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Effectivity and risks of instruments implemented alongside the EU Emissions Trading System (EU ETS)

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1. Introduction

The EU Emission Trading System (EU ETS) has emerged as the backbone of the EU climate policy, as a crucial driver of decarbonization in particular of the power sector and industry, but also transport and buildings in the future. The cap-and-trade system puts a price on carbon while ensuring GHG emissions decline through its cap. Market participants can trade emission allowances to compensate for the CO_2 they emit. The EU ETS aims to facilitate cost-efficient decarbonization.

This market-based approach is grounded in the principle of technology neutrality, as it allows the market to determine the most cost-efficient manner to decarbonise. This allows economic operators to allocate resources independently and efficiently.

Despite the effectiveness of the EU ETS, certain remaining market and system failures may warrant complementary measures, including:

- **Difficulty hedging long term uncertainty:** Investors often use hedging strategies to protect themselves from potential losses due to uncertainties or risks. However, when it comes to long-term low-carbon investments, uncertainties and risk span many years into the future. This makes predicting and managing their risks challenging and complex, in turn impeding such investments.
    - Instruments like Feed-in Tariffs (FiTs), Contracts for Difference (CfDs), state guarantees for Power Purchase Agreements (PPAs), and Carbon Contracts for Difference (CCfDs) can provide stability and predictability, enhancing investor confidence and lowering discount rates for investments.
- **Sectoral innovation failure**: Limited appropriability, financial market failure, external benefits to the production of knowledge, and other factors suggest that strict reliance on a market system will result in underinvestment in innovation, relative to the socially desirable level[1].
    - Instruments like quotas, i.e. sectoral quotas for renewable energy (RE) or sustainable fuel blending obligations can help overcome these barriers by ensuring a market for new technologies.
    - Dedicated R&D funding and support for first of a kind installations.
- **Coordination failure**: Inefficiencies can arise when different policies or sectors do not align effectively. Addressing these failures may involve targeted interventions to improve coordination and system-wide effectiveness.
    - Instruments like **'**coal phase out plans' (as opposed to 'dates/deadlines') or 'decarbonisation readiness plans' of unabated combustion power plants are examples of tools to manage and coordinate the energy transition such that there is no risk to security of supply in case many early plant closures coincide.
- **Lack of political will and confidence in the market**, often translating in ad-hoc discretionary interventions (e.g. increase/decrease in emissions allowances in circulation) that suppress prices and impact the signal for decarbonisation.

[1] Martin, Stephen and John T Scott, *The nature of innovation market failure and the design of public support for private innovation*, Research Policy, Volume 29, Issues 4–5 , April 2000, Pages 437-447

The EU ETS has so far not functioned on its own. Other measures including subsidies were put in place to deal with issues such as: timing of decarbonization[2], concurrent decarbonisation of all sectors[3], price of EUAs that for political and social reasons, as well as economic realities could not give the full signal for decarbonization[4]. Measures have been introduced alongside emissions trading, as carbon markets can only operate freely up to a certain point, beyond which they are bound to encounter social acceptability issues and create competitive challenges. Showing prices/cost of decarbonization in a visible manner was also deemed to be politically explosive. Complementary policies such as renewable energy targets have kept prices below what would be the market-driven price level as a result of the scarcity of the cap.

These complementary measures introduce additional costs that are partially borne by covered entities and partially socialized. While these measures can complement carbon pricing, over-reliance can lead to inefficiencies, fragmented policies, and increased costs for governments and taxpayers.

Notwithstanding, there is growing recognition that alongside the EU ETS, other policy instruments—such as quantitative targets/quotas, state aid measures, and additional market-based tools—have played and will continue to play an essential role in advancing the decarbonisation of the EU economy.

Complementary measures are even more necessary now that competitiveness and carbon leakage have become critical. The global nature of climate action introduces external pressures on the EU ETS, as it operates in a world of diverse and often fragmented climate policies, but above all, asymmetrical climate ambition. The EU has chosen to be a leader and inspiration to others and that has clearly created competitive stress and the associated risk of carbon leakage, in particular in the context of several other existing drivers of EU competitive challenges (low growth, demographics, high energy & labour costs, regulatory burden).

Against this backdrop, this report provides insights on examples of instruments that coexist alongside the EU ETS, with a view to providing a better understanding of:

- How these instruments work, and the rationale and needs behind their introduction
- The instruments' effectiveness and efficiency
- Their interaction with and impacts on the EU ETS

The following three instruments have been selected for the study:

1. Contracts for Difference (CfD) scheme for Renewable Energy (RE) in Spain
2. Carbon price floor (CPF) in the UK
3. Sustainable Aviation Fuel (SAF) blending quotas in Norway

[2] Carbon pricing alone takes time to push decarbonization; Carbon price signals typically require a number of years to drive major technological transitions and meaningful changes in industries. A second crucial timing challenge emerges from the misalignment between industrial investment cycles and EU ETS regulatory phases.

[3] Through the ETS price, the aim was to move up the MAC curve and to facilitate a sequential decarbonisation that prioritises the least expensive abatement measures before progressing to more costly options. In contrast, by aiming to decarbonise all forms of emissions from all sectors at the same time, the EU is moving up the MAC curve horizontally and not vertically. The EU overlooks the main benefit of economic efficiency that the ETS presents, as it seeks to decarbonize higher MAC sectors, such as transport, at the same time as sectors with lower MAC.

[4] For a detailed discussion see chapter 2 in: Marcu, A., Maratou, A., López Hernández, J. F. Nouallet, P., Caruana, N. (2025), "Future of Emissions Trading in the EU: Role in EU Climate Policy". December 12. https://ercst.org/future-of-emissions-trading-in-the-eu-role-of-emissions-trading-in-eu-climate-policy/

2. Contracts for Difference scheme in Spain

2.1. Instrument description and rationale for its introduction

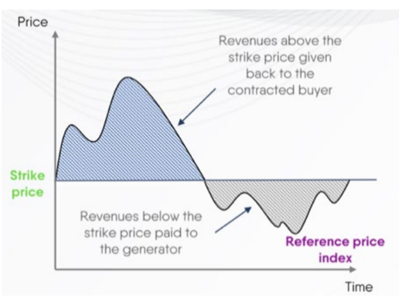
Instrument Overview

In November 2020, Spain introduced a support scheme for renewable electricity called Renewable Energy Economic Regime (REER; in Spanish 'Régimen Económico de Energías Renovables'). It was established through royal decree RD 960/2020. The form of support is a two-sided contract for difference (CfD). The support is allocated through auctions, i.e. through a competitive, market-driven mechanism. The lowest bids receive a CfD, which results from the awarding price, corrected by a market exposure adjustment factor to incentivise wholesale market participation.

Two-sided Contracts for Difference

Two-sided CfDs are a type of financial instrument used primarily in the energy sector as a derisking mechanism for power producers that face high upfront costs when building new capacity, while providing price stability for consumers. They have so far been used in more than 200 auctions across ten European countries, namely Denmark, France, Greece, Hungary, Ireland, Italy, Poland, Portugal, Spain, and the UK (Kitzing *et al.,* 2024).

In a Two-Way CfD, an agreed-upon "strike price" is established between the electricity producer and a counterparty, often a government or utility. This strike price represents the long-term average price at which electricity is expected to be sold. The CfD functions as a hedge, where payments flow between the producer and the counterparty based on the difference between a reference price index (e.g. day-ahead market price or a weighted average across a given period) and the strike price.



Source: Eurelectric and Compass LEXECON (2024)

- **If Reference Price < Strike Price:** The counterparty pays the difference to the electricity producer (CfD 'payout'). This ensures that producers receive stable revenues even when market prices are low, thus reducing their exposure to market volatility.
- **If Reference Price > Strike Price:** The electricity producer pays the difference to the counterparty (CfD 'clawback'). This ensures that consumers do not overpay when market prices surge.

This "two-way" mechanism contrasts with traditional "one-way" CfDs, where payments only move in one direction - usually from the counterparty to the producer when the market price falls below the strike price.

Two-way CfDs have emerged as the key instrument to channeling such support under the latest electricity market design (EMD) reform in the EU, which has made their use mandatory when public funding is involved in direct price support for investments in low-carbon power-generating capacity.

The main features of the REER scheme include:

- **Form of support**: Price-based support through a two-sided CfD and a commitment to deliver a minimum amount of energy by a given date. According to special decree law RD 960/2020, "*the market operator will settle the difference, which can be either negative or positive, between the prices in the day-ahead and intraday markets received for the energy negotiated by each installation subject to the REER and the recognised price for those installations*". The installations participate in the day-ahead and intraday markets and receive a price for energy which will be calculated from the strike price (see next bullet point for more details on the strike price) and the hourly market price. If the strike price (called recognised price - RP) is above the market price (MP), then there is a CfD payout to the installation. If the RP is below the MP the generator needs to pay the counterparty (clawback). The payout (or clawback) is equal to the difference between the RP-MP. The applicable market price (MP) depends on the market on which the unit of electricity was sold, i.e. either the day-ahead or the intraday market.

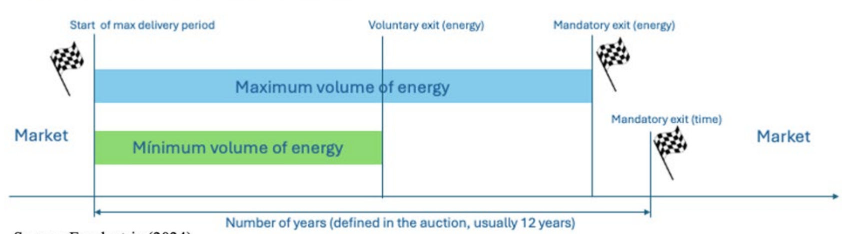
- **Retribution/strike price and market adjustment factor**: The recognised price (RP) is a function of the awarded price (AP) in the auction, but also the market price (MP) in the day-ahead market, with the degree of market exposure set through a market adjustment factor (AF). According to article 18 of RD 960/2020, the RP is calculated as follows:

  RP = AP + AF * (MP – AP)

  To avoid arbitrage, the calculation of the recognised price makes use of the day-ahead price, regardless of the market on which the unit of electricity was sold (day-ahead or intraday market).

  The adjustment factor (AF) represents the percentage of energy to be remunerated at the market price and aims to reduce the scheme's electricity market distortion by providing some exposure to the market price, thereby encouraging generation to shift to hours when electricity is most scarce/valuable. The factor is set by the respective call for auction. It can be in the range between 0-50%, taking inter alia into account the maturity of technologies, their competitiveness, their dispatchability or installation size. Two adjustment factors were set for the awarded technologies (PV, onshore wind) in the 1st, 2nd and 4th round: 25% for dispatchable installations (defined as installations that have storage capacity for 2 hours) and 5% otherwise. In the 3rd round, the factor was set at 15% for biomass (co)generation installations, 15% for dispatchable distributed PV, and 5% for non-dispatchable distributed PV.
- **Remuneration during zero or negative market prices**: A market price threshold is established. When the day-ahead or intraday market prices are below a defined price threshold, the energy sold is remunerated at the market price itself. The default value of the threshold is set at EUR 0/MWh. The objective is to avoid incentives for installations to offer zero or negative market prices.
- **Support period and delivery volumes**: an installation ceases to avail from the support scheme either when the maximum delivery period is reached or when a maximum volume of delivered energy is reached. The maximum support period has ranged between 12 and 20 years, with the majority of awarded technologies so far (PV, onshore wind) having received a 12-year support, with the exception of biomass plants awarded in the 4th round that received a 20-year support. Projects can continue to sell their generated electricity to the wholesale market after this period. For each installation there is a maximum volume of energy which can benefit from the scheme, after which the installation ceases to receive support (the maximum volume might be reached before the end of the maximum period). In addition, there is a minimum volume of energy that each installation must deliver before the end of the maximum delivery period. If this minimum volume is not reached, a penalty applies. When the minimum is reached the installation can opt to leave the scheme before the end of the maximum delivery period without any penalties.

  Figure 1 REER support period and delivery volumes

  Source: Eurelectric (2024)
- **Eligible technologies/ technology neutrality**: According to Article 3.2. of RD 960 (article 3.2), different renewable electricity technologies might be distinguished in the calls of the auction "*depending on their technical characteristics, size, levels of dispatchability, location criteria, technological maturity and those other criteria which guarantee the transition to a decarbonised economy*". In practice, this is defined for

each auction. The first two rounds encompassed a hybrid design, with technology-specific minimum reserve capacities accounting for the bulk of the overall quota, and smaller technology-neutral components. The 3rd and 4th round did not encompass technology-neutral components (see Table 1 for more details). In practice, 84% of the total auctioned volume in the four rounds was reserved for onshore wind and PV, while these two technologies accounted for close to 98% of the total awarded capacity, capturing also most of the technology-neutral quotas.

- **Reference volume/ reference market/ reference period**: payments (EUR/MWh) are calculated based on the dispatched (rather than the metered) generation volume; the applicable market price depends on the market on which the unit of electricity was sold, i.e. either the day-ahead or the intraday market. However, to avoid arbitrage the calculation of the recognised price (RP) only makes use of the day-ahead price. There is an hourly definition of the reference period (no aggregation), where the installation receives (or pays) the difference between the recognised price (RP) and the hourly market price.
- **Determination of the award price, auctioned product and bid variable**: the award price is determined through a pay-as-bid static auction. According to article 7 of special decree law RD 960/2020, the auctioned product will be the installed capacity (MW), electricity generation or a combination of both and the bid variable will be the price per unit of electricity, expressed in EUR/MWh. In practice, capacity has been the product auctioned in the four auction rounds to date.
- **Bid price minimum and maximum limits**: to limit the maximum award prices, a confidential reserve price is set for each auction that serves as the ceiling price above which submitted bids are excluded. Moreover, a risk price can be set that serves as a minimum price below which bids are also excluded in order to avoid extreme underbidding (this has been typically set at EUR 0/MWh).
- **Market participation and complementarity to PPAs**: Article 21 of special decree law RD 960/2020 states that the owners of installations which have been awarded will freely participate in the day-ahead and intraday markets. However, they will not be able to sign bilateral contracts.

Historical evolution of RE support in Spain

As renewable sources of power generation such as wind and PV have progressively become competitive, governments around the world have been replacing early support schemes such as feed-in tariffs (FiT) with auction-based CfDs. They introduced these to enable price discovery, enhance competition, and generally reduce the support renewables received through previous support systems (p.6, Del Rio *et al*., 2021).

This has been the case also in Spain where the national FiT legislation introduced in 1997, and revised in 2007 guided and incentivised a steady growth in installed RE capacity from the early 2000s until 2012. The revised FiT eventually led to a tariff deficit in the energy market, and it soon became unclear who would pay for rising subsidies, which eventually led to an end of the FiT scheme. Following some years of stagnation, the trend of increasing wind energy production continued in 2019, when Spain's National Energy and Climate Plan (NECP) for 2021-2030 committed to introducing auctions as the main policy tool for scaling-up RE development, leading to the introduction of the REER. Auctions under the REER provide price-based support for RE electricity based on the long-term price for RE electricity, marking a significant departure from previously conducted auctions in 2016 and 2017 that provided capacity-based support. The different design may reflect different context conditions, i.e. overcapacity and the need to mitigate the electricity system's chronic tariff deficit, the different goals of respective governments, or a result of the extensive experience (in Spain and internationally) on the design of RES auctions (p.6, Del Rio *et al*., 2021).

Further changes are expected to the current REER scheme, with the Ecological Transition Ministry (MITECO) putting in April 2024 in public consultation possible modifications to the REER with respect to the inclusion of non-price auction criteria (MITECO, 2024), in line with recommendations in the EU Net-Zero Industry Act (EU Regulation 2024/1735) and the EU Wind Power Action Plan (European Commission, 2023). Additional changes can be expected in the future to reflect relevant provisions of the reformed EU Electricity Market Design (EMD) Regulation, e.g. with respect to allowing the combination of CfDs with PPAs.

