emission coverage. The scheme covers approximately 5 billion tCO_2e, representing over 40% of China's total CO_2 emissions. Building on the successes of the eight regional pilot carbon markets, as shown in **Exhibit 11**, the National ETS will integrate entities from these regional markets. Initially, the system targets over 2,000 companies in the power sector with annual emissions above 26,000 tCO_2e, covering a variety of power plants in different sectors.

Exhibit 11. Mainland China's Pilot ETS Programs

Pilot ETS Program	Start Year	Coverage	Cap	Average Secondary Market Price
Beijing	2013	Transport, buildings, industry, power	44 $MtCO_2e$ (2022)	CNY90.96 (USD12.84)
Guangdong	2013	Domestic aviation, industry	297 $MtCO_2e$ (2023)	CNY75.01 (USD10.58)
Shanghai	2013	Maritime, domestic aviation, transport, buildings, industry, power	100 $MtCO_2e$ (2022)	CNY66.96 (USD9.45)
Shenzhen	2013	Transport, buildings, industry	28 $MtCO_2e$ (2023)	CNY46.37 (USD6.55)
Tianjin	2013	Industry	74 $MtCO_2e$ (2023)	CNY32.20 (USD4.54)
Chongqing	2014	Industry	78 $MtCO_2e$ (2020)	CNY29.82 (USD4.09)
Hubei	2014	Industry	180 $MtCO_2e$ (2022)	CNY38.78 (USD5.47)
Fujian	2016	Domestic aviation, industry	116 $MtCO_2e$ (2022)	CNY23.25 (USD3.28)

Source: ICAP.

Coverage

The China National ETS actively sets ambitious climate targets. According to the ICAP, by 2025, China aims to reduce carbon emissions per unit of GDP by 18% from 2020 levels, aligning with the 14th Five-Year Plan.[21] By 2030, the plan is to reach peak CO_2 emissions and reduce CO_2 emissions per unit of GDP by more than 65% from 2005 levels, in line with the "1+N" policy framework and the updated NDC.[22] The ultimate goal is to achieve carbon neutrality by 2060.

The China National ETS set caps of around 4,500 $MtCO_2e$ for 2019–2020 and about 5,000 $MtCO_2e$ for 2021–2022. Currently, the China National ETS focuses on the power sector, with plans to expand coverage to seven additional sectors: petrochemicals, chemicals, building materials, steel, nonferrous metals, paper, and domestic aviation. For 2019–2020, the China National ETS included entities emitting over 26,000 tCO_2e annually at any point during 2013–2019. For 2021–2022, it covered entities emitting at least 26,000 tCO_2e annually in any year during 2020–2021.

Allowance

According to the ICAP, the China National ETS primarily distributes allowances through free allocation, using output-based benchmarking adjusted to different types of power plants. Over time, authorities plan to tighten these benchmarks,

[21]https://icapcarbonaction.com/en/ets/china-national-ets.

[22]According to the UN Development Program China (2021), China's "1+N" framework is a series of policies and measures developed by the Chinese government to achieve carbon peaking and carbon neutrality goals. This framework includes an overarching plan, "1," formulated by the State Council, and multiple specific implementation or action plans, "N," that cover various industries, local governments, and key projects.

particularly for coal-fired power plants. The system initially allocates allowances covering 70% of the entities' verified emissions but later adjusts to reflect actual production. It also includes a load factor adjustment to benefit entities operating below an 85% load rate. While free allocation currently dominates, definitive plans are in place to introduce and gradually expand auctioning, although the specific timeline remains unclear.

The system provides flexibility through banking and borrowing rules. From 2019–2020 to 2021–2022, banking rules enabled entities to carry forward unused allowances, encouraging early emission reductions and strategic planning. For 2021–2022, borrowing rules permitted entities with over 10% shortfall to borrow up to 50% of their deficit from future allocations, providing additional compliance flexibility. However, the authorities have not yet finalized the details of future banking rules.

The China National ETS allows the use of carbon offset credits with certain limitations. Covered entities can use China Certified Emission Reduction (CCER) credits for up to 5% of their verified emissions. These CCERs originate from emission reduction projects verified and certified by the CCER registry according to standards set by the National Center for Climate Change Strategy and International Cooperation (NCSC).

Price

The price trends in Mainland China's pilot ETS programs show a diverse landscape of allowance prices across different regions, with significant fluctuations over time. Some regions, such as Beijing, had higher price peaks, particularly in the later phase, which indicates a tighter cap or a more aggressive approach to emission reductions in those markets. Over time, most regional markets demonstrated significant volatility, with prices generally converging in a lower price band. The convergence suggests an increasing alignment in how these regions approach carbon pricing and a response to a shared market or policy incentives.

By contrast, in **Exhibit 12**, the China National ETS displays a more stable price trajectory since its inception in 2021. The prices exhibited a gradual increase, followed by a period of relative stability, and then an uptick toward the end. The relative stability reflected the national market's larger pool of participants and allowances, which mitigated the volatility seen in smaller pilot markets. Adjustments in the China National ETS policy, such as the tightening of the cap or the anticipation of stricter future policies, might contribute to the recent increase. The overall increasing trend in the national system's prices aligns with the global movement toward stricter climate policies and reflects growing confidence in the longevity and robustness of the China National ETS.

Exhibit 12. China National ETS Allowance Prices, July 2021–1 July 2024

Source: LSEG.

2.1.5. Summary

The overview of the three representative CCMs shows that their core operating mechanisms are similar. CCMs use the cap-and-trade framework, which sets decreasing caps annually and distributes allowances through a combination of free allocation and auctions. CCMs currently target primarily large and medium-sized emitters, though the inclusion threshold is gradually lowered to cover small emitters. However, the three CCMs exhibit many differences within this core framework. Notable differences include varying emission reduction targets, timelines, covered percentages, covered sectors, auction proportions, auction revenue uses, and acceptance of offsets. These differences mainly stem from their respective emission baselines, economic development conditions, and individual goals. Overall, since its establishment in 2005, the EU ETS has led the development of this mechanism as the most mature CCM, promoting continuous improvements of the system. Currently, CCMs have a relatively stable cap-and-trade structure with improving allowance allocation and pricing mechanisms. The development of the California Cap-and-Trade Program and the China National ETS also enhances CCM efficiency and promotes global convergence.

