Influence of market structures and market regulation on the carbon market

Interim report

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Abbreviations

CHP	combined heat and power
CPP	critical peak pricing
ETS	emission trading system
GATS	General Agreement on Trade in Services
GATT	General Agreement on Tariffs and Trade
GDP	gross domestic product
GHG	greenhouse gas
MAC	marginal abatement cost
MSM	market stability mechanisms
ToU	time of use pricing
VAT	value added tax
VRE	variable renewable energy
WTO	World Trade Organisation

1 Introduction

In this study, we aim to identify the relevant factors that influence the effectiveness and efficiency of carbon markets for greenhouse gas (GHG) mitigation. We focus on the regulations that establish the carbon market and govern the transaction of allowances as well as the structure and regulation of the product markets that covered entities participate in, focusing on the electricity market in particular. We seek to understand which regulations can lead to a distortion of the allowance price signal and where market structures and regulations limit the effectiveness of the emission trading system (ETS). On the one hand, the design of carbon markets affects the volatility, transparency and the predictability of the carbon price signal and, therefore, the incentive to invest in low-carbon technologies, energy efficiency improvement and innovation. On the other hand, product market regulation (in our case electricity market regulation) determines whether the allowance price signal is transmitted to producers and consumers in a way that creates an incentive to reduce emissions, both in the short and medium to long term.

An ETS is a well-established tool for reducing GHG emissions in an effort to mitigate global climate change. For an ETS to achieve emission reductions at least cost, markets ideally must function freely and transmit uniform and non-distorted price signals to all decision makers in the economy. This requires an active and liquid market for emission allowances which reveals a high-quality price that reflects the marginal cost of abatement. The cost of emission allowances (allowance costs) must then be freely reflected in the price of carbon-intensive goods, providing economic signals to emitters to adjust their operations and investment decisions (Boute and Zhang, 2017). The ability of the covered entities to pass through some of the costs of CO_2 allowances to consumers is also fundamental for recouping the costs of long-term low carbon investments and enhancing the credibility of future reduction targets (Hintermann, 2014).

However, the design of the carbon market and the regulatory environment within which an ETS is implemented will have a direct impact on: (i) the allowance market and hence the strength of the price signal transmitted; and (ii) the options available to participants in terms of changes to their consumption, production and investment decisions. As an example, regulations surrounding allowance allocation as well as regulations surrounding "who can trade" allowances will have implications for market liquidity and price discovery. Without a high-quality price signal firms may be reluctant to trade, particularly where there is uncertainty surrounding future stringency of the policy and resulting abatement costs. Further, the legal definition of an allowance will have implications for accounting principles. Together, these factors may disrupt price discovery resulting in a low-quality allowance price signal.

At the same time, regulations and market designs determine whether the allowance price signal is transmitted to producers and consumers in a way that incentivizes clean production, investment and consumption. Energy sector regulation is particularly relevant here given the high share of global emissions that results from fossil fuel combustion, the relatively cheap abatement options for the sector as well as the large scope for policy interaction between market-based policies and additional regulation (Boute, 2017).

Yet, several jurisdictions that have recently implemented or are planning an ETS have various forms of electricity market regulation that could pose challenges for carbon pricing (Acworth et al., 2019). At one end of the regulation spectrum, vertically integrated utilities deliver all services of the electricity sector, from generation to electricity retailing, and operate as monopolies. In partially reformed markets, regulators cap power prices without consideration of costs (often with other policy objectives in mind such as affordability and reliability) and impose output, investment and technology requirements on firms' industrial activities (Victor and Heller, 2007). Even in liberalized markets, renewable energy targets and portfolio standards can influence the role for and strength of the allowance price signal (Abrell and Wegit, 2008).

This is an interim report commissioned by the German Environment Agency to investigate the influence of market structures and regulation on the carbon market. We seek to better understand how carbon market regulation influences the quality of the allowance price signal. Then in a second step, we assess regulation and market structures, particularly in the electricity sector, that influence how actors respond to the allowance price. This interim report provides the conceptual framework for subsequent case studies in California, China, the European Union, the Republic of Korea and Mexico.

The report is structured as follows. Chapter 2 outlines the functioning of carbon and electricity markets. Chapter 3 distils evidence from the economic, legal and political economy literature regarding the effect of carbon market design on the strength of the allowance price signal.

Design features are separated to those that affect allowance supply, demand, transaction rules and additional regulations that govern a market. Chapter 4 focuses on the interaction between the carbon market and electricity market regulation and Chapter 5 on interactions between the carbon market and electricity market structures. Chapter 6 concludes and outlines the next steps of this work.

2 The functioning of carbon and electricity markets

In an ETS the regulator determines an emission target and creates allowances to emit. Regulated entities need to cover each emissions unit by purchasing an allowance. These allowances are tradeable. Therefore, each installation needs to decide whether to trade an allowance or whether to abate emissions. If the cost of reducing an additional unit of emissions, the so-called marginal abatement cost (MAC), is below the allowance price, it is cheaper to reduce emissions and sell allowances on the market. In contrast, if the MAC is above the allowance price, it is preferable to buy allowances on the market instead of abating. Consequently, the system will have an allowance price equal to the MAC if all market participants guarantee that the emission target is achieved in a cost-effective way (Phaneuf and Requate, 2017). An allowance price is distorted and the cost-effectiveness of the system is reduced if the allowance price is not equal to the MAC of all market participants.

Definition

A high quality or undistorted allowance price equals the marginal abatement cost (MAC) of *all* market participants.

Emission abatement takes place in three major forms that vary over different periods of time (See table 1 for a summary).

First, enhancing the efficiency of existing production units and reconfiguring the way in which these units supply electricity is a short-term abatement opportunity. In the electricity sector, this includes changes in production patterns and processes as well as switching to a less carbon intensive facility, e.g., from coal-fired to natural gas-fired power plants (fuel switch). The increase in fuel costs due to using (more expensive) natural gas instead of (cheaper) coal then determines the (short-run) abatement cost; the larger the spread between natural gas and coal prices, the larger the abatement cost.

Second, cleaner forms of electricity become more profitable, meaning that in the long run producers develop and invest into less carbon intensive production facilities. In the electricity sector, this in particular includes the installation of less carbon intensive power plants, such as, renewable energy technologies like wind and solar power, or gas-fired plants.

Third, given that emissions result from the production of a final product, reducing output reduces emissions. In the short-run consumers might either reduce consumption or switch to alternative products. The potential for short-run reduction of electricity demand is, however, rather limited. Given that electricity demand is determined by the energy demand of end-user appliances, a reduced demand (such as e.g. increased efficiency of lighting, heating, and cooking) is necessary, but quite often only possible at high costs. In the long run, consumers can invest in more energy efficient appliances that deliver the same services while using less electricity.

Table 1: Types of abatement costs

	Reconfiguring Production	Investments	Output Reduction
Short-run	▸ Cost of production reconfiguration, in particular fuel-switching costs	▸ Enhancing efficiency of existing production units.	▸ Foregone profits by producers ▸ Consumer cost of using alternative products or foregoing consumption
Long-run		▸ Producer cost for developing and installing new equipment/power plants	▸ Foregone profits by producers ▸ Consumer cost of using alternative products or foregoing consumption

Finally, it is noteworthy that the demand reduction channel of carbon abatement is special, as both sides of the product market – producers and consumers – determine the abatement cost. This implies a close connection between how an ETS functions and the product market. Consumers need to receive a correct carbon price signal embedded in the product price in order to incentivize efficient abatement on the demand side. If the pass-through of carbon prices is too low (high), consumers' incentives to invest in more energy efficient appliances is too low (high). The result is that abatement costs do not converge to the efficient level and, in turn, the carbon price signal is distorted, as it deviates from the efficient MAC level.

Two *interdependent* major factors affect the pass-through of carbon cost: (1) producers need to receive a correct carbon price signal from the emission market, and (2) producers need to be able and willing to correctly pass-through the price signal to consumers. Whether producers receive a correct price signal depends heavily on the design of the emissions market. Likewise, the structure of the product, in our case electricity market, substantially affects the possibility for passing through carbon costs. In summary, the design and interplay of allowance and product markets determines whether an ETS achieves abatement in a cost-effective, undistorted fashion.

The quality of the prices signal is an indicator for the cost effectiveness of the carbon market. Design features might, however, also be assessed in terms of environmental effectiveness.

Definition

The environmental effectiveness of an ETS equals the amount of emissions abated.

It might seem that the environmental effectiveness is constant in an ETS (as the supply of allowances is fixed by the regulator). However, different design alternatives might alter the supply of allowances. We therefore also list influences on the environmental effectiveness of alternative ETS designs.

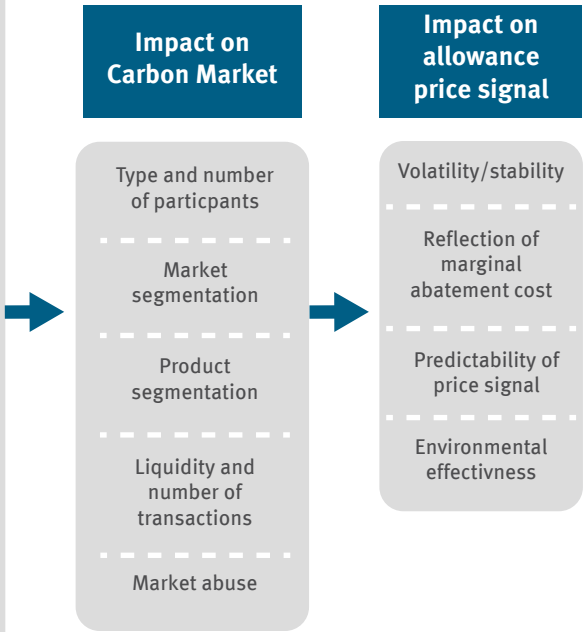
3 Carbon market design and regulation

As of late 2019, there are more than 20 mandatory ETS operating across Europe, North and South America as well as the Asia Pacific region (ICAP, 2019). Each of these ETS's is defined by design features tailored to the specific local context. In this chapter, we analyse these carbon market design features within three categories: (1) supply side; (2) demand side; and (3) transactions and additional regulations.

Throughout this analysis, we concentrate on the impact of design features on the allowance price. We define the quality of the price signal across four dimensions: (1) price volatility, (2) reflection of MAC; (3) long-term price predictability; and (4) environmental effectiveness. First, examining the MAC enables to examine whether the price signal is distorted. Second, because investors have a planning horizon of several years, the long-term credibility and predictability of the price signal and the possibility to form correct expectations about future price is essential to foster investments into carbon abatement. Third, price volatility is important for multiple reasons. 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. In particular, volatility increases investment risk, which increases the overall cost of capital (Neuhoff, 2011).

Figure 1 summarizes the connection between the quality of the price signal and design options of an ETS. The quality of the price signal (right column) is impacted by the design of the trading system (left column) through various channels (middle column). In the sections that follow, we use tables to provide an overview on the impact of design features on the price signal. A ↑ indicates an increases of the feature, a ↓ denotes a decrease of the respective quality criteria. A ↑/↓ indicates that the effect can go in both directions. A 0 indicates a negligible impact.

Feature	Options/range
Supply	
Allowance cap	Absolute/intensity
Long term target	Adopted/not adopted
Allocation	Grandparenting Benchmarking Auctioning
Banking/borrowing	Allowed/prohibited
Additional sources of supply	Linking/Offsets
Market Stability Mechanisms (MSM)	Price/quantity triggered
Voluntary cancellation	Allowed/prohibited
Demand	
Coverage	Narrow/broad scope
Market participation	Open/closed
Legal nature of allowance	Property right/private property
Transactions and Market Oversight	
Fiscal nature	Commodity/fin. instrument
Market place	High no. of market places
Transparency	High/low frequency
Market oversight	Primary/derivative/spot market



Authors illustration

Figure 1: Carbon market design alternatives and functioning of carbon markets[1]

3.1 Allowance supply

The supply side of the carbon market encompasses design features that influence how many allowances are available to participants at a given point in time. These include: the allowance cap and allocation mechanism, provisions for banking and borrowing, the function of any market stability mechanisms (MSM), and supply of additional compliance units through links to offset markets or other trading systems.

