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Emissions trading in pursuit of electricity decarbonisation - market structures and regulations matter

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Emissions trading in pursuit of electricity decarbonisation - market structures and regulations matter

Synthesis report

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Abstract: Emissions trading in pursuit of electricity decarbonisation - market structures and regulations matter

This report assesses the role of emissions trading systems (ETS) in electricity sector decarbonisation through analyses of carbon market designs and interactions with electricity market regulations, market structures and additional policies. We do so through the lens of four carbon price quality criteria (volatility, reflection of marginal abatement cost, predictability, and environmental effectiveness) and three abatement channels (clean dispatch, low-carbon investment, and demand-side response). The analytical framework originates from an earlier conceptual study and has been applied to five case studies comprising seven jurisdictions in the Americas, Europe, and Asia. We find that ETSs are especially effective in capitalising on short-term abatement opportunities when embedded within liberalised electricity markets (e.g., merit order effects or fuel switching). In this context, they may also send long-term signals on fuel choices and investment decisions; however, the strength of these signals will depend on ETS design and companion policies. ETSs can also be designed to cater to hybrid electricity markets where carbon cost pass through might initially be absent. Limited pass through to industrial consumers and diluted price signals in final electricity bills can result in untapped mitigation potential and require careful assessment across systems. Moreover, path dependency in terms of previous investments in the sector to a certain extent preordain the abatement options that can be induced by the ETS in the short to mid-term. Overall, ETSs form an increasingly indispensable tool in the policy toolkit, assisting jurisdictions in their transition to net-zero electricity production.

Kurzbeschreibung: Emissionshandel zur Dekarbonisierung des Elektrizitätssektors - Marktstrukturen und -regulierung sind wichtig

Dieser Bericht untersucht die Rolle von Emissionshandelssystemen (EHS) bei der Dekarbonisierung des Elektrizitätssektors durch Analysen der Designmerkmale von CO2-Märkten und deren Interaktionen mit Regulierungen des Strommarktes, Marktstrukturen und zusätzlichen politischen Maßnahmen. Die Untersuchung verläuft entlang von vier Qualitätskriterien eines CO_2-Preises (Volatilität, Widerspiegelung der Grenzvermeidungskosten, Vorhersagbarkeit und Umweltwirksamkeit) und entlang von drei Kanälen zur Emissionsminderung (sauberer Dispatch, CO_2-arme Investitionen und nachfrageseitige Reaktionen). Der hierbei verwendete analytische Rahmen stammt aus einer früheren konzeptionellen Studie und wurde auf fünf Fallstudien angewandt, die sich mit sieben Ländern in Nord- und Südamerika, Europa sowie Asien beschäftigen. Wir kommen zu dem Ergebnis, dass EHS besonders effektiv in der Ausnutzung kurzfristiger Minderungsmöglichkeiten sind (z.B. Änderung der Reihenfolge des Kraftwerkseinsatzs und Wechsel zu emissionsärmeren Brennstoffen), wenn sie in liberalisierte Strommärkte eingebettet sind. In diesem Zusammenhang können sie auch langfristige Signale für die Wahl von Brennstoffen und Investitionsentscheidungen aussenden; die Stärke dieser Signale hängt jedoch von der Ausgestaltung des EHS und der begleitenden politischen Maßnahmen ab. EHS können auch so gestaltet werden, dass sie hybride Strommärkte bedienen, in denen die Weitergabe von CO_2-Kosten zunächst nicht möglich ist. Eine begrenzte Weitergabe des CO_2-Preises an industrielle Verbraucher sowie verwässerte Preissignale in den Stromrechnungen können zu ungenutztem Emissionsminderungspotenzial führen und erfordern eine sorgfältige systemübergreifende Bewertung. Die Pfadabhängigkeit in Bezug auf frühere Investitionen im Sektor bestimmen bis zu einem gewissen Grad die Minderungsoptionen, die durch das EHS kurz- bis mittelfristig ausgelöst werden können, vor. Insgesamt bilden EHS ein zunehmend unverzichtbares Werkzeug im politischen Instrumentarium, das die Länder bei ihrem Übergang zu einer Netto-Null-Stromerzeugung unterstützt.

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List of abbreviations

APCR	Allowance Price Containment Reserve
AUC	Auctioning
BM	Benchmarking
CaT	California Cap-and-Trade
CCA	California Carbon Allowance
CCS	Carbon capture and storage
CE	Clean energy
CFE	Comisión Federal de Electricidad
CHP	Combined heat and power
CO2e	Carbon dioxide equivalent
CR	Capacity ratio
EE	Energy efficiency
EPS	Energy Portfolio Standard
ETS	Emissions Trading System
EU ETS	European Union Emissions Trading System
FiP	Feed-in Premium
FiT	Feed-in Tariff
GP	Grandparenting (allowance allocation)
HB ETS	Hubei Pilot Emissions Trading System
IPP	Independent Power Producer
IRR	Internal Rate of Return
ISO	Independent System Operator
K-ETS	Korea Emissions Trading System
LMP	Locational marginal prices
MAC	Marginal abatement cost
MEX ETS	Mexico Emissions Trading System Pilot Program
MSM	Market Stability Mechanism
MSR	Market Stability Reserve
Mt	Megatonne
OPEX	Operational Expenditures
OTC	Over-the-Counter
PPA	Power Purchasing Agreement
PX	Power exchange
RE	Renewable energy
RPS	Renewable Portfolio Standard
RTM	Real-time market

SCED	Security-constrained economic dispatch
SH ETS	Shenzhen Pilot Emissions Trading System
ToU	Time-of-Use (tariffs)
TSO	Transmission system operator
USD	United States Dollar
VRE	Variable Renewable Energy

Executive Summary

This report is the culmination of a three-year research project commissioned by the German Environment Agency on the "*Influence of market structures and market regulations on the carbon market".* It assesses the role of emissions trading systems (ETS) in electricity sector decarbonisation through analyses of carbon market designs and interactions with electricity market regulations, market structures and additional policies.

The analysis distils major project findings building on a conceptual study published in 2019; case studies in Germany, Poland, Korea, China (Hubei, Shenzhen), the United States (California) and Mexico published over the course of 2020-2021; and regional expert workshops and stakeholder consultations. Through a uniformly applied conceptual framework, we evaluate the quality of the carbon price signal along four criteria (volatility, reflection of marginal abatement cost, predictability, and environmental effectiveness) and abatement opportunities along three main channels (clean dispatch, low-carbon investment, and demand-side response) across the case studies that differ widely in terms of market design and regulation.

An ETS is most effective when it sends a credible long-term price signal that balances responsiveness to new market information with volatility and reflects the marginal abatement cost of the aggregate sectors covered by the system. Design options that ensure sufficient scarcity, promote price discovery through allowance trade, bolster resilience through predefined criteria for automatic market interventions, and that reflect long-term political commitment and transparent decision-making will in principle contribute to a high-quality carbon price signal.

Once such criteria are met, an ETS's performance in unlocking least-cost electricity sector abatement is shaped by three interrelated factors: electricity market regulations (market design and pricing mechanisms), market structure (prior investments in infrastructure and generation capacity), and companion policies. Counter to conventional wisdom that liberalisation is required prior to introducing carbon pricing, ETSs can be deployed in hybrid markets where institutional constraints prevent, or delay, the organisation of electricity supply based on market competition. As jurisdictions seek to accelerate clean energy development and reduce emissions on a short time horizon, additional regulations can ensure carbon costs are reflected in dispatch decisions at minimal administrative burden and in parallel to long-term market reforms.

Where wholesale electricity prices fully reflect carbon costs, it becomes an indispensable tool for day-to-day dispatch and long-term investment decisions aligned with climate targets. However, even in fully liberalised sectors with cost-reflective pricing, limited pass through to industrial consumers and diluted price signals in final electricity bills mean that untapped potential remains for supporting demand-side responses through the ETS. Due consideration on preserving the price signal, such as through rebate schemes, is also required in systems where the phase out of consumer subsidies is considered unfeasible.

Prior investments in the electricity sector will interact with the ETS and predetermine the range of abatement options it can promote. Both fuel switching and the decommissioning of carbon-intensive assets can provide countries with rapid emissions reduction potential but will be most effective where there is diversity in the fuel mix and coal generation assets have recovered their capital costs. Additional policies and forms of remuneration will likely be required where electricity production approaches zero emissions.

As countries forge ahead with climate neutrality targets, decarbonised electricity sectors will provide the backbone for a zero-carbon future. Understanding how interactions impact mitigation choices will better equip us to design effective carbon markets, avoid policy overlap,

and help unlock least-cost abatement options as jurisdictions enter the subsequent stages of electricity sector decarbonisation. This report aims to provide constructive insights into precisely these aspects.

Zusammenfassung

Dieser Bericht ist das Ergebnis eines dreijährigen Forschungsprojekts im Auftrag des Umweltbundesamtes zum "Einfluss von Marktstrukturen und Marktregulierungen auf den Kohlenstoffmarkt". Er bewertet die Rolle von Emissionshandelssystemen (EHS) bei der Dekarbonisierung des Stromsektors durch Analysen der Gestaltungsmerkmale des CO_2-Marktes und der Wechselwirkungen mit Strommarktregulierungen, der Marktstrukturen und der begleitenden politischen Maßnahmen.

Die Analyse führt wichtige Projektergebnisse zusammen, die auf einer 2019 veröffentlichten konzeptionellen Studie, Fallstudien zu Deutschland, Polen, China (Hubei, Shenzhen), den USA (Kalifornien) und Mexiko, die im Laufe der Jahre 2020-2021 veröffentlicht wurden, sowie regionalen Expertenworkshops und Stakeholderkonsultationen beruhen. Anhand eines einheitlich angewandten konzeptionellen Rahmens bewerten wir in den Fallstudien, die sich in Bezug auf Marktdesign und -regulierung stark unterscheiden, die Qualität des CO_2-Preissignals entlang von vier Kriterien (Volatilität, Widerspiegelung der Grenzvermeidungskosten, Vorhersagbarkeit und Umweltwirksamkeit) und die Möglichkeiten zur Emissionsminderung entlang von drei Kanälen (sauberer Dispatch, CO_2-arme Investitionen und nachfrageseitige Reaktionen).

Ein EHS ist am effektivsten, wenn es ein glaubwürdiges langfristiges Preissignal sendet, das ein Gleichgewicht zwischen Reaktionsfähigkeit auf neue Marktinformationen und Volatilität herstellt und die Grenzvermeidungskosten aller vom System erfassten Sektoren widerspiegelt. Ausgestaltungsoptionen eines EHS, die eine ausreichende Knappheit an Zertifikaten sicherstellen, die Preisfindung durch den Handel mit Zertifikaten fördern, die Widerstandsfähigkeit durch vordefinierte Kriterien für automatische Markteingriffe stärken und die ein langfristiges politisches Engagement und eine transparente Entscheidungsfindung widerspiegeln, tragen prinzipiell zu einem hochwertigen CO_2-Preissignal bei.