Rationale and Objectives

CfDs are designed to encourage investment in renewable energy by mitigating the risks associated with volatile electricity prices: by guaranteeing a certain price for low-carbon electricity generators, they essentially provide a stable, long-term revenue stream for renewable energy projects, enhancing their bankability and attractiveness for investors to fund them. The guaranteed long-term revenue stream enables developers to secure financing at rates close to that of government bonds, fostering the realisation of ambitious renewable energy targets.

According to the legislative framework (RDL 23/2020 and RD960/2020), the REER scheme encompasses the following main objectives:

- Enhance predictability and certainty, and encourage new investments in RE capacity;
- Favour the stability of the revenue streams and encourage the financing of new installations;

Additional objectives of the government are to (MITECO 2020, 2021a):

- Meet Spain's commitments with respect to RE and greenhouse gas emissions;
- Facilitate the financing of new projects, avoiding the risk of '*price cannibalisation*'[5];
- Transfer to consumers the cost savings from renewable energy generation;
- Facilitate planning through a schedule which provides certainty to the entire value chain of the associated industry, avoiding periods of technology and equipment shortages; and
- Foster the green economy and facilitate economic recovery.

It is worth noting that, complementary measures like CfDs introduce additional costs that are partially socialized (this might hold less true for the case of two-sided CfDs that generate also revenues). Policymakers should carefully weigh these economic implications when evaluating such schemes, as over-reliance on them can lead to inefficiencies, fragmented policies, and increased costs for governments and taxpayers.

Legal Framework and Administration

The legal framework establishing and implementing REER is based on several pieces of legislation, including:

- the Royal Decree Law RDL23/2020 that introduced the obligation to develop a support scheme for RES-E based on the long-term recognition of a price for energy;
- the Royal Decree RD960/2020 that regulates the juridical and economic regime of the REER;
- the Ministerial Order TED/1161/2020 that regulates the auction mechanism, adjusts the general bid selection methodology, and sets out an indicative auction schedule for 2020-2025;
- In addition, the Secretary of State for Energy issues Resolutions that serve as the auction calls that define the auction's details and technical aspects.

The involved administrators and counterparties include:

- The Secretary of State for Energy who decides and publishes the call of the auction;
- The market operator OMIE is the institution that manages the auction;
- The energy sector regulatory authority (Comisión Nacional de los Mercados y la Competencia - CNMC) is the institution that supervises the auction;

[5] In the context of the current marginal pricing-based electricity market design in the EU, '*price cannibalisation*' refers to the phenomenon whereby zero marginal cost variable renewables depress wholesale power prices at times of high output, thereby cannibalising their own profits and success on the power market. With renewables increasingly participating in the electricity markets on a merchant basis and the amount of renewables in the grid set to greatly increase, this could pose a threat in the long run to the viability of renewables operating on the market.

- The market operator OMIE and the national electricity system operator REE (Red Eléctrica) are responsible for the control of the energy sold and its payment (settlement).

2.2. Instrument effectiveness, efficiency and market impacts

This section discusses the scheme's effectiveness in meeting objectives with respect to enabling RE project development and financing, before moving on to discuss the scheme's efficiency with respect to encouraging the deployment of least-cost RE technologies, its impact on consumer/system costs, the electricity market and competition, as well as total support costs (static efficiency). It finally discusses the scheme's role in encouraging technology diversification and promotion of less mature technologies (dynamic efficiency).

Effectiveness

As a result of the advent of the energy crisis soon after the 1st REER auction was held and the prevalence of high wholesale market electricity prices, no facility as of today is actually connected to the REER scheme. Although awarded facilities have opted to renounce it, we still deem it as somewhat effective in promoting RE development. In what follows, we consider the scheme's ex-ante effectiveness based on auction results, and discuss its ex-post effectiveness in a broader and more theoretical sense.

Since 2021, four auction rounds have allocated CfDs of a total volume of ~ 6.38 GW, including ~ 3 GW in the 1st round, ~ 3.1 GW in the 2nd one, ~ 0.2 GW in the 3rd one, and ~ 0.05 GW in the 4th one. Total awards correspond to an estimated GHG emissions reduction of 2.1-3.3 million tonnes per year (Table 1).

Table 1 Overview of auctioned and awarded volumes in REER auction rounds

Auction round	Round 1 (Jan. 2021)	Round 2 (Oct. 2021)	Round 3 (Oct. 2022)	Round 4 (Dec. 2022)
Auctioned volume (MW)	3000 (increased to a max. of 3180)	3300 (increased to a max. of 3498)	520 (increased to a max. of 562.2)	3300 (increased to a max. of 3498)
Technologies included in the auction (MW)	Single quota, with: • two technology-specific minimum reserves: 1000 MW for PV and 1000 MW for onshore wind • 1000 MW technology neutral	Single quota, with: • four technology-specific minimum reserves: 600 MW for wind and PV with accelerated availability; 300 MW for distributed PV, 700 MW for PV; 1,500 MW for onshore wind • 200 MW technology neutral	Quota 1: 380 MW with four minimum reserves: 220 MW for CSP with storage capacity of at least 6h; 100 MW for biomass; 40 MW for biomass up to 20 MW; 20 MW for other RE technologies (e.g marine, geothermal), hydro plants, (co)generation plants using biogas or bioliquids. Quota 2: 140 MW for new distributed PV	Single quota, with two technology-specific minimum reserves: 1800 MW for PV; 1500 MW for onshore wind
Total awarded volume (MW)	3034	3124	177	45.5
Awarded technologies (MW)	Solar PV: 2036 Onshore wind: 998	Solar PV: 866 Onshore wind: 2258	Biomass: 146 Distributed PV: 31	Onshore wind: 45.5
Estimated GHG emissions reduction *	0.8-1.3 million tonnes per year **	1.2-1.8 million tonnes per year **	0.1-0.2 million tonnes per year **	0.015-0.024 million tonnes per year **

Notes:
* The range depends on whether the min. or max. equivalent hours contemplated for the facilities covered by the REER are taken as a reference
** Calculated by ERCST using the average emission factor for 2020 of 153 gCO_2eq/kWh, the min. or max. running equivalent hours contemplated for the facilities covered by the REER and the awarded capacities in MW
Sources: ERCST, based on CNMC (2021, 2022, 2023), MITECO (2021b, 2021c, 2022a, 2022b) and own calculations

The RE power volume awarded through the four REER auctions held by the end of 2022 amounted to 6380 MW (see Table 1), i.e. 71.2% of the total 8960 MW planned volume for the years 2020-2022 in the indicative schedule for the allocation of the REER established by Article 23 of Order TED/1161/2020 (Table 2). The awarded capacity corresponds to an estimated GHG emissions reduction of 2.1-3.3 mt CO_2eq per year.

Table 2 Indicative schedule for the allocation of the REER in the years 2020-2026

		REER auctions' minimum power volumes (MW)						
		2020	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**
Wind	Increase	1000	1500	1500	1500	1500	1500	1500
	Cumulative	1000	2500	4000	5500	7000	8500	10000
Photovoltaic	Increase	1000	1800	1800	1800	1800	1800	1800
	Cumulative	1000	2800	4600	6400	8200	10000	11800
CSP	Increase		200		200		200	
	Cumulative		200	200	400	400	600	600
Biomass	Increase		140		120		120	
	Cumulative		140	140	260	260	380	380
Other technologies	Increase		20		20		20	
	Cumulative		20	20	40	40	60	60

Source: Article 23 of Order TED/1161/2020

The annual average awarded capacity in 2020-2022 was ~2.1GW, compared to the ~6 GW annual capacity addition needs that Spain's National Energy and Climate Plan (NECP) foresees between 2021 and 2030 (slide 3, MITECO, 2021a). Merchant plant RE capacity or PPAs would come on top of the auctioned capacity. Had the entire available volume been awarded, the aforementioned annual average would stand at ~3.7 GW.

This was not however the case: While the 1st round was oversubscribed and awards in the 2nd round nearly reached the total volume available, only 34% and 1.3% of the total available volume was awarded in the 3rd and 4th rounds respectively. The 4th round in particular awarded only 45.5MW out of the 1.5GW available volume for wind "*due to insufficient consideration of higher production costs, which led most developers to bid above the threshold price of 47€/MWh. This exemplifies one of the problems of the CfD-mechanism, requiring governments to set a functioning price cap that is not too high to enable low energy prices, but not too low to hinder the final realisation of the project*" (European Commission, 2024). The reserve price was quite low relative to forward market prices (see Table 3) and led to an undersubscribed auction.

Moreover, there is a distinction between ex-ante effectiveness (auction results) and ex-post effectiveness (actual projects built thanks to the scheme), given that there is a time lag between the auction and project construction. Project realization rates depend inter alia on whether projects will have secured the necessary permits and financing (Marquez 2021), as well as on the general market and economic environment including, developments in the short-term electricity market and supply chain considerations (Del Rio *et al*., 2021). Moreover, depending on electricity market developments, some awarded projects will have been realised, but opt to give up REER support and instead either sell to the market or via PPAs if the latter are more favourable.

In that light, there is something to say regarding ex-post effectiveness with respect to the first two auction rounds, given that the construction and start of energy delivery deadlines have now being reached for most awarded facilities (apart from onshore wind in the 2nd round). For these facilities, there was no evidence as of July 2023 that they were receiving REER support, and "*given the current price context, the aforementioned facilities […] could have opted to renounce the REER and instead be selling their energy to the market and/or through PPA contracts*". (CNMC, 2023). The situation remains the same, i.e. as of September 2024 there was not a single facility receiving REER support[6]. It is unlikely that this situation change when it comes to already awarded facilities in the first four rounds, with the exception perhaps of the 31 MW of distributed PV awarded in the 3rd

[6] This can be deduced from the cost components of the regulated tariff (the one subscribed by the majority of domestic customers in Spain) that REE makes public since the revenue/cost of the REER is allocated to the demand.

round and that can be connected until 15/03/2025, given that the awarded price (53.88 €/MWh) could be attractive compared to the rapidly declining PV captured prices in Spain in recent years, a trend expected to continue in the next years.

A project-level analysis would be needed to understand the realisation rates of projects participating in the auctions (as well as other RE projects under development at the time of the auctions), which would be beyond the scope of this report. Although there is currently no facility that receives REER support, and while *"the awarded power capacities in the first years after introducing the auctions were overall too low to be in line with Spain's overall energy goals […], stakeholders in the energy and climate sectors have praised the mechanism as a functional way of organising renewable energy development*" (European Commission, 2024).

Indeed, before the connection of RE projects to the power system, their development involves several years of preparation (e.g. pre-development, development, and construction stages) that entail significant costs before they hit the ground (e.g. land and permitting costs, securing grid connection). For project developers, the REER has provided a valuable "insurance/ fallback" policy that has helped them to secure project financing and continuity/stability of their business and the project pipeline. The awarded projects in the first two auctions progressed in their development and reached certain milestones (nomination of the awarded capacity, administrative building permit) that allowed the release of 50% of the guarantees paid for participating in the auctions. Developers decided not to reach the final milestone of including the plants in the registry of the REER, and opted to not avail from the scheme in terms of remuneration because of the attractive prices that eventually emerged on the spot market following the recent energy crisis. In practice, awardees of the 1st and 2nd auctions decided to renounce the REER and lose their guarantees (~ EUR 30.000 /MW at that moment) because of the market price evolution. From a finance point of view, the REER scheme acted as an "option" i.e. it provided value to the holders (developers) during project development (when spot and forward market prices were at pre-crisis levels) even if eventually they decided not to "exercise" the option (with the lost guarantees being the price for not exercising it). The situation was different at the time of the 3rd and 4th auctions that were held during the peak of the energy crisis (exceptionally high market prices) and with auction reserve prices set at low levels (4th auction). This led to undersubscribed auctions with project developers either not bidding at all or bidding above the reserve price and not being awarded. In finance terms, developers did not buy the "option" offered by the REER scheme in the last two auctions held in 2022.

Therefore, even if no facility has to date received remuneration through the REER, the Spanish CfD scheme (the first two auction rounds in particular) can be deemed as relatively effective in promoting renewable energy: by providing certainty over a minimum level of revenues, it facilitated project financing and investment decisions, thereby serving as a key enabling condition for renewable energy development and investment in the country.

Operational and Market Efficiency

This section discusses the scheme support costs and participation, auction results with respect to promoting least-cost technologies and the resulting award prices (compared to long-term contract prices and LCOE), as well as the scheme's design features and impact on competition and market exposure.

Policy support costs

The total policy support costs to date amount to EUR 0, given that there are no facilities currently connected to the REER.

As already discussed, the fact that there have not been any flows through the scheme does not mean that the projects have not been realised, but rather that it has in general been more profitable for them to go merchant.

The scheme would provide long term guarantee of revenue stability, while opting for the market is more risky (in terms of price and capture rates risks). The specific context of exceptionally high prices probably allowed developers to earn significantly more out of the scheme. From a society point of view, however, the renouncing of the scheme most likely implies higher costs in terms of electricity prices and windfall profits compared to a scenario with REER flows. The magnitude of the guarantees that the facilities renouncing the scheme were willing to forego (about EUR 185 million in total[7]) can provide an indication of the lower bound estimate of this cost increase. The level of guarantees needs to be set high enough to provide an incentive to stay within the scheme but low enough to not deter participation in the auction and thereby the scheme. It is doubtful that higher guarantees could have safeguarded awarded facilities' connection to the REER, given the context of unforeseen circumstances with respect to the surge in energy prices following the conception of the scheme. This points perhaps to the need of incorporating other types of incentives or conditionalities in the future e.g. making grid access conditional upon connection to the scheme.

Auction results & potential impact on consumer and system costs

The following table presents the results of the four auction rounds for the allocation of the REER, including the resulting award prices. It compares these to long-term contract prices (i.e. the bidders' expected opportunity cost) and the Levelised Cost of Electricity (LCOE) for PV and onshore wind, given that the optimal received price level would be close to the LCOE, ensuring a limitation of profits by power producers.

Table 3 Auction results for the allocation of the REER

Auction round (year)	Round 1 (Jan. 2021)	Round 2 (Oct. 2021)	Round 3 (Oct. 2022)	Round 4 (Nov. 2022)
Award price range (EUR/MWh)	PV: 14.89 – 28.9 Onshore wind: 20 – 28.89	PV: 24.40 – 34.90 Onshore wind: 27.90 – 36.68 Accelerated availability PV: 31 – 33.97 Distributed PV: 34.64 – 36.88	Biomass: 72.38 – 108.19 Distributed PV: 44.98 – 62.50	Onshore wind: 38.88 – 45.12
Weighted average awarded price (EUR/MWh)	All technologies: 24.75 PV: 24.47 Onshore wind: 25.31	All technologies: 30.59 PV: 31.60 Onshore wind: 30.18 Accelerated availability PV: 32.08 Distributed PV: 36.35	Biomass (quota 1): 93.09 Distributed PV (quota 2): 53.88	Onshore wind: 42.78
Average day-ahead market price (EUR/MWh)	33.96 in 2020	86.95 in 2021 (data up to 19 October 2021, the date of the auction)	167.52 in 2022	167.52 in 2022
PV capture rate**	~95% in 2020	~90% in 2021	~90% in 2022	~90% in 2022
Price of contracts with longer term settlement in the OMIP market on the day of the auction (EUR/MWh)	EUR 39-40/MWh for contracts with longer term settlement (from 2026 onwards)	EUR 34-40/MWh for contracts with longer term settlement (from 2027 onwards)	EUR 49-53/MWh for contracts with longer term settlement (from 2029 onwards)	EUR 51-54/MWh for contracts with longer term settlement (from 2029 onwards)
Levelised Cost of Electricity (EUR/MWh)	Onshore wind (European weighted average in 2021): EUR 38 /MWh Utility scale PV (in Spain in 2021) EUR 39/MWh	Onshore wind (European weighted average in 2021): EUR 38/MWh Utility scale PV (in Spain in 2021) EUR 39/MWh	Onshore wind (European weighted average in 2022): EUR 42/MWh Utility scale PV (in Spain in 2022) EUR 44/MWh	Onshore wind (European weighted average in 2022): EUR 42/MWh Utility scale PV (in Spain in 2022) EUR 44/MWh

[7] Amount calculated for EUR 30.000 lost in guarantees for each of the 6158 MW of total awarded capacity in the first two rounds. The total guarantees to participate in the auction was EUR 60.000/MW. Awardees could release up to 50% of the total amount if two intermediate milestones were reached (nomination of the specific units of the awarded capacity, and obtaining the administrative building construction permit). That means that only EUR 30.000/MW could be lost if, finally, the plant was not included in the registry of REER scheme.