However, CCMs do not provide a complete solution to carbon pricing. On one hand, CCMs focus mostly on allowances rather than offsets. Even in CCMs that accept offsets, such as the California and China CCMs, there are strict qualitative and quantitative restrictions on their use. Carbon offsets play a crucial role in achieving cost-effective emission reductions. On the other hand, CCMs do not offer convenient participation opportunities for investors, which impedes the global effort to reduce emissions. VCMs can fill these gaps in CCMs.

2.2. Voluntary Carbon Markets

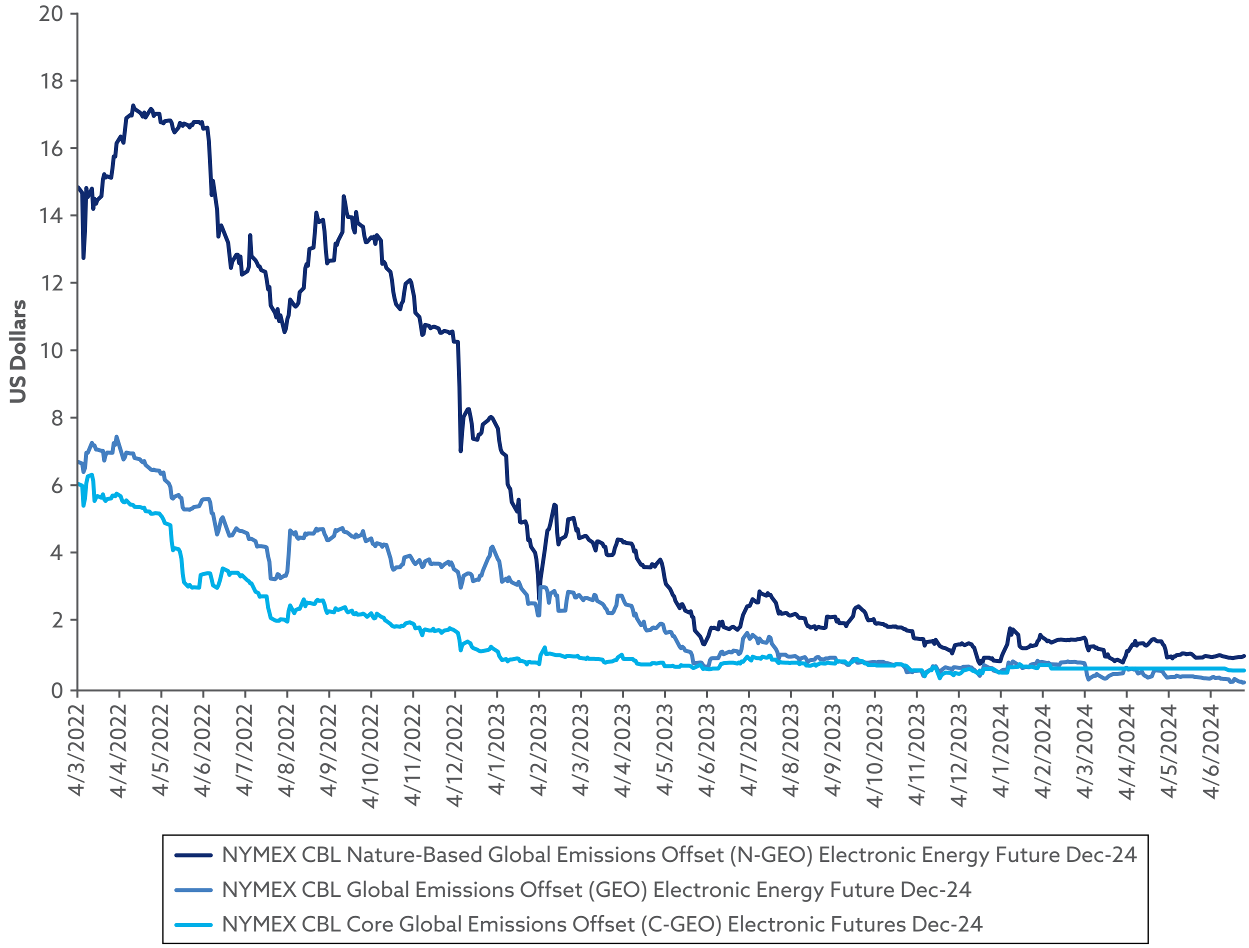
VCMs complement global initiatives to reduce GHG emissions and address climate change. Operating alongside CCMs, these voluntary platforms enable emitters, governments, and individual firms to purchase carbon credits to offset their emissions. Shell PLC, a global group of energy and petrochemical companies, projects that by 2030, VCMs will expand to at least five times their current size, with transaction volumes reaching levels comparable to the annual emissions of the global aviation industry in 2019 (Reuters 2023). VCMs trade carbon offsets/credits, with each credit generally representing one tCO_2e either prevented from entering the atmosphere or removed through various initiatives (e.g., reforestation, investment in renewable energy, energy efficiency measures, or methane capture). The participants in VCMs include multinational corporations, small businesses, nonprofit organizations, governments, and individuals. Participants choose to neutralize their emissions not because of regulatory requirements but to meet corporate social responsibility, customer expectations, or individual environmental values. **Exhibit 13** displays the prices of three standardized VCM futures contracts—carbon-based contracts (CBLs)—traded on the New York Mercantile Exchange (NYMEX), which is part of the Chicago Mercantile Exchange (CME) Group. According to CME Group, N-GEO futures represent nature-based offsets sourced exclusively from agriculture, forestry, and other land use (AFOLU) projects.[23] GEO futures provide delivery of physical carbon offset credits that have undergone stringent screening. C-GEO futures track offset projects across energy, renewables, and other technology-based offsets from the Verra registry.[24] The prices of the three futures contracts in the exhibit are consistently trending downward. According to LSEG's monthly reports and yearly review of VCMs, the main reasons for the price decline are market doubts about the actual environmental impact of VCM projects and concerns about potential overcrediting.[25]

[23]See www.cmegroup.com/markets/energy/emissions/cbl-nature-based-global-emissions-offset.html.