Sobald diese Kriterien erfüllt sind, wird die Leistung eines EHS bei der Erschließung kostengünstiger Emissionsminderungen im Stromsektor durch drei miteinander verbundene Faktoren bestimmt: die Regulierung des Strommarktes (Marktdesign und Preisbildungsmechanismen), die Marktstruktur (frühere Investitionen in Infrastruktur und Erzeugungskapazität) und die begleitenden politischen Maßnahmen. Im Gegensatz zum konventionellen Standpunkt, dass vor der Einführung von CO_2-Preisen eine Marktliberalisierung erforderlich ist, können EHS auch in hybriden Märkten eingeführt werden, in denen institutionelle Beschränkungen die Organisation der Stromversorgung auf der Grundlage von Marktwettbewerb verhindern oder verzögern. Da Regierungen versuchen, die Entwicklung sauberer Energien zu beschleunigen und Emissionen in einem kurzen Zeithorizont zu reduzieren, können zusätzliche Regelungen sicherstellen, dass CO_2-Kosten in Dispatch-Entscheidungen mit minimalem Verwaltungsaufwand und parallel zu langfristigen Marktreformen berücksichtigt werden.

Wenn die Großhandelsstrompreise die CO_2-Kosten vollständig widerspiegeln, wird dies zu einem unverzichtbaren Instrument für den täglichen Dispatch und langfristige, mit den Klimazielen übereinstimmende Investitionsentscheidungen. Doch selbst in vollständig liberalisierten Sektoren mit kostenorientierter Preisgestaltung bedeuten die begrenzte Weitergabe des CO_2-Preises an industrielle Verbraucher sowie verwässerte Preissignale in den Stromrechnungen, dass ungenutztes Potenzial für die Unterstützung nachfrageseitiger Maßnahmen durch das EHS bestehen bleibt. Auch in Systemen, in denen die Abschaffung von Verbrauchersubventionen als nicht durchführbar gilt, muss die Erhaltung des Preissignals, z. B. durch Rabattsysteme, berücksichtigt werden.

Vorangegangene Investitionen im Stromsektor werden mit dem EHS interagieren und die Bandbreite der Emissionsminderungsoptionen bestimmen, die das EHS fördern kann. Sowohl die Umstellung auf andere Brennstoffe als auch die Stilllegung CO_2-intensiver Anlagen können den Ländern ein schnelles Emissionsminderungspotenzial bieten, sind aber am effektivsten, wenn der Brennstoffmix vielfältig ist und die Anlagen zur Kohleverstromung ihre Kapitalkosten gedeckt haben. Begleitende politische Maßnahmen und Formen der Vergütung werden wahrscheinlich dort erforderlich sein, wo die Stromproduktion sich der Nullemissionsgrenze nähert.

Während die Länder ihre Klimaneutralitätsziele vorantreiben, werden dekarbonisierte Stromsektoren das Rückgrat für eine CO_2-freie Zukunft bilden. Wenn wir verstehen, wie sich die Wechselwirkungen auf Entscheidungen zu Emissionsminderungen auswirken, sind wir besser in der Lage, effektive CO_2-Märkte zu gestalten, Überschneidungen begleitender politischer Maßnahmen zu vermeiden und kostengünstigste Emissionsminderungsoptionen zu erschließen, während die Länder in die Phasen der Dekarbonisierung des Stromsektors eintreten. Dieser Bericht zielt darauf ab, konstruktive Einblicke in genau diese Aspekte zu geben.

1 Introduction

Given the relatively small number of large point source emitters with clear installation boundaries and simple monitoring and verification, the electricity sector is ideally suited to emissions trading. By capping emissions and allowing trade, an allowance price signal is transmitted along the supply chain from producers to industrial and retail consumers (ICAP & PMR, 2021). Yet the quality of the allowance price signal cannot be guaranteed ex ante and will depend on the underlying carbon market design provisions that shape both allowance demand and supply (Acworth et al., 2019). Similarly, the role for ETS in power sector decarbonisation will differ across jurisdictions based on the electricity market structure (i.e., the configuration of existing assets and infrastructure), market regulations (i.e., monopoly, hybrid and liberalised systems) as well as the suite of companion policies (technology support schemes, phase out mechanisms, and fiscal incentives) that will be jointly applied to drive the net-zero transformation (Acworth et al., 2019; De Gouvello et al. 2019).

Understanding how these interactions impact mitigation choices will better equip us to design effective carbon markets. This is precisely the aim of this project. We have developed an assessment of the impact of ETSs on electricity sector decarbonisation by analysing: 1) the interplay between ETS design provisions and the quality of the price signal; and 2) the interactions of the carbon price with electricity market structure, regulations, and companion policies. We do so through the lens of four price quality criteria (volatility, reflection of marginal abatement cost, predictability, and environmental effectiveness) and three abatement channels (clean dispatch, low-carbon investment, and demand-side response) (Chapter 3) elaborated upon in Acworth et al. (2019).

This framework has been applied to five ETSs and seven case study regions which represent a wide spectrum of ETS and electricity market designs, namely: California (Abrell et al., 2020), Germany and Poland (EU ETS) (Abrell, Betz & Kosch, 2020), Mexico (Graichen, Inclán and La Hoz Theuer, 2021), the Republic of Korea (Kuneman et al., 2021), and Shenzhen city and Hubei province (Republic of China)1 (Zhang, Boute, & Acworth, 2021). This synthesis report distils the project findings, drawing upon previously conducted stakeholder interviews in each case study region, carbon and electricity market data analysis, and complemented by additional desk research on market regulations as well as findings from expert workshops and discussions organised for the purpose of this study.

Our findings indicate that careful ETS design is required to ensure a stable and sufficient allowance price signal. Once these criteria are met, the fuel mix and age of the fossil fuel fleet are important. These will shape the short- to medium-term mitigation choices such as fuel switching and the decommissioning of assets – both core abatement options that the ETS can induce and will deliver most effectively in liberalised electricity sectors. However, counter to conventional wisdom that liberalisation is required before market-based approaches can be applied to decarbonise the electricity sector, we find evidence that carbon markets can be designed to incorporate allowance costs into regulated electricity dispatch, investment, and consumption decisions. Through mechanisms, such as green dispatch and indirect emission coverage, choices on allowance allocation provide policymakers a tool to incrementally increase net allowance costs and slowly pass through the carbon price, while balancing other objectives such as ensuring reliably and affordable energy. ETSs can thus be deployed to provide long-term signals

[1] The Chinese Pilots (eight in total) were established to gain experience with emissions trading and inform the design of the national ETS which started operating in 2021. The pilots continue to operate in the short term for entities not covered by the national ETS. Entities from the power sector are transitioning into the national market. Hubei along with the Shanghai pilot system are leading the development of the national ETS registry and trading platform (ICAP 2021).

on the required transition pathway in the many jurisdictions where institutional constraints prevent, or delay, the organisation of electricity supply based on competition.

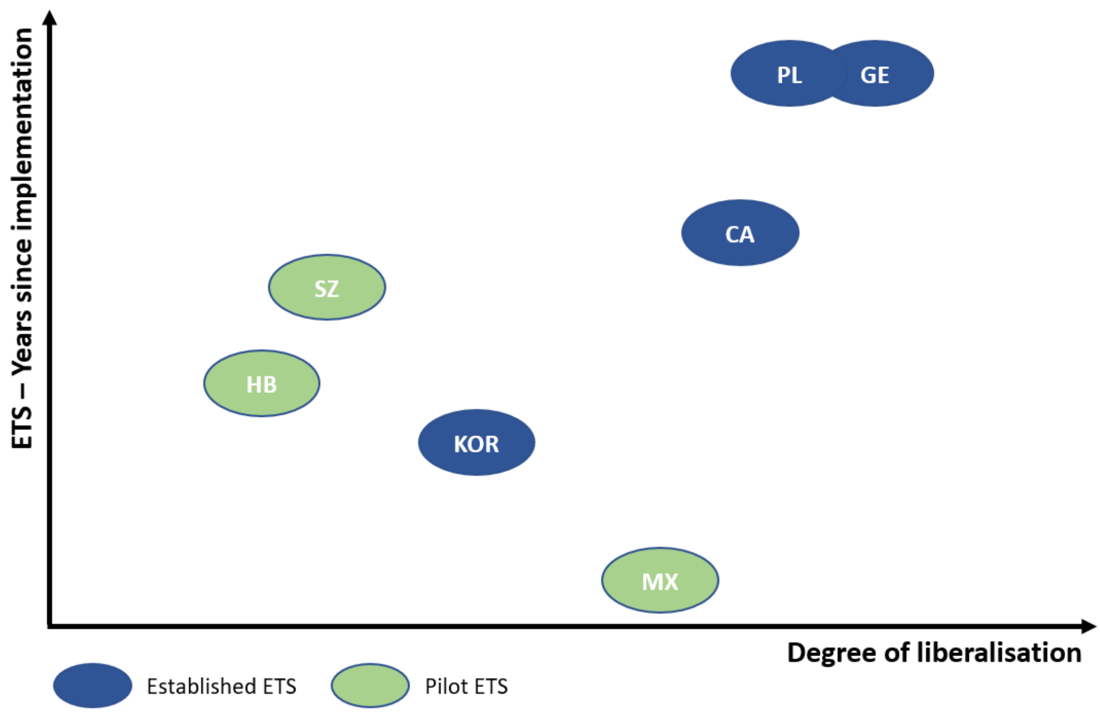
This report is structured in two parts. Chapter 2 provides an overview of carbon market and electricity sector designs for the jurisdictions analysed. In Chapter 3 we assess the quality of the price signal and in Chapter 4 its impact on dispatch, investment, and demand-side responses. Conclusions follow.

2 Carbon market and electricity sector regulation across case studies

The seven jurisdictions analysed in this study (Germany, Poland, Republic of South Korea, Mexico, California, Shenzhen, and Hubei province) represent a wide spectrum in terms of ETS design and maturity (summary Table 1), reflected by a price range of EUR 1 to EUR 32 across systems at the end of 2020 (Figure 1). Where the EU Emissions Trading System (EU ETS), California Cap-And-Trade program (CAL CaT) and the Korea Emissions Trading System (K-ETS) are consolidated systems, Shenzhen, Hubei and Mexico have pilot systems in place (SH ETS, HB ETS, MEX ETS). The case studies also reflect large differences in electricity market structure and design. Europe, California and Mexico have liberalised their electricity systems to varying degree, whereas the Asian ETSs analysed here operate in regulated market contexts. The diversity of the cases along these two dimensions is visualised in Figure 1.

The divergences in ETS design, maturity and market regulations enable a broad range of interactions to be analysed through which we seek to identify opportunities and challenges for ETS-driven abatement in the electricity sector. In the sections that follow, we describe the case study jurisdictions along their carbon market designs and electricity market structures.