3.1.1 Allowance cap

A tighter cap implies less allowance supply and therefore higher abatement requirement and, consequently, higher (marginal) abatement cost and allowance price (see e.g. Baumol Oates, 1988; Phaneuf and Requate, 2017). The allowance cap itself does not directly affect predictability, the representation of MAC or volatility of the price signal. However, the design of the cap can impact the price signal across these features. Two major forms of allowance caps exist: absolute and intensity-based (see Ellerman and Wing, 2003). Under absolute caps the regulator limits emissions to an absolute amount of allowances for a pre-specified timeframe. In contrast, intensity-based caps limit the emission intensity, i.e., the ratio between emissions and some measure of input, output, or economic activity, e.g., gross domestic product (GDP). In doing so, allowance supply fluctuates.

Feature	Options/Range	Impact on			
		Volatility	MAC	Predictability	Effectiveness
Allowance Cap	Absolute	0	0	0	↑/↓
	Intensity	↓	0	↑	↑/↓

1 The list of design features included in the figure is non-exhaustive. A more rigorous and complete treatment of design features is provided in subsequent sub-chapters.

- **Volatility:** *An intensity-based cap might reduce volatility.* Under an absolute cap, volatility reflects the uncertainty and known information about baseline emissions. In an intensity cap system, the cap adjusts to baseline emissions meaning volatility may be reduced.
- **MAC Reflection:** *The choice of the base of the allowance cap does not affect the reflection of MAC by the price signal.* Whether the regulator sets an intensity-based or an absolute emission target influences the environmental effectiveness. It does not influence, however, the functioning of the market itself, which is determined by other design features.
- **Predictability:** *An intensity-based cap might increase predictability.* Intensity-based caps adjust the allowance supply to baseline emissions. Thus, the availability of allowances can be better forecasted which likely increases predictability of the price.
- **Environmental Effectiveness:** *The environmental effectiveness of an absolute cap as compared to an intensity-based emission cap depends on the expectation and realization of GDP (power and industry production) growth.* If GDP (production) growth is higher than expected, an absolute cap demands higher emission reductions and costs than an intensity cap (Fischer and Springborn, 2011; Quirion, 2005; Jotzo and Pezzey, 2007). Conversely, if actual GDP (production) falls below expectations, an intensity-based cap will require more abatement and will therefore incur higher costs.

3.1.2 Long-term target

To achieve long run abatement many firms must make investment decisions concerning assets with lifetimes of several decades, e.g., power plant investments that last for 40 years or more. Therefore, firms have to be able to form correct expectations about future allowances caps and allowances prices to calculate the profitability of their investment alternatives. With increasing regulatory uncertainty surrounding long-term targets the profitability of investments becomes more uncertain and risk premiums may rise, increasing the overall cost of abatement (Blyth et al., 2007; Hoffmann 2007; Hoffmann et al., 2008; Reinelt and Keith, 2007).

The challenge for policy makers is to provide certainty for firms but still allow flexibility to adjust the target e.g. if under the global stock-take (Art. 14 Paris Agreement) more stringent targets are required (see also Hepburn, 2016). This trade-off can be managed through the cap setting process including the cap period, the relationship of the cap with long-term climate targets of a jurisdiction, the institutional setting for changing the cap and the use of MSM (see Section 3.1.6) (Acworth et al., 2017). Specifically, in setting legally binding long-term targets, the regulator can reduce regulatory uncertainty and enhance system function.

Feature	Options/Range	Impact on			
		Volatility	MAC	Predictability	Effectiveness[1]
Long-term Target	Adopted	↓	0	↑	↑
	Not-adopted	↑	↓	↓	↓

Note: [1]Effectivness includes political economy considerations and should therefore be interpreted with caution.

- **Volatility:** *The adoption of a long-term target decreases volatility.* Albeit uncertainty on future emission targets increases the cost of emission abatement, it may also increase the flexibility of the regulator. By not committing to future targets, the regulator is able to respond more flexibility to future changes in the economic environment, or to the availability of future abatement technologies. The uncertainty about future targets increases the volatility of allowance prices as prices react to expected changes of allowance supply (see Koch et al., 2016).
- **MAC Reflection 1:** *The adoption of a long-term target does not affect the reflection of MAC.* The announcement of a long-term target decreases uncertainty about future regulations and their impact on the future allowance price. Thus, because capital costs decrease, the risk premium on investment cost decreases, and overall MAC decreases as well. Therefore, long-term targets have a large impact on MAC. However, they do not have an impact on the reflection of MAC in allowances prices.

- **MAC Reflection 2:** *Where future targets are not adopted or where targets are not considered credible by market participants, the allowance price may not reflect the MAC*. Where future commitments are not credible, speculation about the commitment embedded in the announced cap driven by disagreement between political parties and other actors, can encourage market participants to heavily discount future allowance prices and in doing so distort current prices (Fuss et al., 2018; Koch et al., 2016; Brunner et al., 2012).
- **Predictability:** *The adoption of a long-term target increases the predictability of the price*. If the regulator is able to credibly commit to long-term targets, the predictability of carbon prices increases as the future supply of allowances is known.
- **Environmental Effectiveness:** *The adoption of a long-run target is assumed to increase environmental effectiveness*. Where the absence of long run targets encourages participants to discount current prices, commitment to and hence the environmental effectiveness of the cap may be threatened by steeply rising allowance prices in the future (Fuss et al. 2018). Similarly, where low prices and uncertainty surrounding future program stringency increase costs of capital, policymakers may trade off higher costs for lower ambition in future periods (Blyth et al., 2007). Conversely, where credible commitment to long term targets decreases capital costs over all compliance costs will also decrease. This could allow for more stringent targets in future periods.

3.1.3 Initial allocation of allowances

The three major forms of initial allocation are: (1) grandparenting; (2) benchmarking; and (3) auctioning.[2] The first two mechanisms allocate emission allowances free of charge and are forms of ex-ante allocation, meaning that allowances are allocated before emissions are generated. Grandparenting is based on a firm's historical emissions, whereas benchmarking uses a rate based on the most efficient installations or technology within a regulated industry. Through auctioning, the regulator sells emission allowances to firms and is thus able to generate revenues. The implementation of a mixed form, which combines these different allocation options, is possible and known as partial auctioning.

In general, the discussion on the type of allocation method (i.e. free allocation or auctions) in an ETS is subject to difficult negotiations and driven by political economy considerations and international competitiveness concerns. Economists tend to favour auctioning (Hepburn et al., 2006). Yet, the implementation of free allocation is politically more feasible than auctioning, as industry is generally more supportive (Hepburn et al., 2006). This support can be attributed to the distributional effects associated with the different allocation mechanisms: under free allocation, regulated firms only face costs for abatement but not for their emissions, meaning they have more money for investment in abatement opportunities (Hepburn et al., 2006).

In addition, international competitiveness concerns are used to justify the use of free allocation. Competitiveness issues arise in the context of geographically limited ETS, i.e. in the absence of a world-wide ETS. The introduction of a carbon price in a regulated area e.g. country incurs a competitive disadvantage for domestic firms that operate in international markets, as they, unlike their competitors, are confronted with an increase in their marginal production costs (Naegele and Zaklan, 2017). This can lead to concerns of carbon leakage, which can result in two different effects.[3]

First, regulated firms might relocate their production to another region with no or less stringent policy, so called pollution havens. The relocation undermines the target of the policy, as emissions are simply transferred to other regions (CPLC, 2019; Naegele and Zaklan, 2017). Second, domestic firms could suffer a loss in their market share due to the competitive disadvantage caused by the costs for emissions (Naegele and Zaklan, 2017). Depending on the design, free allocation shields firms deemed at risk of leakage from additional costs.[4] However, it may create perverse incentives for emission abatement when not combined with benchmarking or where updating provisions based on changes to production activity or plant capacity are present (Stern, 2007; Sartor et al., 2014; also see Stenqvist and Ahman, 2016; Verde et al., 2018). Further, under benchmarking with updating based on output, agents might not realize their opportunity cost of holding allowances allocated for free and only abate emissions to comply with the benchmark, resulting in a deviation of the price from MAC, as market participants forego trades that would be preferable for them (Ellerman et al., 2010).

2 Auctioning can be combined with an upper or lower price bound following a rationing mechanism that alters the number of permits supplied. Section 3.1.6 will analyse the pros and cons of such market flexibility mechanisms in further detail and as such they are not considered here.

3 Both of these effects decrease the global environmental effectiveness. Although domestic emission under the cap remain unaltered, emissions abroad increase and thus global environmental effectiveness decreases.

4 For a detailed comparison of how free allocation provisions differ in terms of leakage protection, see Neuhof et al. (2015) and PMR (2015).

Feature	Options/Range	Impact on			
		Volatility	MAC	Predictability	Effectiveness
Primary Allocation	Grandfathering	↑	↓	↓	0
	Benchmarking	↑	↓	↓	0
	Auctioning	↓	↑	↑	0

- **Volatility:** *Auctioning decreases volatility.* If there is little trade on the secondary market and no auctioning, prices may be rather volatile and it may take time to discover the correct price. Introducing auctioning sends a market-driven price signal and reduces volatility caused by price discovery.
- **MAC Reflection:** *Free allocation distorts the representation of MAC by the price signal compared to auctioning.* If participants receive allowances for free, they might trade less as they do not recognize the opportunity cost of allowances. The price will then deviate from the MAC (Burtraw and McCormack, 2016). Conversely, under auctioning, market participants are forced to reveal their willingness to pay for allowances, i.e., their MAC. When free allocation includes updating, this may induce perverse incentives to increase emissions or outputs in order to increase the reference level for future free allocation. Thus, MAC no longer equals the allowance price (Neuhoff et al., 2015; PMR, 2015).
- **MAC Reflection 2:** *Benchmarking, as compared to grandparenting (with updating)*[5]*, leads to better representation of the MAC.* In the case of benchmarking, individual firms have a lower incentive to increase emissions to achieve a higher reference level of free allocation, and thus distort the price signal, as they have to comply with the best available technique.
- **MAC Reflection 3:** *The reflection of MAC improves with the frequency of the auction.* More frequent auctions might cause market participants to reveal their MAC more often.
- **Predictability:** *Free allocation can reduce predictability.* Under auctions, prices are revealed in the primary allocation mechanism. In contrast, under free allocation prices have to be revealed by trades on the market. The higher the share of free allocation, the smaller the predictability. This is particularly pertinent where there is uncertainty over future allocations that might lead to hoarding behaviour (Burtraw and McCormack, 2016).
- **Environmental Effectiveness:** *As long as the number of certificates remains unaltered, the environmental effectiveness of the system is not affected by the method of allocation.* However, free allocation may reduce the incentive to abate, thus shifting the abatement requirement to other sectors or installations which do not or receive less free allocation.

3.1.4 Banking and Borrowing

Banking allows firms to accumulate unused allowances over time. Likewise, borrowing allows regulated entities to use future allowances for current compliance periods. This inter-temporal flexibility reduces overall compliance costs and increases cost efficiency. Banking and borrowing essentially allows participants flexibility surrounding when abatement takes place, allowing them to make choices surrounding the timing of investments - whether to abate now, or to compensate another firm to abate now while delaying abatement at their own facilities to a later point in time. Importantly, an ETS allows market participants to form expectations about future carbon prices, connecting today's investment decisions with expected future carbon prices and abatement costs (Hepburn et al., 2016). Theoretical and empirical analyses provide evidence that banking reduces overall compliance costs and increases economic efficiency by allowing inter-temporal flexibility (see e.g. Ellerman et al., 2003; Ellerman and Montero, 2002; Kling and Rubin, 1997; Rubin, 1996; Schleich et al., 2006). In practice, holding limits or institutional constraints sometimes limit the number of allowances that entities can bank. Furthermore, where banking results in a surplus that is considered excessive, the market may no longer function effectively (see Neuhoff et al., 2015) and therefore result in allowance cancellation by policy makers or the introduction of an automatic adjustment mechanism.

5 Many of the downsides of grandparenting can be avoided if periodic adjustments or updates to the allocation baseline period are not made. However, in this case significant changes in production would either result in large windfall profits or alternatively leakage risk for certain sectors. Therefore, in almost all cases, grandparenting is coupled with some form of updating provisions.