Adjustment factors (% of energy remunerated at the market price)	Dispatchable installations*: 25% Non-dispatchable installations: 5%	Dispatchable installations*: 25% Non-dispatchable installations: 5%	Biomass: 15% Distributed PV:15% for dispatchable installations*;5% for non dispatchable installations	Dispatchable installations*: 25% Non-dispatchable installations: 5%
Support period (for awarded technologies)	Solar PV: 12 years Onshore wind: 12 years	Solar PV: 12 years Onshore wind: 12 years	Biomass: 20 years Distributed PV: 12 years	Onshore wind: 12 years
# of awarded bidders	32	26 agents belonging to 16 business groups or companies	Quota 1: 3 agents belonging to 3 business groups Quota 2: 5 agents belonging to 5 business groups	2 companies belonging to 2 business groups

Notes:
* Defined as an installation that has storage capacity for 2 hours or more
** The captured price for PV was ~95% in 2020, it was maintained at ~90% levels in 2021 and 2022 but started to drop in 2023 to ~83% and in 2024 is below 70% with a clear downward trend.
Sources: ERCST, based on CNMC (2021, 2022, 2023), IRENA (2022), IRENA (2023), MITECO (2021b, 2021c, 2022a, 2022b), OMIE electricity market results data, and information provided by Eurelectric (capture rates).

Overall, onshore wind and solar PV represent the majority (98%) of the total awarded capacity. The REER has thus been efficient in terms of encouraging the deployment of technologies that displayed the lowest costs.

The weighted average award price in the first two as well as the 4th auction rounds was lower than the prices of contracts with longer-term settlement on the day of the auction in the OMIP organised market:

- In the 1st round, the weighted average was 43% lower on average than the estimated long-term prices (MITECO 2021a). The very low minimum awarded prices in the 1st round might indicate the possible presence of underbidding (Ojea, 2021), with some developers likely sacrificing profitability in order to enter the market or increase market share (Del Rio *et al.*, 2021), or could reflect the integration in the bidding of the opportunity costs linked to the auction participation guarantees.
- In the 2nd round the weighted average award price was ~10-25% lower than the long-term contract price range. The increase in the average award price by €5.84/MWh in the 2nd auction round compared to the 1st round occurred in a context of strong increases in spot and forward electricity prices, general increase in raw material prices and regulatory risk (CNMC, 2022).
- In the 3rd round, results varied by technology, with the average award price for distributed PV (~EUR 54/MWh) marginally above prices for contracts with longer-term settlement (EUR 49-53/MWh) and the average award price for biomass (~EUR 93/MWh) close to double the same price.
- In the 4th auction, the weighted average price of the awarded bids was about 15-20% lower than the price range for long-term contracts, however there was overall a small volume awarded due to inter alia the reserve price having been set too low.

Amortization and production costs and therefore the LCOE can serve as an indicative reference for an optimal strike price level of a two-way CfD, as it ensures the limitation of profits by power producers:

- Average award prices in the 1st and 2nd auctions were below the LCOE for both solar PV and onshore wind in 2021 provided by IRENA (IRENA, 2022). The award prices in subsequent auctions did not continue to be at levels significantly lower than the LCOE, which would have given rise to concerns with respect to the mid- to long term viability of the electricity system.
- The average award price for distributed PV in the 3rd auction was ~22.5% higher than utility scale PV LCOE in Spain of EUR 0.044/kWh in 2022 provided by IRENA (IRENA, 2023).
- The average award price for onshore wind in the 4th auction was aligned with (marginally higher than) the European weighted average LCOE for onshore wind in 2022 of EUR 0.042/kWh (IRENA, 2023).

Finally, the REER design encompasses a market adjustment factor that encourages exposure to the market, thereby reducing system costs through encouraging generation when it has the most value for the system and avoiding negative market prices.

Market distortions & exposure

A key design question for CfDs is how to prevent or minimise electricity market distortions, while preserving the scheme's effectiveness.

The Spanish scheme is a financial CfD, i.e. the energy is sold on the short-term wholesale markets, circumventing some (but not all[8]) of the shortcomings typically associated with conventional CfDs that distort dispatch and investment decisions.

In addition, installations can participate in the market after the maximum support period is over, or the maximum delivery volume is reached, or when the minimum delivery volume is reached and the installation opts out of the support scheme or even when the minimum volume is not reached (but with a penalty). Finally, there is no CfD payout (i.e. remuneration at market price) during negative market prices (zero hour tolerance[9]), and no negative price bidding.

The REER might still have a market distortive impact however in particular with respect to:

- The scheme's reference price being based on the hourly spot prices, which:
    - incentivises to some degree "produce-and-forget" because they mute electricity price variation such that there is no benefit in producing electricity when it is most scarce/valuable. The REER's market adjustment factor is an interesting design feature that lessens this type of market distortion by providing some exposure to the market price, thereby encouraging generation to shift to hours when electricity is needed most (other CfD schemes have typically addressed this distortion by using a yearly-average or other aggregation to define the reference price);
    - may draw liquidity away from other market timeframes e.g. forward markets (Eurelectric and Compass LEXECON, 2024).
- The energy of the contract is the scheduled (dispatched) energy, which distorts the market price signal.

Impact on competition

The design of the auctions include elements to ensure a minimum level of competition between participating bidders (the volume of product offered needs to exceed the volume of awards by at least 20%, otherwise the auctioned volume is reduced accordingly), as well as maximum concentration rules according to which no single company or business group can be awarded more than a certain share of the total volume (defined separately for each auction and product quota, i.e. 50% of the volume in the 1st, 2nd auction and product quota 1 of the 3rd auction, reduced to 30% for product quota 2 of the 3rd auction and 25% in the 4th auction).

Notwithstanding, there have also been some critical voices from local parties and citizen groups, who have criticized the system for benefiting primarily large companies and impeding smaller entities including energy communities to participate in the tendering processes (European Commission, 2024). In that light, the regulatory authority CNMC has recommended that the adjustment factor (which represents the percentage of energy to be

[8] E.g. For CfDs based on the actual scheduled production of the plant, once the generator knows the result of the CfD settlement, this will influence its behaviour in the market. The result of the CfD settlement is known once the day ahead market is cleared, which means it will affect the bids in the intraday and balancing markets.

[9] In Germany, wind and PV support is suspended after 4 consecutive hours of negative prices, that will reduced step-by-step to 1 hour from 2027, the same level as in Great Britain and the Netherlands. In Austria, Italy and Poland there is a 6 hour tolerance (Source: table 6, Kröger and Newbery, 2024).

remunerated at the market price) be set at 0 for auctions calls oriented towards smaller installations (p.9, CNMC 2020a), as a way to help increase participation by smaller entities.

Another criticism of the Spanish CfD scheme is that it does not allow participants to sign PPA contracts. However, developers may in general have the possibility to combine the use of PPAs and CfDs. CfDs are public-based instruments, that can be complementary to market-based PPAs. PPAs and CfDs can work together to provide long term signals for decarbonization and to create secure and stable investment conditions for renewable energy developers. While PPAs provide revenue certainty and direct buyer relationships, two-way CfDs focus on price stabilization and risk mitigation. In that light, the EU EMD reform foresees that bidders to two-way CfDs are allowed to reserve part of their project's generation for a market-based revenue stream and access to the PPA market. Hence, future CfD schemes in Europe (and future modifications to the REER) are bound to allow the combination of CfDs and PPAs.

Overall, the Spanish scheme has been somewhat efficient in encouraging the deployment of least-cost RE technologies, however it has not provided incentives to facilities to stay within the scheme. The REER also encompasses interesting design features with respect to the treatment of negative market prices, incentives for participation in and exposure to the wholesale market, as well as elements to ensure a minimum level of competition. Additional adjustments to the REER design could further enhance its potential efficiency, such as for instance incorporating incentives or conditionalities to safeguard the awarded facilities' connection to the scheme. Moreover, the auction calls could set the adjustment factor values such that they provide greater market exposure for mature technologies, or incentivize participation by smaller installations or entities.

Innovation and Long-Term Impact

The technology specific component of the 1st auction only encompassed mature RE technologies (wind, solar PV), while the technology neutral component (1/3 of the total auctioned volume) was fully captured by solar PV (given that it has the least LCOE). In the same vein, the 2nd round encompassed minimum capacity reserves for mature technologies, and a small (7% of the total auctioned volume) technology neutral component (see Table 1). Other generation technologies such as biomass and concentrated solar power (CSP) or storage were not awarded. Subsequent auctions have included minimum volumes for these technologies as well as a design that is more favourable for storage, however these technologies were still not awarded. Notwithstanding, the results of the auctions may be used as a reference for supporting demonstration projects using less mature technologies, which do not participate in the auction.

In practice, 84% of the total auctioned volume in the four rounds (8540 MW out of a total auctioned volume of 10120 MW) was reserved for onshore wind and PV. Wind and PV accounted for close to 98% of the total awarded capacity (6234.5 MW out of 6380 MW), capturing most of the technology-neutral quota.

In the first two auction rounds, the price level of the offers for PV and onshore wind technologies in the auction was aligned, with the average award prices for both technologies being relatively similar, indicating that there is potential competition between the two technologies (CNMC, 2022). In view of the results obtained in the first two auctions, it could be concluded that for future auctions there would be no need to establish minimum reserves for wind and photovoltaic technologies, while it is necessary to establish minimum reserves, or to call for specific auctions, for other technologies if the energy policy objective is to achieve greater technological diversification or promote immature technologies. (CNMC, 2022).

In addition, there is the possibility of setting the value of the market adjustment factor (which represents the % of energy to be remunerated at the market price) such that it favours the uptake of less mature technologies. For example, the regulatory authority has recommended that this factor be set to 0 for auctions oriented towards less mature technologies given that such installations would not be economically viable if they received prices close to those of the market (p.9, CNMC, 2020a).

2.3. Interaction with and impacts on the EU ETS

CfDs and the EU ETS are two distinct mechanisms aimed at reducing carbon emissions within the EU, but they interact in ways that can affect the carbon pricing landscape and investment incentives. Their interaction can be summarized in terms of their combined impact on carbon pricing, market dynamics, and renewable investment incentives.

Impact on carbon pricing

The EU ETS directly affects carbon pricing by establishing the cost of emitting CO_2 through the price of allowances (EUAs). High EUA prices make fossil-fuel-based electricity generation more expensive, benefiting low-carbon technologies like wind and solar.

CfDs, while not directly tied to carbon pricing, promote the development of renewable energy, which helps reduce overall carbon emissions. As more renewables enter the market due to CfDs, the demand for emissions-intensive power generation decreases, potentially reducing the need for EUAs.

However, large-scale deployment of renewables through CfDs could lower wholesale electricity prices due to the merit-order effect, indirectly reducing the EUA price by lowering the demand for fossil fuel generation.

Investment in low-carbon technologies

The EU ETS provides a direct financial incentive for power plants to reduce emissions or invest in cleaner technologies (at least refrain from continued investments in high emitting technologies like coal), as reducing emissions means purchasing fewer EUAs.

CfDs complement this by providing a stable revenue stream for renewable projects, reducing investment risk and making it more attractive for investors to finance low-carbon technologies.

However, because CfDs insulate renewable energy developers from electricity market price fluctuations, they reduce developers' exposure to rising carbon prices under the EU ETS. This means the impact of EU ETS price signals on investment decisions is dampened for projects benefiting from CfDs.

Potential overlap and challenges

- Risk of Double Incentives: Both CfDs and the EU ETS aim to encourage low-carbon energy generation, but if not carefully coordinated, there could be situations where renewable projects receive both CfD support and benefit from high EUA prices, potentially leading to excessive subsidies.
- Price Suppression Effects: As CfDs support the deployment of more renewable energy, this can lead to lower wholesale electricity prices[10] and reduced EUA demand, which might suppress the carbon price in the EU ETS, reducing the incentive for fossil fuel power plants to decarbonize.
- Interaction with the ETS Cap: While the EU ETS cap ensures a declining limit on overall emissions, the deployment of renewables through CfDs accelerates decarbonization. This could lead to a situation

[10] Spain's Ministry for the Ecological Transition expected the 1st auction to lead to a reduction in the market price of electricity of EUR 1.3/MWh.

where the cap becomes non-binding (i.e., emissions reductions are achieved faster than the cap requires), leading to a surplus of allowances in the system and a further drop in the EUA price.

Market reforms and adjustments

To address potential challenges in the interaction between CfDs and the EU ETS, market reforms such as adjusting the ETS cap to reflect accelerated decarbonization could be a way to address these. The Market Stability Reserve (MSR) within the EU ETS is one mechanism designed to address the surplus of allowances by adjusting the supply of EUAs based on market conditions.

Overall, the interaction between CfDs and the EU ETS is complex, with both mechanisms aiming to reduce carbon emissions but through different pathways. The challenge is ensuring that both systems work in harmony to drive decarbonization without creating market distortions or over-subsidization. Careful policy coordination, including potential adjustments to the ETS cap and the design of CfD schemes, is critical for maximizing the effectiveness of both instruments in achieving the EU's climate goals.

3. Carbon Price Floor in the UK

3.1. Instrument description and rationale for its introduction

Instrument overview

To support the EU ETS price signal, the United Kingdom (UK) implemented a Carbon Price Floor (CPF) between 2013 and 2020, i.e. until the UK ceased to be part of the EU and the EU ETS.

The CPF aimed to provide long-term certainty and ensure that the carbon price in the UK remained at a level that incentivised investment in cleaner technologies, adequate at supporting the country's ambitious climate change and transition goals.

First proposed in 2010, the CPF was designed to "top up" rather than backstop the price of carbon at a level that the government deemed necessary "to drive investment in the low-carbon power sector" (HM Treasury, 2011, p. 32). In March 2011, the UK Government announced the CPF's implementation for the power sector, effective from the 2013-2014 budget year (HM Treasury, 2011a).

Starting by adding £4.94/tCO_2 on top of the prevailing EU ETS price with a view to reaching a total carbon price target of £15.70 in 2013, this price floor was originally intended to gradually increase by roughly £2/year until it reached a targeted combined carbon price of £30 in 2020.

It was introduced against the backdrop of the EU ETS's historical low carbon prices, which had been typically fluctuating between €5 and €10 per tonne of CO_2 since the early 2010s - far below the estimated social cost of carbon (Newbery et al., 2018). This was considered insufficient to encourage the level of investment needed for a transition to a low-carbon economy.

Electricity generation was the focus of the CPF. This sector had historically been a major contributor to the UK's carbon emissions. By increasing the cost of burning fossil fuels—particularly coal—the CPF encouraged power generators to switch to cleaner alternatives.