Figure 1. Variation in electricity market design and experience with ETS across the case studies



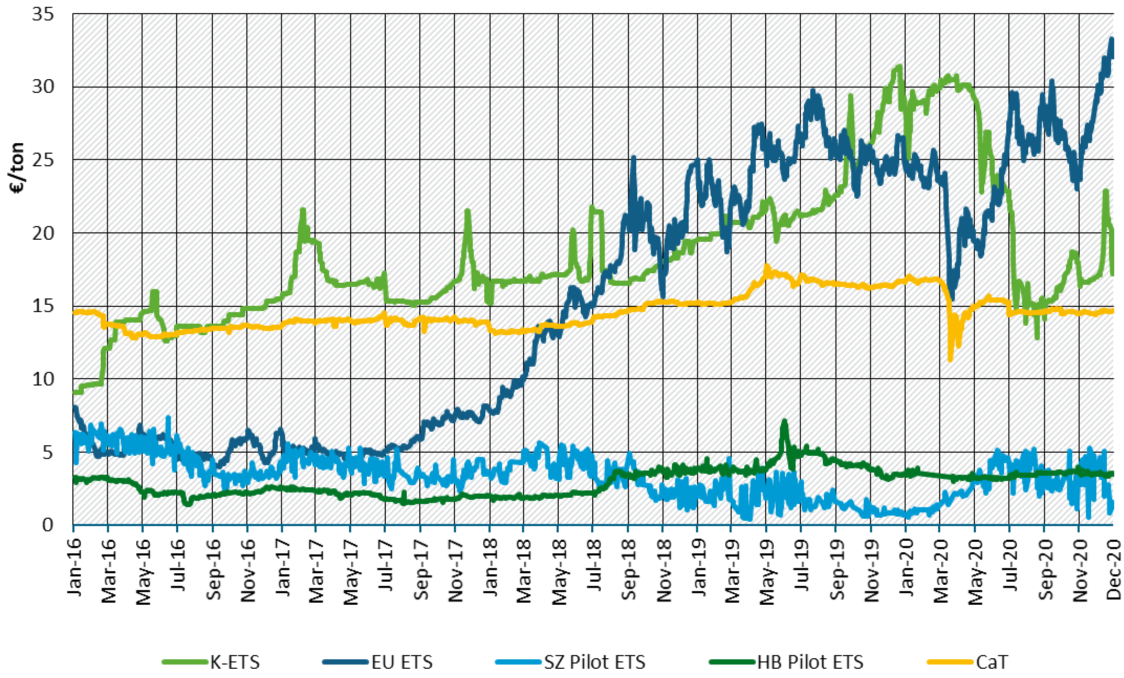
Source: Authors' own illustration.

2.1 Carbon market design

Table 1 provides a summary of each ETS along key design features. Having gone through multiple phases and evolved into consolidated systems, the CAL CaT and EU ETS share several features such as increasing cap stringency, the phase down of free allocation and high auction shares, and the use of automatic market stabilisation mechanisms to provide long-term price certainty in liquid market environments. Despite such convergence as both systems enter the subsequent stages of decarbonisation, they differ in scope and in their approach to supporting market resilience, reflected by their use of price versus quantity-based stabilisation triggers (ICAP, 2021).

Figure 2. Allowance price developments across systems during 2016-2020

Secondary market settlement prices, converted to euros using average quarterly exchange rates



Source: Authors' own illustration based on data from: KRX 2021; EEX 2021; California Carbon 2021; and Sinocarbon. Exchange rates from IMF 2021.

At the other end of the spectrum, in the K-ETS, Hubei pilot ETS and Shenzhen pilot ETS, the regulator has higher discretion to implement measures for market stability once certain market conditions are met. No market stability mechanism has yet been implemented in the MEX ETS. These four systems all feature high shares of free allocation, which in the K-ETS has been slowly but gradually reduced with increasing auction shares. Banking is allowed in all jurisdictions, albeit with different rules. Only the K-ETS allows for the explicit borrowing of allowances. The CAL CaT covers the largest share of its jurisdiction's emissions by combining upstream fuels coverage with downstream coverage of industrial facilities. The K-ETS is the only system to cover the waste sector and targets some passenger transport emissions. The EU ETS, K-ETS, and Chinese pilots cover domestic aviation. Finally, both the K-ETS and SH ETS include indirect emissions from electricity consumption.[2]

Cap-setting differs across all case studies, ranging from automatic reduction factors (EU ETS, CAL CaT), phase-specific targets (K-ETS), or updates in line with intensity-based climate targets (HB ETS, SH ETS). Caps have been declining in the EU ETS and the CAL CaT and have recently started to decline in the K-ETS, thereby delivering tangible emission reductions as these jurisdictions press ahead with decarbonising their economies. All jurisdictions but Mexico have announced climate neutrality targets, which likely indicates steeper emission reduction trajectories in the coming years. The extent and pace at which emission caps are aligned with updated climate targets will be an important determinant of the scope of the ETS in delivering

[2] In these systems, large consumers (e.g., industry) are liable for surrendering emissions associated with their electricity use (i.e., scope 2) next to (direct) point source emissions (scope 1).

on these objectives. In this environment, ensuring an optimal functioning of the ETS that can drive least-cost abatement in the electricity sector remains a key priority going forward.

A brief summary of each of the carbon markets included as case studies is provided in the sections that follow. Detailed analysis of each carbon market can be found in the supporting case studies.

2.1.1 European Union Emissions Trading System

Launched in 2005, the **EU ETS** is the oldest system in operation, covering the second largest number of compliance entities (>10,000) and featuring the highest price level across jurisdictions towards the end of 2020 (Figure 2). Cap reductions have gradually accelerated, declining with an annual linear reduction factor of 2.2% (of a 2010 reference level) at the start of the fourth phase in 2021, an increase from 1.74% in the previous phase. As a general rule, electricity generators do not receive free allowances and must purchase 100% of their surrender obligations through auction or market transactions. Unlimited banking, open market participation, and a liquid futures market have enabled forward price discovery within and across phases in the EU ETS. The Market Stability Reserve (MSR) launched in 2019 supports allowance prices against exogenous demand shocks and to some extent ensures the EU ETS operates in addition to the impact of companion policies. The MSR, together with the announcement of increased ambition for the EU by 2030, has supported the EU ETS allowance price through the demand shock that occurred because of the response to the COVID-19 pandemic (Figure 2).

2.1.2 California Cap-and-Trade Program

The **CAL CaT** began operating in 2012 and covers over 80% of California's greenhouse gas (GHG) emissions through downstream coverage of the power and industry, and upstream coverage of the buildings and transport sectors – approximating 500 covered entities. Taking into account high interconnection capacity and regional electricity trade, emissions from imported electricity (i.e., distributors) are also covered by the program. The emissions cap has declined progressively, averaging 4% annually during 2021-2030, up from approximately 3% in previous years. About 58% of the allowance supply was auctioned in 2020 (ICAP 2021), partly through consignment auctions whose proceeds are earmarked for rebates to end-consumers and mitigation projects. Intra-phase and carry-over banking are allowed in the CAL CaT subject to holding limits tied to the emissions cap. Entities can further use a restricted quantity of offset credits for compliance (4-6%). California Carbon Allowances (CCA) have largely followed the annually increasing auction reserve price (Figure 2), reflecting the system's underlying objective of serving as backstop to complementary policies aimed at achieving the 2045 carbon neutrality target. An Allowance Price Containment Reserve (APCR), which has not been triggered so far, releases allowances for sale at two price tiers and a price ceiling (USD 41.40, 53.20, and 65.00 respectively), providing higher price certainty while limiting compliance costs.

2.1.3 Shenzhen Pilot Emissions Trading System

The **Shenzhen pilot ETS** commenced in 2013, marking the first of eight pilot programmes in China launched in preparation for a national ETS. Contrary to other systems, the SH ETS sets an intensity-based cap covering both point source emissions at facility level and indirect emissions from power generation of 707 entities in 2019. Electricity generators, currently transitioning to the national ETS, received allowances through output-based technology benchmarks. Regular auctioning (3% of primary allocation) has been announced but is yet to be implemented. The SH ETS is the smallest but also the most liquid market of China's pilot systems, supported by third-party participation. However, the absence of a long-term target for the ETS and uncertainties surrounding the allocation process have adversely impacted expectations of future net scarcity and contributed to a low-price environment (Figure 2).

2.1.4 Hubei Pilot Emissions Trading System

The **Hubei pilot ETS** was launched in 2014 as the second trading system to come online in China. It features an absolute cap pegged to the provincial emissions intensity target and projected GDP growth that covered approximately 338 entities from the power and industrial sectors. Electricity generators, currently transitioning to the national ETS, received allowances through output-based technology benchmarks. A separate reserve is available for ad hoc auctioning. Where unlimited banking (<3 years) is allowed in the SH ETS, banking in the HB ETS is limited to one year and, in support of market liquidity, to allowances obtained through trading. The regulator can draw on a reserve for market stabilisation once certain price trends are reached but has to consult an Advisory Committee before intervening in the market, which it can do at discretion by auctioning or buying back allowances. Price controls have applied to exchange trade, which concurrently with ex-post allocation adjustments, reduce price volatility but have also given rise to market distortions (Zhang, Boute & Acworth, 2021).

2.1.5 The Korea Emissions Trading System

The **Korea ETS** was launched in 2015 as the first mandatory national ETS in Asia. The system covers close to three quarters of national GHG emissions as of Phase 3 (2021-2025) from the heat and power, industry, buildings, and transport sectors.[3] In addition to direct emissions, the K-ETS also covers some indirect emissions from large electricity consumers. Aggregate caps are established per trading phase and have been reduced by 4.7% in Phase 3. Primary allocation to electricity generators consists of a mix of benchmarking and auctioning, which are both undergoing revisions to better align with Korea's net-zero target for 2050. There are several flexibility provisions embedded in the K-ETS: borrowing is allowed within phases according to a predetermined formula; banking is allowed within and across phases with quantitative limits tied to an entity's net amount of units sold (to support market liquidity);[4] and domestic and international offsets can be used for compliance subject to strict qualitative criteria and limited to 5% of an entity's surrender obligation. An Allocation Committee can intervene at discretion in the market (measures include supply adjustments, allowance retention limits, a temporary price ceiling and adjustments to the rules on banking, borrowing and offsets) once predefined market thresholds are reached. Allowance prices in the K-ETS had been among the highest across systems but dropped towards the end of Phase 2 following a reversal in market dynamics, partly induced by the COVID-19 pandemic, and a growing allowance surplus.

2.1.6 Mexican Pilot Emissions Trading System

The **Mexico pilot ETS** is the first system in operation in Latin America. The system came into effect on 1 January 2020 and runs a three-year pilot phase that ends in a transition phase (third year) before continuing into the operational period (beginning in 2023). The MEX ETS regulates 300 stationary sources from the electricity and energy-intensive sectors that contribute to 40% of national GHG emissions. Grandparenting with ex-post adjustments when emissions exceed initial allocation is the main allocation method in the pilot phase, which from the second year onwards may be complemented by the auctioning of allowances from a separate reserve. Unrestricted banking is allowed within—but not across—trading phases, and entities may meet up to 10% of their compliance obligation with domestic offsets outside the scope of the ETS. The

[3] Large transport companies and domestic aviation are included in the K-ETS.

[4] Different limits apply to intra-phase and carry-over banking of allowances.

system features a closed market limited to over-the-counter (OTC) transactions. Regulations for the operational phase, expected by 2022, will be an important indicator of the role of the MEX ETS in Mexico's climate mitigation strategy going forward.

