Carbon Contracts for Difference as essential instrument to decarbonize basic materials industries

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Abstract
Contracts for difference are an instrument to provide security in case of volatile or unsure price evolvement. They have been successfully used in the context of market opening for renewable energies. The contract guarantees the agreed contract price and thereby basically funds a price gap between market prices for a good and its actual costs for the project developer.

Project-based Carbon Contracts for Difference (CCfD) are now being discussed as a means to advance the adaptation of breakthrough technologies, i.e., to incentivise emission intensive basic industries to shift to low-emission production processes. In Germany, the federal government committed itself to deploy a project-based pilot funding program for such CCfDs, for the steel, ammonia, cement, and lime sectors. The basic idea is simple: to cover incremental costs between a novel climate-friendly technology and its conventional baseline, while considering existing and evolving CO_2 prices and other relevant risks. The implementation as a CCfD might also encompass paybacks in case CO_2 market prices (in the EU ETS) exceed the contract price, depending on the design of the instrument. The detailed design of this policy instrument, contrariwise to the basic idea, can be rather complex. Important questions are: how to set a suitable reference for the project to be contracted in terms of costs and emissions, which kinds of costs and revenues to consider, how to allocate funding and determine which projects are awarded, and how to consider the interaction with the ETS – and many more.

The paper presents preliminary findings from a research grant from the German Federal Ministry for Economic Affairs and Climate Action (BMWK), considering the aforementioned questions of policy design in the context of the expected German pilot program, and discusses their respective trade-offs. It outlines explicitly how a CCfD payment can be derived considering the difference costs between a climate friendly and a respective reference production as well as the effective CO_2 price based on market price and free allocation. In a broader perspective, it addresses how CCfDs are embedded in the existing and anticipated policy framework for carbon intensive industries in Germany and in the EU such as, e.g., CBAM.

Introduction
By the middle of the century, industrialized countries need to be carbon neutral to be in-line with the Paris Agreement. While targets for climate neutrality vary slightly in terms of the timeline (e.g., EU: 2050, Germany: 2045), the need to phase out fossil fuels and also substantially reduce non energy-related emissions in a rather short period of time is uncontested. As a result, industries must also be completely decarbonized, including hard to abate process emissions, which are caused by the use of carbon-containing raw materials (carbonates, natural gas) or by the use of fossil fuels as reducing agents. Today, many of the incumbent basic materials' processes are technologically not capable of reducing GHG emissions in any extent necessary to be compatible with mitigation targets. Therefore, they

need to be replaced with innovative, climate friendly processes, which requires tremendous investments in production assets. Moreover, these new processes are currently not competitive with the incumbent technologies, due to higher operational and capital expenditures as well as insufficiently high and secure carbon prices. High price volatilities for energy and raw materials add to the risk of investment decisions, as they lead to high uncertainties concerning carbon abatement costs. For example, the price index for coal import prices to Germany (with 2015=100), went from 125 in 2019 down to 95.9 in 2020 and then up to 168.8 in 2021 (Destatis, 2022a). In addition, there are uncertainties connected to regulation which might have impacts on abatement costs, especially regarding the further development of the ETS regime.

Relevant examples for affected industrial sectors, in terms of specific and absolute emissions, are the production processes for primary steel, cement, and ammonia. For the case of Germany, 53.7 Mio. t of CO_2 can be currently attributed to the production of steel, i.e., steelmaking alone is responsible for ~30 % of Germany's total industry emissions (UBA, 2021). The overwhelming share of these emissions stems from primary steelmaking via the blast-furnace, basic-oxygen-furnace route (BF-BOF), where coke, coal and other fossil carbon-carriers are used as reducing agents. Considering all the emissions caused by basic materials industries, their shares add up to approximately 70 % of Germany's total industrial emissions (cf. e.g. BCG, 2021). Several required technological alternatives are essentially sufficiently mature to be deployed at commercial scale (cf. e.g. Material Economics, 2019). Nonetheless, they are currently often employed only, if at all, in the form of pilot plants. CO_2-prices are not reliably high enough over a longer time horizon to ascertain economic viability of industrial decarbonization projects (Material Economics, 2019; European Commission, 2021). This hampers broader market diffusion even though fundamental technological showstoppers are not existent. Relevant examples include the hydrogen-based direct reduction route for the production of primary steel, the use of green hydrogen as raw material for ammonia production, and the use of oxyfuel burners for the mineral industry (cement, lime) in conjunction with Carbon Capture and Utilization (CCU) or Carbon Capture and Storage (CCS).