Whilst the UK policy is referred to as a "Carbon Price Floor", in practice it functions more as a surcharge than a minimum price. Instead of having a standard price floor, the UK government opted for a domestic price support rate which acted as a "top up" to the EU-wide allowance price, in effect creating a separate UK national price path (see option (d) in Fig. 1.). This rate was meant to progressively increase.

The Theory Behind a Price Floor

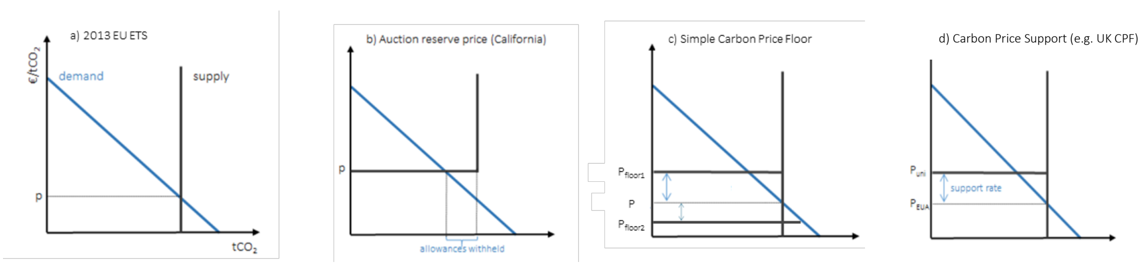
A price floor is a minimum price set by a regulator in a market to prevent the price from declining below a chosen level. This is akin to the imposition of a minimum wage in a competitive labour market by governments. In carbon markets, the price floor ensures that even if market demand for emissions allowances drops, the price of emitting carbon does not fall below a level that undermines climate targets set by the Climate Change Act in 2008 (UK Parliament, 2008).

In static markets, such as labour markets, economic theory suggests that a price floor placed below the equilibrium price will have no effect, whilst a floor inserted above the equilibrium will raise the price to the level of the floor.

Yet, the implication of this mechanism differs greatly when implemented in dynamic markets, such as cap and trade schemes. In cap-and-trade systems, equilibrium prices depend not just on static supply and demand but also on the expectations of future price developments (Salant et al., 2020). As such, the present price is always connected to the future price, and even if the price floor is set below the immediate equilibrium, it can still influence market behaviour and cause price fluctuations.

The primary benefit of a carbon price floor is its ability to enhance long-term investment certainty. By setting a minimum carbon price, regulators send a clear signal of their commitment to achieving ambitious decarbonisation targets. This is particularly important when market distortions or policy uncertainties drive the allowance price below its cost-effective pathway, reducing the incentive to invest in low-carbon technologies (Burtraw, Palmer, and Kahn, 2010).

There are various methods to implement a price floor, each with distinct designs. The diagram illustrates several possible approaches to establishing a carbon price floor (options b, c, and d), in comparison to an open market without a price floor (option a):



Source: ERCST, based on Edenhofer et al., (2017) and own elaboration

a. 2013 EU ETS: Open market with price at the intersection of demand and supply.

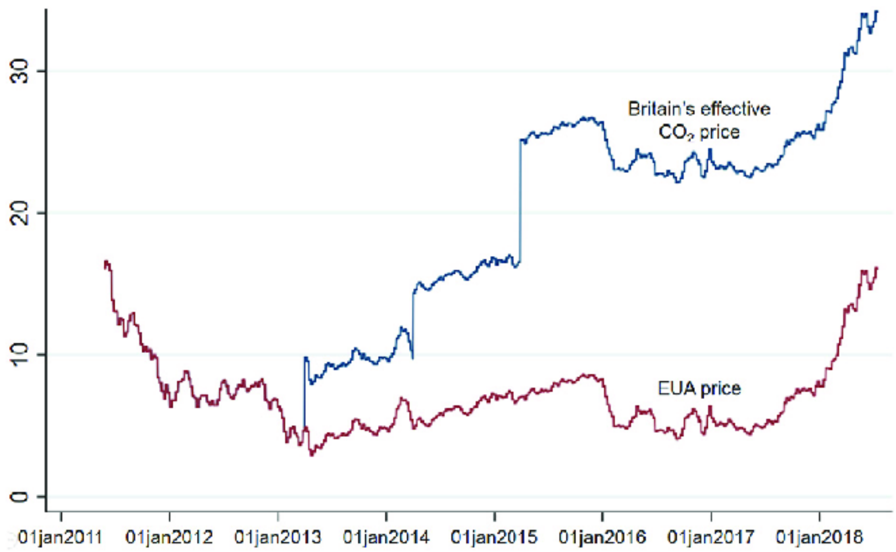
b. Auction Reserve Price: As seen in California, this approach includes some allowances that are not auctioned and are instead withheld from the market, differing from a simple price floor.

c. Simple Carbon Price Floor: This design features a floor price that aims at setting either a higher price than the present market price at P_{floor1} or creating a backstop price to ensure that future prices never fall below P_{floor2}.

d. Carbon Price Support (e.g. UK CPF): This design features a domestic price support rate that bridges the gap between the targeted nationally determined carbon price (in the UK this is set by the Climate Change Act 2008) and the EU-wide carbon price (UK Parliament, 2008).

This means that even in the event of an EUA price of zero, the carbon price could not fall below the CPS rate (Gugler, Haxhimusa, and Liebensteiner, 2020). As a result, the carbon price in the UK followed the same variation as the EUA price (see Figure 1.).

*Figure 2 EUA price & Britain's effective CO_2 price (€/tCO_2) paid by energy generators**



* Note: Britain's effective CO_2 price = EUA price + CPS. 1 April 2013-31 March 2014: CPS = £4.94 (= €5.84); 1 April 2014-31 March 2015: CPS = £9.55 (= €11.46); 1 April 2015-31 March 2021: CPS = £18.08 (= €24.63).

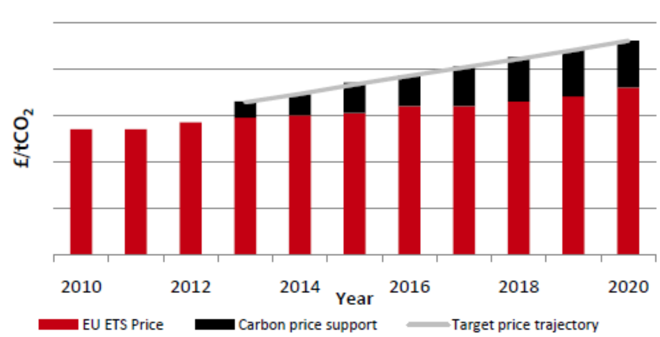
Source: Gugler, Haxhimusa, and Liebensteiner, 2020

The implementation of CPF implies two key carbon price components paid for by energy generators:

(i) The EU ETS allowance price: Generators purchase the EU ETS allowances through regular Government auctions or the carbon markets.

(ii) The Carbon Price Support (CPS): This tops up EU ETS allowance prices paid by energy generators, as projected by the Government, to the carbon floor price (CFP) target.

Figure 3 Illustration of Carbon Price Support (CPS) mechanism



* Note: Prices are illustrative

Source: HM Treasury, 2010

The CPS rate per tonne of CO_2 was the UK-only additional element to the applicable EU ETS carbon price.

- If the carbon price within the EU ETS fell below the CPF target, the CPS would make up the difference, effectively setting a minimum price for carbon emissions (Edenhofer et al., 2017). For instance, if the

EU ETS price was £5 and the UK carbon price floor was set at £20 per tonne, the resulting CPS would be £15.

- Conversely, if the EU ETS price exceeded the UK floor price, the CPS rate would be zero (see text box below for an explanation of how the CPS is calculated and charged).

CPS rate calculation

The CPS is applied via the Climate Change Levy (CCL), which taxes fossil fuels used for electricity generation. CPS rates[11], expressed in £/kWh, are paid by owners of power generating plants and are set by the Treasury three years in advance. These rates are based on the carbon content of the used fuel, with higher carbon emissions sources, such as coal, facing higher CPS rates, making them more expensive to use for electricity generation.

This is calculated by multiplying the difference between the Government's target carbon price through the CPF and the EU ETS carbon market price using the formula below.

CPS rate formula

CPS Rate = (target UK carbon price floor – EU market carbon price) x (emission factor of the fuel)

The CPS rate concerning a given year was set through the government budget two years ahead of its implementation. For example, the first CPS rate in 2013 was announced in the 2011 budget. This means that the rate has been set based on expectations with respect to the EU ETS price for the given year and the distance between this expected price at the EU level and the targeted CPF at the national level. Once the rate was fixed based on the expected 'distance to target' it stayed at that level, i.e. there was no ex-post adjustment to take into account the prevailing EU carbon price. This means that there is a disconnect between the target carbon price floor and the achieved carbon price floor. E.g. the CPS was set in 2011 for the year 2013 at £4.94/tCO_2 with a view to reaching a total carbon price target of £15.70 in 2013. However, as EU carbon prices in 2013 turned out to be lower than what had originally been anticipated in 2011, the CPS effectively translated to a carbon price floor of about ~£9/tCO_2.

In total, there were three confirmed CPS rates for the years 2013, 2014 and 2015 set by the annual budgets in 2011, 2012 and 2013 respectively, as well as indicative rates concerning 2016 and 2017 that were however never implemented as a result of the freeze (Table 4).

Table 4 CPS Rates

CPS rates set before the price freeze at Budget 2014

	Confirmed rates			Indicative rates	
	2013-14	2014-15	2015-16	2016-17	2017-18
Carbon price equivalent (£/tCO2)	4.94	9.55	18.08	21.20	24.62

Source: Hirst, 2018

The additional sums required to meet the floor price are levied at the point of sale of fossil fuels based on their emissions factors. These sums are paid by suppliers of coal and gas sold into the electricity market. Oil suppliers were exempted from paying the CCL since they were already taxed under fuel taxation policies (in fact, because the latter charge was higher than the CCL, they were able to claim a rebate to reduce the level of fuel tax to the equivalent level of the CCL).

[11] For exact rates see: https://www.gov.uk/guidance/climate-change-levy-rates

When initially introduced in 2013, the CPS stood at £4.94/tCO_2 (Figure 3). This effectively set the CPF at £9/tCO_2 in 2013 (based on the actual EU ETS carbon price plus the CPS). The intention was to gradually raise the CPF over time to reach a target of £30 (around €35) /tCO_2 by 2020 (House of Commons Briefing Paper, 2016).

The CPS increased to £9.55/tCO_2 for 2014 and £18/tCO_2 for 2015. However, in the 2014 budget, the Government announced the freezing of the CPS at the 2015 level for the years between 2016 and 2020 due to concerns over its economic impacts on consumers including energy-intensive industries (Hirst, 2018). The UK-only CPF ultimately meant that the UK energy providers were facing costs six times that of their EU counterparts. By 2019-2020 the reality of Brexit began to settle in, and any further revisions of the policy were effectively postponed until clarity settled on the final outcome of a post-Brexit carbon market, with the UK eventually leaving the EU ETS and implementing a standalone UK ETS from January 2021.

In light of this, it is important to underline the competitiveness and broader economic inefficiency such fragmented policy approaches lead to, and how such societal implications can alter the effects of complementary policies.

Rationale and Objectives

The UK CPF was introduced in 2013 within the context of two major challenges:

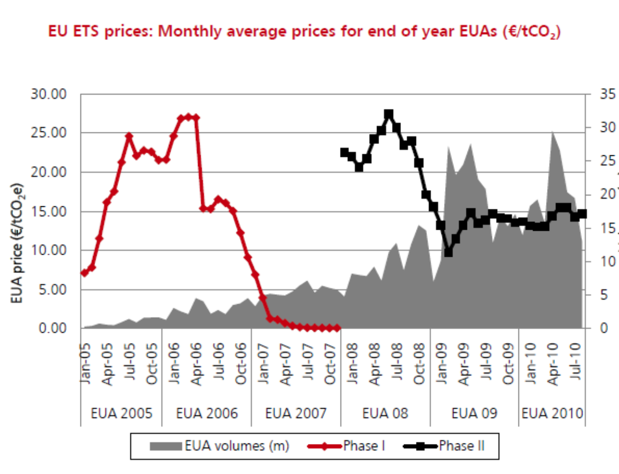
1. Persistently low carbon prices in the EU ETS and associated uncertainty.
2. The UK's legally binding emissions reduction targets are as outlined in the Climate Change Act of 2008.

Low Prices and Uncertainty

Low prices are not inherently proof of market failure, as they can still transpire in an efficient functioning market when mitigation costs are low (Ellerman, Marcantonini and Zaklan, 2016). However, they should raise some alarm on signs of potential market failure.

EUA prices prior to the UK CPF

Figure 4 EUA prices prior to the UK CPF.



According to the UK's consultation:

"The carbon price decreased significantly at the end of the first period of trading (2005-2007). This was primarily due to an over-allocation of carbon allowances and the inability to bank allowances between Phases.
In 2008, (Phase II 2008-2012), the carbon price peaked at almost €30 per tonne CO_2 (t/CO_2) (£26/tCO_2). Following the global financial crisis and subsequent economic recession, the price then fell below €10/tCO_2 (£9/tCO_2) in the first quarter of 2009. Over the past 12 months, the carbon price has fluctuated between €12-16/tCO_2 (£10-14/tCO_2). However, even allowing for periods of price instability, the volume of carbon traded has grown significantly since 2005."

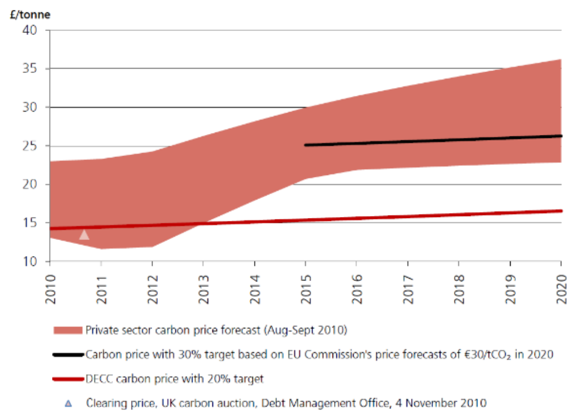
HM Treasury, 2011, p.14

Source: HM Treasury, 2010

According to Edenhofer et al., (2017), the diagnosis of low prices as a market failure can be attributed to the following factors:

- Political nature of allowance supply: Governmental interventions created credibility issues, affecting the stability of the market.
- Myopia or inefficient discounting: Short-term thinking among market participants led to mispricing of long-term carbon costs.
- Uncertainty & unpredictability: Uncertainty over the future price of allowances at an EU-wide level, following historic unpredictability.

Figure 5 2010 EU ETS Carbon Price Forecast for 2020.



Source: HM Treasury, 2010

Source: HM Treasury, 2011

In 2010, when UK authorities adopted the CPF decision, projections for the EU carbon price in 2020 varied widely, with estimates ranging from £20 to £36 per tonne. The significant variations in carbon price forecasts in 2010 for the 2020 period underscored the uncertainty over the future price of EUAS (See Fig. 5).

According to a UK government consultation, this reflects "*underlying market and regulatory uncertainty, including the timing, method and amount that the EU ETS cap might be tightened.*" This context of the EU carbon market in 2010, proved to be an important rationale behind the introduction of the CPF.

UK's legally binding emissions reduction targets

One key reason for the CPF introduction was the binding obligation imposed by the Climate Change Act 2008, which required the government to demonstrate progress in decarbonising the economy (UK Parliament, 2008). This Act set long-term goals for reducing GHG emissions by 80% by 2050, with interim 5-year carbon budgets to ensure ongoing progress. Under the second carbon budget (2013-2017), the UK needed to cut emissions by 236 $MtCO_2e$ compared to the first budget (2008-2012).