Table 1. Carbon market design across case studies[5]

Jurisdiction / feature	EU ETS	California CaT	Korea ETS	Shenzhen ETS pilot	Hubei ETS pilot	Mexico pilot ETS
Coverage • ***% emissions*** • ***Number of entities***	• 40% • ~11,000	• 80% • ~500	• 73.5% • 685 ('21)	• 40% • 707 ('19)	• 45% • 338 ('18)	• 37% • ~300
Cap in MtCO2e	1816 ('20)	334 ('20)	592 ('20)	34.78 ('15)	270 ('19)	271.3 ('20)
Annual cap reduction[6] • ***2015–20*** • ***2021–30***	• -1.98% (LRF 1.74%) • -3.1% (LRF 2.2%)	• -3.26% • -5.1%	• +1.21% • -4.7%[7]	No data	• -3.58% ('14-'19)	*n/a*
Long-term targets • ***2030*** • ***2050***	• At least -55% below 1990 • Net zero	• 40% below 1990 • Net zero '45	• 24.4% below 2030 • Net zero	• 60-65% below 2005 (intensity) • Net zero '60 (national)	• 60-65% below 2005 (intensity) • Net zero '60 (national)	• 22% below BAU • 50% below 2000
Allowance allocation	Phase 3: AUC (57%), BM (43%)	2019: AUC (65%), BM (35%)	Phase 3: AUC (10%), BM (60%), GP (30%)	GP, BM	GP, BM	GP
Rules on banking and borrowing	• Unlimited banking	• Banking with limits	• Banking with limits • Borrowing with limits	• Unlimited banking up to 3 years	• Banking limited to 1 year & traded allowances	• Banking within pilot years
Offsets Compliance limit (%)	• 50%[8] (2020), none thereafter	• 8% (–2020), 4% (–2025), 6% (2025–)	• 10% (–2020), 5% (2021–)[9]	• 10% — domestic credits	• 10% — domestic credits	• 10% — domestic credits

[5] The table data are derived from the respective case study reports unless indicated otherwise.

[6] Compounded annual average growth rates for actual cap level reductions during indicated period. The values may deviate from cap reduction factors that are based on baseline emissions. For the K-ETS, the annual average caps of Phase 1 and Phase 2 were taken for 2015 and 2020, respectively. Data from CARB (2019a), European Commission (2021), GIR (2020), Korea MoE (2020) and SinoCarbon.

[7] The K-ETS cap decreases by 4.7% in Phase 3 (2021-2025) compared to a 2017-2019 baseline. The cap trajectory for Phase 4 (2026-2030) is not yet available.

[8] Approximately 1.6 billion credits were used between 2008-2020 (EC, 2020b). This amounts to roughly 7% of verified ETS emissions over the same period (EEA, 2021).

[9] In Phase 2 (2018-2020) of the K-ETS, offsets were limited to 10% of entities' compliance obligations, half of which (5% of total) could be met through overseas credits. In Phase 3, a single limit of 5% applies.

Jurisdiction / feature	EU ETS	California CaT	Korea ETS	Shenzhen ETS pilot	Hubei ETS pilot	Mexico pilot ETS
Market Stability Mechanisms	• Rule-based, quantity triggers to avoid large surplus coupled with limit on allowances that can be held in the reserve	• Auction reserve price • Tiered price triggers to contain price hikes	• Auction reserve price • Trigger prices for discretionary measures	• Fixed allowance reserve price used at discretion	• Trigger price for discretionary measures	• None in pilot phase
Market participation	• Entities, 3rd parties	• Entities, 3rd parties	• Entities and public banks; 3rd parties from 2021	• Entities, 3rd parties	• Entities, 3rd parties	• Covered entities
Market places and products	• Auction, spot, futures, SWAP, options, OTC	• Auction, spot, futures, options, OTC	• Auction, spot, SWAP, OTC. (Futures Phase 3, tbd)	• Reserve auction, spot	• Reserve auction, spot	• OTC, reserve auction (tbd)
Trade activity[10]	561%	104%[11]	6%	42%[12]	4%	n/a

2.2 Electricity sector structure and market regulation

Electricity sectors across the world have undergone profound changes over the past three decades, in both their structure and the regulations that govern their operation. Within the general trend of market liberalisation, a diverse landscape of regulated, hybrid and competitive electricity markets has emerged. Most countries have restructured their electricity markets, albeit to varying degrees. Electricity markets that use wholesale markets to coordinate daily operations span 40% of global electricity demand; hybrid systems with partial unbundling and limited competition in the electricity generation segment comprise 47% of demand; while vertically integrated regulated monopolies where a (often state-owned) utility controls the generation, transmission, and distribution of electricity sold to end-consumers in a regulated pricing regime are still present and encompass 13% of global demand (IEA, 2020a).

Electricity market structures (i.e., the capacity mix, ownership, and age of assets) will interact with market regulations by preordaining the range of latent abatement options available for the ETS to promote under cost pass through conditions. This mostly concerns the potential for fuel switching and decommissioning of assets. Of the cases analysed in this study, Germany, California, China (national), and Korea have all surpassed a 30% low-carbon generation share including renewables, nuclear, biomass and hydropower. A large reliance on coal power is still observed in China, Korea, Poland, and until recently Germany (>40% of total electricity

[10] Calculated as the percent share of allowance transactions of total primary allocation in 2018. Includes OTC transactions. Data from: DEHSt (2019); European Commission (2020b); CARB (2017); CARB (2020b); Québec Ministry for the Environment and the Fight Against Climate Change (2021); GIR (2020); SinoCarbon

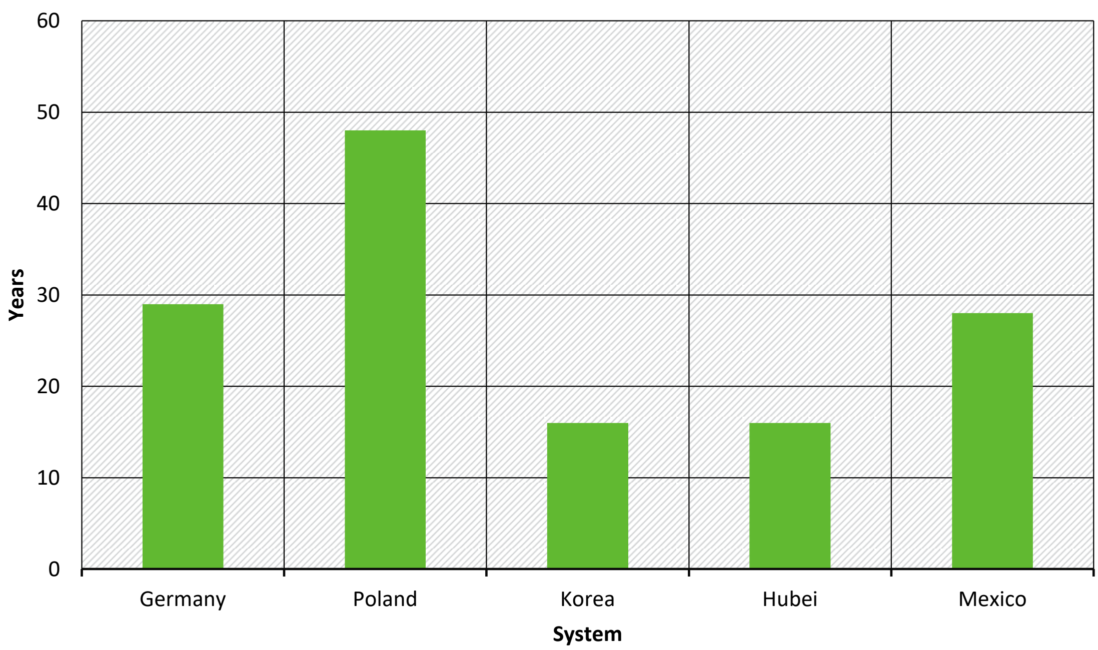
[11] Trade activity calculated for the linked California-Québec allowance market.

[12] Without OTC trades, market liquidity in the SH ETS stood at 4.3%.

generated). In markets where carbon-intensive assets contribute to a significant share of total electricity supply, a carbon price can incentivise short-term abatement through fuel switching (next to supporting investment in low-carbon electricity sources). The potential for reducing emissions through this avenue will depend on the presence of gas infrastructure and available gas-fired capacity. To this effect, latent fuel switching potential is high in Germany and Korea, but low in China and Poland. In jurisdictions where gas is highly competitive and often cheaper than emissions-intensive fuels (such as California and Mexico), the ETS will play a smaller role in inducing short-term abatement in the electricity sector. Nevertheless, a carbon price remains indispensable for providing long-term signals on fuel choice and investment as energy markets are volatile and could shift back in favour of carbon-intensive fuels absent such policies.

Similarly, opportunities for decommissioning will be affected by the age of the coal fleet and the extent to which capital costs have been recovered. In young fleets, the focus of the ETS will hence shift towards abatement within given infrastructural constraints, such as retrofitting. As illustrated in Figure 4, the average age of coal capacity differs greatly across case study regions, creating different opportunities and challenges for phase out trajectories.

Figure 3. Average age of coal capacity across case study jurisdictions



Source: Authors' own illustration based on case studies and Bundesnetzagentur (2020) for Germany.

Ensuring that carbon costs are reflected in electricity cost structures and prices is paramount for an ETS to unlock least-cost abatement options in the sector. The opportunity for carbon cost pass through depends on whether electricity markets are present, or additional (administrative) price regulations are introduced. The first instance can be observed in Germany, Poland, and California. Pass through will likely be imperfect in Mexico and remains absent in Korea and the Chinese pilots until market reforms are fully implemented (Chapter 3.2.1).

Electricity market reform involves a range of steps aimed at increasing competition and reducing barriers to entry through the creation of markets and the institutions that ensure their effective functioning (e.g., IEA, 2005; Joskow, 2008).[13] A key objective of electricity market reform has been to improve cost efficiency, and more recently, to accommodate shifting supply and load patterns as a result of high variable renewable energy (VRE) uptake (Figure 3).

Guangdong **(Shenzhen)**, **Hubei**, and Korea each have hybrid designs combining monopolistic and competitive market elements. Since reforms in 2015, wholesale electricity pricing in the Chinese provinces is increasingly settled through mid- and long-term contracts (bilateral and auction), in most cases based on benchmarks set by the government. While electricity trade has increased, the dispatch of generation sources is still largely based on administrative criteria. Reforms in China have been underway to establish short-term markets with least-cost dispatch (currently being piloted in some regions), complete the functional unbundling of grid companies, and create competition in the retail sector (also see IEA, 2019).

In **Korea**, on the other hand, IPPs compete with state-owned companies in a functioning day-ahead market operated by an independent system operator. Generators are dispatched according to a least-cost principle following technology-specific operational expenditures (OPEX) profiles[14] that are set monthly by the regulator and have so far not included carbon costs. This so-called cost-based pool market is a first step in the creation of short-term energy markets. There are discussions to transition from this model towards a price-based pool market that would enable generators to submit supply bids to the market according to their individual cost profiles.

Mexico, California, Poland, and Germany each have liberalised electricity sectors in place, though their market designs differ in important aspects. The main divergence lies in whether supply and demand is balanced through a gross pool (central dispatch) or through a bilateral market with voluntary power exchanges (PX) (self-dispatch) (e.g., see Barroso et al., 2005).[15] The PX model delegates more autonomy to the market operator in balancing supply and demand closer to real time through sequential short-term markets, where the former has a bigger role for (independent) system operators that centrally dispatch sources, allowing a range of technical aspects to be considered to the benefit of overall system stability. In principle, both models enable carbon costs to be reflected in wholesale electricity markets. Where market reforms are not yet fully implemented and legacy contracts exist in parallel, such as in Mexico, carbon cost pass through will likely be more limited (Chapter 3.2.1).