Borrowing has been limited across all existing ETS for two reasons: (1) borrowing can threaten short-term targets; and (2) borrowing creates stakeholders with allowance debt that have an active interest in lobbying for a reduction in the stringency of the program or its removal, threatening the credibility of the ETS (Fankhauser and Hepburn, 2010).

Feature	Options/Range	Impact on			
		Volatility	MAC	Predictability	Effectiveness
Banking / Borrowing	Allowed	↑/↓	↑	↑/↓	0

- **Volatility:** *The impact of banking and borrowing on volatility is ambiguous.* On the one hand, volatility might increase as the allowance price reflects expectations about future market fundamentals. On the other hand, without banking and borrowing allowance prices tend to rapidly increase or decrease at the end of trading periods (as they are rendered invalid at the end of the period). From this perspective, the introduction of banking and borrowing smooths prices across trading periods and decreases volatility.
- **MAC Reflection:** *Banking and borrowing lead to a better reflection of MAC by the price over a longer time horizon and thus enhance intertemporal optimization.* Given a cumulative emission target, banking and borrowing allow market participants to equate their MAC over time (time-flexibility). This enhances the functioning of the ETS as prices better reflect expected future MAC. This effect will be reduced where regulations prescribe binding holding limits that restrict banking as market participants are constrained in their ability to smooth prices over time (Shobe and Holt, 2014).
- **Predictability:** *The impact of banking and borrowing on the price predictability is ambiguous.* Banking allows for intertemporal optimisation and can therefore smooth the forward curve for allowances. However, intertemporal flexibility also allows external shocks to be transmitted between phases.
- **Environmental Effectiveness:** *Banking and borrowing have no impact on the environmental effectiveness.* In the absence of cancellation provisions from policy makers or automatic adjustment provisions, banking and borrowing do not affect the supply of allowances and therefore should not impact on effectiveness. However, interactions with MSM are possible and are discussed in section 3.1.6 below. Conversely, borrowing can create stakeholder with allowance debt that lobby against the stringency or continuation of the ETS, resulting in discounted allowance prices where participants anticipate a loosening of the cap (Fuss et al., 2018).

3.1.5 Provisions for additional allowances supply

While banking and borrowing adds inter-temporal flexibility to the market, linking an ETS to other systems exposes market participants to new sources of allowances. These flexibility options can be integrated into an ETS by: (1) linking to other ETS's; and (2) allowing emissions reductions outside the scope of the ETS to be included, following predefined crediting mechanisms (carbon offsets). Depending on whether offsets are converted into allowances or whether they can be used for compliance, either the number of allowances increases or the demand for allowances decreases. As supply from offset markets is generally difficult to predict, quantitative limits have mostly accompanied links to offset systems (PMR and ICAP, 2016). In contrast, linking to other trading systems may increase or decrease supply depending on whether the domestic trading system becomes a net-importer or –exporter.

A linked market should lead to an increase in overall abatement efficiency by increasing the number and type of abatement options and therefore the gains that come from trade (Santikarn et al., 2018). The cost savings increase with high differences of carbon prices before linking (Beuermann et al., 2017). Linking of ETSs means that a certain level of mitigation will not take place within a jurisdiction with higher abatement costs, which in turn may undermine domestic ETS targets (Santikarn et al., 2018). Finally, linking will provide a larger market with more participants that will on the one hand increase liquidity and likely decrease price volatility. On the other hand, linking exposes a jurisdiction to external political and economic shocks which can increase volatility, depending critically on dynamics of the linking partners GDPs and as a consequence allowance demand (Doda and Taschini, 2016).

Feature	Options/Range	Impact on			
		Volatility	MAC	Predictability	Effectiveness
Additional sources of Supply	Linked System	↓	↓	↓	↑/↓
	Offsets	↓	↓	↓	↓

- **Volatility:** *Additional sources of supply likely decrease volatility.* The linking of ETS and the creation of offsets should, in theory, stabilize demand fluctuations for allowances via the creation of a larger and more liquid market. This can reduce price volatility as well as the risk of market power (Kachi et al., 2015).
- **MAC Reflection:** *Additional sources of supply lead to a distortion of the reflection of (domestic) MAC.* Providing additional sources of allowance supply leads to a distortion of the domestic price signal. As a result, the allowance price no-longer reflects the domestic MAC but the overall MAC of the linked systems. This deviation from the domestic MAC is intended, as it lowers the cost of emissions reductions by extending the scope of the system.
- **Predictability:** *Additional sources of supply reduce the predictability of the price.* Due to the distortion of the domestic price signal, additional sources of supply can reduce price predictability. In the case of linked ETSs, the exposure of small systems to systematic risk may increase. For example, if the larger market enters an economic recession, the demand for allowances declines following lower production levels. Even if the smaller partner is not in recession, its allowances prices would decrease, reducing the incentives for low carbon investments (Beuermann et al., 2017). Similarly, the cost and supply of offset units can be difficult to predict over the medium term.
- **Environmental Effectiveness:** *Additional sources of supply can increase or decrease (domestic) effectiveness.* Linking to other trading systems may increase or decrease domestic abatement depending on whether the domestic trading system becomes a net-importer (lower effectiveness) or net–exporter (higher effectiveness) of allowances. Independent of whether offsets are converted into allowances or whether they can be directly used for compliance, domestic abatement effort decreases when offsets are allowed into the system. Moreover, if offsets are of low quality, i.e., reflect only minor abatement, environmental effectiveness decreases further.

3.1.6 Market stability mechanisms

In recent years, multiple jurisdictions have reformed their ETS to include supply-side flexibility provisions with which more stable allowance price signals can be secured (ICAP, 2018). Provisions for MSM come in two different forms as price or quantity control mechanism: (1) caps or lower bounds on the allowances price; (2) minimum or maximum abatement requirements within a given time period (i.e. adjusting the supply of allowances in circulation) (Abrell and Rausch, 2017). Both of these mechanisms can be either symmetric or asymmetric. A symmetric system imposes both, minimum and maximum requirements, while asymmetric systems only impose one of the two.

MSM have to be seen in the context of uncertainty (Fell, 2016; Jacoby and Ellerman, 2004; Perino and Willner, 2016; Philibert, 2009; Pizer, 2002; Schopp et al., 2015). For example, a regulator needs to impose a cap on carbon emissions without knowing future abatement cost or future emissions in the absence of regulation, i.e., the abatement requirement implied by the chosen cap. Imposing MSM allows the regulator to alter the supply of allowances after learning new information about abatement costs and the amount of abatement required to meet the cap.

A key decision in the design of MSM is whether or not this supply adjustment is temporary with allowances being moved to a reserve available for future compliance; or permanent where the cap is adjusted based on the invalidation of allowances. In the case of temporary adjustments, minimum requirements help to reduce volatility of the carbon price by eliminating the risk that the carbon price falls below a certain threshold and providing additional allowances to quell spiking prices. The permanent invalidation of allowances also reduces volatility and in doing so increases long run average carbon prices and reduces cumulative emissions (see Edenhofer et al., 2017; Kollenberg and Taschini, 2015; Hepburn et al., 2016; Neuhoff et al., 2015).

Feature	Options/Range	Impact on			
		Volatility	MAC	Predictability	Effectiveness
Market Stability Mechanism	Price bounds	↓	0	↑	↑/↓
	Quantity bounds	↓	0	↑	↑/↓

- **Volatility**[6]**:** *MSM reduce volatility. Even if the altering of allowance supply is non-permanent, MSM help to reduce volatility and, therefore, enhance investment incentives.* This is particularly true for minimum requirements, which eliminate the risk of unprofitable investments.
- **MAC Reflection**[7]**:** *MSM do not have an impact on the reflection of MAC.* MSM alter the supply of allowances and thus the MAC, but they do not impact the reflection of MAC by the price signal.
- **Predictability:** *MSM increase predictability.* With a market stability mechanism, prices or allowance quantities stay within a certain price range and are, thus, more predictable.
- **Environmental Effectiveness:** *MSM can increase or decrease environmental effectiveness.* MSM may alter the environmental effectiveness of the ETS if allowance creation or deletion is permanent. Binding minimum (maximum) requirements decrease (increase) the supply of allowances and as such, increase (decrease) the environmental effectiveness of the ETS.

3.1.7 Allowance cancellation provisions

Under allowance cancellation provisions, the regulator, market participants or other third parties can directly exert influence on the supply of allowances in an ETS by purchasing allowances and deleting or retiring them. A number of opportunities exist for voluntary cancellation. Gerlagh and Heijmans (2019) discuss the options of buy-and-burn strategies by third parties such as NGOs or climate conscious consumers. Despite some initial concerns from market participants that such behaviour would bid up the allowance price, given liquidity constraints of consumers and NGOs, voluntary cancellation of these parties has traditionally been small.[8]

Another possibility is to allow sectors that are not regulated under the ETS to cancel allowances in order to fulfil their emission targets outside the ETS. Alternatively, the regulator can cancel allowances in order to account for accompanying policies such as the closure of fossil power plants or renewable support policies. Both approaches decrease the supply of allowances available for firms regulated under the ETS.

The cancellation of allowances can also interact with invalidation provisions built into MSM. Specifically, invalidation provisions may affect the additionality and hence environmental effectiveness of cancellation, if cancellation reduces the volume of allowances that are invalidated within the MSM. Additionally, where cancellation puts upwards pressure on prices that then trigger release from a price based MSM, the environmental effectiveness may be compromised.

Feature	Options/Range	Impact on			
		Volatility	MAC	Predictability	Effectiveness
Voluntary Cancellation	Allowed	↑/↓	↓	↑/↓	↑

- **Volatility:** *Voluntary cancellation may increase volatility.* Volatility increases as the price reflects uncertainty of the expectations on the cancellation of allowances. However, if cancellation is undertaken by the regulator in order to account for accompanying policies, it may also help to stabilize the price in a situation of decreasing demand induced by these accompanying policies (e.g. closure of fossil fuel plants).

6 Here we consider MSM in a general sense. The specific design of a MSM could in theory also increase volatility.
7 Where a MSM corrects for a market or regulatory failure, it is possible that it results in a positive reflection of the MAC.
8 In the EU-ETS, the volume of voluntary cancellations has so far been marginal, limiting its overall effects on the market. For example, there were 315,083 EUAs cancelled in 2018 (European Commission, 2019).

- **MAC Reflection:** *Under voluntary cancellation, the allowance price does not reflect the MAC of the ETS.* In the case of voluntary cancellation, the allowances price no-longer reflects MAC of firms under the ETS but the MAC of other sectors, or the marginal willingness of climate-conscious consumers to pay for environmental effectiveness.
- **Predictability:** *Voluntary cancellation reduces predictability.* The long-term predictability of the carbon signal decreases as the amount of future cancellation is uncertain. Early commitment and communication from a regulator regarding voluntary cancellation for the impact of companion policies (e.g. closure of fossil fuel plants) can limit this effect.
- **Environmental Effectiveness:** *Voluntary cancellation is likely to increase the environmental effectiveness of an ETS.* Overall environmental effectiveness is increased in the case of climate-conscious consumers, as these tend to "burn" allowances. Environmental effectiveness of the ETS alone, however, always increases when allowances are taken out of the market. In the case of non-ETS sectors using allowance cancellation to fulfil their emission target, the overall emission target of the whole economy remains constant.

3.2 Demand

In this chapter we shift from a focus on supply-side design to demand-side design elements, including: (1) scope i.e., which GHGs, industries or activities are regulated under the system and (2) market participants, i.e., which parties are allowed to trade in the system. The tables below summarizes our findings of the impacts of different design features on the volatility of the allowance price signal, the reflection of MAC, long-term price predictability signal, and the environmental effectiveness of the ETS.

3.2.1 Coverage

The coverage (or scope) of an ETS determines the type of installations obliged to submit allowances for each ton of emitted GHG. Coverage directly impacts the number of regulated entities in the market and therefore, the number of market participants; and the type and characteristics of regulated firms, including the nature of their allowance demand.

The number of regulated entities is important in defining the degree of market concentration. With a high degree of market concentration, participants might exert market power to strategically manipulate the allowances price. Market power leads to a deviation of allowance prices from MAC. If the firm has market power only in the allowance market, the price establishes below (above) the MAC if the firm is a net-seller (net-buyer) (Hahn, 1984; Liski and Montero, 2011). If the firm is in addition able to exert market power in the product market, there is an incentive to increase allowance prices in order to increase the cost of competitors and, therefore, to keep them out of the product market (i.e. electricity market) (Sartzetakis, 1997; Hintermann, 2017).