The electricity sector, where a transition from coal to gas was straightforward, presented an immediate opportunity to deliver on this requirement (Newbery et al., 2018). However, the low prices on the EU carbon market threatened the effectiveness of these goals. Hence, the sector's low-hanging fruit potential for rapid emissions reduction formed the rationale behind the UK's decision to target the electricity sector with the CPF policy.

Beyond addressing these two challenges the CPF also posed additional benefits for the UK government. Outlined explicitly was its aim to stimulate the transition and fund low-carbon investment, with the HM Treasury/HMRC projecting that the CPF could drive investments of between £30 and £40 billion by 2030 (2011).

The literature outlines multiple benefits of carbon price floors, but it is important to distinguish between market-wide price floors and national price floors within a general system. In general, price floors are implemented across market-wide systems, equally regulating all participants. However, the EU's political economy and the EU ETS architecture presents a unique situation whereby even though the EU ETS is an EU-wide market – regulated by the EU, individual MSs still have the freedom to implement complementary national policies in their respective domestic jurisdictions. This additional complexity implies that the benefits of an EU-wide CPF may differ from those of a national UK CPF. Similarly, the rationale behind implementation, motivating aims and impacts may also differ depending on the national circumstances.

Taking into account this distinction, the table below outlines the theoretical potential benefits of a carbon market price floor that underpin the rationale behind its introduction (without prejudice to the presence of associated costs and inconveniences) .

Table 5. Benefits of a Carbon Price Floor

	Benefit	Description
Benefits Applicable to Both National and Broader Carbon Price Floors	**Provides Investment Certainty**	Increases predictability of allowance prices in cap-and-trade systems, particularly in times of economic fluctuation, making it easier for businesses to make long-term investment decisions aimed at decarbonising their operations (Borenstein et al., 2019).
	Reduces Price Volatility and Risk	Prevents extreme price fluctuations in periods of market or policy changes, and creates a more stable environment (Hintermayer, 2020; Flachsland et al., 2020). Allows for effective hedging to manage the financial risks associated with fluctuating carbon prices by locking in future prices through contracts (Tietjen, Lessmann and Pahle, 2021).
	Guarantees a Minimum Return on Emissions Reductions	Guarantees a minimum return on long-term emissions reduction investments by ensuring that the carbon price will not fall below a set level (Newbery, et al., 2018) and hence ensure that investments remain viable.
	Clear Regulatory Intentions	Provides a strong signal of a government's long-term aims and whether or not other reforms are likely to gain pace reassuring investors.
	Facilitates Ambitious and Additional Emissions Reductions	Allows for greater emissions reductions when allowances prices are lower than expected. If market prices fall or abatement costs decrease, it ensures that emissions do not rise again by maintaining a minimum price for carbon, incentivising continued reductions (Wood and Jotzo, 2011; Abrell, Kosch and Rausch, 2019).
	A Hybrid System Increases Efficiency	Hybrid instruments, which combine elements of both quantity-based systems (like the ETS) and price-based mechanisms (such as a carbon tax), are more efficient than using either system alone (Newbery et al., 2018). A hybrid approach offers greater flexibility, allowing adjustments to market conditions while maintaining strong decarbonisation incentives. These arguments are based on the economics of instrument choice under uncertainty (Roberts and Spence, 1976; Pizer, 2002; McKibbin, Morris and Wilcoxen, 2009).
Benefits Specific to National Carbon Price Floors within a Broader System	**Demonstrates Climate Leadership**	A national carbon price floor, like the UK's, can demonstrate climate leadership, and positions the country as a leader in global climate action, increasing political influence (Newbery et al., 2018). This leadership can also bring in additional foreign investment in line with the theory of the first mover advantage.
	Low Regret Policy	It addresses the risk of a too-low carbon price in the absence of stronger EU ETS reforms, regardless of the pace of EU reforms (Newbery et al., 2018).
	Contributes to meeting Ambitious National Targets	In the case of the UK, the CPF helps achieve the legally binding ambitious target set by the Climate Change Act 2008, which aims to reduce greenhouse gas emissions by 80% by 2050 (HM Treasury, 2011).
	Easier Implementation at a National Level	Implementing at the national level is generally more straightforward than coordinating a broader EU-wide price floor across multiple member states. National carbon price floors allow countries to act independently of slow-moving international negotiations, tailoring the policy to their specific needs and political contexts (Newbery et al., 2018).
	Generates Revenue for National Governments	It can generate additional revenue through mechanisms like the Carbon Price Support (CPS), which acts as a top-up tax on carbon. These revenues can be used to fund clean energy projects, offset the costs of decarbonisation, or support social welfare programmes to mitigate the impact of higher energy prices on vulnerable groups (Flachsland et al., 2020).
	Allows for Narrower Focus	A national CPF allows the country to target specific sectors. The national carbon price floor allowed the UK to target specifically the power generation sector. By making carbon-intensive electricity generation (e.g., coal) more expensive, it can encourage a shift to cleaner energy sources (Leroutier, 2022).

Source: ERCST, based on sources indicated in the table

Legal framework and administration

The pieces of legislation implementing the UK CPF are the following:

- Finance Act 2011 (Budget 2011): Introduced the CPF and CPS rates,
- Finance Act 2013 (Budget 2013): Further amended provisions relating to the CPF, particularly with regard to setting and adjusting the CPS rates.
- Climate Change Levy (General) Regulations 2001: These regulations were amended to introduce the CPF and incorporate the CPS rates in line with the Finance Acts.

The involved administrations are:

- HM Treasury is tasked with the proposal and implementation of the CPF and CPS
- The administration of the CPF is overseen by HM Revenue & Customs (HMRC). The CPS rates are applied to the carbon content of fossil fuels used in power generation, and the tax is collected alongside other fuel duties.

3.2. Instrument effectiveness, efficiency and market impacts

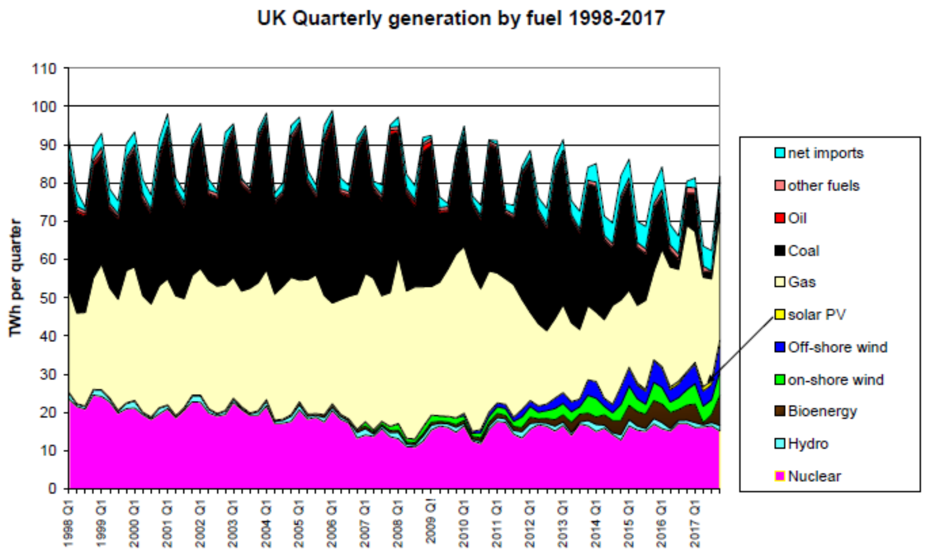
Effectiveness

Upon its introduction, the CPF evoked mixed reactions from industry and environmental groups. Some environmental organisations commend the CPF's overall objective, they have been critical of its implementation (Carbon Brief, 2016), while industry representatives posit that it has placed UK businesses at a disadvantage in the global market. Additionally, consumer advocates have expressed concerns about potentially increased costs for billpayers (Hirst, 2018). The Confederation of British Industry (CBI) welcomed the CPF but emphasised the need for its coordination with other measures to avoid creating a fragmented policy landscape (CBI, 2014). Similarly, the Renewable Energy Association and many energy companies supported the CPF but urged a commitment to extend it beyond 2020 to provide greater certainty to investors (Hirst, 2018).

Notwithstanding, the CPF can be deemed as highly effective with respect to its impact on emissions reduction in targeted sectors and the energy mix. The stable and predictable price signal created by the CPF was crucial in dispatching low-carbon electricity generation, and supporting the expansion of wind, solar, and natural gas capacity.

Preliminary analysis conducted after the implementation already indicated that the price floor had contributed to the phase-out of coal in the UK power system (IEA, 2016; Edenhofer et al., 2017). In the 2017 budget, the Treasury stated that it was “confident” that the Total Carbon Price was set at the right level, and would continue to target a similar total carbon price until unabated coal was no longer used (HM Treasury, 2017).

Figure 6 Fuel mix in UK electricity generation 1998-2017.



Source: Newbery et al. 2018

It should be noted that the UK's reduction in carbon-intensive power sources cannot be attributed solely to this policy. This sector falls under the influence of a wider Electricity Market Reform, which includes other key components such as a capacity market to ensure sufficient backup for intermittent renewable energy, Contracts for Difference (CFDs) to support investment in renewables, Emission Performance Standards to prevent the construction of new coal-fired plants without Carbon Capture and Storage (CCS), in conjunction with other EU influences such as the EU's Large Combustion Plant Directive regulation. Therefore, the CPF's effectiveness of emission reduction must be assessed within the broader context of the UK's comprehensive energy policy package.

Leroutier (2022) accounts for these other factors and policies, and his findings indicate that the CPF, through its CPS mechanism, led to a reduction of 143 -191 $MtCO_2e$ over the 2013–2017 period. This estimated reduction represents up to 60% to 81% of the 236 $MtCO_2e$ emissions reduction target the UK was obliged to meet over the same period. The same findings outline how from 2012 to 2017, the share of coal in electricity generation decreased from 40% to 7% and power sector greenhouse gas emissions decreased by 57%. These results demonstrate the CPF's effectiveness in stimulating long-term changes in the UK's energy mix, as well as its role in helping the UK meet its climate targets.

The CPF's effectiveness was however restricted by the government's decision to cap the CPS rate at £18/tCO_2 from 2016-17 to 2019-20 due to concerns over its costs (see more details under the efficiency section). At the time the Committee on Climate Change (CCC) examined the impact of the freeze on reducing emissions concluding that its impact would be marginal. However, they also concluded that the price freeze was not conducive to CPF's original aim of providing a clear and consistent signal to investors. The freeze limited the CPF's ability to push further investments in low-carbon infrastructure. Leroutier (2022) goes as so far as to argue that due to the freeze and the disparity between expected and actual carbon prices, the role of the CPS shifted from its original design to essentially evolve into a carbon tax, with rates being determined several years ahead of implementation.

Operational and Market Efficiency

The static efficiency of the UK CPF refers to its ability to achieve short-term emissions reductions at a reasonable cost. Overall, the price floor rendered coal generation increasingly more expensive/uneconomical compared to gas. This provided the right short-term price signal in terms of dispatching low carbon electricity generation.

Notwithstanding, the efficiency of the CPF has also been contested, particularly regarding its impact on energy prices.

Impact on household costs

The extra expenses incurred due to the CPF have been paid by consumers, resulting in elevated electricity bills for both households and businesses. The table below outlines the estimated increase in electricity bills, according to which households experienced an increase of £14/year rising to £30/year in 2020. However, there have been a number of policy changes since the time of the research which are likely to have impacted the estimates of the 2020 and 2030 costs.

Table 6. Estimated impact of the CPF on electricity bills (£/year)

	2014	2020	2030 [1]
Average household	14	30	80
Small business	1,100	2,300	5,600
Medium sized business	47,000	97,000	230,000
Large business (including EEI compensation)	149,000	356,000	-
Large business (no EEI compensation)	427,000	890,000	-

Source: House of Commons Briefing Paper, 2016

Impact on Businesses and Price Freeze

From 2011-2014, the EUA price fluctuated between €5-10/tCO_2, and so only a year after the implementation of the CPF, calls for a price floor freeze started being voiced. In February 2014, the Confederation of British Industry (CBI) wrote to the Chancellor to address their concerns that the CPF was harming competitiveness stating, "*important tool to promote investment but with continuing disappointment with the level of the EU ETS price, the CPF puts UK industry, particularly those that are energy-intensive and trade-exposed, at a considerable competitive disadvantage*" (CBI, 2014).

As the market price for EU carbon allowances continued to falter, the amount of price support required to meet the floor price increased, nearly doubling each year. The day before the price support was set at £18.08/tCO_2 for 2015, the futures price for 2015 settled at ~£3.3/tCO_2, meaning UK energy generators faced carbon costs six times higher than their European counterparts. This created a dilemma for the Treasury, as it resulted in higher-than-expected revenues from the EU ETS, but also imposed significantly higher costs on British industry compared to its European competitors. The UK Government acknowledged this potential knock-on effect and proposed compensation measures for companies affected by these costs (Newbery et al., 2018; Hirst, 2018 p. 19).

In that light, in the 2014 Budget, the Chancellor of the Exchequer announced that it would cap the CPS rate at £18/tCO_2 from 2016-17 to 2019-20. In the 2016 Budget, this was extended up to 2021 (HMRC, 2017). The justification was that "*EU ETS carbon prices are now substantially lower than was expected when the CPF was introduced. If kept in place, the current CPF trajectory would cause a large and increasing gap between the carbon price faced by UK energy users and those faced abroad*" (HMRC, 2014)[12]. The Government stated that British businesses could save "*up to £4 billion by 2018-19 over £1.5 billion in 2018-19 alone, and £15 off a typical household energy bill in the same year*" (HM Treasury, 2014)[13]. Despite these accomplishments, the CPF's effectiveness has been constrained by the implemented price freeze (see more under the effectiveness section).

Innovation and Long-Term Impact

The dynamic efficiency of the CPF focuses on its ability to drive long-term emissions reduction and long-term innovation in low-carbon technologies.

The CPF's ability to provide long-term certainty has been important for unlocking investment in renewables and carbon capture technologies. In addition, it has also helped to avoid a carbon lock-in, where industries remain reliant or remain susceptible to falling back to high-carbon technologies due to a lack of a strong carbon price signal.

By the end of its lifetime in 2020, the CPF had reinforced the carbon price signal, to an extent where carbon-intensive energy sources became less viable than their renewable counterparts. In fact, coal power plants reduced their output throughout the CPF's lifetime up to the point where the last coal power plant was recently shut down in 2024 (BBC News, 2024).

The price floor rendered coal generation increasingly more expensive/uneconomical compared to gas and provided an incentive to invest in low-carbon technologies, ultimately contributing to the complete phase-out of coal power plants and avoiding carbon lock-in. The price floor also meant that the UK could do away with the need for coal phase out policies that can involve sizeable compensation payments.

3.3. Interaction with and impacts on the EU ETS

The UK CPF interacted in complex ways with the EU ETS, particularly given its role in setting a higher minimum carbon price exclusively in the UK compared to the broader EU market. While the CPF aimed to provide more certainty and stability in the UK carbon pricing market, its introduction raised questions about market harmonisation, competitiveness, and potential price distortions within the EU ETS.

Impact on EUA Demand

One significant issue associated with the CPF was its potential to affect the demand for EU Allowances (EUAs) within the EU ETS. Since the CPF increased the cost of high-carbon energy in the UK, it led to a reduction in coal use and other carbon-intensive activities. As a result, UK power generators reduced their demand for EUAs, leading to lower demand for carbon credits in the EU ETS (Leroutier, 2022). This reduction in EUA demand can have a depressing effect on EUA prices across the broader EU market, undermining the effectiveness of the EU ETS in achieving Europe-wide emissions reductions (e.g., Fischer et al., 2020).