For Germany, with the amendment of the Climate Protection Act 2021, the climate-neutrality target was advanced to 2045. CO_2 emissions must be reduced by 65 % by 2030 and by 88 % by 2040 compared to 1990. On the target path, the Climate Protection Act defines remaining annual emissions for the industrial sector of 118 Mio. t $CO_{2\ eq.}$ in 2030 (Bundesministerium der Justiz, n.d.). This corresponds to a reduction of 60 Mio. t of $CO_{2\ eq.}$ or approximately one third compared to the current (2020) level of 178 Mio. t $CO_{2\ eq}$ (UBA, 2021). Given the high shares of the emission-intensive basic material industries relative to Germany's industry as a whole, achieving this goal requires replacing considerable production capacities before 2030.

The situation of non-competitiveness and price uncertainties outlined before makes, for the case of Germany, achieving the 2030 target in the industrial sector unlikely without additional, appropriate policy instruments. A number of co-funding schemes to promote innovation and investment exist. At the European level funding instruments are e.g. the Innovation Fund[1] and the Invest EU Programme from the EU's recovery plan[2]. At national level in Germany, the programme "Decarbonisation of industry"[3] is available to support industrial transformation. Still, progress is hampered by the lack of competitiveness due to higher operating costs compared to conventional production processes, uncertainty about abatement cost of early large-scale applications as well as by uncertainty about sustained (high) carbon prices (European Commission 2021). This is where project-based CCfDs for the basic materials industries fit in, as an instrument to hedge price risks and (partially) finance abatement costs thereby speeding up industrial low-carbon transformation. The paper presents current findings regarding the design elements of such CCfDs, trade-offs between different design options, and the integration of this instrument into the evolving climate policy framework.

THE CONCEPT OF CARBON CONTRACTS FOR DIFFERENCES (CCFDS)

In its original form, project-based CCfDs provide a guaranteed CO_2 price for emission reductions below a conventional baseline, for example defined by existing best available technology benchmarks (Richstein, 2017). They do so by establishing a contract-for-difference on the CO_2 price between the operator of an innovative project and the government, linked dynamically to the actually achieved emissions reductions. As a result, when the CO_2 market price is below the strike price, the CCfD pays out the difference to the CO_2 market price to the project, whereas in case of high CO_2 market prices, the project owner needs to pay back the difference to the agreed-upon price to the government. As a result of the CCfD, the project is incentivised by a constant CO_2 price at the contract price level. As CCfD strike prices for energy-intensive industries may well be above current market prices, Richstein (2017) proposed to make contracts project-specific, as otherwise contracts could be fulfilled by a portfolio of incremental emissions reductions unsuitable to achieve long-term emissions targets.

More general carbon contracts were discussed by Helm & Hepburn (2007), arguing that they offer a solution to the credibility problem of governments committing to a carbon policy, and the resulting carbon price risks for private actors. Similarly, instruments such as put options were also discussed (Ismer & Neuhoff, 2009). In the political debate, various designs of CCfDs have been discussed for implementation. Next to the discussion whether to implement carbon contracts as CfDs or as put options (McWilliams & Zachmann, 2021), whether to use technology-neutral or specific tenders, as well as linkages to other policies (Sartor & Bataille, 2019; Gerres & Linares, 2020), an important design question is whether in addition to pure carbon price risks, further risks may also be covered. On the one hand this relates to the effective CO_2 price, which may be different from the CO_2 market price. The effective CO_2 price may be muted for novel technologies, depending on the lacking carbon cost pass-through and the current and future implementation of free allowance allocation. This, if lacking for inno-