The type and characteristics of regulated firms are of particular importance for transaction cost. If firms are small and do not have significant trading experience, they face higher transaction costs for allowance trading and, thus, are less likely to trade, i.e. sell, allowances. Where trade is seldom, the allowance price no longer reflects the MAC of all market participants and, thus, the cost-effectiveness of the trading system is lowered (Betz et al., 2010; Jaraite-Kažukauské and Kažukauskas, 2015). Firm characteristics and allowance demand may also vary depending on the sector they represent. Therefore by including a greater number of (diverse) trading entities in a market, broad scope generally makes for a more stable price and reduces the potential for any one entity to gain market power (PMR and ICAP, 2016).

Feature	Options/Range	Impact on			
		Volatility	MAC	Predictability	Effectiveness
Coverage	Wider scope	↓	↑	0	0

- **Volatility:** *A wider scope might decrease volatility.* Under a narrow scope, participants are rather homogenous, leading to infrequent trades. Thus, single trades have large price impacts leading to higher volatility. Increasing the size and scope of an ETS is therefore likely to decrease volatility.

- **MAC Reflection:** *A wider scope ETS can lead to a better reflection of MAC by the price*. The quality of the price signal depends on the type of market participants: first, when including rather small emitters, transaction costs might disturb the price signal resulting in a deviation from MAC. Second, privately owned enterprises behave more efficiently in markets as compared to publicly owned firms. Increasing the coverage reduces the risk of only having small or publicly owned firms in the market which will result in a price signal that better reflects the MAC. Finally, by including a greater number of trading entities in a market, broad scope generally makes for a more stable price and reduces the potential for any one entity to gain market power (PMR and ICAP, 2016).
- **Predictability:** *The scope of the ETS does not impact the predictability of the price*.
- **Environmental Effectiveness:** *Environmental effectiveness is not altered by choosing the scope of the ETS*.

3.2.2 Market participation

Besides coverage, the number and type of market participants are determined by whether the system is designed to be open or closed. In a closed system, only regulated firms are allowed to trade. In contrast, in open systems non-regulated actors, such as financial intermediaries and NGOs, are allowed to trade allowances as well. Opening trading systems for non-regulated actors offers the advantage of a more liquid market with lower transaction costs, as regulated entities outsource their allowance trading to intermediaries. Betz and Schmidt (2016) show that non-regulated actors are amongst the most active traders in the EU-ETS. Betz and Cludius (2016) further find that large firms and companies are more likely to interact with financial intermediaries.

Feature		Impact on			
		Volatility	MAC	Predictability	Effectiveness
Market Participation	Open	↓	↑/↓	0	0

Note: Table shows impacts of opening a system compared to a system of trades restricted to compliance entities.

- **Volatility:** *Opening the trading system might decrease volatility*. In a closed system, market participants usually trade only right before compliance deadlines leading to large price movements in these periods. Opening the system to intermediaries creates more consistent trading which reduces volatility.
- **MAC Reflection:** *Opening the market can have ambiguous effects*. Opening ETS systems to non-regulated actors lowers transaction costs, leading to a higher probability of trading and, therefore, increases the quality of the price signal. However, financial intermediaries or other third parties might have different trading strategies not driven by MAC (Schopp et al., 2015).
- **Predictability:** *Opening the market does not affect predictability*.
- **Environmental Effectiveness:** *Environmental effectiveness is not affected by market participation*.

3.3 Transaction and market oversight rules

3.3.1 Legal nature of allowances

A sometimes-overlooked aspect of ETS design is the legal regime in which allowances are established. The legal nature of an allowance determines the regulator's flexibility to change the rules of the system such as rules on the trade of allowances and accounting practices.

Much of this depends on whether allowances are regarded as "property rights" or as "private property" in the national law. An allowance as a property right facilitates transferability and establishes protection against confiscation. Conversely, allowances as private property limit the possibility for regulators to manage an ETS through creating or cancelling allowances. Therefore, establishing allowances as private property limits the flexibility to react to future changes and also to correct for past failures, such as over allocating allowances.

Feature	Options/Range	Impact on			
		Volatility	MAC	Predictability	Effectiveness
Legal Nature	Property right	0	0	0	0
	Private property	0	0	0	0

- **Volatility:** *The legal nature of allowances does not affect volatility.* The legal nature does not affect the possibility to trade and has no effect on volatility.
- **MAC reflection:** *The legal nature of allowances does not affect the reflection of the MAC in the allowance price.* Like volatility, reflection of the MAC will not be directly affected by the legal nature of an ETS.
- **Predictability:** *The impact of the legal nature of allowances on price predictability is unknown.*
- **Environmental Effectiveness:** *The legal nature of allowances does not affect effectiveness.* The legal nature of allowances does not affect the quantity supplied and, therefore, does not affect the environmental effectiveness.

3.3.2 Fiscal nature of allowances

The fiscal nature of allowances determines the taxation regime in which the ETS operates. This relates to whether allowances are taxable services under the value added tax (VAT) or corporate tax (direct taxation). Furthermore, allowances may be classified as commodities or financial instruments (e.g. forward, future), which has implications for the legal regime in which they will be regulated for trading purposes. Stricter reporting obligations, licensing and organizational requirements for market participants and market places are to be respected when financial market law regulates trading. At the same time, when allowances are governed by financial market law, they may become more mainstream financial products and therefore traded more often. To avoid VAT fraud, the majority of countries apply the reverse-charge mechanism on domestic transactions involving allowances, which moves responsibility for the payment of the VAT from the seller to the buyer of a good or service.[9]

Feature	Options/Range	Impact on			
		Volatility	MAC	Predictability	Effectiveness
Applicable Regulation	Commodity	0	0	↓	0
	Financial instrument	0	0	↑	0

- **Volatility:** *The impact of classifying allowances as commodities on volatility is unclear.* Given that derivatives of commodities are fiscal instruments and are treated as intangible assets in accounting standards, they have a lower impact on the value of the company since they are not included on the balance sheet. The existence of a derivative market allows companies to hedge price risk and thus increases the derivative market volume, which might reduce volatility. The effect on volatility is, however, uncertain.
- **MAC reflection:** *Fiscal nature does not affect the reflection of MAC.* The fiscal nature does not affect the incentive to trade and, therefore, the reflection of MAC remains undistorted.
- **Predictability:** *Allowances as financial instruments might increase predictability.* The definition of an allowance as a commodity or financial instrument also has an impact on oversight rules. If financial market oversight rules are more stringent compared to commodity oversight rules, predictability increases.
- **Environmental Effectiveness:** *Fiscal nature of allowances does not affect the environmental effectiveness.* The fiscal nature of allowances does not affect the quantity of allowances supplied. Thus, the environmental effectiveness stays constant.

9 This is not governed by financial regulation as such, but rather by taxation law.

3.3.3 Market places

One can distinguish between primary and secondary markets. The first is the market or auction platform where allowances, which are created by an authority, enter the system (see section on allocation). Secondary markets incorporate all platforms (e.g. exchanges) on which a variety of participants (e.g. brokers) trade different instruments (e.g. standardized derivatives such as futures) in various ways (Ellerman et al., 2010). The secondary market also encompasses bilateral trade between for example two covered entities.

Trade of allowances occurs through two different product types: spot and derivatives. When allowances are traded through spot, the ownership of the allowance is traded from the buyer to the seller. With derivative products the value of the product is determined by the underlying emission allowance, but the allowance itself is not traded. Derivative products include futures contracts, which represent the obligation to trade an allowance at a set price in the future and option contracts that provide the option but not obligation to buy or sell an allowance once a strike price is reached.

Moreover, functioning forward markets decrease the risk of market power in the allowance markets (Allaz and Vila, 1993) and a higher number of intermediaries will likely reduce trading costs, as competition increases. This should have a positive impact on liquidity, as more players may participate in the market. Higher liquidity more easily absorbs private information, which has a positive impact on the quality of the price signal (Ibikunle et al., 2016).

Feature	Options/Range	Impact on			
		Volatility	MAC	Predictability	Effectiveness
Market Places	High number of market places	↓	↓	↑/↓	0
	Nature of market places (derivatives, spot, OTC)	↓	↑	↑/↓	0

- **Volatility 1:** *Volatility decreases with the number of market places.* If more market places open, the amount traded in each market decreases, but thanks to arbitrage prices on the different market places should converge.
- **Volatility 2:** *Volatility decreases through the introduction of secondary markets.* Derivatives and spot exchanges improve price information compared to OTC and bilateral trading which reduces volatility.
- **MAC Reflection 1:** *With more market places, the reflection of MAC may decrease.* The number of market places will increase market segmentation and will have a negative impact on the reflection of MAC at each market place if arbitrageurs are not active. Moreover, with more and, thus smaller, markets the probability of market power increases.
- **MAC Reflection 2:** *The existence of secondary markets increases the reflection of MAC.* A functioning derivative market decreases the risk of market power in the allowance markets and thus improves the reflection of MAC (Allaz and Vila, 1993).
- **Predictability:** *The nature of market places does not affect predictability, however exchanges, i.e. open/transparent regulated markets, are favourable to OTC markets in that regard.* The existence of several market places and their nature does not alter the long-run predictability of the price as long as the market works efficiently, i.e., arbitrage is possible leading to converging prices. However, if transaction costs prevent arbitrage leading to differential prices across markets, predictability is decreased. Thus, the effect on predictability is ambiguous.
- **Environmental Effectiveness:** *Environmental effectiveness is not altered by the number and nature of market places.* The nature of market places does not affect the quantity of allowances supplied.

3.3.4 Transparency regulation

How and when information is publicly released is important for the market, as this information will influence the expectation of scarcity which has consequences on prices. Different types of information can be distinguished: allowance allocations; information on transactions; verified emissions; surrendering of allowances; sanctions; and prices. Information on allocations and verified emissions are expected to have the highest impact on the price, since they reveal information on the scarcity of the market. This is supported by Mizrach and Otsubo (2014), who find that volatility and bid-ask spreads declined with verified emission releases in the EU ETS.

Feature	Options/Range	Impact on			
		Volatility	MAC	Predictability	Effectiveness
Transparency	High frequency of reporting	↓	↑	↑	0

- **Volatility:** *Continuously revealing information on emissions and cancellation of allowances decreases volatility.* Revelation of information decreases uncertainty about allowances supply and demand and thus volatility decreases.
- **MAC reflection:** *Continuously revealing information on emissions and cancellation of allowances increases the reflection of MAC.* Revealing information decreases uncertainty about allowance supply and demand. Consequently, risk premiums decrease and the market price better reflects MAC.
- **Predictability:** *Transparency might increase predictability.* Revelation of information allows market participants to gain knowledge about market fundamentals.
- **Environmental Effectiveness:** *Environmental effectiveness is not altered by the level of transparency.* Transparency does not affect the quantity of allowances supplied.

3.3.5 Market oversight

Carbon markets need to be regulated in order to prevent fraudulent activities, detect potential abuse and ensure the integrity as well as the functioning of the system. The best practice to implement market oversight depends on the regulation of the market places as well as the existing financial and institutional frameworks and legal infrastructure. Market oversight must be based on a holistic approach including primary as well as secondary markets; it starts with disclosure requirements and data reporting on trading behaviour and compliance.

The governance structure must balance comprehensive and effective oversight with administrative burden for regulators and market participants. Advances in data management technology help to manage this trade off through for example, simplifications to data reporting and assist regulators with the management and analysis of emissions and market data.