[24]Verra manages the world's leading voluntary carbon market program: the Verified Carbon Standard (VCS) Program. The Verra registry is the central repository for all information and documentation relating to Verra projects and units. See https://verra.org/registry/overview/.

[25]An examination of the issues associated with VCMs is beyond the scope of this report, and these issues are an area for further research.

Exhibit 13. Prices of Standardized Carbon Credit Contracts, March 2022–June 2024



Source: LSEG.

The market has a wide range of project types, each using distinct methodologies to quantify emission reductions. Key project types include the following:

- *Forestry and land use:* These projects focus on reforestation, afforestation, enhanced forest management, and agroforestry, which facilitate CO_2 removal through vegetation growth.
- *Renewable energy:* These projects involve wind, solar, hydroelectric, or biomass energy, which replace fossil fuels and thus avoid carbon emissions.
- *Energy efficiency:* These projects aim to decrease emissions by improving energy consumption efficiency across various sectors.

- *Waste management:* These projects capture methane from organic waste for energy use, avoiding potential carbon emissions.
- *Methane capture:* These projects prevent methane emissions by capturing them from agricultural or waste sources.

To generate carbon credits, VCM projects must complete validation and verification through independent bodies following established standards, such as the Verified Carbon Standard, the Gold Standard, or the Climate Action Reserve. This process ensures that projects meet essential criteria and achieve the intended emission reductions. In VCMs, the dynamics of supply and demand primarily determine credit prices. Specific factors affecting prices include the type and location of projects, additional benefits they offer, and their certification standards.

Despite their growth, VCMs face several challenges regarding credibility, transparency, and actual impact. Specifically, participants are concerned about the double-counting issue (the assignment and traceability of credits to unique projects), the additionality, and the permanence of emission reductions.[26] However, growing awareness of climate change has heightened interest in VCMs. The rising demand for carbon credits can advance VCMs' evolution and progress. Market participants use such methods as blockchain technology to improve the transparency and traceability of projects and carbon credits. Innovations in project development and monitoring, along with enhanced standardization and robustness in the crediting process, will potentially strengthen VCMs' trustworthiness and effectiveness. Additionally, such initiatives as the Taskforce on Scaling Voluntary Carbon Markets aim to enhance VCMs' contributions to emission reduction.

By offering a flexible way for various participants to contribute to global GHG emission reduction, VCMs complement CCMs and foster broader participation in climate action efforts.

[26]Additionality is a key criterion for evaluating the quality of carbon credits. The Integrity Council for the Voluntary Carbon Market (ICVCM), which establishes the Core Carbon Principles, states, "The greenhouse gas (GHG) emission reductions or removals from the mitigation activity shall be additional, i.e., they would not have occurred in the absence of the incentive created by carbon credit revenues" (https://icvcm.org/core-carbon-principles/).

3. GLOBAL CARBON MARKETS AS AN EFFECTIVE TOOL FOR NET ZERO

GCMs, with their operational models and market-driven pricing mechanisms, play an important role in supporting net-zero targets. Four specific aspects demonstrate this effectiveness:

1. GCMs contribute to the gradual reduction of national carbon emissions, effectively pushing forward global carbon reduction efforts consistent with net-zero time frames.
2. GCMs price carbon emissions, determining carbon prices through market-based mechanisms to make emitters internalize their emissions' costs, thus encouraging reductions.
3. GCMs, especially VCMs, provide emitters (both covered and not covered) and other organizations with opportunities to participate in the global carbon reduction process, broadening accountability for carbon reduction efforts.
4. The development of GCMs has supported the growth of other green technologies and green/transition finance.

