Market Design for the Environment[*]

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1 Introduction

Nature provides a number of essential goods and services that support our lives and economies (Costanza et al., 1997). These include seafood and timber, life-supporting processes (such as water purification and photosynthesis), regulation of ecosystems, (for example, through carbon storage and erosion control), and cultural and recreational services. These goods and services are all subject to externalities, leading to overexploitation, degradation and underprovision. Climate change, biodiversity collapse, eutrophication of oceans and lakes, soil and groundwater pollution are some of the symptoms of our collective inability to manage natural capital sustainably.

Property rights organize our relationship with Nature and determine the types of governance that can be established to conserve and manage this natural capital. When it comes to natural resources and ecosystems, Schlager and Ostrom (1992) distinguish between, on the one hand, the right to access and to use (e.g. obtain the product of a natural resource or release toxic effluents) and, on the other hand, management and control rights (deciding who has access, how usage rights are transferred, ...). Clearly, these rights affect the incentives that individuals face to conserve and develop the natural capital on which these rights apply. Sterner and Coria (2013) describe how these rights differ across countries and contexts, and how they have evolved over time, as a result of societal demands. To the extent that these property rights can be traded, we have a market.

Environmental markets are not new. In fact, communities and governments have used markets to allocate fishing rights, water withdrawal rights and pollution rights for decades. But improvements in monitoring technology and increasing pressures to address environmental degradation and resource scarcity have increased their scope of application over time.

This chapter reviews existing and developing uses of markets for natural capital from a market design perspective. We first provide a typology of environmental problems for which markets can provide a solution. This leads us to distinguish between overexploitation, degradation and

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underprovision problems. Overexploitation and degradation problems happen when the goods and services provided by Nature are not excludable and property rights are shared or nonexistent. Underprovision problems arise when the natural resource, over which well-established access and usage rights exist, creates positive externalities for agents who do not benefit from any property rights to the resource. We argue that each natural resource is characterized by its specific bio-physical process which constrains the definition of what can be traded and the choice of design to support the goals of the market. We illustrate these considerations in the context of climate change mitigation, where compliance emissions markets and voluntary carbon markets are playing an increasingly important role. The history of the EU emissions trading scheme over the past 20 years illustrates how apparently small design decisions can impact the performance of a market and its ability to generate an informative and stable price signal, an important desideratum to foster cost efficiency. The current discussions around the integrity of voluntary carbon markets shows the importance of the definition of what is traded, and how technology and nature constrain it.

An important remark at the outset is that markets may not be the only way, let alone the best way, to address environmental overexploitation, degradation, and underprovision. Ostrom (1990) has powerfully argued that communities can successfully overcome the so-called "tragedy of the commons", where natural resources are overexploited, without the recourse to markets or even price mechanisms. Others have raised the concerns that markets, and the price tag that they bring to the goods and services produced by Nature, are incapable of capturing the complexity of human societies' interactions with Nature (Kosoy and Corbera, 2010) and can even change the way individuals and firms view and interact with it (Bowles, 2016; Sandel, 2012).

In this chapter, we set these discussions aside and take as starting point the observation that the reach of markets for environmental goods and services is expanding on the ground and that there is, therefore, need for scholarship and expertise to design these markets so that they meet their goals.

2 Typology of environmental problems

For our purpose, it is useful to distinguish three types of environmental problems for which markets can and often already do provide solutions. These problems are defined by the nature of the environmental good or service at hand and existing property rights arrangements.

2.1 Overexploitation of renewable resources

The first category of environmental problems consists of environmental goods and services that are not excludable or, at least, difficult to exclude but rival in use, and for which property rights are shared or nonexistent. This is the classic case of what has been called common pool resources.

Fish stocks in oceans or in lakes, game in forests, water in rivers, are all examples of common pool resources. These resources are additionally renewable. Fish, game and other animal species reproduce. Their natural reproduction rate depends on environmental conditions and is often modelled as a bell-shaped relationship between the population growth rate and specie density. At low levels of specie density, mating probabilities are low and so are reproduction rates. Likewise, at high levels of specie density, the carrying capacity of the ecosystems is stretched and competition for food limits population growth. Maximum sustainable yields are obtained at intermediate density levels when fish or game harvest is equal to the natural growth rate of the population. Harvest in excess of the natural reproduction rate drives specie density down. Water withdrawal (from a river or basin) is similar, except that water stock dynamics is determined by hydrological and weather conditions and users upstream impact users downstream but not those upstream to them.

The prime concern for sustainability in these situations is to ensure that harvest levels and withdrawals (a flow) are set at a level where the stock of the underlying resource is stable at a desirable level. The challenge is that this condition is unlikely to be met in the presence of multiple users and shared or non-existent property rights. Each user individually does not account for the externality that they exert on other users, potentially leading to the collapse of the natural resource in what has been coined the "tragedy of the commons" by Hardin (1968).

Quotas have long been used around the world to address the risk of overexploitation of renewable natural resources (Costello et al., 2008). Fishermen, hunters, and farmers receive quotas that determine how much they can fish, hunt, or withdraw water. These quotas specify the quantity of the renewable resource holders can harvest or withdraw over a specific period in a specific area. They are coupled with monitoring and enforcement systems. Once a holder has reached their quota, they must cease all harvest and withdrawal activities. The number of quotas can be adjusted over time based on the stock of the natural resource. Effectively, quotas create property rights on the use of the natural resource and address the sustainability issue (making sure catch levels and withdrawals are not too high).

Not all quota systems operate as markets. For example, since 1983, the European Union allocates fishing quotas to its Member States but leave it to them to decide how they allocate these to their fishermen. In some countries, quotas are not transferable (van Hoof, 2013).

The main motivation for using markets and market-based mechanisms in these contexts is to enhance the efficiency of the allocation and encourage reasoned use of scarce natural resources (productive efficiency). Given the increasing pressures on natural resources, we can expect that these efficiency concerns will drive further adoption of markets.[1]

Markets can be useful at three levels. One approach is to allow quota holders to trade them. These are often referred to as Individual Transferable Quotas (ITQ). Users who have the highest value for the natural resource will buy quotas from those with a lower value, enhancing efficiency. Another approach, feasible when no pre-existing property rights exist, is to auction these quotas. Again, this will ensure that the quotas end up in the hands of those who value them the most

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[1] See Wheeler et al. (2023) for a similar point in the context of water markets. For good starting points to these literatures, see Tietenberg (2002), Newell et al. (2005) for fish markets and Wheeler (2021) for water markets.

and that users have incentives to save the natural resource. Finally, markets can also be used to induce pre-existing property rights holders to relinquish their rights in order to promote superior allocations (see Paul Milgrom's contribution in this volume).

Depending on pre-existing rights, these markets can be organised by a regulatory authority (public governance) or by users themselves (private governance). For example, private governance is observed for sedentary species, such as lobsters off the coast of Maine, where local fishermen play an important role in regulating fishing activity.