Feature	Options/Range	Impact on			
		Volatility	MAC	Predictability	Effectiveness
Market oversight	Primary market (auctions)	0	↑	↑	0
	Derivative market	0	↑	↑	0
	Spot market	0	↑	↑	0

- **Volatility:** *Market oversight does not affect volatility.*
- **MAC reflection:** *Market oversight is likely to improve MAC reflection.* Market oversight may reduce fraudulent activities. As fraud activities reduce the reflection of MAC (agents particularly with respect to VAT may sell below MAC in order to increase trading speed), market oversight likely increases the reflection of MAC.
- **Predictability:** *Market oversight increases predictability.* The oversight by independent monitoring authorities of primary markets such as auctions as well as oversight over secondary markets such as exchanges for spot and derivative products will reduce the risk of fraud. As fraud activities might impact prices, market oversight increases the predictability of the price.
- **Environmental Effectiveness:** *Market oversight does not directly affect environmental effectiveness.*

4 Carbon markets and electricity market regulation

In the previous chapters, we outlined which elements of carbon market design will affect the quality of the allowance price signal. However, even when there is a well-functioning allowance market that generates a clear price signal, actors might be constrained in how they respond. The structure and regulation of energy markets determines the extent to which the cost of emission allowances can be freely reflected in the price of carbon-intensive goods, and how economic entities can adjust their consumption, production and investment decisions (Acworth et al., 2018; Boute, 2017).

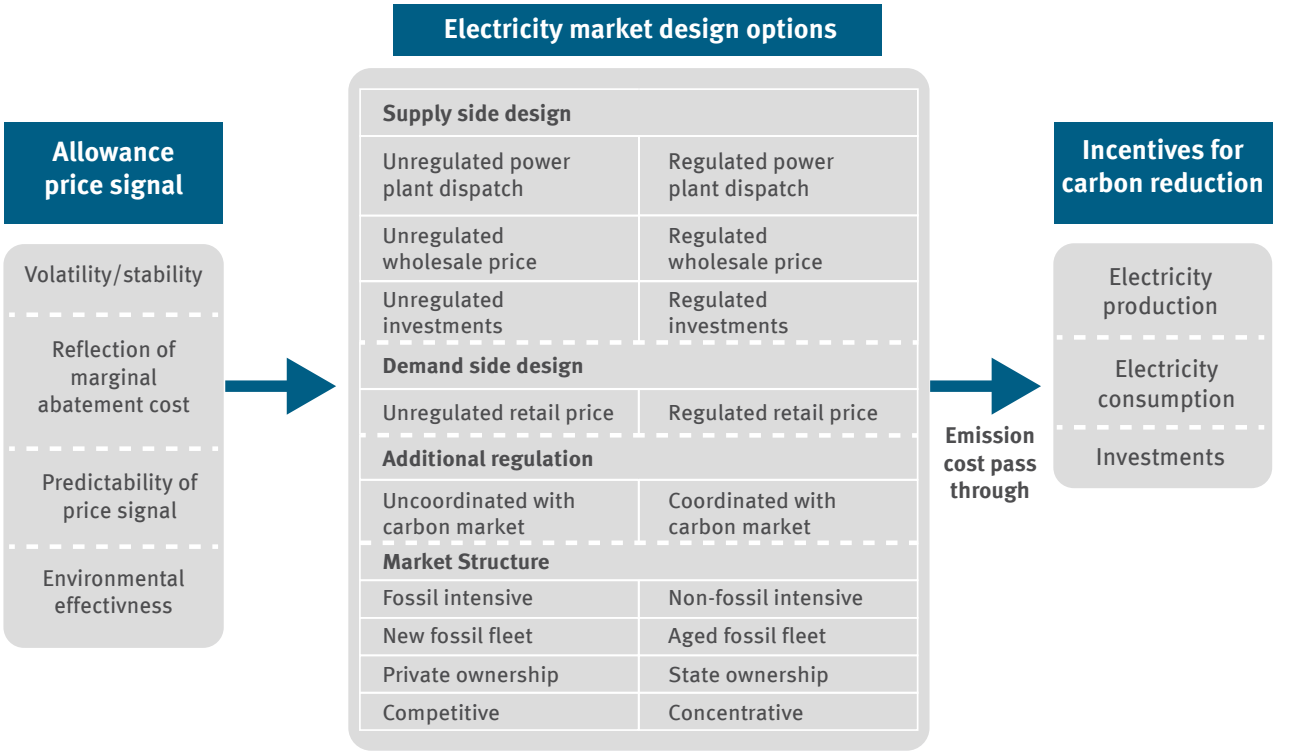
In theory, liberalized power markets with competitive pricing mechanisms allow electricity generators to effectively internalize the cost of the allowance. The allowance price signal incentivizes emissions reductions through three main abatement channels as outlined in the points below.

- **Short term: low carbon production/ dispatch channel:** an allowance price makes low-carbon electricity generation more competitive, encouraging a shift away from fossil-based generation technologies toward low-carbon alternatives.
- **Short – long term: low carbon consumption channel:** where the allowance price is passed through to electricity prices, consumers are encouraged to reduce electricity consumption and switch to more energy efficient appliances.
- **Long term: low carbon investment/(dis)investment channel:** cleaner forms of electricity generation become relatively more profitable, incentivizing investments in low-carbon technologies and their development. Similarly, high-carbon assets earn lower margins and are encouraged to shut down.

Energy economics and policy scholars have argued that electricity market liberalization reforms are a prerequisite for the introduction of an ETS (Jotzo and Loeschel, 2014; Teng et al., 2014; Fan, et al., 2014; Kahrl, et al., 2011). However, electricity markets rarely function on a fully liberalized basis. Even though liberalization provides for an 'ideal' context for ETS implementation, carbon market regulation can be adjusted to the specific regulatory conditions governing regulated electricity markets, in particular with respect to price and investment regulation (Boute, 2017; Acworth et al., 2019; Acworth et al., 2018).

In the following sections, we assess how the structure and regulation of energy markets either precludes the transmission of the allowance price signal through the economy or constrains actors' response to it. We build the analysis around a typology of electricity markets: supply side market design, demand side market design, and additional regulations (Figure 2). We trace the interactions of the allowance price with each of these market components and show how they impact on the functioning of the abatement channels identified above taking into account different carbon market regulations.

The tables in the sections below provide a ↑ or ↓ if the introduction of the feature increases or decreases the respective quality criteria. Where an effect is present but constrained, this is illustrated through the term (limited). A ↑/↓ indicates that the effect can go in both directions. A 0 indicates a negligible impact and n.a. indicates that the effect is not present or not assessed.



Authors illustration

Figure 2: Electricity market design and carbon markets

4.1 Carbon markets and supply-side electricity regulation: Wholesale Pricing

How electricity producers and consumers respond to an ETS depends partly on how allowances are allocated and to a large degree on the formation of wholesale and retail electricity prices. In liberalised wholesale markets, electricity is traded on future, short-term and real-time markets in which prices are formed based on supply/demand dynamics and commodity prices (coal, natural gas, oil). As generators aim to recover costs, they also include the costs of emissions in their bids to the market, setting in motion short- and long-term emission abatement opportunities. When prices are administratively set, such cost-reflection and pass through is no longer guaranteed but depends on the tariff rules and how the cost of allowances are treated. Therefore, the way in which prices are formed or regulated together with the method of allowance allocation has large implications for the role of an ETS in driving abatement options in the power sector.

4.1.1 Electricity dispatch

Electricity dispatch refers to the rules according to which electricity sources are called upon to meet demand. Dispatch systems vary. At one end of the spectrum, fully competitive markets organize dispatch based on economic operating cost (Keppler, 2010). At the other end of the spectrum, planning agencies instruct electricity dispatch based on predetermined technical, economic or political considerations. In between, electricity may be dispatched according to economic, environmental or broader criteria (Ho et al., 2017).

Following economic dispatch, electricity markets dispatch the generation sources with lowest marginal cost first and then source from increasingly expensive options until demand is met. The market price paid to all generators —regardless of their bid— is set at the value of the final (and most expensive) MWh supplied (Cook et al., 2013). This process usually takes place on the day-ahead market for supply of electricity the following day (e.g. daily day-ahead auctions on EPEX Spot[10]).

10 https://www.epexspot.com/en/market-data/dayaheadauction

The allowance price interacts in such a system by increasing the marginal cost of fossil-based generators according to their carbon intensity (CO_2/MWh). As such, the total variable costs of carbon-intensive generators increase compared to low (or zero) carbon generation, penalizing the former in the dispatch or merit order. The result is that low-carbon producers are ranked first and will be able to increase their share of total electricity generation. At the same time, the allowance price signal increases the bids of carbon-intensive generators, in turn creating higher margins for low-carbon installations that operate at very low marginal costs. In competitive markets, this will occur irrespective of the initial allowance allocation as the opportunity cost of allocated allowances will be considered in generators bids.

The impact of an allowance market in dispatching decisions is often central to debates surrounding minimum prices in allowance markets (Newbery et al., 2018). In setting a floor price, generation technologies can be assessed to set a minimum price that would guarantee that the most carbon-intensive fuels are no longer competitive (Fuss et al., 2018; Neuhoff et al., 2015).

When electricity is dispatched following administrative instructions, operation will no longer follow the least cost approach and investment decisions will not be driven by current and expected prices. Plants with the lowest variable costs will not necessarily be dispatched first. Electricity dispatch will not follow the merit order and cannot, in consequence, be altered by emissions allowance costs resulting from the ETS. In consequence, the clean dispatch effect that the ETS is designed to deliver, will not take place (Kahrl et al., 2011; Ho et al., 2017; Acworth et al., 2018; Acworth et al., 2019).

Market operators could consider the allowance price or a shadow price when making dispatching decisions, referred to as environmental dispatch. Alternatively, electricity dispatch could be prioritized based on technical specifications, such as emission levels and fuel efficiency (Kahrl et al., 2013). In such cases, instead of minimizing costs, the merit order would minimize environmental externalities, including CO_2 emissions. Operators would thus be ranked by fuel efficiency or emissions levels. While such an approach could see some form of low carbon prioritisation in the dispatch process, it will likely face challenges particularly where long term power purchase agreements are in place for fossil-based generators (Acworth et al., 2019).

Feature	Options/Range	Impact on low carbon		
		Product/dispatch	Consumption	(dis)Investment
Dispatch	Economic dispatch	↑	n.a.	↑
	Administrative dispatch	↓	n.a.	↓
	Environmental dispatch	↑ (limited)	n.a.	↑ (limited)

- **Production/dispatch:** *Where electricity is dispatched according to the merit order, an ETS will favour low carbon alternatives.* An ETS will not be effective when dispatch is administrative and based technical or political considerations rather than the variable cost of production. Some of the incentives an ETS is designed to deliver can be replicated by including environmental criteria into administrative dispatching decisions.
- **(Dis)investment:** *Operating power plants according to the merit order facilitates the financial viability of low-carbon investments to the detriment of carbon intensive assets.* Passing through the allowance price in generators' bids increases the wholesale price during periods of high demand when carbon-intensive generation is needed. During these hours, variable renewable energy (VRE) producers receive higher margins. At the same time, both the margins and amount of running hours for carbon-intensive assets decrease. These day-to-day market signals strengthen the business case for investing in low-carbon generation technologies and the early decommissioning of fossil-based generation assets.

4.1.2 Liberalized markets with price caps

The price formation process on the day-ahead market can be distorted through price caps, which can prevent wholesale electricity prices from fully reflecting the cost of allowances. Price caps can be justified for reasons of consumer protection, competitiveness of strategic industries, and market failure (Brunekreeft and McDaniel, 2005). However, public interference with electricity and capacity prices generates a "missing money" problem that can significantly reduce the amount of investment in electricity production (Oren, 2007).

With price caps, marginal electricity prices can artificially remain below the real operating cost of electricity production. As a result, price caps can impose losses on marginal electricity producers, and restrict revenue for low-carbon producers. In addition, price caps can prohibit the allowance price from being fully passed on to end consumers (Sijm et al., 2006; Ellerman and Joskow, 2008). Price caps will therefore dampen the production, investment and consumption effects of an ETS.

Feature	Options/Range	Impact on low carbon		
		Production/dispatch	Consumption	(dis)Investment
Price formation	Liberalised	↑	↓	↑
	Liberalised markets with price caps	↓	↓	↓

- **Production/dispatch:** *By distorting the economic precedence that governs the dispatching process, price caps limit the merit order effect of an ETS.*
- **Consumption:** *Price caps can prevent the allowance price from being fully passed on to consumers, thus distorting incentives for abatement along the consumption channel.*
- **Investment:** *By keeping prices below the market equilibrium, price caps result in 'missing money' and dampen the investment signal.* Where price caps hold marginal electricity prices below operating costs, they can impose losses on marginal electricity producers as well as reduce the margins for carbon free generators.