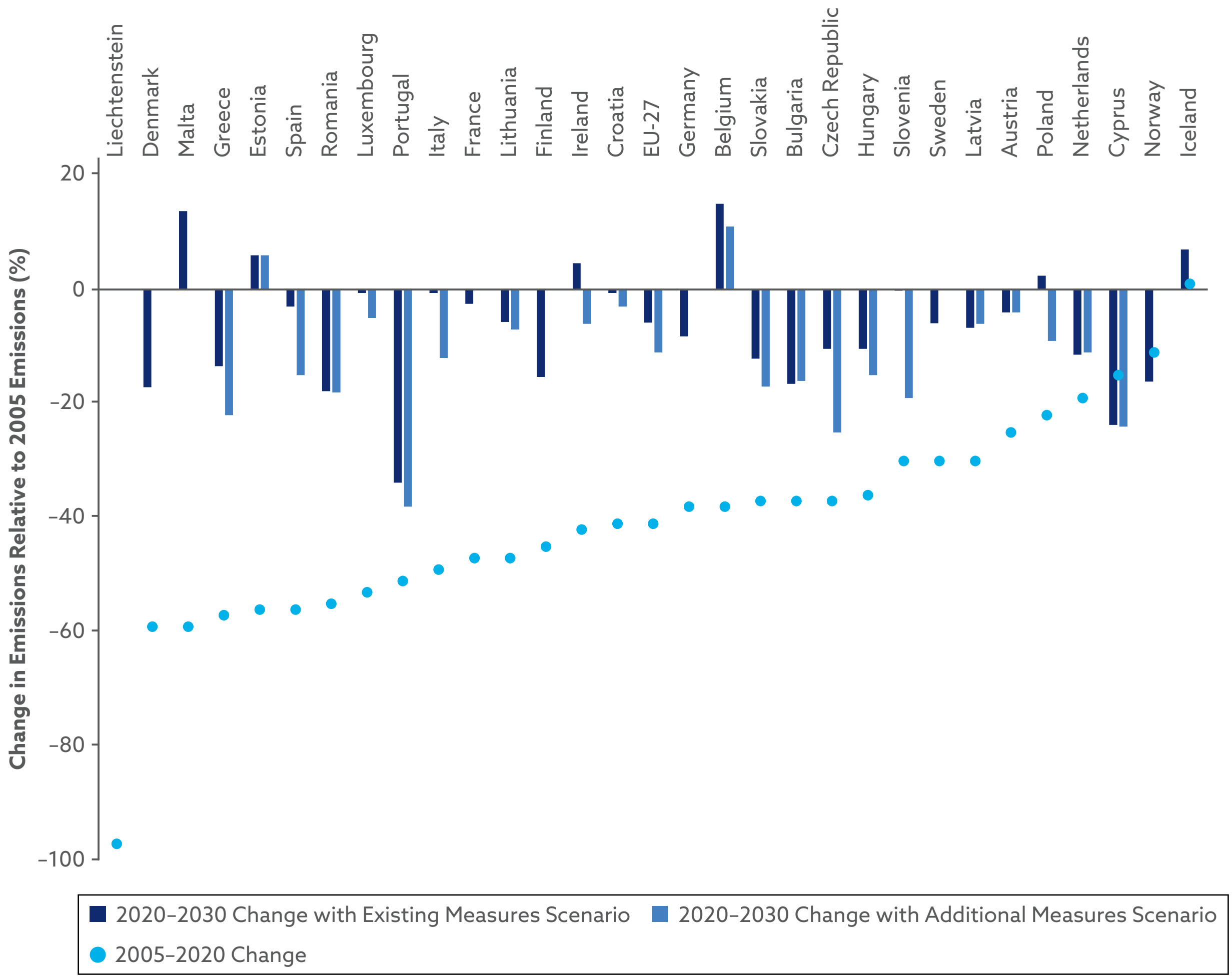
We elaborate on each of these four aspects in this chapter.

3.1. Reduction in Total Carbon Emissions

Countries can use the cap-and-trade system to set a firm, clear, and enforceable overall emission cap. By establishing a cap and an annual reduction, countries make their emission reduction plans and targets concrete and actionable. **Exhibit 14** presents historic and projected changes in emissions under the EU ETS by country relative to 2005 emission levels. The majority of the countries have reduced their emissions between 2005 and 2020, with reductions primarily in the –40% to –60% range. Existing measures should allow many countries to further reduce emissions by 2030, while additional efforts could achieve even greater reductions, as shown in Exhibit 14. Overall, the 27 EU member states (EU-27) have achieved a 41% reduction in emissions from 2005 to 2020 and are on track to reduce emissions by an additional 6% by 2030. Implementing further measures has the potential to decrease emissions by up to an additional 11%. These examples illustrate the effective role GCMs play in reducing carbon emissions.

Other, less mature markets with high current emissions also establish targets to achieve similar carbon reduction impacts. As noted earlier, according to the ICAP, China plans, through the China National ETS, to reduce CO_2 emissions per unit of GDP by over 18% from 2020 levels by 2025 and by 65% from 2005 levels by 2030 and to achieve carbon neutrality by 2060. The California Cap-and-Trade Program aims to reduce GHG levels by 40% relative to 1990 levels by 2030 and by 85% while achieving carbon neutrality by 2045.

Exhibit 14. Historical and Projected Changes in the EU ETS by Country Relative to 2005 Emission Levels



Note: The exhibit shows the change in emissions under the EU ETS since 2005 by country and the projected changes in emissions in 2030.

Source: European Environment Agency (www.eea.europa.eu/data-and-maps/daviz/historic-and-projected-changes-in-3#tab-googlechartid_chart_61).

3.2. Carbon Pricing

Another major feature of GCMs is the use of market mechanisms to price carbon emissions, thus forcing emitters to internalize the costs of carbon emissions into their production costs to compensate for the social costs caused by the externalities of carbon emissions. Once emitters incorporate carbon costs into their production decisions, like any other raw material cost, they have an incentive to reduce emissions to achieve cost control. On the one hand, emitters will control carbon emissions as much as possible to reduce the cost of purchasing allowances. On the other hand, emitters can likely best achieve long-term cost control by accelerating the transition to clean energy and green production methods. The market trading system of GCMs further provides emitters with additional incentives to reduce emissions. Companies with lower emission reduction costs can earn additional income by selling allowances.

3.3. Stakeholder Participation

The carbon market system synthesizes the efforts of all parties to advance the net-zero process through the combination of compliance and voluntary modes. CCMs cover medium and large emitters with legal mandates, thereby reducing emissions with immediate impact. VCMs offer a way for companies not covered by CCMs and individuals to participate in the global carbon reduction process. Although these contributions are relatively small, they have the potential to play an important role in fostering global cooperation and participation in moving toward net zero. VCMs can also provide a pathway for (uncovered) emitters to fulfill their corporate social responsibilities.

3.4. Driving Green Market Development

By setting caps and pricing carbon, GCMs encourage covered entities to strategically transform toward green development in the medium to long term. One major challenge for companies in investing in green transformation and energy-saving emission reduction technologies is the significant capital investment and long-term commitment required. As the long-term costs of carbon emissions rise, investing in green technologies becomes more economically viable than in the past. Additionally, the long-term horizon of net-zero targets and carbon market regulations increasingly makes green transformation a necessary choice for more companies. This trend accelerates the growth of related markets, such as green technology, green energy, and green/transition finance. These related markets play a crucial role in the process of moving toward net zero. They help enhance asset allocation efficiency, thus drawing more resources, capital, and market participants into the net-zero process. Meanwhile, the development of the carbon market also creates new investment opportunities for investors in these related markets.