2.2 Pollution and environmental degradation

Environmental degradation problems are essentially mirror problems to overexploitation problems. Environmental quality is a (local) public good and ownership on the environmental resource is either shared or nonexistent. Because pollution is typically a by-product of an otherwise profitable activity, economic agents will tend to generate too much pollution because they do not bear its full consequences.

Governments use different approaches to regulate pollution, starting from command-and-control approaches, such as imposing a technology standard or forbidding the use of some toxic substances as inputs, to more market-based solutions. Among these, cap-and-trade markets have gained prominence as a cost-effective approach to pollution. This has especially been the case in contexts where polluters are numerous and heterogeneous, the source of pollution is well-defined, measurement and monitoring of pollution is relatively easy, and the pollution's geographical impact is sufficiently large that concerns for pollution hot spots, whereby trading results in pollution being geographically concentrated, are low.

The idea originates with Dales (1968) who imagined a cap-and-trade market for water discharge rights as a cost-effective solution to regulating water quality in lakes. In his solution, public authorities would partition space into regions and set a cap on the yearly volume of waste discharge in each region. They would issue a commensurate amount of "pollution permits" and impose the obligation on polluters to surrender as many permits as their volume of pollution over the year. Permits could be bought and sold. Montgomery (1972) provided a formal proof of Dales' conjecture in a static competitive equilibrium framework, essentially showing cost-efficiency as a corollary of the First Welfare Theorem. In the competitive equilibrium, marginal costs of abatement are equalized across firms. Firms with high abatement costs abate less and buy surplus allowances from firms with low abatement costs.

Early applications of cap-and-trade markets for pollution took place in the 1980s in the US but the first grand scale experiment was the nationwide 1990 Clean Air Act that imposed a cap on sulfur dioxide emissions from electricity production. The market launch was preceded by extensive testing and fine-tuning of different aspects of the design (see Joskow et al., 1998 and Ellerman et al., 2000 for extensive accounts of the design phase and early performance).

The Clean Air Act provided a template for the introduction of emissions trading as part of the Kyoto Agreement, which, in turn, paved the way for the introduction of the EU carbon emissions trading scheme in Europe in 2005. Carbon markets are particularly well-suited for

Table 1: The use of markets for solving environmental problems

	Overexploitation	**Degradation**	**Underprovision**
Typical legacy ownership	Shared or nonexistent property rights	Shared or nonexistent property rights	Private property rights
Policy objective	Ensure sustainable exploitation	Limit pollution	Encourage provision
Role for markets	Efficiency	Cost-effectiveness	Efficiency
Market governance	Public or private	Public	Public or private
Applications	Fishing quotas, water rights, hunting permits	Pollutants at different scales (SO2, CO2, NOx, pollution discharge)	Carbon sequestration, biodiversity, other ecosystemic services

trading because sources of carbon emissions are heterogenous and face different abatement costs and carbon's impact on climate is the same independently of where it was emitted. Hence, the cost-efficiency gains from trading are likely to be large and concerns for pollution hot spots limited.

Today, "pollution markets" are used for pollutants as diverse as CO2 (a global, long-lived point-source pollutant mostly connected to the combustion of fossil fuels), other greenhouse gases (all global and point-source pollutants but with different life-times in the atmosphere), sulfur dioxide (a regional, short-lived point-source pollutant, produced by the combustion of coal), nitrogen oxides (a local short-lived point-source pollutant that is a precursor of ground-level ozone), nitrogen and phosphorous effluents from farms (a local non-point source pollutant responsible for eutrophication and groundwater pollution), waste water discharges (a local point-source pollutant). In each case, careful consideration must be given when designing the permits and the market to the underlying biophysical process, the geographical reach of the pollutant, and how to measure it.[2]

2.3 Underprovision of natural capital

Unlike the other two environmental problems reviewed so far, ownership rights on the natural resource are well established for the third category of environmental problems. Think about a forest, a lake or a nature reserve under private ownership. The issue now is that the benefits that this natural resource generates are not entirely captured by its owner. As a result, the owner may not invest in or conserve its natural resource at a sufficiently high level.[3] The challenge therefore is to find a way to provide this incentive.

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[2] The original article of Dales provides an early illustration of the kind of design questions wannabe market designers need to ask themselves. See also Kerr et al. (2007), Cox et al. (2013) and McDonald and Kerr (2011) for a discussion of design considerations in the context of nutrients trading, Fisher-Vanden and Olmstead (2013) in the context of water quality trading, and Tietenberg (2010) for a general introduction to markets for pollution.

[3] Formally, the development of the natural resource (increase in natural capital) and its conservation are not exactly the same. Harstad (2016) defines conservation goods, as goods whose owner is tempted to consume them whereas a third-party benefits from their conservation, whether they own them or not. He shows that conservation markets are necessarily inefficient in dynamic settings.

Payments for ecosystem services (PES) are defined as a voluntary transaction where a well-defined environmental service (or a land use likely to secure that service) is bought by one or several buyers from one or several providers on the condition that they secure this service provision (Wunder, 2005; Engel et al., 2008). Put simply, the idea is that the beneficiaries of the environmental service pay the owner of the natural resource for the difference in value and costs borne by this owner from adapting their practice or use, to conserve or develop the natural resource.

The origins of payments for ecosystem services can be traced back to the 1930s when the United States governments paid farmers for soil conservation (Claassen et al., 2008). The practice further developed as intensive agricultural practices increasingly competed with other uses of natural resources. Perrot-Maître (2006), Depres et al. (2008) and Defrance (2015) provide detailed descriptions of the contractual arrangements between, respectively, Vittel and Evian, and the local farmers whose lands run off into the aquifers used to extract these mineral waters. One lesson from these cases is that the financial component of the arrangement is only a small part of the overall negotiation and that these PES can be quite complex and long to negotiate. This effectively rules them out when beneficiaries are numerous and diverse, as in the case of a global public good like climate change mitigation.

An important step forward in terms of scaling up market mechanisms for conservation was the introduction of project-based credits in the Kyoto Protocol, whereby investors in signatory countries could claim carbon credits, eligible for compliance, from emission reduction or removal projects in third countries.[4]

The creation of carbon credits was a major breakthrough because it transformed a non-excludable environmental benefit (climate mitigation) into a private good, used for compliance. While Clean Development Mechanisms and Joint Implementation projects have had their teething problems (Schneider 2009)– essentially around additionality, measurement and verification– the logic underlying their creation has remained. In 2008, the United Nations launched the Reducing Emissions from Deforestation and Forest Degradation (REDD) program to support conservation projects in the Global South and help channel funding to them through the issuance of credits. Since then, increasing demands from the private sector to support their climate commitments have also spurred the development of a sizable voluntary carbon market, a subject to which we return in section 4.