[12] A Tax information and impact note (TIIN) published by HM Revenue and Customs (HMRC) alongside the 2014 budget, explained
[13] Budget 2014, HC 1104, March 2014, para 1.106

This could have contributed to lower EUA prices at a certain point. However, the overall impact on the EU ETS has been limited by the fact that the CPF is a UK-specific policy, and its effects are most pronounced within the UK market.

Policy Overlap, waterbed effect, and carbon pricing fragmentation

Some stakeholders raised concerns that the CPF led to a potential waterbed effect. This phenomenon occurs when unilateral national policies, reduce emissions in one country but fail to lower overall EU-wide emissions due to the fixed cap set by the EU ETS. This means that while emissions fell in the UK, surplus allowances remained available for use in other EU countries, potentially allowing emissions to rise elsewhere.

The CPF's existence outside of the formal EU ETS framework also raised concerns about further fragmentation in carbon pricing across the EU. The CPF's unilateral nature contrasts with the EU ETS's main aim of harmonising carbon pricing across member states. If countries pursue their own carbon pricing mechanisms without coordination, it can lead to an over-complex and multi-layered policy system. Such a system is prone to market distortions that are more difficult to identify and thus tackle.

Inspired by the UK's CPF approach some have argued for the implementation of a European-wide CPF. In theory, apart from tackling the market failures CPF aimed to solve, an EU-wide price floor could also avoid further policy fragmentation by creating a more consistent and predictable carbon price across all EU member states. However, reaching a unanimous agreement on an EU-wide CPF has proven economically and politically difficult, as distributional effects vary between countries. For example, France's nuclear sector would have benefited from higher carbon prices, while Germany and Poland's coal sectors would have faced significant challenges (Newbery et al., 2018).

4. Sustainable Aviation Fuel blending quotas in Norway

4.1. Instrument description and rationale for its introduction

Instrument overview

Announced in 2017, Norway's Sustainable Aviation Fuel (SAF) blending quota is a regulatory instrument targeting the aviation sector, specifically fuel suppliers and aircraft operators. The quota mandates a minimum percentage of SAF - of advanced biofuels specifically - to be blended with conventional jet fuel for flights departing from Norwegian airports, applicable as of January 2020.

Norway was the first country to introduce a SAF blending quota, setting a worldwide precedent (ECAC, 2023). This approach has inspired similar measures at the EU level, notably shaping the development of the ReFuelEU Aviation[14] initiative agreed upon in 2023.

The instrument establishes a blending obligation quota of at least 0.5% from 1 January 2020[15], with a longer-term target in the National Transport Plan 2018- 2029 to reach 30% by 2030 conditional upon sufficient technical production capacity and thus market availability of SAF (however this is not translated into legislation). The quota applies to all aviation fuel suppliers operating at Norwegian airports.

The SAF blending quota works by requiring fuel suppliers to incorporate a specified percentage of SAFs into their overall fuel supply. Airlines are then obligated to use this SAF-blended fuel for flights departing from Norwegian airports[16]. This creates a guaranteed market for SAF, stimulating production and uptake. The instrument focuses on promoting biomass-based SAFs, leveraging Norway's abundant forest resources and aligning with the country's broader bioeconomy strategy.

To ensure compliance, the policy includes a monitoring and reporting system. Fuel suppliers must document their adherence to the blending mandate, providing transparency in the SAF supply chain. This system is crucial for verifying that the mandated SAF percentages are indeed being incorporated into the fuel mix at Norwegian airports.

While the initial blending requirement is modest, Norway plans to gradually increase the quota in the run up to 2030. However, the mandate's path to reaching 30% by 2030 has not been ex-ante defined (Avinor, 2020).

In practice, the current mandate in Norway stands at the initial 2020 level of 0.5%. Although the Norwegian government has on several occasions considered and consulted on the potential increase of the mandate level (e.g. to 2% from mid-2023), the decision to increase it has been delayed (QCINTEL, 2023a, 2023b, 2024). The Norwegian government has shown flexibility in implementing the quota, maintaining the 0.5% level despite initial plans for increases (QCINTEL, 2024). This adaptability reflects the challenges in SAF availability and production capacity, demonstrating a balance between ambition and practical constraints in the nascent SAF market.

[14] Regulation (EU) 2023/2405 of the European Parliament and of the Council of 18 October 2023 on ensuring a level playing field for sustainable air transport (ReFuelEU Aviation)
[15] It is worth noting that in the earlier stage of policy development a more ambitious initial mandate was foreseen, with the Norwegian Parliament adopting in June 2017 the National Transport Plan for the 2018-2019 period that included a proposal for a mandatory drop-in requirement of 1% aviation biofuel starting in 2019 (Kalimo, H., et al., 2018).
[16] Oslo Gardermoen Airport was the world's first airport to offer regular SAF availability for all flights. The airport has since expanded its SAF operations, with Norwegian Air Shuttle and Scandinavian Airlines (SAS) being the primary airlines using SAF.

It is important to note that the SAF mandate came into effect just as aviation was grounded due to COVID-19. The global pandemic led to a significant reduction in air travel, which impacted fuel demand and may have influenced the decision to maintain the blending mandate at 0.5%.

The SAF blending quota is part of a broader strategy to decarbonize the aviation sector in Norway. It complements other measures such as the country's participation in the EU Emissions Trading System and its long-standing CO_2 tax on fuel for domestic aviation. By creating a stable demand for SAF, the quota aims to drive investment in SAF production facilities and accelerate the transition to more sustainable aviation practices.

Norway's approach aligns with broader European efforts to promote SAF use. The EU's ReFuelEU Aviation initiative, in particular, introduces EU-wide harmonized obligations on fuel suppliers and aircraft operators to scale up SAF usage.

Sustainable Aviation Fuel types

Sustainable Aviation Fuels (SAFs) are fuels used to power aircrafts with a lower carbon footprint compared to conventional jet fuels. They can be produced in different ways using different feedstock types. The main types include:

- **Bio-based SAFs**, using biomass-based feedstocks such as used cooking oil, animal fats, and agricultural residues, as well as lignocellulosic biomass like wood residues and energy crops. Algae can also be cultivated to produce oils that are converted into SAFs.
- **Power-to-liquid (PtL) or electrofuels (e-fuels)**, produced by using renewable/low-carbon electricity to split water into hydrogen and oxygen, and then combining the hydrogen with CO_2 (extracted from the air or from industrial processes) to create liquid hydrocarbons. Their manufacturing requires significant amounts of electricity (hence the name).

There is a need for green or blue hydrogen not only in the e-fuels production process, but also in the bio-based process in order to upgrade the resulting complex hydrocarbon to the final product.

While Norway is not an EU member, it aligns its policies with EU regulations due to its membership in the European Economic Area. The EU-wide SAF blending mandates can thus be expected to be legislated in Norway, which would see modifications to the current Norwegian mandate[17].

Indeed, the 2023 Norwegian Aviation Strategy mentions participation in the EU quota system as a key instrument in the transition towards more climate-friendly aviation (Norwegian Govt., 2023a), with the government subsequently stating its intention to increase the current mandate in line with ReFuelEU Aviation, meaning an increase of the mandate to 2% from 2025 (Norwegian Govt., 2023b).

It is to be seen whether modifications will also entail that the scope of the mandate be broadened to cover both bio-based and synthetic SAF, rather than only advanced biofuels.

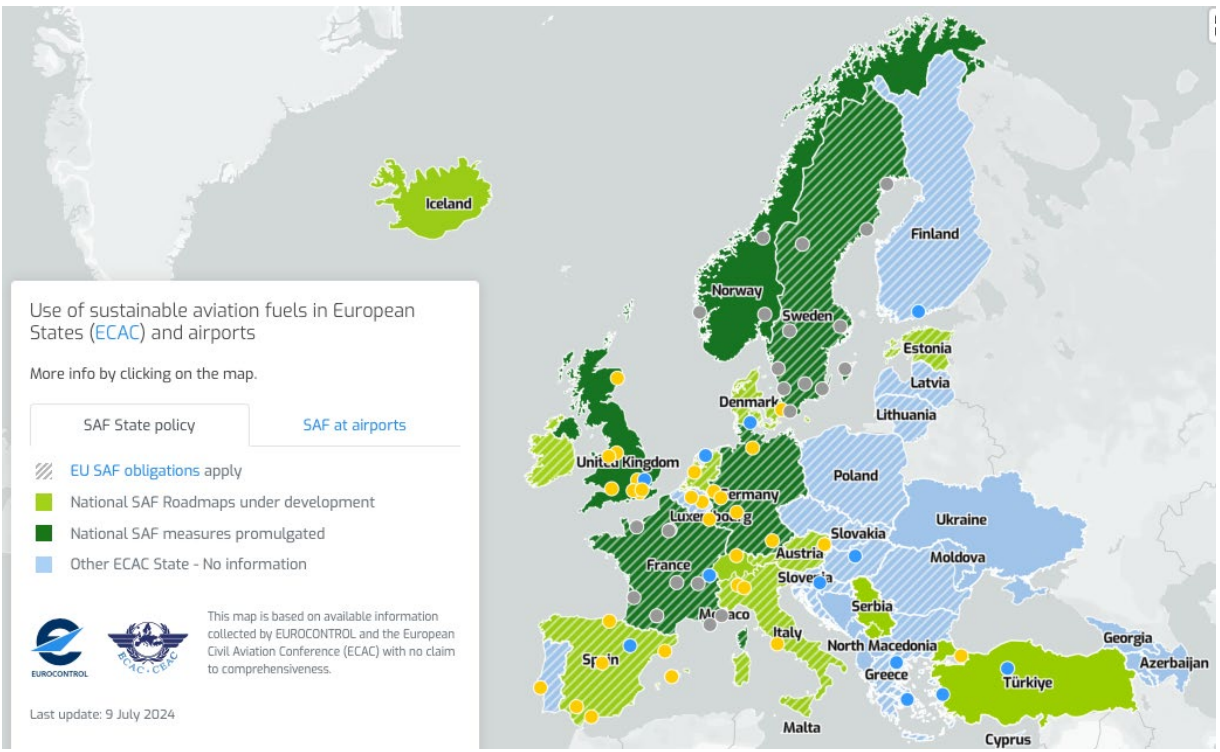
[17] Through the European Economic Area Agreement, most of the regulations for SAF and green fuels that are adopted by the EU are also expected to be legislated in Norway, however with a delay, which can also impact the timeline of new production projects (DNV, 2023).

EU and national SAF blending requirements

The EU's ReFuelEU Aviation initiative, has set requirements for aviation fuel suppliers to gradually increase the share of SAF blended into the conventional aviation fuel supplied at EU airports. Starting in 2025, the mandatory EU-wide SAF minimum supply share will amount to 2%, scaling to 6% by 2030, 20% by 2035, gradually reaching 70% by 2050. The initiative is expected to drive SAF demand and investment in production capacity. In addition to the overall SAF blending quota, ReFuelEU Aviation has also introduced a synthetic aviation fuel sub-mandate that will start at 1.2% in 2030 and gradually increase to 35% in 2050.

At country level, in addition to Norway, several European countries, including France, Germany, Sweden and the UK have introduced national SAF blending quotas.

Figure 7 Map on sustainable aviation fuels in Europe



Source: EUROCONTROL-ECAC map on the use of SAF in European States, https://www.eurocontrol.int/article/sustainable-aviation-fuels-saf-europe-eurocontrol-and-ecac-cooperate-saf-map

Rationale and Objectives

Norway's implementation of SAF blending quotas is driven by a multifaceted rationale aimed at addressing specific issues in the aviation sector and broader climate goals. The primary objective is to reduce greenhouse gas emissions from aviation, which is one of the most challenging sectors to decarbonize.

The SAF blending quota addresses several challenges:

1. Lack of demand certainty: The aviation fuel market is dominated by conventional jet fuel, creating little incentive for producers to invest in SAF production. The quota creates a guaranteed market for SAF, reducing investment risks

2. Price disparity: SAF is currently more expensive than conventional jet fuel. The quota helps to create a level playing field by ensuring all operators face the same requirement, thus distributing the cost across the industry

3. Technological lock-in: The aviation industry has long relied on fossil fuels, creating a technological lock-in. The quota encourages innovation and investment in SAF production technologies.

The theoretical rationale for this type of instrument is based on the concept of market-based environmental regulation. By setting a mandatory blending requirement, the government creates a predictable demand for SAF, which is expected to stimulate supply and drive down costs through economies of scale and technological improvements over time.

The stated objectives of the SAF blending quota, as outlined in Norway's climate action plan, include:

1. Reducing greenhouse gas emissions from the aviation sector

2. Stimulating the production and uptake of sustainable aviation fuels

3. Fostering innovation in clean aviation technologies

4. Contributing to Norway's overall climate goals and international commitments

Additionally, the policy aims to position Norway as a leader in sustainable aviation, potentially creating new economic opportunities in SAF production and related industries (forestry, agricultural waste management, biofuel refineries, biotechnology firms, logistics). The gradual increase in blending requirements over time is designed to allow the industry to adapt and scale up production capacity, while also providing a clear signal for long-term investment in SAF technologies.

It is worth noting that, at the current state of affairs, an increase in blending requirements, while advancing decarbonization goals, would impact market efficiency and price level due to the Sustainable Aviation Fuel market's structural constraints. Policymakers should carefully weigh these economic and societal implications when evaluating such mandates.

Legal Framework and Administration

Norway's SAF blending quota is established within a comprehensive legal framework that aligns with the country's climate action goals and international commitments. The policy is primarily governed by the National Transport Plan for 2018-2029, adopted by the Norwegian Parliament in June 2017 (Kalimo, H., et al., 2018). This plan introduced the proposal for a mandatory 1% aviation biofuel requirement starting in 2019, with the intention to increase to 30% by 2030, subject to sufficient production capacity.

The implementation and administration of the SAF blending quota fall under the purview of the Norwegian Ministry of Climate and Environment, working in close collaboration with the Ministry of Transport. These ministries are responsible for developing and refining the regulatory framework, setting targets, and ensuring compliance with the mandate.

The Norwegian Civil Aviation Authority (NCAA) plays a crucial role in overseeing the practical implementation of the quota. It is tasked with monitoring compliance, collecting data on SAF usage, and reporting on the progress towards meeting the blending targets. The NCAA works closely with airport operators, particularly Avinor, the state-owned company that operates most of Norway's airports, to ensure the availability and proper handling of SAF-blended fuels.

Other key entities involved in the process include: the Norwegian Environment Agency, which provides scientific advice on the environmental impacts and sustainability criteria of SAF (Norwegian Govt., 2021); fuel suppliers and distributors, who are directly responsible for meeting the blending requirements; airlines operating in Norway, who are obligated to use the SAF-blended fuel for flights departing from Norwegian airports (DNV, 2023).
The implementation of the quota involves a multi-step process:

1. Setting of annual blending targets by the Ministry of Climate and Environment.
2. Certification of SAF suppliers and their products to ensure compliance with sustainability criteria.
3. Monitoring of fuel supply and blending at airports by the NCAA and Avinor.
4. Reporting by fuel suppliers on the volume and type of SAF supplied.
5. Verification of compliance and potential enforcement of penalties for non-compliance.

It's worth noting that while Norway has been at the forefront of SAF policy, the implementation has faced challenges. Initial plans to gradually increase the target have been postponed, and the current 0.5% mandate represents a more cautious approach (QCINTEL, 2024). This demonstrates the flexibility built into the legal framework, allowing for adjustments based on market realities and technological readiness.