California has a legally unbundled system with a two-sided gross pool market that is overseen by the independent system operator, CAISO. Generators' multipart bids are reflected in the day-ahead dispatch schedule. The marginal unit can receive uplift payments in the case where the clearing price is below its incurred costs. After gate closure[16] (the moment after which submitted bids cannot be adjusted), generators and suppliers update their energy commitments in the real-time market (RTM) and indicate reserve capacity that the system operator may use

[13] For a summary of the main steps in electricity sector reform, see Joskow (2008). Key components include the privatisation of assets; the unbundling of generation and retail supply from transmission and distribution activities; the horizontal restructuring of generation assets; the creation of wholesale energy and ancillary service markets; the creation of institutions to facilitate demand-side participation, grid access, and grid management; and the creation of an independent regulatory agency.

[14] Operational expenditures are the recurring costs for a generation facility in the production of electricity.

[15] Both systems hence have key advantages. A pool model (comprising either producers, or producers and consumers) allows for optimised dispatch decisions through a central algorithm that accounts for technical considerations such as power plants' constraints and grid congestion at specific nodes (i.e., higher granularity of prices). On the other hand, the PX model (featuring decentralised trading between producers and consumers) offers higher temporal flexibility and price adjustment through intraday price signals that facilitate cost efficient balancing and the integration of VREs. There is ongoing debate on how to improve market designs as to leverage the advantages of both approaches (e.g., Herrero, Rodilla & Bataille, 2016; IRENA, 2017).

[16] Gate closure is the moment up to which market agents can either submit or modify their buy and sell orders. After that point, the final binding schedule is determined for all participants (IRENA, 2019a).

for grid stability (CAISO, 2020). The retail market features limited competition and fixed block tariffs.

Mexico undertook major steps to restructure its electricity market in 2015, including the legal unbundling of the main utility and the introduction of wholesale markets for energy, capacity and ancillary services. Retail tariffs continue to be regulated for small end-consumers. Like the Californian model, Mexico's wholesale market uses a two-step settlement process based on (central) security constrained economic dispatch (SCED) with locational marginal prices (LMP).[17] As a transitional tool, legacy assets of the utilities' (CFE) newly established subsidiaries can opt to retain long-term contracts with the retail supplier. This serves to provide cost certainty, and limit price volatility and potential risks of market power being exercised but retains a regulated segment in the market for a substantial share of total supply. An intraday (hour-ahead) market is planned to be introduced in the coming years. However, President Obrador's administration's embrace of state-owned infrastructure has led to delays in the market's restructuring (Lujambio, 2019). It recently introduced changes to the Electricity Industry Law to reverse privatisation efforts and curb further horizontal unbundling, prioritising the dispatch of state-owned assets, amongst others (Brown de Vejar & Páramo Fernández, 2021). The amendments were adopted by congress in March 2021, but implementation has stalled until and if ruled constitutional by the federal judiciary.

The **Polish** electricity market combines aspects of the gross pool and PX model. Most assets in the Polish market are state-owned, following the legal unbundling of assets without large-scale privatisation seen in other member states. Conforming to European market design, the grid is owned and operated by the same entity, energy is traded OTC and via the exchange in a bilateral contracts model that includes intra-day markets, and the transmission system operator (TSO) operates a balancing market. Operators are required to sell at least 15% of their energy through the exchange (RAP, 2018). Contrary to most other EU member countries, generators are centrally dispatched according to a cost minimisation mechanism based on bids in two separate and differentiated day-ahead markets. Large generation units and flexible loads are required to bid their capacity in the real-time market (gate closure 14:30 D-1) to adjust for deviations in the day-ahead schedule. Due to the dual use of day-ahead and the RTM, intra-day markets play only a marginal role in the Polish electricity sector. Consumers are free to choose between electricity suppliers. However, with the introduction of price caps in 2019, retail competition has been limited to some extent.

Germany has the most liberalised electricity sector among the seven jurisdictions analysed. This is reflected by more far-reaching unbundling across the supply chain in line with EU energy policy (Agora Energiewende, 2019),[18] and matured competitive wholesale and retail energy markets with extensive use of both financial and physical contracts. Trading facilitated by power exchanges takes place from years ahead (forward/futures), day-ahead, to five minutes before delivery (intra-day) at 15-minute intervals. European markets are designed to limit the role of the system operator, which oversees real-time system management following market closure (IRENA, 2017).[19] Accordingly, the TSO procures capacity and operates the balancing market. So-called balancing groups (i.e., an aggregation of generation assets) are responsible for balanced feed-in and offtake of energy on the short-term markets and incur the TSO's costs for control

[17] Under LMP, electricity prices reflect the costs associated with grid congestion and losses at specific locations (nodes) of the grid, providing a long-term information signal on where network investments are needed and facilitating efficient dispatch decisions that consider system constraints.

[18] Ownership unbundling in large, previously integrated utilities, fully separating transmission from generation activities. Legal unbundling of distribution companies, and (at a minimum) the functional unbundling of suppliers with generation assets.

[19] Contrary to the pool market model, transmission and distribution companies are the system operators for their region.

energy in the event of an imbalance, also referred to as the imbalance settlement process. While featuring fully fledged markets and balancing procurement mechanisms, market concentration is high. Furthermore, the regulator mandates reserve capacity outside the scope of the market to be available in case of extreme events that may result from fluctuations in intermittent energy sources.

The seven jurisdictions analysed here feature unique market designs that each set a framework for carbon cost pass through and their corresponding internalisation in operators' generation cost profiles. Cost pass through is possible but not guaranteed in hybrid market designs and has so far been (largely) absent in China and Korea. Furthermore, the jurisdictions adopt different strategies to technology promotion policies, phase out policies, and investment regulations which interact with the carbon price in different ways, as explored in Chapter 3.

Table 2: Electricity sector regulation

Jurisdiction / market element	Germany	Poland	California	Korea	Shenzhen	Hubei	Mexico
Power sector emissions (% of ETS emissions)[20]	67.6% ('19)	78.9% ('19)	14.5% ('19)	44.3% ('18)	No data	No data	50.9% ('20 est.)[21]
Key companion policies	RE target and priority dispatch; sliding FiP (until '21); coal/nuclear phase out; CHP support	RE target and priority dispatch; sliding FiP; CHP support	RPS; tax exemptions (solar); FiT (biomass, CHP); EPS	technology targets; RPS; fuel taxes; emission standards; fine dust reg.; coal lifecycle cap	RE targets; FiT; EE performance standards; air pollution standards	RE targets; FiT; EE performance standards; air pollution standards	CE targets; CE certificates; carbon tax
Generation mix[22] *1. Low carbon* *2. Medium carbon* *3. High carbon*	2019 1. 52.6% 2. 15.0% 3. 29.2%	2019 1. 16.0% 2. 10.4% 3. 73.2%	2019 1. 56.7% 2. 43.0% 3. 0.3%	2019 1. 32.6% 2. 25.8% 3. 41.2%	China (national) – 2019 1. 31.7% 2. 3.3% 3. 65.0%		2019 1. 20.4% 2. 60.2% 3. 19.4%
Average age of coal fleet[23]	29 years (2020)[24]	48 years (2019)	N/A	16 years (2019)	26 years (2019)	16 years (2019, approximation)	28 (2019)
Market concentration • *CR*[25] • *Ownership of assets*	• 76% (of conventional assets) • Mixed but mostly private	• 77% • Mixed but mostly state-owned	• 27% • Mostly private (75%)	• 71% (state) • ≥18% private	• No data • Mostly state-owned	• No data • Mostly state-owned	• Mixed, 57% state-owned

[20] For Germany and Poland, fuel combustion emissions of ETS-covered entities (an approximation of power sector emissions) are used with national emissions covered by the EU ETS taken as the denominator. Using the same method, in 2019, the aggregate EU-wide share amounted to 62.4% of total emissions covered by the EU ETS (EEA 2021). Data from CARB (2020); EEA (2021); GIR (2020).

[21] Calculation based on 2020 cap and allocation to electricity generators. See SEMARNAT (2019).

[22] Electricity generation shares: low carbon sources include renewables, nuclear, biomass and hydropower, medium carbon refers to gas-fired capacity, high carbon generation sources include coal, oil, and peat. Data from AGEB (2020); California Energy Commission (2020); EPSIS (2020); IEA (2020b); Eurostat (2021).

[23] Capacity-weighted average of installed coal-fired power plants in operation. Own calculations based on Bundesnetzagentur (2020), EPSIS (2020), and case studies.

[24] Includes the new Datteln 4 plant and coal plants listed under "Sicherheitsbereitschaft" that can be called upon in case of severe system instability up to four years after being decommissioned.

[25] The capacity ratio represents the share in total installed capacity of the five largest utilities or electricity producers.

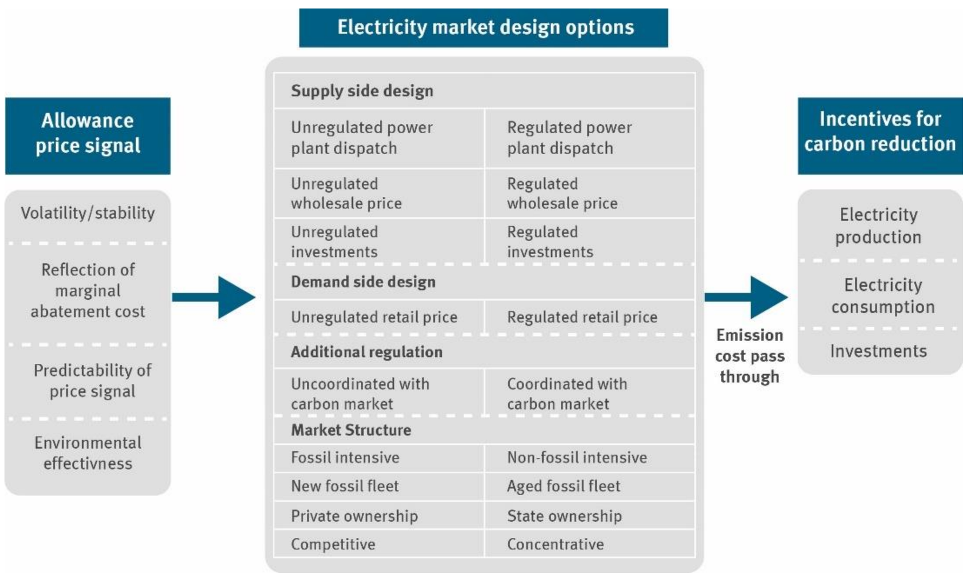
Jurisdiction / market element	Germany	Poland	California	Korea	Shenzhen	Hubei	Mexico
Competition	Wholesale and retail competition	Wholesale, limited retail	Wholesale competition	Limited wholesale competition	Nascent wholesale competition	Nascent wholesale competition	Wholesale competition, limited retail
Wholesale market design	Bilateral contracts market with voluntary exchange	Bilateral contracts market with semi-voluntary exchange	Security constrained economic dispatch, ISO model (gross pool)	Regulated pricing with least cost dispatch in one-sided cost-based pool	Regulated pricing and equal-hour dispatch	Regulated pricing and equal-hour dispatch	Gross pool market, security constrained economic dispatch
Market places	Forward/futures; day-ahead; intra-day auction and continuous; balancing	Forward/futures; capacity; forward (e); day-ahead; intra-day OTC (f) and auction (e); real-time	Day-ahead; real-time; both including energy and reserve component	Day-ahead market	Day-ahead market (tbc); bilateral PPAs on annual and monthly basis	Day-ahead market (tbc); bilateral PPAs on annual and monthly basis	Day-ahead; real-time; hour-ahead (tbc); capacity balancing market; long-term auctions
Other revenue and compensation	• Network reserve • Capacity reserve • Last-resort reserve Compensation for indirect carbon cost (large electricity consumers)	Compensation for indirect carbon cost (large consumers)	• Uplift payments • Capacity procurement mechanism	• Capacity remuneration • Ancillary service payments • Allowance cost compensation (generators)	• Cost-plus regulation	• Cost-plus regulation	• Vesting contracts
Retail price-setting	Competitive volumetric tariffs (ToU)[26]	Volumetric tariffs. Semi-competitive due to price cap for certain suppliers	Volumetric block tariffs	Regulated volumetric tariffs separated into different end-user groups	Volumetric with cross-subsidisation component	Volumetric with cross-subsidisation component	Multi-part tariffs, with dynamic pricing for industrial consumers

[26] IRENA (2019b).