The potential is enormous: Griscom et al. (2017) evaluate that nature-based climate solutions could contribute 37% of cost-effective emissions reductions through 2030 and Grassi et al. (2017) document that land use and forests contribute a quarter of the emissions reductions planned by countries in their nationally determined plans submitted in fullfillement of their obligations under the Paris Agreement. The scope for markets to address underprovision is not limited to climate. The recent Kunming-Montreal Global Biodiversity Framework agreed in December 2022 has increased interest in biodiversity credits and markets.

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[4] Specifically, Clean Development Mechanisms (CDM) covered carbon reduction or removal projects in developing countries and Joint Implementation (JI) mechanisms covered carbon reduction or removal projects in developed countries.

3 Compliance carbon markets

Today, carbon markets play a central role in countries' efforts to mitigate their greenhouse gas (GHG) emissions. According to the World Bank's Carbon Pricing Dashboard, there were 36 carbon markets in operation in 2023, covering approximately 17.64% of global GHG emissions. Twenty-five emissions trading schemes were also scheduled or under consideration. As a comparison, only 5.62% of global GHG emissions were covered by a carbon tax in 2023.

As argued in the previous section, the economic case in favor of carbon trading is strong. However, the ability of emissions markets to lower total abatement costs hinges upon their ability to generate an accurate price signal that reflects the distribution of firms' opportunity costs and can guide companies' abatement investments.

3.1 Market Design parameters

There is a wide range of market design parameters that have to be decided when setting up a carbon market. While cost efficiency remains the primary objective, other considerations are also relevant. In this section, we review the main design parameters for compliance carbon markets, underlining the arbitrages that they involve.

Market Scope. A first important design choice is the scope of the market in terms of sectors, geographies, pollutant and time. In terms of geographies and sectors, theory suggests that the larger the market, the better, given the global nature of the pollutant and the heterogeneity in abatement opportunities across countries and sectors. There are nevertheless some caveats. At the sectoral level, the availability of a consistent, affordable and accurate monitoring and reporting system is key to the integrity and environmental efficiency of the climate policy. The regulating authority must balance the gains from increasing the coverage of the program with the costs necessary to accurately measure emissions and monitor the data reported by regulated entities.[5] Another caveat is that the unilateral adoption of climate policies in one jurisdiction might lead regulated companies to shift their activities (and therefore their carbon emissions) to countries with less stringent environmental policies. This is the well-known pollution haven hypothesis, also referred to as *carbon leakage* in the context of climate change (see Dechezleprêtre and Sato 2017 for a review). Here as well, there is a trade-off between gains from expanding sectoral coverage and environmental efficiency losses of including sectors with a high risk of leakage.

Expanding the geographical scope by linking carbon markets constitutes a possible solution to carbon leakage concerns. However, when discussing the possibility of linking carbon markets, it is important to take into account the level of design alignment, including the similarities in policy objectives, between the two systems, and the increased transmission of political or economic shocks across jurisdictions (Flachsland et al., 2009; Fankhauser and Hepburn, 2010; Doda and Taschini, 2017).

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[5] This is also true when discussing the market coverage within a given sector. Excluding some small emitters within a sector, for which measurement costs are likely to be higher, may help lower the administrative cost of the market.

While CO2 is the most common greenhouse gas, other gases, emitted primarily through human activities, contribute to global warming (e.g. methane and nitrous oxide). Including other GHG can bring additional cost efficiency gains, but requires reliable conversion factors and a consensus on which ones to use.[6]

Finally, allowing regulated companies to trade allowances across compliance periods (i.e. to save carbon allowances for future use or to borrow allowances from future compliance periods) provides further cost efficiency gains, as it allows firms to exploit intertemporal arbitrage opportunities (Rubin, 1996; Schennach, 2000; Newell et al., 2005). Depending on the nature of the pollutant, unrestricted banking and borrowing of permits may not be socially desirable, however. For example, CO2 is a stock pollutant and the time path of emissions matters (Leiby and Rubin, 2001). Allowing firms to delay their investments in abatement (through massive allowances borrowing) may increase total social damages.[7] Allowing for unrestricted banking and borrowing can also affect companies' trading and compliance behavior. Banking and borrowing could reduce the incentives for firms to participate early in the market slowing down the price discovery process. Borrowing, combined with the ability of the regulating authority to adjust the stringency of the climate policy in the future, might result in the so-called *ratchet effect* and *hold-up problem* (Hepburn, 2006). First, borrowing allowances from future compliance periods and failing to pay the borrowed allowances back might be used by firms to signal to the regulator that the environmental policy is too costly. This could lead to the negotiation of a more lenient target for the next compliance phase (ratchet effect). Second, the payoffs from long-term investments in clean technologies depend on the stringency of future climate policies. As the regulators have the discretion to adjust (relax) those policies after the investments have been made (hold-up problem), borrowing might be used to delay these investments.

Market cap. Decisions about the cap do not exclusively boil down to choosing the desirable supply of allowances. GHG emissions are directly tied to economic activity. Any major technology advances or economic shocks will affect business-as-usual (BAU) emissions and lead to large surpluses or deficits of allowances in the market and low or high carbon prices.

One potential regulatory response first discussed in Roberts and Spence (1976) is a price collar (see also Pizer, 2002; Burtraw et al., 2010). The carbon market effectively becomes a *hybrid mechanism*, where the system works as a regular cap-and-trade system so long as the allowance price is between the floor and ceiling prices. When either the floor price or the ceiling price are reached, the system behaves like a tax, fixing the price but leaving emissions to adjust. One drawback of this mechanism is that it loosens the environmental target when the price ceiling is reached. One solution is to accompany the price collar with an allowance reserve and a pre-set maximum number of allowances that can be added to the market when the price ceiling is reached (Murray et al., 2009; Fell et al., 2012). However, if the market is still short when the

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[6] To aggregate different greenhouse gases, the Paris Agreement relies on the *Global Warming Potential* (GWP) by the IPCC. The GWP is a conversion factor from physical units of greenhouse gases to CO2 equivalent, taking into account how long these greenhouse gases remain in the atmosphere. The current GWP conversion factors are those calculated for 100 years (CO2 has a normalized value of 1 and every other gas has a value that corresponds to their warming power relative to CO2, during that time frame).(Denison et al., 2019).

[7] In the scenarios assessed in the last IPCC report (2023), limiting global warming to around 1.5°C requires immediate action and global GHG to peak before 2025 at the latest.

reserve is empty, the price might rise above the ceiling price or there will be rationing.

An alternative mechanism, used in the European Union since 2019 is a *quantity collar* in which a pre-set number of allowances are added to a reserve and allowances are removed from or injected in the market in response to the total number of allowances in circulation being above or below a certain threshold at any point in time (Perino and Willner, 2016).

Another related design parameter is the choice between temporarily or permanently placing allowances in the reserve (Kollenberg and Taschini, 2019). If placement in the reserve is temporary and allowances can be cancelled (when a certain threshold is reached), the total cap on emissions is affected. Kollenberg and Taschini (2016) examine the optimal adjustment rate of this type of dynamic cap adjustment mechanism.