4.2. Instrument effectiveness, efficiency, and market impacts

Effectiveness

Norway's Sustainable Aviation Fuel (SAF) blending quota policy has shown limited effectiveness in achieving its initial goals. The policy, which mandated a 0.5% SAF blend in 2020, has not progressed as rapidly as initially planned. Despite the original intention to increase the mandate over time (1% by volume in 2021 to 30% in 2030), Norway has announced that it will continue to implement the current 0.5% SAF blending mandate, delaying the planned increase (QCINTEL, 2024).

This delay in increasing the SAF quota suggests that the policy has faced challenges in meeting its intended targets. The Norwegian government's initial ambition was to gradually increase the SAF blend to 30% by 2030, with all short-haul flights becoming 100% electric by 2040 (WEF, 2020). However, the maintenance of the 0.5% mandate may indicate that the policy's effectiveness in driving rapid SAF adoption has produced mixed results. However, given that the scheme has been implemented relatively recently, it may be too early to fully assess its effectiveness. The initial implementation coincided with the COVID-19 pandemic, which significantly impacted aviation activity, potentially affecting the policy's outcomes.

The slow progress in increasing the SAF blend can be attributed to several factors. One key limitation is the limited availability of SAFs at competitive prices, due to challenges with respect to scaling up production and reducing the price gap between fossil and sustainable aviation fuels. The challenge with bio-based aviation fuels in particular that the Norwegian instrument focuses on is to obtain large enough quantities of sustainable biomass, at an acceptable cost and with use of available infrastructure (Avinor, 2021). In general, SAF production costs remain significantly higher than conventional jet fuel, with estimates suggesting that SAF is currently 1.5-6 times more expensive than fossil fuel (EAFO website). This price disparity has likely contributed to the reluctance in increasing the blending mandate, as it could potentially lead to higher costs for airlines and passengers.

Moreover, aviation was granted a considerable amount of free allowances in the past under the ETS. Aviation will only pay for the entirety of their emissions by 2026. Hence, it's not surprising that conventional kerosene is way more competitive. This dynamic complicates the interaction of the ETS and the SAF quota in this case study, as the cost incentives to switch to SAF are reduced when airlines are not fully paying for their emissions.

Given the limitation of the ETS, it's also not surprising that just addressing the demand was insufficient for making available more quantities of SAF (hence, the quota remained as low as it is). One could argue that, with a scheme supporting the build-up of supply, the market ramp-up effect would have been bigger. Supporting the supply side could involve incentives for producers, subsidies, or investments in production infrastructure to increase SAF availability.

Despite the slower-than-anticipated progress, Norway's policy has still positioned the country as a pioneer in SAF adoption. The implementation of even a 0.5% mandate has created a baseline demand for SAF, potentially stimulating investment in production capacity and research. However, the policy's effectiveness in driving significant emissions reductions from the aviation sector has been limited due to the low blending percentage.

It's worth noting that Norway's approach aligns with broader European efforts to increase SAF usage. The European Union's ReFuelEU Aviation initiative sets EU-level harmonized obligations on fuel suppliers and aircraft operators for scaling up SAF use. This suggests that while Norway's policy may not have achieved its initial ambitious targets, it has contributed to a wider momentum towards SAF adoption in European aviation.

In conclusion, while Norway's SAF blending quota policy has established a framework for sustainable fuel use in aviation, its effectiveness so far in driving rapid SAF adoption and significant emissions reductions has been limited. However, it may be too early to definitively assess its effectiveness, and ongoing evaluation will be necessary to determine its long-term impact on emission reductions and industry practices. The delay in increasing the blending mandate beyond 0.5% - influenced by the COVID-19 exogenous shock - indicates that the policy has faced challenges in achieving its more ambitious goals, highlighting the complexities involved in transitioning to sustainable aviation fuels. This offers valuable insights for future sustainable aviation fuel initiatives. While mandates can provide a framework, they may prove insufficient on their own to drive rapid SAF adoption. A more effective approach would involve implementing a comprehensive policy strategy that goes beyond simple blending requirements and addresses production, infrastructure, and economic barriers to effectively accelerate SAF adoption in aviation. Additionally, policymakers must recognize that the effectiveness of national policies can be limited by external factors such as global SAF availability and cost. To address these challenges, fostering international cooperation is crucial to tackle supply chain issues and promote the development of a global SAF market.

Operational and Market Efficiency

Norway's SAF blending quota policy has faced challenges in achieving optimal operational and market efficiency. The policy's static efficiency, which relates to its operational effectiveness and cost of emission reduction, has been limited by several factors.

The cost-effectiveness of emission reductions through the SAF mandate has been constrained by the high production costs of sustainable aviation fuels. This price disparity has likely contributed to the government's decision to maintain the 0.5% blending mandate rather than increasing it as initially planned.

The policy's market exposure has been somewhat limited due to the low blending percentage. At 0.5%, the mandate creates a baseline demand for SAF but does not significantly impact overall market dynamics in the aviation fuel sector. This limited market exposure may have reduced the policy's ability to drive down SAF production costs through economies of scale and market competition.

Distributive effects on competition have been minimized due to the uniform application of the mandate across all fuel suppliers. However, the policy may have created additional administrative costs for both businesses and national administrations in terms of compliance monitoring and reporting (WEF, 2020).

The SAF blending quota policy's impact on market signals has been modest. While it has established a guaranteed market for SAF producers, the low blending percentage has not provided strong enough signals to stimulate significant investment in production capacity or drive rapid technological advancements.

Given the limitation of the ETS, where aviation has been granted free allowances and will only pay for their emissions entirely by 2026, conventional kerosene remains significantly more competitive. This reduces the economic incentive for airlines to switch to SAF, affecting the efficiency of the policy.

Also, in terms of transparency, it's important to mention that the mandates came into effect just as aviation was grounded due to COVID-19. The pandemic led to unprecedented reductions in air travel, possibly undermining the policy's initial market impact and complicating assessments of its efficiency.

To enhance the policy's operational and market efficiency, Norway could consider a swift alignment of its approach and targets more closely with broader European initiatives[18]. The European Union's ReFuelEU Aviation regulation sets EU-level harmonized obligations for scaling up SAF use, which could create a more efficient and competitive market for sustainable aviation fuels across Europe.

In conclusion, while Norway's SAF blending quota policy has established a framework for sustainable fuel use in aviation, its operational and market efficiency has been limited by high production costs, low blending percentages, and delays in increasing the mandate. Addressing these challenges will be crucial for improving the policy's effectiveness and driving the transition to more sustainable aviation practices.

Innovation and Long-Term Impact

Norway's SAF blending quota policy, despite its current limitations, has the potential to drive innovation and create long-term impacts in the sustainable aviation fuel industry. The policy's initial implementation, even at a modest 0.5% blend, has established a foundation for future growth and technological advancements.

One of the key areas where the policy could spur innovation is in SAF production technologies. As demand for SAF increases, even incrementally, it creates incentives for producers to invest in research and development to improve production efficiency and reduce costs. This aligns with the broader European goal of scaling up SAF production.

The long-term impact of Norway's policy extends beyond its borders, potentially influencing global SAF adoption. As one of the first countries to implement a SAF mandate, Norway's experience provides valuable insights for other nations considering similar policies. This pioneering role could contribute to the development of best practices in policy design and implementation for SAF adoption worldwide.

Furthermore, the policy has the potential to drive innovation in feedstock diversification. Currently, SAF can be produced from various sources, including advanced biofuels and synthetic e-Fuels. The mandate, even at its current level, encourages exploration of different feedstock options, potentially leading to breakthroughs in more sustainable and cost-effective SAF production methods.

To fully realize the innovation potential and long-term impact, Norway may need to consider increasing the mandate as originally planned. For instance, the European Union, which is targeting progressively increasing SAF blending mandates up to 70% by 2050, is setting more ambitious targets that could drive faster innovation through its ReFuelEU Aviation initiative.

[18] While Norway is not an EU member, it aligns its policies with EU regulations due to its membership in the European Economic Area. Therefore, the EU SAF blending mandates are also expected to be legislated in Norway, which would see modifications to the current Norwegian mandate, however, with a delay, which can also impact the timeline of new production projects (DNV, 2023).

It may be too early to determine whether the policy is effective in driving innovation. After all, the scheme has only relatively recently started. The full impact on technological advancements and industry practices may become clearer over a longer time horizon.

The policy's long-term impact could also be enhanced by focusing on specific SAF types. For instance, Germany emphasized Power-to-Liquid (PtL) fuels as part of its National Hydrogen Strategy (EASA website). Maintaining the German PtL-quota within RED is being considered, although this may complicate reporting EU compliance. In larger aviation markets like Germany, having their own quotas may be easier, but this is speculative. Norway could consider similar targeted approaches, but the feasibility may vary due to market size and other factors.

In conclusion, while the current 0.5% mandate may seem modest, it has laid the groundwork for future innovation and long-term impacts in the SAF industry. By potentially increasing the mandate and focusing on specific SAF technologies, Norway can further strengthen its role as a catalyst for sustainable aviation innovation, contributing to global efforts to decarbonize the aviation sector.

4.3. Interaction with and impacts on the EU ETS

Norway's sustainable aviation fuel (SAF) blending quotas and the EU Emissions Trading System (EU ETS) interact in a complementary manner, reinforcing each other's objectives to reduce aviation emissions. The EU ETS covers around 75% of flights and 90% of emissions in and from Norway, providing a broad framework for emissions reduction (Avinor, 2020). Meanwhile, Norway's SAF mandate, which began with a 0.5% blending obligation in 2020, directly targets the carbon intensity of aviation fuel.

This dual approach creates a synergistic effect. The EU ETS puts a price on carbon emissions, incentivizing airlines to reduce their overall emissions, while the SAF mandate ensures a minimum uptake of low-carbon fuels. As airlines increase their use of SAF to meet Norway's quota, they simultaneously reduce their need for ETS allowances, potentially lowering their compliance costs under the EU ETS.

Moreover, Norway's participation in both schemes contributes to a more comprehensive approach to aviation decarbonization. The SAF mandate addresses the supply side by requiring fuel suppliers to blend in sustainable fuels, while the EU ETS tackles the demand side by incentivizing airlines to optimize their operations and invest in more efficient technologies.

This integrated approach also supports Norway's ambitious goal of fossil-free aviation by 2050. By combining the market-based mechanism of the EU ETS with the direct regulatory approach of SAF mandates, Norway is creating a robust policy framework that accelerates the transition to sustainable aviation while remaining aligned with broader European climate objectives.

While Norway's SAF blending quotas and the EU ETS generally complement each other, there are potential areas of overlap that could present challenges:

1. Cost burden: Airlines operating in Norway face a dual cost burden from both the EU ETS and increased fuel costs due to SAF mandates[19]. This could potentially lead to competitive disadvantages for Norwegian airlines compared to those operating in countries with less stringent regulations.

[19] However, this dual burden is lessened by a re-investment mechanism created by the latest EU ETS reform that sets aside 20 million allowances for aircraft operators from January 2024 to cover up to 100% of the cost difference for higher cost sustainable aviation fuel (SAF) production. This support is 'first come, first served' on an annual basis from January 2024.

Additionally, aviation has been granted a considerable amount of free allowances in the past. Aviation will only pay for the entirety of their emissions by 2026. Hence, conventional kerosene remains more competitive than SAF, affecting the incentive for airlines to switch fuels and complicating the interaction between the ETS and the quota.

2. Regulatory complexity: The interaction between Norway's national SAF quotas and the EU-wide ETS adds a layer of regulatory complexity for airlines and fuel suppliers operating across borders. This could increase compliance costs and administrative burden.

3. International flights: While the EU ETS currently covers only intra-EEA flights, Norway's SAF mandate applies to all fuel uplifted in Norway. This discrepancy could create complications for international flights and potentially lead to carbon leakage. For example, an airline flying from Oslo to New York must blend SAF with conventional fuel due to Norway's mandate. However, since the EU ETS does not cover this international route, the airline incurs higher costs without emissions trading benefits for the non-EEA portion. To avoid these costs, airlines might refuel in countries without SAF mandates, which can shift emissions rather than reduce them, leading to carbon leakage.

Given the limitations of emissions trading, it is also not surprising that just addressing the demand was insufficient for making available more quantities of SAF (hence, the quota remained as low as it is). One could argue that, with a scheme supporting the build-up of supply, the market ramp-up effect would have been bigger. This could involve financial incentives for producers or investments in production infrastructure to increase SAF availability and reduce costs.

Addressing these challenges will require careful policy coordination between Norwegian authorities and the EU to ensure that the SAF quotas and EU ETS work in harmony to achieve their shared goal of aviation decarbonization.

5. Concluding remarks

This chapter provides an overview of the three instruments, followed by concluding remarks and policy considerations.

Instrument overview

In what follows, we provide a three-paragraph summary of each instrument's effectiveness, efficiency and interaction with the EU ETS.

1. Spanish CfD scheme

The Spanish CfD scheme's ex-ante effectiveness (auction results with respect to awarded capacity) can be characterised as high initially (first two rounds), but diminishing to low with time (i.e. the reserve price in the 4th round was set at quite a low level and led to an undersubscribed auction). In terms of ex-post effectiveness (actual projects built thanks to the scheme), no facility as of today is actually connected to the scheme, as a result of the advent of the energy crisis soon after the 1st auction and the prevalence of high wholesale market electricity prices. Although awarded facilities have opted to renounce it, it can still be deemed as somewhat effective in promoting RE development: the scheme has provided a valuable "insurance/ fallback" policy that has helped project developers to secure project financing, thereby enabling investment decisions and continuity/stability of the project pipeline.

The Spanish scheme has been efficient in encouraging the deployment of least-cost RE technologies, however it has not provided incentives to facilities to stay within the scheme. The renouncing of the scheme by facilities in favour of selling to the market at high prevailing prices, most likely implies higher costs from a society point of view in terms of electricity prices compared to a scenario with flows through the scheme. Some adjustments to the REER design could further enhance its efficiency, such as for instance incorporating incentives or conditionalities to safeguard the awarded facilities' connection to the scheme. Notwithstanding, the scheme overall encompasses innovative design features, in particular incentives for participation in and exposure to the wholesale market (through a market adjustment factor), the treatment of negative market prices (zero hour tolerance), as well as elements to ensure a minimum level of competition that could inspire the design of other CfD schemes in the EU in the future.

CfDs, are not directly tied to carbon pricing, yet they indirectly interact with the carbon price. As more renewables enter the market thanks to CfDs, the demand for emissions-intensive power generation decreases, reducing the need for EUAs, all other things equal leading to a downward pressure on the carbon price. Lower carbon prices might in turn reduce the incentive for covered entities to decarbonise. Moreover, the impact of EU ETS price signals on investment decisions is dampened for projects benefiting from CfDs: because such schemes insulate RE developers from electricity market price fluctuations, they reduce developers' exposure to rising carbon prices under the EU ETS. This effect is somewhat lessened in the case of the Spanish scheme, through the inclusion in its design of a market adjustment factor. Overall, the interaction between CfDs and the EU ETS is complex, with both mechanisms aiming to reduce carbon emissions but through different pathways. The challenge is ensuring that both systems work in harmony to drive decarbonization without creating market distortions or over-subsidization. Careful policy coordination, including potential adjustments to the ETS cap and the design of CfD schemes, is critical for maximizing the effectiveness of both instruments in achieving climate goals.

2. ETS carbon price floor in the UK

The UK Carbon Price Floor (CPF), operational from 2013 to 2020, was effective in achieving its primary objectives. Introduced to support the EU ETS price signal, the CPF aimed to provide long-term certainty and maintain carbon prices at a level that would drive investment in cleaner technologies. Through its 'top-up' tax mechanism called the Carbon Price Support (CPS), which started at £4.94/tCO_2 in 2013, with intentions to reach £30/tCO_2 by 2020, the policy proved highly effective in driving emissions reductions. The CPF contributed significantly to decarbonisation targets, delivering 143-191 MtCO_2e reductions over 2013-2017, representing 60-81% of the UK's required emissions reduction for that period. This success was particularly evident in the power sector, where the stable price signal supported expansion of renewable energy and accelerated the phase-out of coal-fired generation.