For example, transition finance, which provides financial support for emission reduction and decarbonization processes, offers a vital financial drive for companies to achieve net zero. VCMs effectively link the transition finance market (capital providers) with polluting businesses that need decarbonization (capital demanders), integrating forces toward net zero. Transition finance is crucial for advancing net zero but requires collaboration among all parties involved. See Mak and Vinelli (2024) for a detailed overview of the market for transition finance.

4. ISSUES OF GLOBAL CARBON MARKETS

As a market still in development, GCMs naturally encounter several issues and face many challenges. These include the following areas:

- Caps may be perceived by market participants as unreasonably high compared with actual emission levels.
- Prices exhibit significant fluctuations.
- There is a vast disparity in the development of various markets.
- Severe market fragmentation leads to carbon leakage and carbon arbitrage.
- The high uncertainty and rapid changes in market and policy developments impose additional costs on businesses.
- Access for direct investor participation is limited.

We address each of these areas in this chapter.

4.1. The Challenge of Setting Reasonable Caps

Setting reasonable caps is challenging and is critical for carbon markets to function effectively. The EU ETS serves as a notable example. Due to the absence of reliable emission data, the initial caps for Phase I were based on estimates. As a consequence, the total allowances issued exceeded actual emissions, leading to an excess supply over demand, which caused the allowance prices to drop to zero in 2007. A reasonable cap must rely on comprehensive and accurate long-term emission data and consider various other factors, such as impacts on business costs, feasibility, and long-term changes. Obtaining high-quality emission data remains a challenge, especially over broad coverage areas. Additionally, the changing economic conditions further complicate market planning. Like all policy and system designs, the information available to regulators and policymakers is imperfect. Particularly in the new area of carbon markets, cap settings are based on emission estimates affected by numerous factors, such as the state of the economy, corporate strategy, industry coverage, and costs. Thus, they exhibit uncertainty and variability. Setting caps significantly depends on accumulating multiyear samples from a large number of businesses to enhance the quality of estimates and requires continuous annual adjustments. Therefore, establishing reasonable caps may remain a major challenge for CCMs in the short term, particularly for less mature markets than the EU ETS. When analyzing CCMs' caps and total allowances, investors should be aware that these figures may be inaccurate and subject to annual changes. Additionally, the CCM allowances primarily consider Scope 1 emissions, with only limited consideration for Scope 2 emissions (California carbon market) and almost no consideration for Scope 3 emissions. While Scope 1 emissions are the easiest to measure accurately, they do not typically represent the majority of total emissions. Therefore, even though there may be valid reasons for excluding Scope 2 and 3 emissions from allowance calculations and cap setting, it is important to note that CCMs typically do not measure and, consequently, do not manage these other emissions.

4.2. Large Price Fluctuations

Continuous changes in caps, allowance allocation, and policies, combined with changes in market participants' expectations, inevitably lead to significant fluctuations in carbon prices. As shown in previous chapters, carbon markets have experienced significant volatility, particularly the EU ETS, which has the longest history and most mature system. Although the futures and options offered by exchanges facilitate the improvements of market efficiency and price convergence, fluctuations in allowance supply are also due to policy changes or shifts in the proportion of free versus auctioned allowance distribution. In the meantime, emitters' expectations of regulatory and market developments have evolved from initial uncertainty to anticipation of their long-term existence, thus leading to demand fluctuations. Investors should note that while price volatility is a natural part of market development, regulators of many carbon markets have recognized this issue and are using reserves to stabilize prices.

4.3. Significant Development Differences between Markets

There are substantial differences in emission reduction targets and outcomes between carbon markets. First, each market has set different reduction targets and baselines. For example, China uses 2005 as a baseline, while the EU and California use 1990. The timelines for achieving carbon neutrality also vary: California aims for 2045, the EU targets 2050, and China plans for 2060. Additionally, considerable differences in phase planning, sector coverage, and thresholds make it difficult for investors to compare carbon markets horizontally. Specifically, the California Cap-and-Trade Program covers up to 80% of its emissions, while the EU ETS and China National ETS currently cover around 40%. The differences in their caps are also significant, with China at 5,000 $MtCO_2e$, California at 280.7 $MtCO_2e$, and the EU at 1,386 $MtCO_2e$. Moreover, the regulations on the use of allowance auction revenues differ among the three markets.

Second, the effectiveness of emission reductions varies among carbon markets. Even within the same carbon market system, there are differences in emission reduction outcomes among member countries. For example, as shown in Exhibit 14, under the EU ETS system, there is significant variation among countries in terms of both achieved and projected emission reductions. Such countries as Greece, Romania, and Portugal have shown significant reductions by 2020 and will continue this trend according to projections. Authorities project that some countries will achieve substantial emission reductions between 2020 and 2030. For example, Slovakia and Cyprus are on track to significantly reduce their emissions under the "Change with Existing Measures Scenario" and even more under the "Change with Additional Measures Scenario." Iceland had a slight increase in emissions from 2005 to 2020, contrasting with the general trend. These variations hinder the coordination of global emission reduction efforts.

Several factors contribute to these differences. Countries have different energy policies. Countries with aggressive renewable energy policies and heavy investment in clean energy infrastructure tend to achieve more significant emission reductions. For example, some countries provide subsidies for renewable energy projects or enforce stricter regulations on fossil fuel usage. They also offer incentives for installing solar, wind, and other renewable energy sources, facilitating a faster and cost-effective transition from fossil fuels. Additionally, the economic structures of countries also differ, which influences emission levels. Compared to service-oriented economies, it is more challenging for industrialized countries that rely on manufacturing and energy-intensive industries to reduce emissions. Countries with substantial industrial bases typically have higher baseline emissions and require more significant efforts to achieve reductions. Furthermore, the development and application of advanced emission reduction technologies, the effectiveness of monitoring, reporting, and verification (MRV) mechanisms, and the strictness of regulatory enforcement also impact the success of emission reduction efforts. In summary, as global goals, the Paris Agreement and net zero require enhanced global coordination and cooperation, and the world is quite far from a globally coordinated approach to net zero.