Allowances allocation. Regulators are faced with three alternatives: free allocation, auctioning, or a combination of the two. Auctioning allowances forces all market participants to actively participate, whereas free allocation makes it possible, when banking is allowed, for firms with surplus allowances not to interact with the market. This, in turn, can affect the price discovery process. For example, Joskow et al. (1998) argue that the EPA yearly auctions that preceded the first compliance phase of the SO2 market contributed to price discovery.

Nevertheless, free allocation of allowances is common in the early stages of carbon markets. It alleviates concerns about international competitiveness and contributes to early acceptance by market participants. This choice is further supported by the idea that the initial allocation of allowances has no impact on the performance of the market, a property known as the independence property and initially shown by Montgomery (1972). However, the independence property relies on the absence of market frictions and fails e.g. in the presence of market power (Hahn, 1984) and transaction costs (Stavins, 1995). Zaklan (2023) documents that the independence property fails for small emitters from the power sector in the EU ETS but holds for large emitters.

Free allocation of allowances, and in particular grandfathering (i.e. allocations based on historical emissions or output) may also lead to a perverse effect (the ratchet effect) where companies have an incentive to emit more in the short-term to increase their future allocation (Böhringer and Lange, 2005; Harstad and Eskeland, 2010).

Compliance. The rules regarding compliance will affect the behavior of regulated firms and as a result the cost efficiency of carbon markets. For example, Holland and Moore (2013) show that, depending on other design parameters (delayed allocations, existence of a price ceiling with reserve), the compliance timing can affect regulated entities' abatement behavior. The nature (and level) of the non-compliance penalty might also have very different implications. If the payment of the penalty is an alternative to surrendering the missing allowances, this penalty is effectively a price ceiling. This is not the case if non-compliant firms have to pay the penalty and are still obliged to surrender the allowances corresponding to their past emissions.

[place Table 2 about here]

Legal status of allowances. As shown in Table 2, the legal status of allowances varies considerably across jurisdictions. Allowances can be considered as a physical asset, as an administrative authorization to emit CO2, or as a financial instrument. The choice of legal status can have important consequences. For example, in Europe, commodities are subject to a value-added tax (VAT) but financial assets are not. In a carbon market involving several jurisdictions, a lack of legal status harmonization between them could hamper cross-border allowances trading and reduce the liquidity and efficiency of the market.

Market organization and governance. Last but not least, the way the market is organized (i.e. who is allowed to trade, where, what type of assets) also affects a carbon market's ability to aggregate information about the distribution of abatement opportunities. There is a long and rich literature in finance on the effects of market design choices on information aggregation and the price discovery process (see O'hara 1998 for a review).

3.2 A market design perspective on the history of the EU ETS

We illustrate these design considerations in the context of the EU ETS, the oldest and, until now, largest carbon market in value in the world. The market was launched in 2005 as what was planned as a trial phase before the 2008-12 Kyoto compliance period. The market covered the carbon emissions from around 11,000 installations from the power and energy-intensive industrial sectors, representing about 45% of the greenhouse gas emissions of the European Union.[8] Since then, the market has continued to be organized in phases, each with clear rules (sectors covered, initial allocations, total cap, etc) announced a few years before (see Table 3 for an overview). We are currently in the fourth phase (2021-2030).

The history of the EU ETS is a vivid illustration of the importance of design and the continuous need to adjust it as circumstances change (on this, see also Alvin Roth's contribution in this volume). This was not anticipated by the early architects of the EU ETS who envisaged a limited role for market design:

"*The legal framework of the ETS does not lay down how and where trading in allowances should take place. Companies and other participants in the market may trade directly with each other or buy and sell via a broker, exchange or any other type of market intermediary that may spring up to take advantage of a new market of significant size. The price of allowances will be determined by supply and demand as in any other market.*" (European Commission, 2005)

As a result, and unlike the US SO2 market, the EU ETS benefited from very little support, beyond the creation of allowances and the registries to record ownership and transfers of allowances. This hands-off view changed over time as new problems arose and changes in rules were required. Today, thorough discussions take place several years before the beginning of a phase to evaluate the performance of the market and potential reforms.

As a background to the discussion in this section, Figure 1 plots the observed allowance prices between March 2005 and November 2023. These prices have been extensively commented upon in the specialized press as well as the academic literature. During the first phase, the price increased from around 10 euros in March 2005 to nearly 30 euros in April 2006. The price then dropped to around 10 euros within three days, upon the release of verified emissions in

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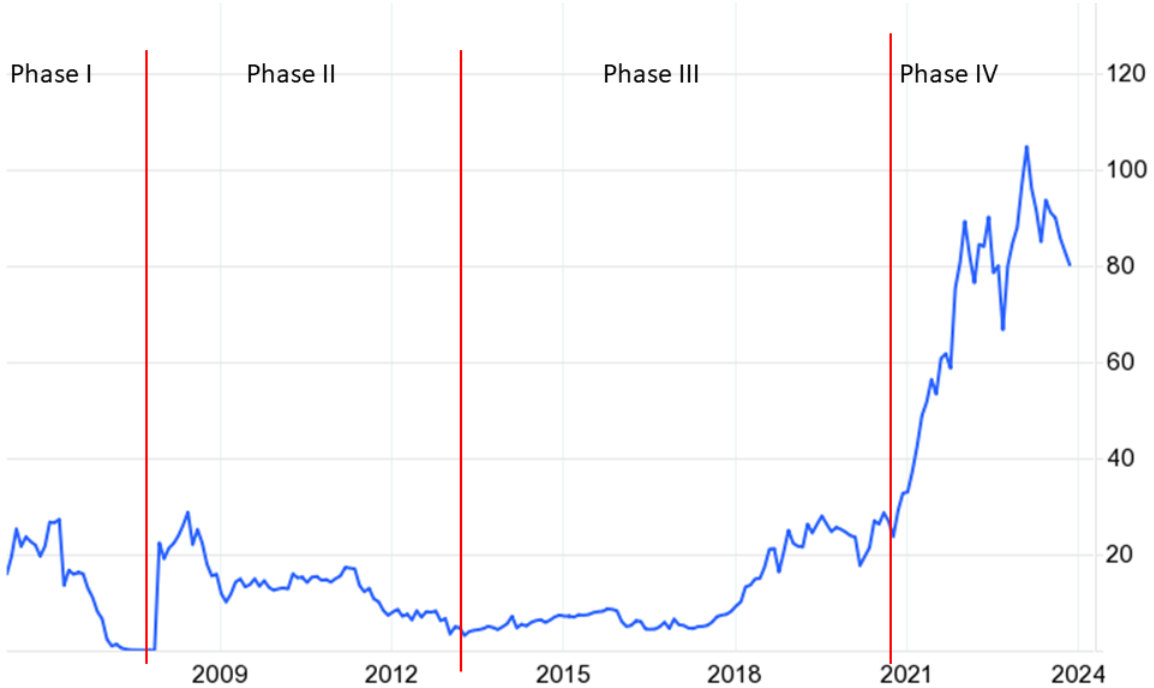
[8] For an early account of the EU ETS, see Ellerman et al. (2010).