The price floor rendered coal generation increasingly more expensive/uneconomical compared to gas. This provided the right short-term price signal in terms of dispatching less emitting generation, as well as the incentive to invest in low-carbon technologies. The operational efficiency of the CPF faced challenges, primarily due to competitiveness concerns: British energy generators encountered carbon costs up to six times higher than their European counterparts, leading to slightly increased electricity bills for both households and businesses. These pressures prompted the government to freeze the CPS rate at £18/tCO_2 from 2016-17 to 2019-20, limiting the policy's effectiveness in providing long-term price certainty. Despite these challenges, the CPF demonstrated strong dynamic efficiency by successfully encouraging investment in low-carbon technologies, ultimately contributing to the complete phase-out of coal power plants by 2024 and helping avoid carbon lock-in. The price floor also meant that the UK could do away with the need for coal phase out policies that can involve sizeable compensation payments.

The CPF's interaction with the EU ETS revealed complex market dynamics and raised several concerns. While effectively reducing UK emissions, the policy potentially affected EUA demand within the broader EU market and introduced the risk of a 'waterbed effect', where emissions reductions in the UK could be offset by increases elsewhere due to the fixed EU ETS cap. The CPF's existence outside the formal EU ETS framework also highlighted concerns about carbon pricing fragmentation across Europe. Nevertheless, its success inspired discussions about implementing a similar approach EU-wide, although reaching unanimous agreement on such a measure has proven politically and economically challenging due to varying impacts across EU Member States.

3. SAF blending mandate in Norway

Norway's Sustainable Aviation Fuel (SAF) blending quota policy has been moderately effective. The policy has faced challenges in meeting its intended objectives, as indicated by the delay in increasing over time the blending mandate beyond the initial 0.5% level. This delay can be partially attributed to the policy's implementation coinciding with the COVID-19 pandemic, which significantly impacted aviation activity. Despite the slower-than-anticipated progress, Norway's policy has still positioned the country as a pioneer in SAF adoption. The implementation of even a 0.5% mandate has created a baseline demand for SAF, stimulating investment in production capacity and research. What is more, Norway was the first country worldwide to introduce a SAF blending quota, and its approach has inspired similar measures in the EU under the ReFuelEU Aviation initiative. However, the policy's effectiveness in driving significant emissions reductions from the aviation sector has been limited by the low blending percentage.

The operational and market efficiency (and therefore the effectiveness) of Norway's SAF blending quota policy has been limited by high production costs, low blending percentages, and delays in increasing the mandate. The price disparity between SAF and conventional jet fuel, with SAF being 1.5-6 times more expensive, has been a significant barrier. While mandates can provide a framework, they may prove insufficient on their own to drive rapid SAF adoption. A more effective approach would involve implementing a comprehensive policy strategy that goes beyond simple blending requirements (demand side) and address also production, infrastructure, and economic barriers to effectively accelerate SAF adoption in aviation (supply side). With respect to dynamic efficiency, while the current 0.5% mandate may seem modest, it has laid the groundwork for future innovation and long-term impacts in the SAF industry.

Norway's SAF blending quotas and the EU ETS interact in a complementary manner, reinforcing each other's objectives to reduce emissions from aviation: as airlines increase their use of SAF to meet Norway's quota, they simultaneously reduce their need for ETS allowances, potentially lowering their compliance costs under the EU ETS. However, this interaction is currently compromised by the fact that aviation has been granted considerable free allowances under the ETS and will only pay for the entirety of their emissions by 2026, making conventional kerosene remain significantly more competitive. While Norway's SAF blending quotas and the EU ETS generally complement each other, there are potential areas of overlap that could present challenges: regulatory complexity and dual cost burden for airlines operating in Norway from both the EU ETS and increased fuel costs due to SAF mandates, risk of carbon leakage, given that the EU ETS currently covers only intra-EEA flights, while Norway's SAF mandate applies to all fuel uplifted in Norway. Looking ahead, Norway's intention to align with ReFuelEU Aviation targets, including increasing the mandate to 2% from 2025, may help address some of these challenges through greater policy harmonization.

The following table provides a summary of the instruments' effectiveness, efficiency and interaction with the EU ETS. The selected instruments encompass a diverse set of measures, each pursuing distinct specific objectives and entailing unique design characteristics and implemented within dissimilar national contexts. They are thus not directly comparable to each other. It also bears noting that the scoring (i.e. "+", "++', etc) of each instrument provided in the table offers considerable scope for discretion that entails a degree of subjectivity, thereby serving as a heuristic metric to summarily assess and visualize a diverse range of factors and considerations in the assessment of complex policy instruments.

Instrument / country	Effectiveness*	Efficiency (short term)*	Dynamic efficiency*	Interaction with the EU ETS
CfD RE scheme – Spain	"+" Scheme (first two auctions) provided an "insurance" policy, enabling project financing and continuity/stability of RE project pipeline	"+" • Encouraged least-cost RE technologies • No incentives for facilities to stay within the scheme. Opt out of scheme's remuneration, likely implies higher electricity prices / society costs • Design features: incentivising participation in /exposure to the market; treatment of negative market prices (zero hour tolerance); elements to ensure competition	"0" 98% of the total capacity awarded to mature RE technologies, i.e. wind and PV	Indirect interaction: • Complementary to EU ETS • Potentially leads to reduced demand for EUAs, all other things equal leading to a downward pressure on the carbon price • Lower carbon price might in turn reduce the incentive for covered entities to decarbonise • Dampens impact of EU ETS price signal on investment decisions for projects benefiting from CfDs that insulate RE developers from electricity market price fluctuations. This effect is lessened in the case of the Spanish scheme, through the inclusion in its design of a market adjustment factor

Instrument / country	Effectiveness*	Efficiency (short term)*	Dynamic efficiency*	Interaction with the EU ETS
Carbon price floor – UK	"++" Scheme was highly effective in providing an ambitious price signal to drive decarbonization and transform the energy mix	"+" • Rendered coal generation increasingly more expensive/ uneconomical compared to gas, providing the right short-term price signal to dispatch low-carbon generation • Efficiency hindered by competitiveness concerns, with British energy generators facing costs 6 times higher than EU counterparts, leading to CPS rate freeze	"++" Rendered coal uneconomical, successfully contributing to complete coal generation phase-out by 2024, thereby avoiding carbon lock-in.	Direct interaction: • The UK CPF worked as a top up price on the ETS prices. Both followed the same volatility and fluctuations. Indirect interaction: • Potentially affected (reduced) demand for EUAs • Waterbed effect • Led to concerns about carbon pricing fragmentation across Europe
SAF blending mandate - Norway	"+" Limited effectiveness so far due to slow progress in increasing the SAF blend beyond 0.5%. Initial goals not fully met, influenced by COVID-19 and SAF availability challenges. Too early to assess definite effectiveness.	"+" • Limited short-term efficiency due to high SAF production costs and low blending percentage. • The policy has not significantly impacted market dynamics or reduced costs	"+" Potential for dynamic efficiency by laying groundwork for future innovation in SAF production technologies and feedstock diversification. Long-term impact yet to be fully realized.	Indirect interaction: • Complementary to the EU ETS, reinforcing emissions reduction objectives • Potentially affects (reduces) demand for EUAs • Potential challenges include cost burden, regulatory complexity, and risk of carbon leakage for international flights

Table Notes:
* highly negative (--), low negative (-), no impact (0), low positive (+), highly positive (++)

Concluding remarks and policy considerations

The different instruments' degree of effectiveness has been influenced by their timing, as well as by evolving and sometimes highly unpredictable circumstances. With respect to timing, the relatively earlier introduction of the UK carbon price floor (first implemented in 2013) meant that in terms of effectiveness it could reap low-hanging fruit with respect to emissions reduction from switching from coal to cleaner power generation. Unlike the UK carbon price floor scheme, the Spanish CfD scheme and the Norwegian SAF mandate only count a few years of implementation, which means that it may be too early to fully assess their effectiveness. With respect to changing circumstances, the design of the Spanish CfD scheme could not have anticipated the surge in electricity prices brough about by the recent energy crisis; similarly, the timing of the Norwegian SAF blending mandate meant that it came into effect just as aviation was grounded by the COVID-19 pandemic, which likely limited its impact. There have also been different responses to evolving circumstances: The Norwegian government has shown leeway in implementing the SAF quota, maintaining the 0.5% level despite initial plans for increases. In the case of the Spanish REER scheme, it was scheme participants that had the flexibility to respond to the evolving circumstances and market conditions, while the scheme itself and the auction parameters were not designed in a way that would ensure participation under the newly emerged energy paradigm. These examples highlight the importance of flexibility and adaptability in policy design to account for unforeseen events and market conditions.

While only one of the studied national instruments (UK carbon price floor) interacted with the EU ETS directly, all instruments interact(ed) with it indirectly through their potential to affect (reduce) demand for EUAs within the EU ETS. This can put downward pressure on EUA prices across the broader EU market, potentially undermining the effectiveness of the EU ETS in achieving Europe-wide emissions reductions, and more broadly raising questions with respect to market harmonisation, competitiveness, and potential price distortions within the EU ETS. This is a known theoretical impact that is difficult to quantify or attribute to a particular instrument, considering the multitude of instruments in place at the national and EU levels.

The existence of national measures (including measures aimed at achieving legislated EU targets) outside of the formal EU ETS framework also raises concerns about fragmentation in carbon pricing and decarbonisation efforts more widely across the EU. Their unilateral nature contrasts with the EU ETS's main aim of harmonising carbon pricing across member states. If countries pursue their own carbon pricing mechanisms without coordination, it can lead to an over-complex and multi-layered policy system. Such a system is prone to market distortions that are more difficult to identify and thus tackle.

Notwithstanding, when it comes to the decarbonisation of the electricity sector, the recent EU Electricity Market Design reform put an emphasis on two-sided CfD schemes, which imply a stronger role for national governments in the development of their national energy systems. Given the interconnectivity of the EU power system, this emphasis on national incentives and planning requires coordination at the EU level of investment decisions if we are to not lose sight of the aspiration of having an efficient and resilient power system at the European level. One could envisage EU-wide or regional CfD schemes in the future, and/or some kind of common guiding principles for their design, that would incentivize production in hours where there is most value for the system, as well as optimal siting of facilities at the EU level while avoiding competition to attract investments among Member States that have CfD schemes of diverse designs (e.g. countries with CfDs with payouts during zero or negative market prices will attract RE project developers from countries that have a 0-hour tolerance for zero or negative prices). The role of the EU in avoiding a race for subsidies and the emergence of an unlevel playing field reflecting national administrative and financial capabilities across Member States needs to be deliberated. Harmonizing SAF mandates across the EU could lead to a larger, more predictable market for sustainable fuels, encouraging investment and lowering costs. In a similar vein, international cooperation can also benefit the decarbonisation of some sectors, for instance in the case of SAFs it can help to tackle supply chain issues and promote the development of a global market and address challenges with respect to their availability and cost.

Another observation is that additional complementary measures might be needed to make some of the studied complementary measures more effective. Comprehensive policy strategies need to encompass measures that address both the supply and the demand side. For example, while SAF mandates like those in Norway can provide a framework to foster demand, they may prove insufficient on their own to drive rapid SAF adoption. A more effective approach to accelerate SAF adoption in aviation would involve going beyond blending requirements to address also the supply side, through for example accurately designed incentives schemes for investment in production capacity to reduce costs and make SAF more competitive vis a vis conventional jet fuel. Similarly, when it comes to CfDs, policy makers would need to consider whether there is a need for a downstream mechanism to derisk also the consumer side[20], and whether and how the fee/revenue structure for schemes like CfDs could become a tool for competitiveness.

There will need to be significant financial outlays and the question that needs to be squarely faced is "*who pays the bill*". In some countries with a larger industrial base it has been largely the consumer, with industry in many cases shielded. More broadly, governments would need to consider a portfolio of different policy instruments and its macroeconomic and other impacts: an emphasis on subsidies for low-carbon generation investments reduces the need for carbon price surges and results in lower inflation, while production subsidies boost investment and GDP with little impact on inflation[21]. Put more simply, the mere choice of relying more on complementary measures implicitly means more of the costs socialized rather than borne by EU ETS covered entities who might see a reduction in carbon prices. In the aviation sector, sharing the costs of SAF adoption between governments, industry, and consumers will be crucial to ensure the financial viability of blending mandates without disproportionately burdening any single stakeholder group.

While we may not be able to attribute the success of the EU's decarbonisation exclusively to a single instrument such as the EU ETS, the expectation remains that carbon pricing will contribute to driving decarbonisation and induce a behavioural change. Notwithstanding, the perception of emission trading being the cornerstone of climate policy in the EU is evolving. Now the EU ETS is not seeing in isolation, instead, it is increasingly becoming part of a more complex toolbox not only of EU but also national climate policies. National policies like the SAF blending mandate complement the EU ETS by targeting specific sectors and technologies, contributing to the overall decarbonisation goals.

In the emerging EU ETS landscape to 2030 and beyond, characterised by increasingly low carbon market liquidity and increasing price volatility as we approach net zero in a shorter market, and unknown (likely increased) levels of competitiveness stress related to what other countries do, the EU ETS may not be sufficient on its own to drive the remaining decarbonization efforts. It may struggle to function efficiently in a net-zero world for major emitters (for whom the EU ETS was originally designed). To be fit for purpose and continue to be a central piece in the toolbox, the EU ETS needs not only to be adapted to address liquidity and volatility issues as we approach net zero/net negative (CDRs, international credits, governance or rule-based market behaviour), but also to be complemented to ensure a sufficiently high price signal to drive investments, and address the risk of carbon leakage and competitiveness challenges.

The global nature of climate action introduces external pressures on the EU ETS, as it operates in a world of asymmetrical climate ambition. The EU has chosen to be a leader and inspiration to others and that has created competitive stress and the associated risk of carbon leakage, in particular in the context of several other existing drivers of EU competitive challenges. Given the appetite in the EU for a "concurrent" decarbonisation of all sectors, complementary instruments to the EU ETS like the SAF blending mandate can help to enhance the overall effectiveness of climate policy by addressing sector-specific challenges and promote innovation and decarbonisation of parts of the economy that would have otherwise been untouched by the EU ETS in the short to medium term (sectors with high marginal abatement costs), since the required carbon price level for action is considerably higher than the current carbon price.

Overall, the interaction between these complementary measures and the EU ETS is complex, as both types of tools aim to reduce carbon emissions but through different pathways. While additional measures can complement carbon pricing, over-reliance can lead to inefficiencies, fragmented policies, and increased costs for governments and taxpayers. The challenge is ensuring that they work in harmony to drive decarbonization without creating market distortions or over-subsidization. Careful policy deliberation, including potential adjustments to the EU

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[20] CfDs for RE and low carbon power derisk the producer side but not the consumer. That said, the question arises on whether there a need for a 'reverse' CfD for consumers

[21] IMF, 2022. Chapter 3 Near-Term Macroeconomic Impact of Decarbonization Policies, World Economic Outlook, October 2022, International Monetary Fund. https://www.elibrary.imf.org/display/book/9798400218439/CH003.xml

ETS cap and the design of complementary instruments, as well as coordination of complementary measures to ensure a minimum level of harmonisation across how these are designed and implemented across different EU countries is critical for maximizing their effectiveness and efficiency in achieving the EU's climate goals.

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