4.1.3 Regulated tariffs

In electricity markets with regulated wholesale prices, the internalization of the carbon externality depends on the tariff methodologies and the regulatory discretion of the tariff authorities (Bohi and Burtraw, 1992; Fowlie, 2010; Kim and Lim, 2014; Lanz and Raush, 2015). Regulated prices are determined based on actual costs, rather than opportunity costs. On this basis, allowances that are received free of charge are likely excluded from the tariff basis of the regulated entities, thus limiting the pass-through rate of carbon costs to end-users (Baron et al., 2012). However, where allowances are required to be purchased at auction, an ETS will represent new costs for generators and could be included in the tariff base, up to a certain level. Therefore, both the allocation method and the tariff methodology will be important for how an ETS functions under regulated tariffs.

With ***cost-plus regulation,*** tariffs are based on producer's operating costs plus a reasonable profit which, depending on the regulatory definition of eligible costs, may allow generators to fully recover the costs of purchasing allowances and hence mute the allowance price signal in wholesale generation. However, as purchasing allowances increases the cost basis, some degree of price pass-through to final consumers will occur. With free allocation, the tariff regulator is unlikely to include the opportunity cost of allowances in the electricity tariff basis, neutralizing the pass-through of the allowance cost to electricity consumers.

Indexation of gross necessary revenue may provide an incentive to producers to reduce emissions and save the cost of carbon allowances; if producers are entitled to keep the benefit of their efficiency improvements (i.e. electricity tariffs remain fixed at cost-plus level despite the reduction of producers' operating costs). The ambition of producers' emission reduction programs will depend on the duration of the regulatory period (i.e. the duration during which producers can continue to receive the cost-plus tariff level determined before reducing emissions).

Under ***Rate of Return Regulation***, tariffs are based on invested capital plus a reasonable return, which creates an incentive for generators to inflate their capital expenses (Averch and Johnson, 1962). It also encourages producers to invest in low carbon technologies, which are capital-intensive. Where the producers' capital basis is increased, so too will electricity tariffs.

Coverage of indirect emissions can be applied to transmit the allowance price signal to end users of electricity where tariff regulation prohibits price pass-through. In this way large consumers of electricity are required to hold and surrender allowances for the indirect emissions from their electricity consumption (Acworth et al., 2018).

Feature	Options/Range	Impact on low carbon		
		Production/dispatch	Consumption	(dis)Investment
Price formation	Liberalised	↑	↑	↑
	Regulated tariffs – cost plus	↓	↑ (limited)	↓
	Indexation of gross necessary revenue	↓	↑	↑
	Regulated tariff rate of return	↓	↑ (limited)	↑
	Regulated tariff – cost plus with free allocation	↓	↓	↓
	Regulated tariff with free allocation and coverage of indirect emissions	↓	↑	↑

- **Production/dispatch:** *Regulated tariffs distort the merit order effect of an ETS, preventing clean dispatch.*
- **Consumption:** *The allocation method and tariff structure will determine the incentives for downstream mitigation.* Where the tariff basis is increased, either through purchasing allowances or through investing in low carbon technologies, at least a portion of the allowance price will be passed through to end consumers and therefore trigger downstream mitigation. Where allowances are received freely, they will not increase costs and hence not enter the tariff basis.
- **Consumption:** *Coverage of indirect emissions can compensate for the absence of pass-through and trigger low carbon consumption.* This requires large electricity consumers to surrender allowances for the emissions associated with their electricity consumption and can reinstate the allowance price signal downstream.
- **Investment:** *The allocation method and tariff structure will determine the incentives for low carbon investment.* Rate of return regulation and, to a lesser extent, indexation of gross necessary revenue will send a signal to invest in low carbon technologies. Cost plus regulation will not, if producers can include the cost of purchasing allowances in their tariff basis. Where allowances are received freely, investing in low carbon technologies will also not be incentivized.

4.1.4 Allocation of the carbon cost to combined heat and power installations

The use of Combined Heat and Power (CHP) presents a challenge for implementing ETS within a liberalized electricity market in cases where heat supply remains regulated with heat prices subject to state control (IEA, 2004; Boute, 2012b). The allocation of costs to the electricity and heat output of CHP plants is critical to how the carbon price signal is transmitted to the operators of CHP installations and the consumers of electricity and heat.

Liberalization of electricity and heat supply: If both the heat and electricity markets are liberalized, the market prices will balance the allocation of costs.

Liberalization of electricity supply, regulation of heat supply: Compensation of the carbon cost in heat tariffs will reduce the cost of electricity production and thus benefit the competitiveness of CHP plants on the electricity market. It will however increase heat tariffs and will thus stimulate consumers to switch to individual boilers that are outside of the scope of the ETS. This "boilerisation" (Boute, 2012b) negatively impacts the integrity of the ETS because it artificially reduces ETS emissions by increasing non-ETS emissions.

Feature	Options/Range	Impact on low carbon		
		Production/dispatch	Consumption	(dis)Investment
Price formation	Liberalised electricity and heat prices	↑	↑	↑
	Liberalized electricity prices, but regulated heat prices	↓	↓	↑/↓

- ***Production/dispatch:*** *Regulated heat prices can distort the merit order and thus the clean dispatch process.*

- ***Consumption:*** *Heat tariffs and the method of allowance allocation will determine the incentives for downstream abatement*. Where allowance costs are reflected in heat tariffs this will increase heat tariffs and thus stimulate consumers to switch to individual boilers that are outside of the scope of the ETS. With cost-plus heat tariffs and free allocation, the carbon cost is unlikely to be reflected in end-user prices.
- ***Investment:*** *With the return on investment tariff methodology, regulated heat prices can incentivize producers to invest in emission reduction measures*. With the cost-plus tariff methodology, investments in emission reductions are less likely to take place.

4.2 Carbon markets and supply-side electricity design: Investment

4.2.1 ETS as a driver of low-carbon investment in liberalized electricity markets

In liberalized markets, investment decisions in power generation are in principle decentralized (Bjørnebye, 2010; Baritaud, 2012).[11] The introduction of an ETS provides an incentive to shift production to lower-carbon generation sources in the short run, and invest in low-carbon assets in the long run. Electricity companies – and not the government – are responsible for making investment decisions concerning the construction of new power plants and the refurbishment of existing installations (Battle, 2013; Mäntysaari, 2015). In the investment-making process, the role of state authorities is in principle limited to approving companies' investment proposals to ensure the technical capability and financial capacity of electricity companies, as well as the security and reliability of electricity supply.

However, state authorities often play a more active role in the regulation of electricity investments given concerns surrounding an "energy-only" market approach (Hancher et al., 2015; De Vries, 2007). Mostly, intervention is in the form of capacity markets and tenders for generation capacity (Bjørnebye, 2007). Paradoxically, continued government control over electricity prices is one of the key reasons why liberalized markets have failed to achieve sufficient investments in electricity production (Brunekreeft and McDaniel, 2005). With regards to the ETS, given that the government drives these investments, not the market, this intervention can place downward pressure on allowances prices and negatively affects the relevance of the ETS as driver of investment (see section 4.4). Relatedly due to concerns of security of supply, the decommissioning of carbon-intensive assets of strategic importance for the balancing of electricity systems may be subject to regulatory constraints.

Finally, regulatory uncertainty and price volatility in carbon markets could discourage investors from making large and irreversible low-carbon investments that rely on sufficient carbon prices for investment profitability (Sullivan and Blyth, 2014). Conversely, carbon markets that provide a credible long-term reduction path as well as clarity on the minimum return on investments (e.g. through a floor price) can stimulate low carbon investment.

Feature	Options/Range	Impact on low carbon		
		Production/dispatch	Consumption	(dis)Investment
Decentralised Investment	Liberalised market	n.a.	↑	↑
	Liberalised markets – with tenders or capacity markets	n.a.	↓	↓
	Liberalised markets – with constraints on decommissioning of balancing capacity	↓	↑	↓

- **Production/dispatch:** *Regulatory constraints on the decommissioning of carbon intensive assets prevent clean dispatch*. By prolonging the life-time of carbon-intensive assets, they are maintained in the merit order and therefore when called upon result in higher carbon production compared to where they were replaced by low carbon alternatives.
- **Consumption:** *Regulation on the decommissioning of carbon intensive assets will increase prices as it keeps high carbon emitting plants in the merit order*. Impediments to decommissioning power plants will distort the merit order potentially affecting wholesale electricity prices, where carbon intensive power plants remain within the merit order.

11 Investments in the network infrastructure continue to be regulated as "natural monopoly".

- **(Dis)investment reflection 1:** *Through its impact on the merit order, an ETS in a liberalized electricity market incentivizes electricity companies to invest in low carbon alternatives.*
- **(Dis)investment reflection 2:** *Capacity markets or tenders that generate income streams for fossil generators will push against the carbon price signal.* Tenders that generate income streams for clean energy generators will also dampen the allowance price signal and result in increased emissions by other ETS installations (water bed effect). Lower allowances prices will also reduce incentives for low carbon consumption.
- **(Dis)investment reflection 3:** *Regulatory constraints on the decommissioning of balancing capacity will impede the ETS.* Regulation on decommissioning can lead to the artificial prolongation of the life-time of carbon-intensive assets and thus limit the impact of the ETS on the decarbonisation of electricity systems.

4.2.2 ETS as driver of low-carbon investment in regulated electricity markets

In regulated markets, governments approve and, in some cases, impose investment programs, thus limiting the flexibility for electricity companies to determine their investments. That said, in most jurisdictions, the electricity utilities actively participate in both the development of their investment proposals and the elaboration of the sectoral development plan. Government regulation of investments limits – but in principle does not neutralize – the relevance of the ETS as driver of low-carbon investments. The carbon price can influence utilities' investment proposals, but its impact on electricity investments will ultimately depend on how electricity tariff methodologies regulate the operating cost of purchasing allowances and the capital cost of investing in low-carbon projects.

In markets where the government imposes investment programs on electricity companies, the carbon price can be reflected in the investment decision-making process through shadow pricing, where carbon costs are integrated in investment planning even though utilities can fully recover the costs of allowances.

Feature	Options/Range	Impact on low carbon		
		Production/dispatch	Consumption	(dis)Investment
Regulated Investment	Government determines investment program-without shadow pricing	n.a.	n.a.	↓
	Government determines investment program-with shadow pricing	n.a.	↑	↑
	Regulated Tariffs- cost plus	n.a.	n.a.	↑/↓
	Regulated Tariffs- rate of return	n.a.	↑	↑

Note: The direction of the effect will depend on whether carbon costs are reflected in electricity tariffs.

- **Investment:** *The tariff structure and method for allowance allocation will determine the incentives for investment in regulated electricity markets.* In markets where utilities submit investment proposals for government approval, the tariff methodology will determine the incentive for regulated utilities to propose low carbon investment. Generally, utilities in regulated markets have an interest in proposing low-carbon projects (or less carbon-intensive projects) if the cost of carbon is not automatically reflected in their tariff base, or when investing in low-carbon projects can help them increase their regulatory asset base, and thus their returns (the return on investment methodology). In markets where the government imposes investment programs on utilities, the use of shadow pricing can help integrate the carbon price in the investment decision-making process.

- **Consumption:** *The tariff structure and allocation method will determine the incentives for low carbon consumption.* With the rate of return methodology, the inclusion of low carbon assets in the investment program of utilities will increase the regulatory asset base of utilities, and thus end-user electricity tariffs. While higher end-user prices can promote increases in efficiency, the price increase under rate of return does not reflect the carbon-intensity of production, but rather additional investment costs. This information asymmetry foregoes demand-side responses to low-carbon electricity consumption.

4.3 Carbon markets and electricity demand: Retail pricing

As electricity systems decarbonise, electricity generation and prices are expected to become more volatile. Indeed, the marginal cost of production of electricity from variable sources can be low and therefore affect the wholesale price, creating periods of zero prices. Hence, 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).

In theory an allowance price will create an incentive to reduce fossil-based electricity consumption or to shift towards lower carbon-based electricity sources. In practice, the impact of an ETS on demand will depend on whether or not the allowance price signal is transmitted to end users through electricity prices and how responsive their behaviour is to price changes (elasticity of demand). Large electricity consumers that participate in competitive wholesale electricity markets will likely be exposed to an allowance price signal. The exposure of smaller electricity consumers to an allowance price signal will depend on the retail tariff structure and rate (See box 1 for an overview of retail electricity tariffs).