Figure 1: Evolution of the EUA spot price (May 2005-Nov 2023)



Source: `https://tradingeconomics.com/`

several countries that showed them to be significantly below allocations. The allowance price then slowly converged to zero as it became increasingly clear that there were excess allowances in the market and these allowances could not be banked for the second phase. The allowance price shortly rose again afterwards but remained relatively low until 2018. Since 2018, the price has been steadily increasing. It exceeded 100 euros per ton in February 2023, and is now around 80 euros per ton.

Market Scope. Increasing availability of data and improvement in monitoring have led to the gradual extension of the market to more countries, more greenhouse gases and more sectors.[9] In the second phase of the EU ETS, credits generated by Clean Development Mechanisms and Joint Implementation projects under the Kyoto Protocol could be used for compliance (with restrictions on the quantity). These credits were phased out in phase III following concerns about their reliability (Schneider 2009).

In 2023, as part of the Fit-for-55 package, the EU decided to create a new ETS to cover emissions from fuel combustion in buildings and road transport (ETS2). The new market will come into

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[9] The availability of an accurate monitoring and reporting system was clearly mentioned as one of the reasons why shipping could be included in the EU ETS, while other sectors (such as agriculture) were at the time not considered (see the proposal of the European Commission amending Directive 2003/87/EC, 2008). CO2 emissions from aviation have been included in the EU ETS since 2012, but international aviation was exempted due to concerns regarding competitiveness and carbon leakage. The exemption was established to allow time for the adoption of an international deal at the UN level: the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA)

force in 2027.[10] Instead of simply expanding the scope of the existing ETS, the EU opted for a separate system to balance the efficiency gains from carbon trading with distributional and political considerations. Linking the two systems was likely to increase the allowance price in the existing ETS due to higher abatement costs in the sectors covered by the ETS2 (Edenhofer et al., 2021). This would have had two unwanted consequences. First, it would result in lower emissions reductions in the transport sector, as they could buy allowances from sectors with lower abatement costs. Due to the high share of transport in EU's total GHG emissions, EU regulators were concerned that delaying long-term investments in transport could compromise their net-zero emission ambitions. Second, a higher price in the existing ETS might have exacerbated carbon leakage.

Market cap. Another important evolution of the EU ETS that has been driven by lessons learnt from past performance is the approach to cap setting. Initially, the rules for the allocation of allowances to companies covered by the EU ETS were decided at the national level, under guidelines from the European Commission. This decentralized process determined the EU-wide cap (the overall cap is the sum of the national caps). This setup contributed, at least partially, to the over-allocation of allowances: each Member States in isolation was tempted to be more lenient with its domestic firms. It also contributed to the collapse of allowance prices at the end of the first phase given that banking was forbidden. Since phase III, the cap is set at the European level and there is a top-down and more systematic approach to cap setting, with an annual linear reduction rate (initially set up at 1.74% per annum).

Setting the cap at the EU level was not sufficient to avoid excess allocations, however. Following the 2008 financial crisis, industrial activity and carbon emissions went down. This created a market glut. Annual carbon allowances issued began to exceed actual annual emissions. A large surplus started building up through banking, pushing prices down.

At that time, nothing was set up to deal with this situation. In 2015, the EU took the decision to backload the issuance of some of the allowances to the end of the phase and to introduce a market stability reserve (MSR). Starting from 2019, allowances are removed from the market (and set aside in a reserve) when allowances in circulation are above a threshold, while allowances are injected (from the reserve) when allowances in circulation are below a threshold. Following several criticisms that the MSR would not help increase the prices of allowances, but might instead increase its volatility (Perino and Willner, 2016), the MSR was complemented with a cancellation mechanism: starting in 2023, the reserve cannot contain more allowances than were auctioned the previous year.

Recent research suggests that this cap adjustment mechanism played a role in the increase in carbon prices observed since 2018 (Bruninx et al., 2020; Chaton et al., 2018). However, these articles also emphasize that the MSR can trigger feedback loops that disrupt the normal operation of the market in the presence of tightening caps (see also Quemin and Trotignon 2021 and Perino et al. 2022).

[place Table 3 about here]

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[10] Compared to the existing ETS that regulates direct emitters (point sources), the ETS2 will be an upstream system, focusing on points prior to the emission sources (e.g. fuel suppliers rather than households or car drivers).

Allowances allocation. Allowances were initially allocated freely based on allowances based on their historical CO2 emissions. While useful to build support from the industry, free allocations were found to discourage participation by small compliance traders who faced high transaction costs and could save unused allowances or to borrow the equivalent of one year of allowances instead of interacting with the market (Jaraitė-Kažukauskė and Kažukauskas, 2015; Baudry et al., 2021).

In its Proposal to amend Directive 2003/87/EC, the European Commission recognized the need to improve the design of the EU ETS and acknowledged that *"auctioning best ensures efficiency of the ETS"* (European Commission, 2008). Due to rising concerns regarding carbon leakage and competitiveness, the European Commission decided in 2009 to revise its auctioning phase-in plan for phase III and exempt sectors considered at risk of carbon leakage from auctioning. However, as a way to incentivize cost-effective emissions reductions and avoid the potential perverse incentives generated by allocations based on historical emissions, Directive 2009/29/EC specifies that the allocation method should be based on a benchmarking approach.[11]

While a combination of free allocation based on benchmarking and allowances auctioning is an improvement compared to the initial allocation methods chosen in the EU ETS, Martin et al. (2014) argue that this is still inefficient in addressing competitiveness issues due to the way exposure to carbon leakage is determined.[12] The European authorities exempted from auctioning the firms with the highest probability of relocating their activities, i.e. carbon-intensive and trade-exposed industries. According to Martin et al. (2014), exemption rules should be set to minimize the expected aggregate damages from relocation. Compensations (in the form of free allocation) should therefore be given to firms such that the marginal propensities to relocate, weighted by the damages caused by their relocation, are equalized across firms.

The latest development in the free allocation - carbon leakage saga is the introduction of a *Carbon Border Adjustment Mechanism* (CBAM), taking effect in 2026. Instead of granting free allowances to sectors exposed to international competition, as a way to ensure that domestic and foreign firms face a common playing field in the EU, the CBAM charges imports from select sectors for their carbon content, unless they have been subject to an equivalent carbon price in their source country. Free allowances will be phased-out accordingly. In essence, the CBAM puts again domestic and foreign firms on an equal footing, but this time they both face a carbon price.[13]

Market infrastructure and legal status of allowances. As it was the case for the decisions regarding the cap on emissions, the original infrastructure of the EU ETS was decentralized. National registries were set up to record ownership and transfers of allowances. These national

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[11] A benchmark is defined for each product sold by sectors covered by the EU ETS. The regulating authorities identify the 10 percent best performing installations in the EU that are producing that product. Performance is measured in terms of emissions intensity (tons of CO2 equivalent per unit of output) in 2007-2008. The product benchmark is the average GHG emission performance of these 10 percent best performing installations. Installations that meet the benchmarks will, in principle, receive all the allowances they need to cover their emissions.