4.4. Severe Market Fragmentation

Due to these differences, severe fragmentation within GCMs occurs and leads to two main issues: carbon leakage and increased global costs for achieving net zero. Carbon leakage occurs when a company, facing increased costs due to the carbon emission regulations in its original market, moves its operations to another market without such regulations. This phenomenon indicates that carbon markets and related regulations might decrease the attractiveness of a country's market to businesses and place domestic enterprises at a disadvantage in international competition due to increased costs. These problems hinder the motivation for countries to formulate carbon policies and obstruct the globalization of the net-zero process.

Furthermore, the fragmentation within GCMs results in very limited linkage between different markets, prominently shown by the inability to interchange carbon allowances and offsets between markets. Differences in carbon reduction costs exist naturally between countries due to different economic development stages and geographic conditions. Market-driven carbon trading can minimize global carbon reduction costs by enabling emission reductions where they are most cost effective. In an integrated worldwide carbon market, companies or countries that can reduce emissions at lower costs can sell their excess allowances or credits to those with higher reduction costs, leading to overall cost savings and more efficient resource allocation. However, market fragmentation creates significant barriers to this ideal scenario and prevents the seamless exchange of carbon credits, leading to inefficiencies and higher overall emission reduction costs.

Fragmentation also restricts companies from accessing the most cost-effective reduction opportunities globally. For example, a company in Europe might find cheaper reduction opportunities in Africa or South America. However, since the carbon markets are not linked and the EU ETS does not accept carbon offsets, the company cannot access those opportunities. Consequently, the global effort to achieve net-zero emissions becomes more expensive and less effective.

Additionally, the significant variation in carbon prices both over time and in different markets confirms substantial market fragmentation. This fragmentation limits arbitrage opportunities, preventing prices from converging to a single global carbon price. This issue hinders the broader use of CCMs and their potential to effectively support environmental policy goals. In summary, significant market fragmentation highlights the importance of global coordination and cooperation from both the fairness and cost-effectiveness perspectives.

4.5. Increased Business Costs

The issues discussed in the development of GCMs also directly impose additional costs on business production. First, the constant changes and uncertainties in carbon market policies require businesses to closely monitor policy developments and requirements, incurring additional compliance costs. Second, significant fluctuations in carbon prices make it difficult for businesses to make reliable cost forecasts for production decisions, exposing them to risks associated with carbon price volatility and policy changes. Finally, vast differences between carbon markets pose great challenges for multinational corporations, forcing them to incur higher costs to understand, monitor, and meet the regulatory requirements of different carbon markets. These factors collectively increase operational costs and risks for businesses, impacting their profits and thus affecting investor returns.

4.6. Limited Access for Investor Participation

Currently, participants in GCMs consist primarily of regulators, related businesses, and financial intermediaries (acting as market makers to provide services to businesses). For investors, direct participation is still primarily through investments in VCMs. Indirect methods include investing in related industries, such as green technology and transition finance. Overall, direct ways for investors to engage in GCMs are quite limited at this stage of development. Greater investor participation can provide funds for carbon markets, increase liquidity, lower costs, and thus improve market efficiency.

5. CARBON PRICING: CARBON TAXES VS. CARBON MARKETS

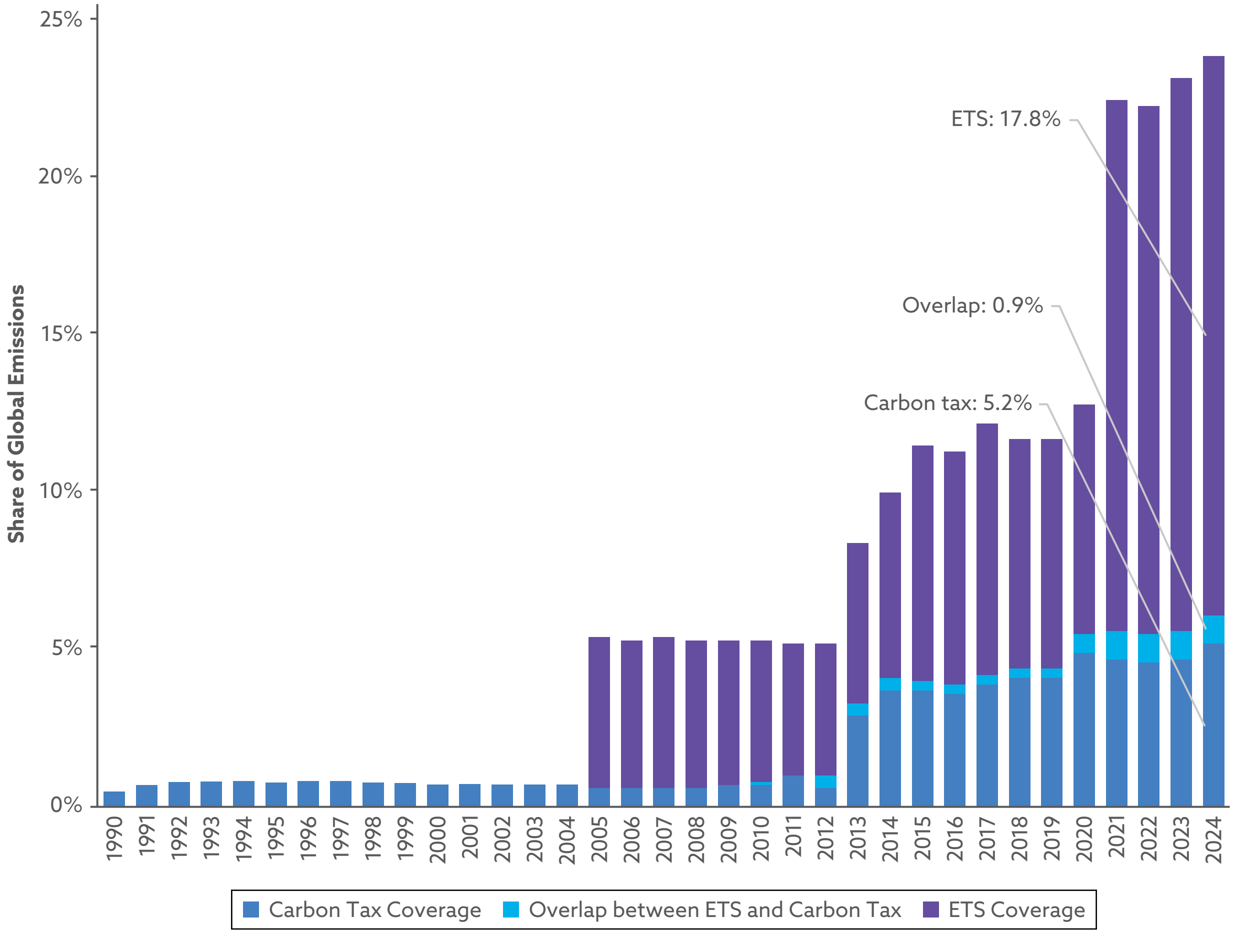
Carbon pricing is effective for tackling climate change. GCMs, driven by market mechanisms, and carbon taxes, determined by fiscal policy, are two methods of implementing carbon pricing. Each has its advantages and disadvantages. According to the Institute for Climate Economics (I4CE; see Fleurence, Fetet, and Postic 2023), as of August 2023, there were 74 carbon pricing mechanisms (carbon taxes and ETSs) worldwide: 31 at the provincial level, 42 at the national level, and 1 at the interstate level (EU ETS). The World Bank reports that in 2024, carbon pricing covered 24% of GHG emissions, or 12.8 $GtCO_2e$.[27] This amount includes 31% of emissions from high-income countries, 22% from middle-income countries, and 0% from low-income countries. As shown in **Exhibit 15**, carbon taxes cover approximately 6% of global GHG emissions, while carbon markets cover 19%. In 2023, carbon pricing generated $104 billion in revenue. In 2022, of the global carbon revenue, governments allocated 58% to subsidize "green" spending on energy efficiency or renewable energy, directed 32% to state general funds, and returned 10% to households or companies affected by carbon pricing (Fleurence et al. 2023).