Retail Electricity Tariffs

- **Volumetric tariffs** – based on electricity consumption e.g.
  - Flat tariffs: fixed price for a fixed amount of energy
  - Fixed tariffs: fixed price per unit of energy/kWh
  - Time of use (ToU): price dependent on the time of consumption or feed-in
- **Capacity Tariffs** – depends on the level of capacity e.g.
  - Flat: fixed price for predefined capacity
  - Variable: definition of different capacity levels: one price per quantity of capacity
- **Multi-part tariffs:** Combination of fixed, volumetric and capacity tariffs e.g.
  - Two (multiple) part tariff: The customer pays a monthly fee for access and a usage fee for consumption of electricity. Can better reflect electricity generators operating costs.

An ETS will be most effective where rate levels and structures reflect the marginal cost of electricity production. This is the case for real time tariffs (or dynamic pricing), where wholesale electricity prices are passed through to final consumers and bills are calculated based on hourly consumption that is metered (Acworth et al., 2018). In this way, hourly electricity prices will reflect changes in the wholesale electricity market as well as developments in the allowance market. While dynamic pricing has been introduced into a number of markets (e.g. Spain), marginal tariffs require sophisticated measurement of consumer electricity use and might not be possible in all jurisdictions (IEA, 2016). The role out of smart metering and other service innovations will help in this regard. Still, time of use pricing (ToU) or critical peak pricing (CPP) may be adopted as a simplified form of dynamic pricing.

Feature	Options/Range	Impact on low carbon		
		Production/dispatch	Consumption	(dis)Investment
Electricity Demand	Dynamic pricing	n.a.	↑	n.a.
	Consumption based tariff	n.a.	↑ (limited)	n.a.
	Subsidised tariff	n.a	↓	n.a.

- **Consumption:** *The tariff structure and allocation method will determine the incentives for low carbon consumption.* Where retail tariffs reflect marginal costs of generators, end consumers are encouraged to consider carbon costs in their consumption decisions. Where tariff structures reflect electricity consumption average costs of generators may be passed onto consumers resulting in a limited price pass through, where retail tariffs are kept artificially low, the allowance price will be ineffective in driving demand side mitigation.

4.4 Carbon markets and additional regulation

In addition to direct energy sector regulation, entities covered by an ETS are likely subject to environmental regulation that might further constrain their ability to respond to the allowance price. These "companion policies" will be guided by more than just emission reduction considerations and can either support the ETS to overcome barriers from existing regulation, or in some cases, erode the efficiency of the system. For example, renewable energy, energy efficiency, carbon capture and sequestration, coal phase out policies and promoting CHP generation will all interact with an ETS, either having implications for the allowance price signal or constraining how actors respond to it. Their impact will be greatest when they are not considered in ETS design or where the ETS cannot respond through MSM.

Generally, the integrity of an ETS can be maintained if the abatement effects of energy policies are reflected in the cap setting or where MSM provide invalidation provisions for the build-up of surplus allowances (Boute and Zhang, 2019). Harmonizing climate and energy policy requires continuous coordination between environmental and energy authorities. Alternatively, MSM indirectly adjust for the effects that companion policies can have on the demand for emission allowances.

Feature	Options/Range	Impact on low carbon		
		Production/dispatch	Consumption	(dis)Investment
Additional regulation	Coordinated with carbon market	↑	↑	↑
	Uncoordinated with carbon market	↓	↓	↓

5 Carbon markets and electricity market structure

The preceding chapters analysed the effects of wholesale pricing and investment structures on the strength of an ETS in promoting a shift to low-carbon energy sources. However, even under 'ideal' market circumstances where the allowance cost is reflected in day-to-day business operations and passed on to consumers, the structure of the electricity market will influence the level of mitigation that can be achieved at a given allowance price. In this chapter we consider the role of the power mix; the age of the fossil fleet; ownership structure; and market concentration on the short- and long-term potential for decarbonisation under an ETS. In the sections that follow, we assume a liberalized market environment with economic dispatch and carbon price pass through, unless specified otherwise.

5.1 The electricity mix

Energy systems will respond differently to a carbon price depending on their level of decarbonisation and the level of diversification of fossil fuel sources. Systems with carbon-intensive generation will incur higher costs for a given allowance price since different generation technologies imply different CO_2 emissions per MWh.

The composition of fuel sources from which electricity is produced will determine short-term opportunities for fuel switching, specifically when the portfolio of generation capacity and level of electricity demand are fixed. For the carbon price to drive abatement from fuel switching, low-carbon generation assets must be available, high emitting plants must be ranked before lower emitting plants in the merit order and the allowance price must be sufficiently high to bridge the gap between generation costs based on the differential in carbon intensity (Sroft, 2002).

Systems that are dominated by coal and lignite but also have access to gas and renewable sources will respond strongly to a carbon price. Conversely, some fossil intensive energy systems with only a small range of different fossil fuel plants (e.g. no or only few gas plants) will – in the short-term perspective - be less responsive to a carbon price as there are only few possibilities for fuel switching. Energy systems in transition, where there is a mix in generation technologies of fossil and renewable sources, will also respond to a carbon price. However, systems constraints can limit this response when the grid infrastructure faces increasing congestion due to high penetration of intermittent renewables and lacks network investments and flexible responses. Decarbonised energy systems will not respond strongly to an allowance price as electricity producers will have little or no surrender obligations.

Feature	Options/Range	Impact on low carbon		
		Production/dispatch	Consumption	(dis)Investment
Electricity mix	Fossil-intensive, diverse fuel sources	↑	↑	↑
	Fossil intensive, Limited alternative fuel sources	↑ (limited)	↑	↑ (limited)
	Transition, with diverse fuel sources	↑	↑	↑
	Decarbonised	0	0	↑

- **Production/dispatch:** *Fuel switching is most likely in fossil-based systems where there is access to lower carbon alternatives, especially naturally gas.* Systems in transition will respond to a carbon price, but might face grid and system constraints. Decarbonised energy systems will not respond to a carbon price. In systems with cheap and abundantly available coal resources or high natural gas prices, ETSs have to deliver higher carbon prices to push carbon-intensive generators up the merit order.
- **Consumption:** *The marginal generator (the final unit supplying electricity at any given time) determines the impact of the ETS on the electricity price.* The wholesale electricity price and hence retail prices will only increase if the marginal generator is fossil based. This is more likely to be the case in fossil intensive systems than those in transition or those that are fully decarbonised.

- **(Dis)investment:** *The marginal generator (the final unit supplying electricity at any given time) determines the electricity price and therefore the margins for all generators.* Low carbon assets will benefit most when the marginal generator is fossil based and there is large scope to displace fossil-based technologies in the merit order. Under these conditions they will earn higher margins than their fossil competitors and also operate for longer. However, in energy systems with direct access to low cost lignite, where lignite-based generators are operating at the margin, it is possible these generators benefit more from the increase to the electricity price, than they are harmed by the allowance price (see DEHSt, 2019). In this case, an increasing allowance price can increase the margins for fossil intensive power plants, potentially delaying their decommissioning or in the extreme case, encouraging new investments. However, with increasing allowance prices and higher penetration of low carbon alternatives, capacity factors for lignite-based generators will also decline, limiting this effect (Sandbag, 2019).

5.2 Age of fossil generation assets

As carbon-intensive assets age, decisions must be made as to whether to modernize and continue operating existing generators, or to close these fleets and make way for new generation capacity (Cleetus et al., 2012). Ultimately, the decision will depend on whether the operating costs of the existing plant and resulting revenue from generation will be competitive with new technologies. An allowance price will directly impact this decision by increasing the operating costs of fossil-based generators above that of their fewer emitting competitors.

As older plants are often less efficient and more carbon intensive, they will feel the impact of a carbon price more than newer, more efficient plants. Older plants will become less competitive in wholesale markets, as they will run less and earn lower margins. To the extent that the capital costs of older plants are more likely to be recovered, decommissioning will become more attractive from a system perspective, when compared to younger plants. From the operator's perspective, keeping an old plant running is economical as long as the short run marginal costs are below the market price. The plant can remain profitable with lower margins as capital cost will have largely been repaid, which could delay decommissioning without a sufficiently high carbon price.

Similarly, in competitive electricity markets with remuneration options for flexibility, a moderate allowance price signal can incentivize coal plant operators to invest in retrofit measures that increase ramp rates, decrease minimum loads and shorten start-up times. This enhanced operational flexibility allows operators to recover costs with much lower capacity factors (and hence emissions) while providing system stability services that facilitate the integration of variable renewable sources (Agora Energiewende, 2017). The presence of a carbon price signal is crucial to limit the plant's operating strategy to provide flexibility on short-term markets, rather than continued baseload production. The emissions that arise from flexibility services provided by coal-fired power plants are higher than when provided by Combined Cycle Gas Turbines or gas turbines. However, in power systems where gas is expensive and the coal infrastructure is locked-in, retrofitting can provide a cost-effective strategy in the transition towards low-carbon energy sources.

Feature	Options/Range	Impact on low carbon		
		Production/dispatch	Consumption	(dis)Investment
Age of generation fleet	High average fleet age	↑	↑	↑

- **Production/dispatch reflection 1:** *The impact of an ETS will be greater in markets with older, more fossil intensive fleets.* Given the higher carbon intensity of the fossil fleet, older generators will be less competitive on the wholesale market and, depending on the scarcity of supply, may be dispatched less frequently. As younger plants are generally more efficient, they are less exposed to a carbon price when compared to older generation technologies. Therefore, a higher allowance price might be required to force a fuel switch.
- **Production/dispatch reflection 2:** *Opportunities for modernisation will be greater in older, more fossil intensive fleets.* Older generation units will reduce their carbon costs relatively more from a modernisation or refurbishment compared to modern plants.

- **Consumption:** *Where prices are passed to consumers, incentives for low carbon consumption will be greater when electricity supply is older and more fossil intensive*. Where the marginal generator is older and more carbon intensive, electricity prices will increase more for a given carbon price, compared to where the marginal generator is a newer, more efficient, fossil-based plant.
- **Investment reflection 1:** *Older, less efficient and more carbon intensive plants, will feel the impact of a carbon price more than newer, more efficient plants*. Changes to the wholesale electricity market induced by emissions trading will favour early retirement, where emission-intensive generators run less and earn lower margins and are hence increasingly less competitive than low emission alternatives (Cleetus et al., 2012). As older plants will experience more substantial changes in their operating costs from carbon pricing, they will be at a competitive disadvantage to newer, more efficient installations and will be encouraged to close.
- **Investment reflection 2:** *The average age of the fossil generation capacity will impact the magnitude of stranded assets*. Regions where fossil-based infrastructure is reaching the end of its lifecycle (approximately 40 years) are provided with an opportunity to replace this infrastructure with renewable capacity. Regions where average fossil generation capacity is relatively new will face a higher cost of stranded assets, which could encourage additional policies to remunerate technologies that push against the allowance price.

5.3 Asset ownership

While systemic factors have an effect on short-term abatement options, firm-level operations and ownership structures have an influence on market participant's responsiveness to a carbon price signal.

State ownership is prevalent in global electricity markets. State Owned Enterprises (SOEs) account for 61% of total installed capacity and 52% of electricity plants currently planned or under construction in 2016 in OECD and G20 countries (Prag et al., 2018). Reasons for state ownership vary. In some countries, vertically integrated SOEs are seen as a means to ensure equitable and reliable access to energy for all residents. SOEs may also be favoured by private enterprises given the strategic importance of energy supply chains (Wehrle and Pohl, 2016). Furthermore, SOEs can be an important source of government revenue (Torso, 2011), or be a vehicle to understand and diffuse foreign technologies in domestic energy markets (OECD, 2016).

Generation asset ownership is complex and comes in different legal structures and forms. According to Röttgers and Brile (2018), SOEs can be categorized along four lines:

- Fully state-owned, utilized enterprise
- Listed companies with majority state ownership
- Listed companies with minority state ownership; or
- Fully private or listed companies without state ownership.