[12] Recent evidence also suggests that carbon leakage was not so prevalent during 2007-14 (Dechezleprêtre et al., 2022).

[13] See `https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en` for a description and Ambec (2022) and Cosbey et al. (2019) for analyses.

registries were linked together through the Community Independent Transaction Log. The decision regarding the legal status of allowances was also left to Member States. Some countries viewed them as commmodities, subject to VAT, while others considered them as financial assets.

During the second phase, several national registries were hit by hackers and allowances were stolen. Additionally, some traders took advantage of the difference in legal treatment of emissions allowances across countries, resulting in a massive VAT carousel between EU countries (Interpol, 2013; Robert, 2012). Fraudsters bought tax-free allowances in one country, sold them in another Member State where they were subject to VAT, pocketed the VAT and then disappeared without ever paying it back to fiscal authorities. According to some estimates, these fraudulent activities lead to a loss of tax revenues of 5 billion euros (Berrittella and Cimino, 2017). In response, operations were centralised in 2012 into a single EU registry operated by the European Commission. Furthermore, allowances are considered financial instruments and regulated under the Markets in Financial Instruments Directive (MiFiD II) since 2018.

3.3 The challenge of producing stable informative signals

The cost-efficiency argument in favor of cap-and-trade schemes rests on the market producing prices that are informative of economic conditions and of firms' current and future abatement opportunities. Cronshaw and Kruse (1996) and Rubin (1996) have extended Montgomery (1972)'s result to a dynamic setting with no uncertainty. They show that arbitrage across periods leads to prices being equated across time periods, up to a discount factor. In practice however, there is some uncertainty about the state of the economy and future emissions. In that case, prices are updated following the arrival of new information. Schennach (2000) shows that, in the full information equilibrium, prices follow a martingale: current prices are equal to expected future prices, up to discounting. New information arrival does lead to price changes but these are typically muted because shocks are spread over all future compliance periods (Cantillon and Slechten, 2018). In other words, we do not expect the kind of price movements seen in Figure 1.[14] Volatility remains surprisingly high in the EU ETS, given the absence of storage costs and the high intertemporal fungibility of EU allowances. For example, in 2018-19, the coefficient of variation of EU allowance prices was between 0.3-0.4, which is much higher than for other leading input commodities for which storage costs are typically larger, including oil (0.23), gas (0.16), and base metal (0.12).

This level of volatility is a concern for the cost effectiveness of the market, given that price uncertainty reduces investment incentives (Dixit and Pindyck, 1994; Bloom et al., 2007). There is a need to understand and address price volatility.

A number of explanations have been proposed. Quemin and Trotignon (2021) have hypothesized that regulated companies do not exploit arbitrage opportunities over time due to shortsightedness. Support for long-term markets for hedging could help mitigate the impact of shortsightedness. For example, on the European Energy Exchange (one of the main exchanges for carbon

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[14] In the presence of constraints on borrowing, prices can rise suddenly following an increase in emissions. However, given the timing of issuance of allowances in the EU ETS, compliance firms can effectively borrow the equivalent of one year of allowances.

allowances in the EU ETS), futures on allowances have a maximum maturity of 8 years. This is considerably shorter than the typical horizon for investments in abatement technologies (e.g. installing a new blast furnace in a steel mill).

A second explanation is that overlapping policies lead to large shocks in business-as-usual emissions that even intertemporal arbitrage cannot smooth (Borenstein et al., 2019). This raises questions regarding cap adjustment mechanisms and how they can incorporate changes in these overlapping policies. For example, with the last reform of the MSR introducing a cancellation mechanism, national abatement policies have the potential to affect the overall EU ETS cap (Carlén et al., 2019).

Market participation (i.e. rules regarding who is allowed to trade) is another explanation that has been proposed for the high level of volatility observed in the EU ETS. Non-compliance entities (e.g. financial intermediaries, speculators, or hedgers) now make up a large share of allowances trading on the European carbon market. Participation by non-compliance traders brings liquidity and can help small emitters have access to the market (Cludius and Betz, 2020). They also provide hedging services to compliance traders. However, Quemin and Pahle (2023) argue that the non-regulated entities that have recently entered the EU ETS are very different from the financial intermediaries and market makers present so far. The new traders are mostly investment funds, that trade for other reasons that are less directly linked to compliance (e.g. hedging against inflation, greening their portfolio, or diversifying the risk of their portfolio...). The concern is therefore that the presence of these new traders induces excess volatility relative to market fundamentals because of spillover effects from shocks in other markets – an argument made in Sockin and Xiong (2015) in the context of commodity markets. Concerns regarding the financialization of carbon markets and its effect on price volatility have also been raised recently by the European Commission.[15]

The choice made by the EU regarding who has access to the EU ETS is very different from the choices made in other jurisdictions (see Table 2). In the Korean emissions trading scheme, only designated market makers are allowed to trade allowances to ensure a level-playing field for all traders. In the Chinese market, non-compliance firms are excluded. It is an open question to what extent these different designs in terms of trader participation facilitate price discovery by compliance traders.

A fourth explanation relates to the microstructure of the EU ETS. The EU ETS has historically been and is still today a highly fragmented market, weaving together centralized exchanges, dealers, brokers, and other financial intermediaries. While fragmentation does not necessarily result in inferior price discovery or higher price volatility (Jensen, 2007; Chen and Duffie, 2021), Cantillon and Slechten (2023) find that, in the EU ETS, it hampered the ability of market participants to get a full picture of the prevailing balance between supply and demand in the market, and failed to ensure an equal playing field among traders. In turn, incomplete

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[15] The Commission asked the European Securities and Markets Authority (ESMA) to analyse the trading of emission allowances. The final report was published in 2022 and concludes that "*the emergence of new participants (and instruments) with buy and-hold strategies warrants future monitoring to the extent that they may lead to a reduction in the supply of physical emission allowances available for trading, even though the available evidence suggests that their impact is only limited so far.*" (European Securities and Markets Authorities (ESMA), 2022).

information aggregation is likely to lead to overreaction to new information. This raises several design questions regarding the way those markets are organized: should we have a centralized exchange? should we have market makers (as it is the case in the Korean ETS)?

Relatedly, carbon markets, typically characterized by annual compliance cycles, tend to be thin, which contributes to price volatility. There have been suggestions to lower the frequency of the market to pool liquidity, or implement staggered compliance cycles to ensure that there is sufficiently liquidity throughout the year.