3 Carbon market interactions and the quality of the price signal

The design of an ETS will ultimately set the conditions under which demand for and supply of allowances interact to generate an allowance price. By looking across case studies, we seek to understand which carbon market regulations can lead to a distortion of the allowance price signal and where electricity market structures and regulations limit or promote the effectiveness of the ETS. Our analysis is guided by the framework introduced in Acworth et al. (2019), outlined in Figure 4 below.

Figure 4: Framework of the analysis, as introduced in Acworth et al. (2019)



3.1 Volatility

Volatile carbon prices are an indicator that a market is able to react to newly revealed information, e.g., changes in fuel prices or the cost of new production technologies. However, excessive volatility makes it difficult for market participants to make abatement and trading decisions and can increase investment risk and hence capital costs.

The case studies underline that ETS design elements have a substantial impact on allowance price volatility. Open market participation, high market transparency, large auction shares and the use of market stability mechanisms (MSM) (especially price floors) are each seen to limit short-run price volatility. These findings are in line with the academic literature and confirm hypotheses of the conceptual precursor of this study (see Acworth et al., 2019).

High auction shares facilitate price discovery, which is particularly important where there is limited trade on the secondary market. This has supported relatively stable price development in both the CAL CaT and the EU ETS. High auction shares also facilitate the implementation and operation of MSMs that aim to increase the resilience of ETSs by providing automatic supply adjustments tied to auctions. Moreover, MSMs that are bound by clear rules, ensuring market participants can anticipate and plan for their impact on the allowance market, reduce volatility (Hepburn et al., 2016). In California, the price floor has provided investment certainty by supporting allowance prices around the price floor during periods of constrained demand (Abrell et al., 2020). In the EU ETS, the MSR has assisted the market to be more resilient to exogenous shocks, including that brought about by the COVID-19 crisis. However, whether the

MSR is well placed to correct for a persistent imbalance in the market has been the focus of recent debate (Abrell, Betz & Kosch, 2020; Gerlagh et al., 2020).

Similar effects were not observed in systems with discretionary market interventions (K-ETS, SH ETS, HB ETS). In Korea, the allowance price remained stable for several months despite a clear fall in economic activity and emissions, as Korea was one of the first jurisdictions to enter a lock down to contain the COVID-19 pandemic. This is likely due to a focus on 2019 compliance and KAU-19 (Korean Allowance Units) vintage allowances for which scarcity remained. However, the allowance price fell in the second quarter of 2020, when consensus emerged that for the 2020 compliance year the market would be long. Despite the introduction of a temporary price floor in spring 2021, prices have not seen the recovery witnessed across other markets. This Korean experience was also exacerbated by a lack of third-party participation, no forward market and limited banking, which preclude market participants from taking a longer term market position.

The case studies further support the theory (Betz & Schmidt, 2016; Betz & Cludius, 2016) that open market participation boosts market liquidity and creates more consistent trading throughout the year by reducing transaction costs, as observed in the CAL CaT and EU ETS. On the contrary, the closed market systems in Phase 1 and 2 of the K-ETS played an important role in recurrent short run volatility centered around compliance periods and new policy announcements (Kuneman et al., 2021). This was likely exacerbated by high shares of free allocation and some uncertainty surrounding future allocation plans. While a closed market was considered necessary for the early phases of the K-ETS, Phase 3 should see a decline in price volatility with the inclusion of third-party participants.

Transparency of information is also critical for a predictable and stable price (Mizrach & Otsubo, 2014). Both the CAL CaT and the EU ETS are highly transparent in their information provision on market dynamics, allocation provisions and compliance processes, thereby facilitating active market participation. The K-ETS also regularly releases market information and is therefore well placed to support a more active market in Phase 3, where third-party participants will be able to trade.

As discussed in Acworth et al. (2019), a higher number of marketplaces should offer increased opportunities for trade, improving liquidity and reducing price volatility. This was generally supported by the EU ETS and CAL CaT case studies. The K-ETS case study also emphasised the importance of public information regarding trades. In a small and non-liquid market, a preference for OTC trade by larger covered entities crowded out trade on the spot market, detracting from price discovery. According to interviewed experts, this has potentially increased price volatility compared to the case where all trades would be required to take place on the exchange, where settlement prices could have been observed by market participants. A similar trend was observed in the Shenzhen pilot. This finding is material for jurisdictions that restrict third-party trade in early phases and may warrant careful design to ensure that those trades that do take place provide information to the market in a way that supports price discovery.

3.2 Reflection of Marginal Abatement Cost

In theory, the allowance price signal is not distorted if it equates to the marginal abatement cost (MAC) of all market participants. This can be supported by an open and functioning market that reveals a clear allowance price signal and where barriers to trade are removed (Allaz & Vila, 1993; Burtraw & McCormack, 2016; Fuss et al., 2018; Neuhoff et al., 2015). In practice, this is rarely likely to be the case as a result of market and regulatory failures, companion policies, as well as ETS design elements such as a floor price or high shares of free allocation. Anecdotal evidence suggests that, across all case studies, the allowance price signal was subject to distortions and therefore did not reflect MAC.

One exception is the EU ETS in 2019 where our analysis and experts[27] agree that the allowance price reflected fuel switching costs of the marginal electricity generator. Beyond this specific case, the following issues identified from the case studies suggest that the allowance price is often distorted from the MAC.

High free allocation shares coupled with risk-averse trading behavior, where covered entities banked allowances rather than engaged in market transactions resulted in uncertainty surrounding the value of allowances in the K-ETS. A large share of the transactions that did take place occurred OTC with prices concealed from the market. These factors precluded price discovery and placed upward pressure on allowance prices, diverting them from the MAC. Recent reforms, such as the inclusion of financial actors in exchange-based trade and reformed banking limits tied to trade activity, have addressed these issues to a large extent in Korea (Kuneman et al., 2021).

In line with meeting intensity-based climate targets, the Shenzhen and Hubei ETSs apply ex-post allocation adjustments to the risks of under- or over-supply. The mechanism has to some extent subsidised additional emissions, leading to low marginal abatement requirements, while reducing allocation when efficiency is improved, reducing the incentive for low-carbon investment (Zhang, Boute & Acworth, 2021). Similar problems are observed in the pilot phase of the MEX ETS, where economic incentives have been limited by design to allow entities time to adjust. The opportunity for price discovery is limited by a closed market, the absence of a trading platforms and thus trades limited to OTC, and a combination of grandparenting with ex-post adjustments (Graichen, Inclan & La Hoz Theuer, 2021).

In the EU ETS, compensation for increased electricity costs for energy-intensive firms deemed at risk of carbon leakage has also dampened the incentive to invest into energy efficiency improvements. Where firms are agnostic to electricity costs because of the compensation they receive, emissions and allowance prices may remain higher than what would otherwise be optimal. The distortions are reduced where they are clearly phased out over time and where benchmarks based on recent data are used to calculate compensation levels (Germany). However, electricity price compensation also plays an important role in reducing leakage risk. Therefore, losses in efficiency must be traded off with the gains from leakage protection.

Electricity market regulations may also interact with the ETS in a way that distorts the allowance price. Market distortions will arise when carbon costs are not internalised in generators' cost profiles or adequately reflected on the market. In the K-ETS, producers have received compensation for net allowance costs, essentially shifting abatement incentives towards more expensive options in industry and, in doing so, raising the allowance price above the MAC (Kuneman et al., 2021).

3.3 Long-term Predictability

In all case studies, long-term climate targets, the role of the ETS in achieving these, and clarity on the ETS framework are key determinants that improve or impede price predictability, confirming earlier findings (Acworth et al., 2017). Regulatory uncertainty can impede participants' ability to forecast future allowance scarcity and expected returns on investment

[27] The analysis was supported by expert opinion at the project workshop that took place virtually in June 2020: https://www.zhaw.ch/de/sml/institute-zentren/cee/forschung-und-beratung/umweltbundesamt-marktregulierung-im-emissionshandel/

(Fuss et al., 2018; Koch et al., 2016). In the CAL CaT, EU ETS and K-ETS, the long-term direction of the system is clear, limiting overall uncertainty. However, the long-term targets for the ETSs are not yet updated for a net-zero reduction pathway, which also relates to the role of the ETS versus companion policies in achieving these targets. Price predictability will improve once this is clarified (Abrell et al., 2020; Kuneman et al., 2021). On the other hand, prospects for a national ETS and the role of the Chinese pilots going forward has limited long-term predictability in the Shenzhen and Hubei ETSs (Zhang, Boute & Acworth, 2021). Policy uncertainty is high in the Mexico ETS due to the lack of long-term direction of the ETS after the pilot phase (Graichen, Inclan & La Hoz Theuer, 2021).

The timely release of information on the cap trajectory and allocation procedures can further play an important role in improving price predictability but can be compromised by prolonged stakeholder negotiations (K-ETS) or ambiguity in the rules for ex-post allocation adjustment (SH and HB ETSs).

Companion policies play an important role in supporting the ETS unlock additional abatement options or options for which market failures prohibit the allowance price sending a clear incentive (e.g., energy efficiency). Where companion policies are well coordinated with the ETS and reflected in the cap-setting process, they play a necessary reinforcing role (Hood, 2011). However, where companion policies are uncoordinated or target the same abatement opportunities as the ETS, they can result in depressed prices and result in confusion surrounding the role of the ETS and future price trajectory. Examples of both cases can be detected through the case studies.

In the EU ETS, this discussion currently focuses on the role of targeted coal phase out policies. Here uncertainty is currently exacerbated by a lack of clarity as to if and how governments will compensate for the impact of these closures through voluntary cancellation provisions. In the CAL CaT, allowance prices are intentionally kept low by means of other energy policy instruments, such as emission performance standards (see Chapter 4.3 in Abrell et al., 2020). In the K-ETS, companion policies drove reduced power sector emissions in 2019, which in turn was a key factor alongside the economic impact of COVID-19 that caused a four-month decline in allowance prices in 2020 (Kuneman et al., 2021).

Even where companion policies are well coordinated with the ETS, their impact is sometimes difficult to predict. To adjust to companion policies and other exogenous shocks, it is now commonplace to include MSMs in the ETS. The case studies indicate a substantial improvement in price predictability where rule-bound and automatic stability mechanisms are in place (e.g., EU ETS, CAL CaT) compared to those where human discretion is involved (HB ETS, SH ETS, K-ETS). These effects are arguably highest with price bounds when both upper and lower bounds are defined. The price floor and cost containment reserve in the CAL CaT are a good example. Quantity bounds provide more clarity on the allowances in circulation. The quantity-based MSR in the EU ETS has improved confidence in the system but leaves a larger spread in price range forecasts compared to price bounds.