Thirty-seven countries or regions, such as Switzerland, Japan, and France, have implemented a carbon tax. As shown in **Exhibit 16**, the carbon tax ranges from $0.08/$tCO_2e$ in Poland to $154 in Uruguay. According to I4CE, currently, prices for over 70% of the GHG emissions covered by carbon taxes or GCMs are below $20/$tCO_2e$.

The specific application of carbon taxes varies according to each country's policy design and implementation methods. Generally, countries levy carbon taxes based on either the carbon content of fossil fuels or the level of carbon emissions. The carbon content approach taxes fossil fuels, such as oil, natural gas, and coal, based on their carbon content (Sweden, Norway, Japan, Denmark, and Switzerland). This means the higher the carbon content of the fuel, the higher the carbon tax. These taxes typically apply to both the production and consumption of fossil fuels. This method directly encourages reducing high-carbon fuels and transitioning to low-carbon or zero-carbon energy sources. For example, Sweden began taxing fossil fuels based on their carbon content in 1991. The tax rate has gradually increased, making it one of the highest carbon taxes in the world. In 2023, Sweden's carbon tax rate was $127/$tCO_2e$ (Fleurence et al. 2023). This tax applies to various activities involving the burning of fossil fuels, including transportation, heating, and industrial production. Nonindustrial sectors, such as households and services that use fossil fuels, also pay the carbon tax. To avoid excessive economic impact, some energy-intensive industries and agricultural sectors receive partial exemptions. Sweden's carbon tax policy has effectively reduced GHG emissions and increased the use of renewable energy while maintaining economic growth.

[27]See https://carbonpricingdashboard.worldbank.org/compliance/coverage.

Exhibit 15. Share of Global GHG Emissions Covered by ETSs and Carbon Taxes, 1990–2024



Source: World Bank (https://carbonpricingdashboard.worldbank.org/compliance/coverage).

Alternatively, the carbon emission level approach taxes entities directly based on their carbon emission levels (Canada, Finland, Chile, and South Africa). For example, Canada's federal carbon tax policy, introduced in 2019, covers fuel distributors and large emitters. The tax rate increases annually. In 2023, Canada's carbon tax rate was $48/t$CO_2$e, a 22% increase from 2022 (Fleurence et al. 2023). Canada's policy aims to reduce GHG emissions across the country while encouraging technological innovation and clean energy transition. Additionally, to mitigate the impact of the carbon tax on living costs, especially for low-income families, the Canadian federal government returns a portion of the carbon tax revenue to households and businesses.

Exhibit 16. Countries/Regions with Carbon Taxes, 2023

Country/Region	Latest Price ($/t$CO_2$e)	Year-on-Year Price Trend
Uruguay	154	–2%
Sweden	127	2%
Switzerland	126	22%
Liechtenstein	126	25%
Norway	91	18%
Slovenia	84	39%
Finland	82	–7%
Ireland	52	10%
Canada	48	22%
Canada: British Columbia	48	22%
Canada: Northwest Territories	48	22%
France	47	–5%
Netherlands	45	–9%
Hungary	42	New
Iceland	34	–1%
Luxembourg	32	13%
Mexico: Queretaro	31	0%
Denmark	26	–6%
Portugal	25	–7%
UK	22	–7%
Latvia	16	–15%
Mexico: Yucatan	15	0%
Mexico: Zacatecas	12	–7%
Mexico: Durango	10	New
South Africa	9	3%
Argentina	6	–24%
Colombia	5	13%
Chile	5	–17%
Mexico	4	0%

Exhibit 16. Countries/Regions with Carbon Taxes, 2023 (*Continued*)

Country/Region	Latest Price ($/t$CO_2$e)	Year-on-Year Price Trend
Singapore	4	–6%
Estonia	2	–16%
Japan	2	–2%
Mexico: Guanajuato	2	New
Mexico: State of Mexico	2	–7%
Ukraine	1	150%
Mexico: Baja California	<1	–7%
Poland	<1	–7%

Source: Institute for Climate Economics (Fleurence et al. 2023).