Finally, in ongoing work, we explore the impact of risk management practices as a potential driver of price volatility. Interviews and descriptive analysis of trading behavior suggest that compliance and non-compliance traders are subject to risk management constraints, accumulating spot allowances close to futures maturities. These risk management constraints introduce an endogenous borrowing constraint on the market and lead the price to deviate from market fundamentals and over-react to shocks on the availability of allowances.

4 Voluntary carbon markets

Voluntary carbon markets bring together projects that reduce carbon emissions or remove carbon from the atmosphere, and individuals, companies or public entities eager to offset their emissions, typically on a voluntary basis.[16] Projects are diverse: some are based on nature (our focus here), some are based on technologies. Some reduce emissions relative to a business-as-usual situation (emissions avoidance), others *physically remove* carbon from the atmosphere (carbon removal). For example, low carbon cookstoves qualify as a technology-based carbon avoidance project. Planting trees is a nature-based carbon removal project.[17]

Projects generate carbon credits, which are then traded on the market. Buyers can hold them for resale later on, or “retire” them, i.e. redeem them against their own emissions. In that case, the credit can no longer be traded.

In 2022, 475 million carbon credits were issued and around 200 million were retired in the voluntary carbon market globally (one carbon credit represents one ton of carbon) (World Bank, 2023). To put this in perspective, the yearly cap on emissions from stationary installations in the EU ETS was 1,536 million tons the same year. Many observers remain bullish about the future size of the market, however, with new participants and intermediaries joining the market *en masse.* First, the number of companies adopting science-based targets is increasing.[18] These companies typically need to complement their internal efforts by carbon offsets. Second, ongoing

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[16] An exception is the aviation sector which can use some of these credits to meet their obligations under the Carbon Offsetting and Reduction Scheme (CORSIA).

[17] While both types of projects reduce net emissions, carbon removal projects tend to be viewed more positively, among others, because their additionality claims are considered more reliable. See Tanzer and Ramírez (2019) for details.

[18] The Science-based Targets Initiative (SBTi) is a partnership between environmental NGOs that seeks to promote best practice in emissions reductions and encourage organisations to adopt mitigation targets aligned with the science and the goal of the Paris Agreement. Science-based targets are climate commitments that align with emissions trajectories compatible with the Paris Agreement.

negotiations around Article 6 of the Paris Agreement will expand the possibilities for countries and companies to use carbon credits to meet their climate mitigation commitments.[19]

4.1 Project qualification and market governance

A number of conditions are imposed on projects before issuing credits. These conditions seek to ensure that the project and the emissions reductions that go with it would not have happened without funding (additionality condition), that the claimed emissions reductions are real (baseline accuracy condition) and permanent (permanence condition) and, finally, that the credits are recorded in a registry for traceability. Projects meeting these conditions can reassure buyers that the credit they buy corresponds indeed to one ton of carbon avoided or removed.

The market is supported by an ecosystem of standard setters, certifiers, registries and trading platforms. Standard setters play a major role. They define what projects can generate credits and set the methodologies to assess the amount of carbon avoided or removed. Independent standard setting organisations, such as Verra and Gold Standard, are responsible for the majority of credits issued. They coexist with public international, national and regional crediting mechanisms, such the Clean Development Mechanism (CDM), established by the Kyoto Protocol, and the California Compliance Offset Program.

The main categories of projects eligible for crediting are forestry and land use, renewable energy, energy efficiency/fuel switching, waste disposal and household devices. Each category is itself divided into subcategories of projects, each with their own methodologies. Credits remain uniquely identified by their projects and their vintage. Buyers know when they buy a credit, the project that generated this credit.

Standard setters work with a network of independent certifiers that apply the standard's methodology to evaluate projects and propose the number of credits to be issued. Registries document credited projects and retirements, ensure that projects are not credited twice and contribute to market transparency.[20]

In 2022, the market was dominated by bilateral deals between project developers and end buyers but intermediaries, exchanges and funds have recently entered the market and are offering their services to this growing market.

4.2 Challenges

As of today, the voluntary carbon market can best be characterized as immature: liquidity and transparency are low, and prices are dispersed and volatile. Credits from carbon removals for example, such as afforestation, trade at a premium relative to nature-based avoidance projects

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[19] Article 6 of the Paris Agreement describes ways in which countries can "pursue voluntary cooperation" to reach their climate targets. Article 6.2 deals with bilateral and multilateral exchanges between countries. Article 6.4. lays the basis for a global carbon market to be supervised by the United Nations. It will eventually replace the Clean Development Mechanism.

[20] Typically, these registries are paired with certification bodies but a database, developed by the Berkeley Carbon Trading Project at UC Berkeley, aggregates the projects from the largest four registries, essentially covering most of the voluntary carbon credit market.

(preventing deforestation) or renewable energy projects. Even within these categories, price differences prevail. The nature of credits traded and buyers' preferences for direct contacts with credit-issuing projects are part of the explanation. Attempts by exchanges to group credits meeting certain requirements together have met resistance by market participants eager to avoid adverse selection (World Bank, 2023).

More damaging for the market, a number of recent scientific articles have raised concerns about the tangibility of the climate benefits provided by certified projects. Researchers have documented large and systematic over-crediting (Haya et al., 2020; West et al., 2020; Badgley et al., 2022; Gill-Wiehl et al., 2023), absence of additionality (Schneider, 2009; Calel et al., 2021), and leakage (Heilmayr et al., 2020).[21] These concerns were further publicized when a syndicate of investigative journalists reported in January 2023 that more than 90% of rainforest carbon offsets certified by Verra, one of the largest standard setters, were worthless.[22] These, and subsequent developments such as increasingly frequent large scale forest fires, have led to large drops in prices for nature-based credits, from around 16 USD per ton at the end of 2022 to 5 USD per ton mid-2023 (World Bank, 2023).

4.3 Market design options

The tribulations of the voluntary carbon market illustrate the complexity of designing markets for environmental goods and services. Scale - the main benefit that markets bring - requires some form of standardization and legal certainty about the asset traded. For technical and economic reasons, these have until now eluded the market: project-based emission reductions are measured with uncertainty and subject to revisions, exposing buyers to reputational and legal risks.

The pragmatic route of certification *cum* market segmentation taken so far has only partially addressed these concerns as evidenced by the continued dominance of bilateral trades between project developers and buyers and the underdevelopment of the secondary market.

Researchers have proposed different solutions to address the credibility issues to which the voluntary carbon market is confronted. Proposed solutions cover project design and qualification, credit use and measurement. For example, Mason and Plantinga (2013) propose to use contract menus, into which project developers self-select, to address exaggerated additionality claims (see also Li et al., 2022). Streck (2021) proposes to address leakage with a combination of project design, intended to minimize leakage, and standards imposed on users of credits. Filewod and McCarney (2023) recommend that upper-bound estimates of leakage be systematically used (unlike today) to derate the estimated carbon saved or avoided. In addition, such credits should not be used for compliance. In non-compliance settings, these credits should only be used to offsets emissions that are themselves quite poorly estimated, such as beyond-value chain emissions.