The ability of quantity-based stabilisation instruments to adjust for structural changes such as a regulatory driven coal phase out has been debated in the EU ETS (Germany). Debate has centered on the role of the MSR versus direct changes to the allowance cap as well as targeted cancellation of allowances to reflect mandatory closures in fossil fuel-based generation (Marcu et al., 2020). Voluntary cancellation by third parties may also play a role here, but empirical evidence for this is limited (EU ETS).

A well-functioning derivatives market is also an important element of providing price predictability (Ibikunle, 2016). Systems with derivatives markets in place can more easily reflect new information through forward price curves. The EU ETS and CAL CaT have such markets; the K-ETS will introduce futures trading during Phase 3 (2021-2025).

3.4 Environmental Effectiveness

The environmental effectiveness of an ETS is whether it can deliver on its intended objectives of controlling or reducing emissions to a certain level, which can be altered by provisions affecting the supply of allowances.

MSMs are evolving to impact the supply of allowances through the removal or injection of allowances into the market. For example, in the EU ETS, automatic cancellations of allowances above a pre-defined threshold as preordained through the MSR will reduce the emissions cap and strengthen the environmental effectiveness of the system. In CaT, the opposite can occur where additional compliance units are added to the market if an upper price trigger is reached. To ensure environmental integrity, revenues from the sale of compliance units are reinvested into mitigation efforts outside of the CAL CaT on a one-for-one basis.

Additional sources of allowance supply from outside the scope of the system can also increase the overall cap and reduce its effectiveness (Santikarn et al., 2018), an issue that occurred in the early years of the EU ETS through an influx of cheap Kyoto credits. In the K-ETS, this risk has been mitigated by using tighter eligibility criteria and quantity limits. Similarly, a fixed quantity of credits may only flow from a limited number of established protocols in CAL CaT, ensuring that the use of offsets provides flexibility but does not detract from the environmental effectiveness of the system. Such lessons are important for Mexico as it moves to develop its own offset protocols and procedures.

Ex-post allocation adjustments can alter the allowance supply when not strictly applied in accordance with pre-set cap levels, a flexibility which is foreseen in the Mexico pilot ETS. Discretionary power for applying ex-post allocation adjustments can reduce the environmental effectiveness of the ETS by reducing the integrity of the cap. The impact will be highest where output is increasing, and output-based allocation reflects a large share of the cap. The Chinese pilots also indicate that the process of optimising data collection and verification can impact the effectiveness in the early years of a system (Zhang, Boute & Acworth, 2021).

4 Carbon Market and Electricity Sector Interactions

Electricity market regulation will interact with the allowance price signal to determine the incentives for mitigation in the sector. Here we synthesis the interactions across case studies along the lines of: pass through of carbon costs in wholesale electricity prices; dispatch of electricity; investment and disinvestment as well as consumer demand. The chapter concludes with consideration of some emerging interactions and future trends.

4.1 Pass through of carbon costs in wholesale electricity prices

Electricity market design is the key determinant of carbon cost pass through, with major differences across jurisdictions. Liberalised systems with self-dispatch (Germany) or electricity pools with price bidding (California, Poland) generally reflect allowance costs in wholesale electricity prices (Abrell et al., 2020; Dagoumas & Polemis, 2020). When this occurs, a sufficiently high allowance price can drive fuel switching and increase the margins for low carbon generators, while decreasing returns for high carbon assets provided a diverse structure of the power plant fleet with a substantial potential for switching from high, emissions-intensive to low carbon generation (see Chapter 3.2.2). The EU ETS case study suggests that the allowance price has contributed to such an effect in recent years. The California case further suggests that pass through does not necessarily correlate with an increase in the wholesale electricity prices owing to variations in relative cost factors and market structure.

The presence of long-term energy contracts for carbon-intensive assets in Mexico and Poland indicate that even in liberalised systems, not all generators are able to pass on their carbon costs, and when receiving free allowances, will not be exposed to the allowance price signal . However, the share of electricity delivered under such contracts declines over time as energy markets become the primary instrument for the allocation of supply and demand and the remaining legacy contracts expire.

Where regulation of wholesale prices remains (K-ETS, SH ETS and HB ETS) ETSs will need to be designed to carefully fit within the regulatory framework. Tweaking existing regulations to reflect carbon prices in investment proposals, in regulated electricity tariffs, and in dispatching decisions or covering indirect emissions to trigger a demand response can be effective in achieving some of the benefits of an ETS even within a regulated wholesale market (Kuneman et al., 2021; Acworth et al., 2020). These features can provide an important transitional tool as the ETSs become more stringent, and power systems are restructured further, after which the allowance price can have a more direct effect through the wholesale market. These are discussed in more detail below (Chapter 4.2).

In designing an ETS to fit within a regulated electricity market, careful consideration of the tariff methodology with regard to allowance allocation will be required. This is because the opportunity costs of freely allocated allowances will unlikely be included in regulated tariffs, given resulting windfall profits for regulated entities. In this research we focused on jurisdictions with cost-based tariffs. Research that investigated the empirical impacts of carbon pricing where rate of return tariff methodologies are in place would be of future interest.

4.2 Abatement through clean dispatch

Where electricity is dispatched according to the merit order, an ETS will favor low carbon alternatives (Wilson & Staffell, 2018). This was seen to be the case in the EU and CAL CaT case studies. However, the existing capacity mix impacts the role of carbon prices for the dispatching of power plants as well as for investment decisions. With a more diverse capacity mix including natural gas like in Germany, carbon prices play a larger role in short-term abatement (fuel switch) than in a coal-focused system like Poland where less fuel switching is possible. On the other hand, in jurisdictions where natural gas is the dominant (fossil) fuel (e.g., California) and/or where natural gas is already cheaper than the more emissions-intensive fuels (e.g., Mexico), the impact of the carbon price on dispatch decisions is rather small.

For systems that have already phased out coal, the role of the carbon price in switching from gas to renewables will be heavily influenced by its interactions with other energy policies. Where portfolio standards, priority dispatch or subsidies are present, the carbon price will play a smaller role in driving renewables but remains critical for precluding further brown investments (California). Where policies supporting renewables are being phased out and carbon prices are steadily increasing, the carbon price will play a larger role (EU ETS).

The age of the fleet can also impact the role of carbon prices for dispatching. An older age profile like in Poland implies less efficient plants and thus a higher impact of the carbon price when these plants set the wholesale market price. This will also result in a larger margin for renewable operators that are able to generate when coal is the marginal generator.

An ETS will not be effective when dispatch is administrative and based on technical or political considerations (China) or based on variable cost benchmarks that do not reflect allowance costs (Korea). This is evident from Korea; given its diversified capacity mix, it should have significant potential for fuel switching, but the carbon price had little impact on electricity dispatch in the first two trading phases as operators were compensated for their carbon costs through an ad hoc compensation mechanism. However, jurisdictions that regulate dispatch can achieve some of the benefits of the carbon price by including net allowance costs into the centrally dispatched economic cost formula. By incrementally increasing the allocation stringency (auctioning and benchmarks), regulators can gradually increase the share of allowance costs reflected in the wholesale electricity price (Kuneman et al., 2021).

Such an incremental approach to reflecting carbon costs in wholesale electricity prices can be useful for jurisdictions that are balancing decarbonisation with broader energy policy goals or where electricity market reform faces institutional obstacles and social and political opposition. However, if increasing costs for generators are not reflected in end-user electricity prices, a cost recovery gap will grow, placing a financial burden on the electricity system. Replacing electricity price subsidies for rebates of carbon revenues to households most vulnerable to increasing electricity prices is one way this tradeoff can be managed. Ultimately, carbon pricing and electricity market design will need to reflect a consensus in society as to how to finance the net-zero transformation.

4.3 Abatement through low-carbon investment and disinvestment (decommissioning)

Under a liberalised market, a carbon price can increase the Internal Rate of Return (IRR) of low carbon technologies and encourage additional investment (EU ETS). The investment signal will be the strongest when the carbon price is embedded within a predictable policy framework and is well coordinated with other companion policies (Boute & Zhang., 2019).

Supply side programs giving support on production basis (renewable and combined heat and power (CHP) support) incentivise the generation of certain technologies, and thus investment into these capacities. Likewise, technology mandates (emission performance standards and phase out) direct investments and divestures towards a less carbon-intensive capacity mix. Consequently, the role of carbon prices for investment decisions is reduced.

Particularly, the regulatory phase out of coal-fired power generators and renewable energy support policies will have a strong effect on the emissions profile of the covered sectors. The incentive for decommissioning will be strongest for older, inefficient assets that have recovered their capital costs and face relatively higher carbon costs (EU ETS, Germany, Poland). The potential for decommissioning carbon-intensive assets through the carbon price signal has been particularly high in the EU ETS, given its role in coal-to-gas switching and the comparatively old age of coal assets across Europe. National coal phase out policies, as described above, provide additional certainty on a coal exit but limit the scope for the ETS in driving this transition. It will, however, continue to be important in supporting the economic rationale behind those decisions providing a strong information signal on which assets to decommission first. The experience in Germany indicates that relative fuel prices are important in the coal exit discussion. At modest carbon prices, power generation from (imported) hard coal is usually more expensive than (domestic) lignite, with negative consequences for emissions and the pace of decommissioning. However, perverse signals for coal-to-lignite switching disappear with increasing allowance prices eventually replacing lignite by gas or other low-carbon generation sources (DEHSt, 2019). Furthermore, where technology-specific benchmarks apply to the electricity sector, as observed in the K-ETS and Chinese ETSs, incentives for low-carbon investment based on carbon price signals will be limited when more stringent benchmarks apply to lower-carbon generation sources.

In systems with relatively young coal-fired plants, fuel-switching where gas is available and retrofit investments are likely to occur before the decommissioning of coal-based generation assets (Korea). This is important for jurisdictions that are considering carbon pricing but have a young and highly efficient coal fleet. It is unclear if there would be political support for the price levels required to decommission some parts of the coal fleet, despite the eroding economics of coal production. Furthermore, such jurisdictions will face stronger resistance from investors that will seek to recoup their capital costs. Careful consideration should then be given to how an ETS can support decommissioning within a broader suite of policies that look to mandatory closures or refinancing instruments that can reduce the costs for asset owners (see e.g., Bodnar et al., 2020).

Across all case studies, the carbon price signal is limited given a suite of additional policies that seek to drive investment and control the decommissioning of fossil fuel-based generation assets. Given the significance of electricity to the economy and public welfare, policymakers have been careful to ensure the low carbon transition is cost effective but also coordinated in a way that does not risk security of supply.

For example, in Germany several reserve mechanisms[28] are in place that are designed to ensure energy adequacy against the backdrop of an increasing share of intermittent renewable energy capacity as well as the nuclear phase out (Abrell et al., 2020). As these mechanisms target power generators outside of the daily energy market, they do not directly interact with the carbon price signal. Payments to fossil-based capacity will delay their decommissioning, but serving as back up capacity, the impact on emissions will be limited. This concern can also be mediated through limits on the GHG intensity of plants that can operate in the capacity market, such as in the European Union. The Polish capacity market grants additional income to incumbent power plants and, thus, is likely to reduce the role of carbon price-driven closures.