While privately listed companies can be relied upon to seek (sustainable) profit maximization for their shareholders, SOEs are often part of complex governance structures and may be mandated to pursue broader public policy objectives alongside or in addition to profit maximization. SOEs may also benefit from preferential treatment (low financing rates, low return expectations, in kind subsidies, access to information, regulatory exemptions, etc.) that alters their operation and investment incentives. Conversely, SOEs are often bound by regulated electricity tariffs, which can be held at artificially low levels and in turn constrain revenues and investment capacity (Röttgers and Brile, 2018).

The existence of SOEs will have an ambiguous effect on how entities respond to the allowance price signal. They are likely to be less responsive to market-based incentives than their private counterparts and unbundling might not have the desired competitive effects if SOEs control both production and distribution networks. Yet, they may have a strong climate-orientated mandate or alternatively lower capital costs given preferential treatment from governments (e.g. low financing rates, low return expectations, in kind subsidies, access to information, regulatory exemptions) and therefore be in a better position to invest in low carbon generation. Either way, if they represent a large proportion of emissions under the cap, their behaviour will be important for market functioning.

Feature	Options/Range	Impact on low carbon		
		Production/dispatch	Consumption	(dis)Investment
Asset ownership	State-owned	↑/↓	↑/↓	↑/↓
	Privately owned	↑	↑	↑

- **Production/dispatch:** *The impact of state ownership on low carbon production is ambiguous.* It will depend on how climate objectives interact with broader social welfare, energy access and energy security objectives, which can be reflected in dispatch principles that deviate from marginal cost pricing.
- **Consumption:** *The impact of state ownership on low carbon consumption is ambiguous.* Price pass through to end consumers is not precluded by state ownership. However, mitigation opportunities from demand response will need to be weighed against broader objectives of social welfare and energy access.
- **Investment:** *The impact of state ownership on low carbon investment is ambiguous.* Given lower capital costs, SOEs may be better placed to invest in renewables and other capital-intensive low-carbon investments. However, their existing carbon entanglement might encourage SOEs to lobby for weaker climate policy or special conditions to protect their existing assets. What's more, SOEs often face significant financing problems because of electricity prices set below operating costs.

5.4 Market concentration

Regardless of ownership, large firms in concentrated markets may enjoy advantages and market power, and have inertia to a carbon price as low carbon assets could affect the profitability of existing assets.

Market concentration refers to the number of entities participating in the market and their relative share of that market. It is often used as an imperfect indicator of market competition (Röttgers and Brile, 2018). Concentrated markets (small number of firms account for a large proportion of activity), reduce competition and impede new firms from entering the market. The reduction in competition can protect incumbent firms from market forces, resulting in inefficiencies, higher costs and higher market prices. Barriers to entry are especially pervasive when new firms offering innovative technologies -such as decentralized renewable energy producers - are precluded from entry. Regardless of ownership, large firms in concentrated markets may enjoy advantages and market power and in some cases be able to influence the policy process to reduce competition (Röttgers and Brile, 2018).

Market concentration is generally high in markets where utilities are vertically integrated. However, market concentration can also be high in recently liberalized markets where formerly vertically integrated utilities still have a large market share. Market concentration can also differ regionally, such that at a national level market concentration may appear low, while in some regions vertically integrated monopolies can still dominate the local market (Röttgers and Brile, 2018).

Feature	Options/Range	Impact on low carbon		
		Production/dispatch	Consumption	(dis)Investment
Market Concentration	Highly concentrated	↓	↑/↓	↓
	Competitive	↑	↑	↑

- **Production/dispatch:** *Market concentration reduces the incentive for low carbon production.* Incumbents in highly concentrated markets will have an incentive to improve the efficiency of their existing fleets when faced with a carbon price signal. However, the opportunities for clean dispatch effects are likely to be limited as incumbents might try to maintain the running hours, and profitability, of existing assets by preventing new players from entering the market.
- **Consumption:** *The impact of market concentration on low carbon consumption is ambiguous.* Price pass through of emissions allowances will depend on the price setting strategy of incumbent firms under imperfect competition and the curvature of the demand curve. Prices may be higher or lower than under competitive markets, depending on the strategy pursued.
- **Investment:** *Incentives for low carbon investment are reduced in concentrated markets with fossil intensive incumbents.* Large fossil-based incumbents (state-owned or not) may face a commercial incentive to avoid investing in renewable capacity. That is because new capacity competes with existing generators and an increasing share of renewables will likely decrease the value and capacity factors of their existing fossil-based assets (Prag et al., 2018).

6 Interim conclusion

Carbon market regulation provides policy makers with many levers in which they can adjust the design of the carbon market to the domestic regulatory, economic and political landscape. Choices will not always be purely economic with political considerations also shaping carbon market design. In this study, we aim to identify the relevant factors that influence the effectiveness and efficiency of carbon markets for GHG mitigation. We focus on the regulations that establish the carbon market and govern the transaction of allowances as well as the structure and regulation of the product markets that covered entities participate in, focusing on the electricity market in particular. We seek to understand which regulations can lead to a distortion of the allowance price signal and where market structures and regulations limit the effectiveness of the ETS in driving low carbon production, consumption and investment.

We define a high-quality allowance price as one that equals the MAC of all market participants, is formed within a framework that allows market participants to make informed expectations regarding medium term price development, and is not characterized by excessive price volatility.

Based on the research to date we have drawn a number of preliminary conclusions. As a next step in this project, interactions between carbon market regulation and electricity sector regulation are assessed through a number of case studies, namely: California, China, the European Union, Republic of Korea and Mexico. The aim is to ground the assertions distilled from the literature in this report in real world examples that may reveal unexpected interactions and further policy considerations.

(1) A quality allowance price signal reflects a binding emissions cap that is consistent with clear medium and long term decarbonisation targets.

This will not only allow market participants to make short term abatement choices based on current allowance prices, but also provide a basis to form longer term price expectations that can inform capital intensive investment decisions. This is critical for the electricity sector where assets are capital intensive and operate for a number of decades. Carbon markets that provide a credible long-term reduction path as well as clarity on the minimum return on investments through a floor price will likely be more effective in stimulating low carbon investment, than those where there is uncertainty surrounding future reduction targets.

(2) The design of MSM has important consequences for both the carbon market and interactions with the electricity sector.

Intertemporal flexibility through banking and (limited) borrowing will allow covered entities to make investments when it is cheapest to do so and are hence an important element of a quality allowance price signal and an effective ETS. However, when banking volumes become too large and market and regulatory failures are present, there is a risk that the allowance price signal becomes distorted. Combined with uncertainty surrounding abatement costs at the time of cap setting and the risk of over allocation, MSM are a crucial element of carbon market design. MSM can automatically adjust the market in a way that maintains scarcity-based price formation and if desirable, through a floor price communicate a minimum return from investing in low carbon abatement technologies.

Where an ETS operates alongside a suite of companion policies that provide incentives for low carbon investments the MSM will be crucial to the relevance of the ETS and the additionality of companion policy emission reductions. MSM that operate with invalidation provisions that ensure excessive surplus is removed from the market permanently will likely provide the strongest incentive for additional low carbon investments. Yet experience with many of these mechanisms is new and there may be interactions with voluntary cancellation, other carbon market design elements as well as with electricity sector regulation that warrants further investigation.

(3) Allowance allocation will affect the functioning of the allowance market but also has important implications for how allowance costs are treated in regulated electricity markets.

Auctioning is the preferred mechanism for delivering a high-quality price signal. Each auction results in real price discovery, which reduces price volatility, and with frequent auctions will increase the reflection of the MAC. Where allowances are provided free of charge, benchmarking is the preferred approach. However, the impact of benchmarked based allocation on the quality of the price signal and the effectiveness of the system will hinge on the fine print of benchmark design as well as any provisions for updating based on output or changes to capacity.

Excessive free allocation can also reduce the requirement to trade and therefore impede price discovery. This effect is exacerbated in closed markets where third party participants cannot trade. Where poor price discovery interacts with uncertainty surrounding future reduction targets, participants may be reluctant to trade. Where possible, the case studies should shed light on how these approaches differ across systems as well as innovative design options that encourage price discovery during initial phases where entities may receive a large share of allowances free of charge.

The method of allocation will also have a large influence on the role that an ETS can play in regulated electricity sectors as actual costs, rather than opportunity costs, are considered in tariff methodologies. Therefore, the tariff methodology combined with method of allocation will be important for how the allowance price signal is transmitted. Where the allowance price signal is not passed through to electricity prices, coverage of indirect emissions represents one option to reinstate the allowance price at the point of consumption. While coverage of indirect emissions is a feature of ETS operating in Asia, there has been little research to assess its effectiveness. Further attention should be given to the appropriateness of this design option in ETS where the share of free allocation declines and the real cost of generators could increase.

(4) Open market participation, linking and access to offsets can improve the quality of the allowance price signal, but introduces risks to environmental effectiveness.

The scope of the market together with rules surrounding the trade of allowances will shape allowance demand. A broad scope potentially leads to a larger market of more heterogeneous participants with less market power and will therefore encourage trade and avoid excessive price volatility. Perhaps more importantly, an open market will allow participation from financial intermediaries that will increase the types of products that can be traded. With increasing liquidity, an active derivative market will reveal a forward curve providing information on market participant's expectations for price developments. The legal nature of the market and fiscal classification of allowances will have implications for the rules that govern secondary market trade and potentially the appetite for third parties to trade carbon. This is an area for which there is little empirical research where the case studies can potentially shed some light.

Use of offsets and linking systems can contribute to reducing excessive volatility by enlarging the scope of the market. However, they also bring risks to the effectiveness of the domestic system shifting abatement abroad. Moreover, the allowance price will no longer reflect the domestic MAC. For this reason, particularly offsets are normally coupled with strict quality and quantity provisions.

(5) An ETS will be most effective in liberalized electricity markets, but the structure of the market will influence the magnitude of abatement that can be incentivized by a carbon price.

Liberalised energy-only markets often provide an ideal scenario for carbon price led decarbonisation pathways by integrating and decentralizing economic efficiency principles in daily dispatch and long-term planning decisions, in which the costs of emissions are fully reflected along the supply chain. In such systems, ETS can deliver on the emissions target in a cost-effective way by incentivising fuel switch, enabling demand-side responses, leveraging low-carbon investments and stimulating the integration of variable renewable energy sources.

The structure of the electricity sector is important for the impact of carbon pricing. Electricity systems that are dominated by coal and/or lignite but also have access to gas and renewable sources will respond strongly to an allowance price in the short term through fuel switching. Competition combined with an ageing fossil fuel-based fleet will open more opportunities for low carbon investments and have fewer stranded assets compared to those with relatively new and efficient plants. Therefore, the costs of, and potentially social resistance to, decarbonisation will be lower in regions with old fossil intensive plants, which have recovered their capital costs, compared to a region where the average fleet age is young and threatened by growing renewable energy penetration. This point is critical when considering vast plans for new coal investments, particularly in Asia.

The analysis also highlights the importance of understanding the marginal generator in liberalized electricity markets. As the marginal generator determines wholesale electricity prices at a given level of demand, their carbon intensity will be important for the signal that an ETS provides. Somewhat counter intuitively, systems that are more likely to have fossil intensive generators at the margin will provide the greatest incentives for decarbonisation across the whole energy system. As the allowance price signal drives increased investments into VRE, the capacity factors of those fossil-based generators will however decline reducing the number of hours at which VRE producers can benefit from higher wholesale prices. This effect will to some extent be offset to the extent if allowance prices are also increasing.

(6) Options to tailor ETS to regulated electricity markets exist and should be the attention of future research.

Liberalised electricity markets can be considered the exception rather than the norm. Even in competitive energy only markets, regulatory intervention (e.g. price caps and restrictions to the decommissioning of power plants) can limit the role that a carbon price is expected to play in the decarbonisation process. As carbon prices rise, consideration should be given to where electricity price caps are set and the impacts of these caps on the mitigation signal, noting that some consumers can be compensated for increased electricity bills through alternative means.

Where electricity dispatch is regulated, shadow pricing might be an alternative approach to ensure that the carbon cost is reflected in dispatching decisions. Similarly, shadow prices could be applied to investment appraisals to ensure low carbon investments return a higher net present value compared to high carbon alternatives. Finally, where electricity prices do not reflect carbon costs, coverage of indirect emissions represents one option to reinstate the allowance price signal at the point of consumption.

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