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[21] Leakage refers to the increase in emissions outside of the accounting boundary of a project, as a result of the project. For example, if protection of a forest in one area, leads to a shift of logging to another area.

[22] https://www.theguardian.com/environment/2023/jan/18/revealed-forest-carbon-offsets-biggest-provider-worthless-verra-aoe

Balmford et al. (2023) suggest to replace the usual buffer approach to the risk of impermanence of nature-based credits, whereby a buffer is added to the issued carbon credits in case the carbon savings do not materialize (e.g. because of a forest fire) by a dynamic accounting approach tracing changes in carbon stocks over time and issuing or cancelling credits accordingly. Their approach, which capitalizes on recent advances in near-time granular satellite imagery and data processing, has the added benefit of encouraging project developers to take all actions to preserve and conserve the benefits of the project.

Developments on the ground point to the direction of stricter standards on credits and standard harmonization, on the one hand, and stricter conditions on disclosure and use for buyers to prevent green-washing.[23]

While these developments are all likely to improve the integrity of current voluntary carbon markets, they do not address more conceptual concerns about carbon credits, such as the intrinsic intellectual difficulty of having different prices for carbon credits that have the same face value (one ton) and the continued market fragmentation that is likely to result. Another conceptual concern is to what extent carbon reduction and carbon removal projects are best served by production-based financing, such as the one provided by voluntary carbon markets, rather than project finance.

5 An agenda for market design research

Nature is essential for our lives and economies. Yet, our ways of living have gradually encroached on Nature to the point that several tipping points have been reached (Richardson et al., 2023). In this chapter, we have reviewed areas where markets are used or being considered to address environmental overexploitation, degradation and underprovision.

The starting point of any such scheme is the definition of what is traded. Defining the object of trade can prove very difficult in environmental contexts because natural capital typically comes as a bundle of services and attributes that may be space and context-dependent (Griscom et al., 2017; von Jeetze et al., 2023). As our discussion has illustrated, this complexity is a challenge for building thick and liquid nature-based markets. Progress in measurement and technology will likely help, but it is likely that more complex asset designs, such as the one proposed by Balmford et al. (2023) for non-permanent carbon credits, will also be needed.

An open question for environmental market design concerns their interactions with other policies and markets. Such interactions are inevitable as climate action and other environmental programs ramp across the world. Interactions with other policies require that caps and allowances are adjusted accordingly, while preserving the efficiency or cost-efficiency that markets provide. Integration between voluntary markets and compliance markets is an area of especially intense policy interest. Ongoing negotiations on Art. 6 of the Paris Agreement and pending legislative proposals in the EU pave the way for the use of carbon credits for compliance. The question is what conditions to put on these credits and on their use so that their interactions do not

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[23] See World Bank (2023) for an overview, and European Commission (2022) and European Commission (2023) for recent legislative initiatives in the EU.

harm the integrity of compliance markets and contribute to cost efficiency and climate goals. Past experience with CDM and JI projects provides some cautionary tale about the risks and benefits of such integration.

Last but not least, reducing environmental over-exploitation and degradation or increasing provision of natural capital may some time require heavy upfront investments. This is for example the case for decarbonising industry. The markets we have discussed in this chapter provide rewards for production (or abatement), not rewards for investment. For such markets to provide sufficient incentives for investment requires that the price signal they generate is sufficiently stable and informative. As described in the context of the EU ETS, this remains a challenge. It is an open question to what extent investment subsidies could provide an effective substitute to compliance or voluntary carbon markets. For example, in the context of voluntary carbon markets, project finance, which funds the owner to invest in conserving or developing their natural capital, rather than pays them for the flow from their investment, might better deal with complexity, credit constraints and ex-post moral hazard.

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Table 2: Carbon market design choices around the world

	EU ETS (2005)	**California ETS (2012)**	**Korea ETS (2015)**	**China ETS (2021)**
Market Scope				
Sectoral Coverage	Domestic Aviation, Industry, Power	Industry, Power, Transport, Buildings	Domestic Aviation, Industry, Power , Waste, Transport, Buildings	Power
Number of entities	9,000+ entities	400+ entities	680+ entities	2,100+ entities
Pollutants covered	CO2, N2O, PFCs	CO2, CH4, N2O, SF6,	CO2, CH4, N2O, PFCs, HFCs, SF6, HFCs, PFCs, NF3, and other fluorinated GHGs	CO2
% of GHG covered	38% of GHG	75% of GHG	74% of GHG	44% of GHG
Allowances Allocation	Daily auctions	Quarterly auctions	Free allocations + some auctions	Free allocations
Status of allowances	Financial instrument	Limited tradable authorizations	Not defined	Physical asset
Market organization				
Secondary market	OTC + EEX, ICE, and Nasdaq	OTC + ICE + CME	OTC + KRX	Shanghai EEE
Derivatives market	EEX, ICE, and Nasdaq	ICE and CME	-	-
Who can trade?	Compliance traders + others (investors, brokers, other service providers)	Compliance traders, holders of offsets, firms offering clearing services	Compliance traders, authorized market makers, brokers (position limit)	Compliance traders
Average Price	83.10 USD/tCO2e	28.08 USD/tCO2e	17.99 USD/tCO2e	8.20 USD/tCO2e

This table was created based on information from the International Carbon Action Partnership (2023). The average price for the EU ETS, California ETS, and Korea ETs are the average auction prices in 2022. The average price for the China ETS is the average secondary market price in 2022.

Table 3: A brief History of the EU ETS

	Phase I (2005-07)	**Phase II (2008-12)**	**Phase III (2013-20)**	**Phase IV (2021-30)**
SCOPE	EU, 5 industrial sectors	Norway, Iceland and Liechtenstein	Integration of aviation, and new gases added (N2O and PFCs)	Phase-in of maritime transport (2024), separate ETS for buildings & road transport (2027)
FUNGIBILITY	Bankability and limited borrowability within phase	Allowances can be banked for the future		
LINKAGES		International credits from CDM and JI	International credits phased out (no new project), Linkage to Swiss ETS (2020)	
MARKET CAP	EC guidelines, national choice		Top-down cap setting Backloading of allowances Market stability reserve (2019)	Accelerated decrease in cap
ALLOCATION	Grandfathering		Default allocation is auctioning. Free allocation based on benchmarking	Phase-out of free allowances (phase-in of CBAM starting in 2026)
INFRASTRUCTURE	National Registries		Single EU Registry	
OTHER EVENTS		Hacking events, VAT fraud, Economic crisis creates a market glut	Market regulated under MiFID	Fit-for-55 reforms (2023)