[28] Including the Sicherheitsbereitschaft (§ 13g EnWG) which mandates lignite plants that are about to be closed remain operational for four years; the Netzreserve (§ 13g EnWG), i.e. the procurement of capacity for additional redispatching measures necessary due to high amounts of renewable generation; and the Kapazitätsreserve (§ 13e EnWG), a mechanism that requires TSOs to procure capacity for winter months from 2020/2021 onwards.

Korea also grants additional income to power producers outside of the energy market to compensate for the costs of compliance with the K-ETS and incentivises cleaner investments through capacity payments. This mechanism pushes against the intended incentives of the carbon price and reduces its relevance for investment and decommission decisions. In jurisdictions where the government plays a stronger role in planning, electricity sector investments are often subject to monitoring by central agencies (e.g., the Integrated Resource Planning (IRP) in California, Shenzhen DRC, Hubei DRC, or congressional approval for investments by Mexico's main utility) and multiple policy objectives may be considered alongside economic cost profiles. When such agencies have decisive influence on new capacity additions, it is imperative that the carbon price is considered in the IRR of the investment proposal (e.g., in the form of shadow prices in regulated markets).

While different polices interact with different ETS design, this finding is consistent across case studies. Because the capacity mix becomes less carbon-intense in the longer run, the role of the allowance price for dispatch is also reduced. On the consumer side, energy efficiency programs stimulate investments into energy saving technologies and thus reduce the role of the carbon price for these decisions (California and EU). However, many of these policies should be working together with the ETS as they target choices that are less directly impacted by the carbon price given information asymmetries and market failures.

4.4 Abatement through demand-side response

The regulation of retail tariffs can preclude consumers from facing the full carbon price (Poland, China, Korea, California). However, cross-subsidisation components (small consumers in Mexico), high shares of levies and taxes (Germany), and price caps (Poland) have meant that even in liberalised retail markets, electricity pricing does not reflect the marginal cost of electricity generation. Going forward, smart metering and real time tariffs can assist consumers in understanding variations in electricity prices and hence respond in their consumption patterns (IEA, 2016). The potential of such reforms will depend on the share of electricity and network costs in the final electricity price and may require levies and taxes to be separated. Where advanced tariff methodologies are not in place, regulated tariffs that reflect average costs will achieve some of the mitigation benefit (California, Poland).

However, where the electricity price is maintained well below production costs, a cost recovery gap will emerge in some segment of the supply chain (in Poland, single buyer in Korea, and in the Chinese provinces Guangdong and Hubei), often requiring additional government support. Where carbon costs are passed on to wholesale electricity prices but retail tariffs remain subsidised, a political discussion on who should bear the costs of abatement under the ETS is inevitable.

In some cases, end-user electricity prices reflect at least in part the allowance price; however, cost compensation is provided to large industry consumers given carbon leakage concerns (Germany, Poland). As these consumers do not receive the carbon price signal, the role of carbon prices for energy efficiency investments is reduced.

Where retail tariffs do not reflect carbon costs, the inclusion of indirect emissions can also trigger downstream abatement given consumers face a net carbon cost, which has been a limiting factor in China and Korea. Coverage of indirect emissions will not result in double charging for electricity consumers, so long as the allowance price is not reflected in electricity prices (Munnings et al., 2015). Where mechanisms are in place to gradually pass on carbon costs to electricity prices, adjustments will also be required to indirect emissions coverage to prevent double charging.

In sum, price subsidies, cost compensation and the dilution of the carbon cost factor in final electricity bills have limited incentives for demand-side abatement under an ETS. This may change with efforts in liberalised markets to adopt smart metering, introduced as part of broader efforts to improve demand-side flexibility, but should be viewed in light of increasing shares of network costs as renewable energy penetration rises further and the limited price elasticity of end-consumers. In this regard, companion policies, such as building codes, energy efficiency and green energy certification, and energy performance standards are particularly useful in driving energy efficiency gains where the ETS can play a complementary role.

4.5 Emerging Market Interactions

The net-zero transition will require reliable and inexpensive low carbon electricity at vast volumes for the electrification of other sectors. As electricity systems decarbonise, electricity generation and prices are expected to become more volatile. With increased renewable penetration, there will be extended periods where VRE can meet demand. Under marginal cost pricing, this implies prolonged periods of zero wholesale electricity prices coupled with periods of much greater prices as fossil capacity supports the system when supply of VRE is low. Reforms aimed at rewarding flexible electricity supply and harnessing the responsiveness of demand through intraday and ancillary markets effectively facilitate the integration of high shares of VRE. As power systems transition to net zero on the back of high VRE supply, strengthened long-term remuneration signals will likely be needed.

Part of the decarbonisation challenge will be to shift electricity demand to periods when low carbon electricity is abundant, and to reduce consumption during periods where solar and wind resources are low and high emitting generators are ramped up to meet demand (IEA, 2016). However, there is growing concern that the electricity market architecture will not sufficiently remunerate investments where prices are likely to remain low for prolonged periods of time (Ela et al., 2019). This could imply a larger role for capacity markets where scarcity peak prices are considered politically unfeasible, a continued role for technology support policies, or even alternative structures to electricity pricing that consider investment costs and system value. Work is needed to understand the potential interaction of the ETS and allowance price on the electricity market under future market design.

The falling costs of renewables are also changing the economics of power systems around the world. The Rocky Mountain Institute (Bodnar et al., 2020) estimates that 39% of existing world coal capacity is currently not competitive with renewables-plus-storage. This is driven largely by the deteriorating economics of coal-based generation in the EU and the USA and, to a lesser extent, China and India. While existing coal capacity remains competitive across many assets in Australia, Japan, Russia, South Korea, and south east Asia, the outlook is bleak. Indeed, as costs of renewables and storage continue to fall, 75% of existing global coal is expected to be uncompetitive by 2025.

This is before carbon pricing is considered, which only worsens the outlook for fossil-based generation capacity. As outlined in this report, many of these assets will be insulated from this new market paradigm given long-term PPAs or tariffs based on cost recovery. The fact that the cost of supplying renewables is now lower than the cost of coal-based generation in most regions provides a significant opportunity for governments to shift to low carbon generation and strengthen supporting infrastructure. In power systems with young, efficient coal plants, additional investments are necessary, including retrofitting for continued baseload (Carbon Capture and Storage (CCS)), retrofitting for system flexibility, as well as the refinancing of assets where viable (see e.g., Bodnar et al., 2020). Over the medium term, as the disparity between fossil and VRE generation costs increases, the economic rationale for a shift towards competitive wholesale markets with short-term price signals will strengthen. Numerous jurisdictions now have plans in place to advance the restructuring of their electricity markets, including the regulated systems analysed in this report; however the speed of implementing such reforms will depend on a complex set of local economic and political considerations. Pending liberalisation, regulatory adjustments that integrate carbon price signals into the regulation of electricity tariffs, investments, and dispatch, will continue to be necessary.

5 Conclusions

Carbon markets and electricity markets interact. The design of the carbon market affects the volatility, transparency, and predictability of the carbon price signal. The structure and regulation of the electricity market determine whether the allowance price signal is transmitted to producers and consumers in a way that creates an incentive to reduce emissions, in the short, medium and long term. Understanding how these interactions impact mitigation choices will better equip us to design effective carbon markets. This study aims to do just that with conclusions that draw from a conceptual framework that was built upon an extensive literature review and tested through five case studies with differing electricity market structures.

In terms of carbon market design, the case studies support the conceptual framework outlined in Acworth et al. (2019). A high-quality allowance price reflects a binding emissions cap that is consistent with clear medium and long term decarbonisation targets. Allowance prices are revealed through market transactions, and therefore participation in auctions or active trade is essential. MSMs that allow the market to automatically adjust to exogenous shocks are a fundamental component of resilient carbon markets. MSMs that are implemented based on discretion can provide added flexibility but introduce uncertainties. Companion polices can support an ETS in unlocking abatement that is precluded from the carbon market due to other market failures and regulatory interventions. However, they can also reduce the role of the carbon market in driving down emissions where abatement options overlap.

Infant carbon markets can suffer from teething problems where uncertainty and low market liquidity prohibit price discovery. This is exacerbated where: (i) information on future design provisions is not forthcoming, (ii) free allocation is the dominant allocation approach, over auctioning, (iii) third-party participants are precluded from trading, and (iv) covered entities prefer bilateral OTC trade. While these aspects are understandable in early phases of ETS design, ETS aspirants can learn from these experiences. Reserving even a small share of allowances for auction can vastly improve price discovery, and the key design elements for future compliance periods must be communicated well in advance. A clear trajectory to third party participation is also helpful. A clear legal definition of the traded unit, e.g., allowances, needs to be in place and effective market oversight ensured so that market abuse is prevented, and the market is trusted.

Carbon markets will be most effective in liberalised electricity markets where the allowance price is reflected in wholesale prices and electricity is dispatched based on economic merit. However, the structure of the electricity market will still be important for the level of mitigation achieved. The underlying fuel mix will dictate the opportunities for fuel switching, and the age of the fossil fuel fleet will shape decommissioning versus retrofitting choices. Furthermore, as full liberalisation is rarely achieved, market regulation (e.g., price caps) can distort the price signal that the ETS is supposed to send to the electricity market. Companion policies also have a fundamental impact on investment and decommissioning decisions as governments seek to manage the transition to a zero-carbon electricity system in a way that ensures reliability and security of supply. In this vein, companion policies that support capacity outside of the energy-only market will likely become of growing importance. So too will discussions on long-term remuneration of renewable generation assets where marginal pricing of electricity implies sustained periods of low to zero electricity prices. How the ETS interacts with these emerging policies is unclear and warrants further attention.

There has been a clear trend towards restructuring and the introduction of competition in regulated electricity sectors increasing the role of markets in allocating supply, demand, investments, and the procurement of ancillary services. Where reforms have recently been implemented, nascent wholesale markets and administrative energy contracts might co-exist, leading to a partial reflection of carbon costs that will increase over time as the role of legacy contracts diminish. In economies where short-term electricity trading or cost-reflective markets are announced but are part of a long-term reform process, careful design can ensure the ETS drives abatement before markets take over from administrative coordination.

Green dispatch, where allowance costs are reflected in the dispatching decisions and cost recovery tariffs, are of particular interest. By incrementally increasing the allocation stringency (level of auctioning and benchmarks), regulators can gradually increase the carbon cost paid by generators, resulting in a shift towards lower carbon electricity. Such an incremental approach to reflecting carbon costs in wholesale electricity prices can be useful for jurisdictions that are balancing decarbonisation with broader energy policy goals or where electricity market reform is ongoing. However, if increasing costs for generators are not reflected in end-user electricity prices, a cost recovery gap will grow placing a financial burden on the electricity system.

Where retail tariffs do not reflect carbon costs, the inclusion of indirect emissions can also trigger downstream abatement. Coverage of indirect emissions will not result in double charging for electricity consumers, so long as the allowance price is not reflected in electricity prices. Where mechanisms are in place to gradually pass on carbon costs to electricity prices, adjustments will also be required to indirect emissions coverage to prevent double charging.

The role of an ETS will be perhaps the most constrained in jurisdictions that have a young fossil fuel fleet and where strong objections to market liberalisation remain. While reflecting allowance costs in dispatching decisions through green dispatch can help, it may not be sufficient to drive fuel switching away from younger, efficient coal plants. In regulated electricity markets, the exposure of electricity generators and consumers to the ETS, and the pace of decarbonisation, will depend on the political willingness to integrate the cost of carbon into investment, pricing, and dispatch decisions.

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