Compared with carbon markets, carbon taxes have several advantages:

- *Simplicity and directness:* As a well-established fiscal tool, a carbon tax is simpler and more straightforward to operate than the still-developing carbon markets. This can save compliance costs for companies.
- *Price stability:* Companies can estimate the carbon tax they need to pay based on the tax rate. Unlike the volatile allowance price, the tax rate is relatively stable, which helps companies reliably estimate costs and make production decisions.

However, like carbon markets, carbon taxes also have certain challenges:

- *Distortion of incentives:* Like all taxes, carbon taxes can interfere with market mechanisms, distorting market participants' incentives and causing deadweight loss.[28] Carbon taxes are a blunter instrument than carbon markets for generating revenue and incentivizing decarbonization activities.
- *No explicit emission reduction target:* Although carbon taxes price carbon, the taxation policy does not specify the exact outcome of emission reductions. The amount of emission reductions depends on the specific tax rate and the business's response to it—the tax elasticity of the business. Therefore, the outcome of actual emission reductions is highly uncertain. Carbon markets, by setting a cap, specify total emissions. Additionally, a fixed tax rate does not provide ongoing incentives for businesses to reduce emissions, whereas the fluctuating allowance price motivates businesses to transition to green development.

[28]Deadweight loss in taxation occurs when a tax prevents the market from achieving equilibrium, causing economic inefficiency. It is the loss of total surplus (consumer and producer surplus) that would have existed without the tax. This inefficiency arises because the tax discourages mutually beneficial transactions between buyers and sellers, reducing the quantity of goods traded below the optimal market level.

- *Use of revenue:* Although a carbon tax generates revenue, the government does not necessarily use this revenue to address climate change. In 2023, carbon tax systems more commonly directed revenues toward government general funds (53%), while carbon market systems earmarked a larger share of revenues (78%) for "green" spending (Fleurence et al. 2023).

Compared with carbon taxes, carbon markets have three additional advantages. First, carbon markets generate more revenue for governments than carbon taxes. According to the World Bank, in 2023, carbon markets generated $75 billion in revenue, while carbon taxes only generated $29 billion (World Bank 2023). Governments can use these revenues for projects that address climate change, further advancing net-zero goals. Second, carbon markets may allow emitters to bank or borrow allowances across different years. This helps businesses smooth costs and hedge against carbon price risks in advance. Third, each country has a completely independent tax system, so there is no linkage between carbon taxes in different countries. In contrast, although carbon markets are also highly fragmented, they still have limited linkage and a greater possibility of international cooperation in the future.

Both carbon taxes and carbon markets are effective ways to implement carbon pricing, each with pros and cons. Countries choose one or both of these forms according to their own situations and goals.

6. CONCLUSION

In this report, we provide a detailed overview of the mechanisms of GCMs, their role in advancing net-zero goals, their current challenges, and their comparison with carbon taxes. The Paris Agreement and net-zero goals have unified the global consensus on addressing climate change, with carbon pricing playing a crucial role in this process. As a market-driven carbon pricing model, GCMs are an effective tool for scientifically determining carbon pricing and promoting the net-zero goal. Climate change can have a substantial and lasting impact on the investment industry, making it crucial for investors to understand GCMs.

This report contributes to the current literature on GCMs in three significant ways. First, we cover the whole GCM system, including both CCMs and VCMs, and examine three representative markets: the EU, California, and China. Our analysis addresses each market from the perspectives of governance, coverage, development, allowance allocation, supply and demand dynamics, market activity, and carbon offset acceptance. Second, we discuss the advantages of GCMs specifically through the lens of their effectiveness for achieving net-zero goals and their role and contributions in promoting emission reductions. We also address the main issues currently faced by GCMs, particularly CCMs, providing investment industry stakeholders with an objective evaluation of GCMs. Third, we compare the two primary carbon pricing mechanisms: carbon taxes and carbon markets. We outline the current status of carbon taxes and carbon markets, their applications, their impact on emission reductions, and their relative strengths and weaknesses. This comparison serves as a reference for industry and policy discussions on the optimal methods for carbon pricing.

In addition to the investment industry, related businesses can use this report to deepen their understanding of GCMs and inform their production decisions and corporate transition planning. Policymakers can also refer to this report to understand the existing issues in GCMs and make targeted policy adjustments.

As a foundational work providing an introduction to GCMs, this report lays the groundwork for future research in this field. There are several possible directions for future studies. First, future research could focus on the market structure of GCMs, including participants, liquidity, trading costs, transparency requirements, instruments, and the ability to build an investment strategy around carbon permits and offsets. These factors determine the ease and feasibility of market-making, trading, and constructing an investment strategy or portfolio focused on emission allowances. Second, future research could explore the auction mechanisms for carbon allowances, examining the main auction methods used in current GCMs, their effectiveness, their advantages and disadvantages, and whether more efficient auction mechanisms exist for GCMs to promote fair pricing and stabilize price volatility. Third, empirical studies on the effectiveness of the cap-and-trade system in achieving real-world emission reductions could be conducted to provide industry stakeholders with a quantitative analysis to support future market developments for improving

GCMs. Fourth, comparative analyses can draw lessons from markets with similar development paths to guide the improvements of GCMs. For example, insights from the market mechanisms of the oil market and the auction mechanisms of the electricity market can contribute to the development of GCMs.

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