1. https://ec.europa.eu/clima/eu-action/funding-climate-action/innovation-fund/legal-framework_en

2. Support is available via member states' recovery and resilience plans that are assessed and supported by the EU https://europa.eu/investeu/invest-eu/investeu-and-recovery_en

3. https://www.klimaschutz-industrie.de/foerderung/foerderprogramm/

vative technologies, may be compensated by additional CCfD payments (Lösch et al., 2021). On the other hand, this relates to the question whether further operational risks, that arise from the distinct input factor cost structure of new technologies, should be covered by a CCfD directly or in combination with other policies, such as renewable policies (Lösch et al., 2021; Richstein et al., 2021; Agora Energiewende et al., 2021).

We will discuss CCfDs as climate protection contracts, as both a risk mitigation/sharing and as a funding instrument, that covers both carbon price and other risks (Lösch et al., 2021). On the one hand, (partial) coverage of technology- or process-related incremental costs of production, for example due to a change of energy carriers, and on the other hand, (partial) coverage of risks, be it production factor risks, CO_2 market price risks, or risks resulting from the (re-)design of the EU ETS. In this, climate protection contracts as discussed here, are similar to other existing funding schemes for decarbonisation in European member states and the EU level, such as the SDE++ program (which addresses several sectors, using a mechanism similar to put options), or the EU Innovation Fund, which uses a funding gap approach.

Discussion of key design elements for CCfDs

In the following, design elements for CCfDs which are considered by the others as highly relevant for the functioning and impact of the instrument, will be considered. We show how a CCfD payout can be derived from the contract price and the effective CO_2 price, and which factors determine both of the latter. We discuss the definition of a suitable reference for a CCfD funded project, and how a system boundary could be plausibly set. Incremental costs depend on reference and project cost factors. We discuss different options to define those factors. Moreover, as to the aforementioned price volatilities, the contract price and subsequently the contractual payment are not fixed but need to be adjusted dynamically during the CCfD duration. We argue which options exists for such adjustments, and which kind of costs factors should be adjusted. Another important issue is the relation between production under a CCfD funding and marketing green products with a green premium on the market. We show which options are available to regulate this within a CCfD instrument and discuss the respective trade-offs for these options. In addition, we formulate some basic reflections on the tender and selection process for a CCfD instrument.

CONTRACT PRICE, EFFECTIVE CO_2 PRICE, AND CCFD PAYOUT

CCfDs are used to guarantee CO_2 prices that are sufficiently high to cover the incremental costs of low carbon production processes compared to the carbon intensive reference technology that is currently price-setting. This is realized via a so-called contract price in Euro/tonne CO_2. This contract price represents these incremental costs divided by the emissions avoided, i.e., the contract price equals the project-specific carbon abatement costs. Determining these abatement costs requires the definition of a suitable reference or baseline both for emissions and costs, referring to the same system boundaries of the production process considered.

As the name suggests, the CCfD payout is defined as the difference to a CO_2 price (see Figure 1). Climate policy such as the European Emissions Trading System (EU ETS) creates gross revenues and gross costs, and the resulting net carbon pricing itself already provides an incentive for lowering carbon emissions. The contract price $p_{CCfD,\,t}$ works to complement this incentive and hence does not include CO_2 cost. The effective CO_2 price is discussed separately below.

Contract price

A CCfD can cover both incremental capital costs (CAPEX) and operational costs (OPEX) of the CCfD-funded/secured production process compared to its conventional reference. Alternatively, CCfDs can target incremental OPEX only, while investment support is granted with other instruments[4] . The choice of a suitable combination of CCfD and other instruments such as investment grants depends primarily on the question to what degree technology and volume risks exist and impact financing costs, as well as on the resulting funding efficiency and the incentives for companies to successfully finish projects (cf. Richstein, 2017, p. 6).

Therefore, the contract price $p_{CCfD,\,t}$ [Euro/ t CO_2] can be written as:

$$p_{CCfD,t} = \frac{\Delta C_{OPEX,t} + \Delta C_{CAPEX,t}}{\Delta E_{CO2,planned,t}} \quad (1)$$

where $\Delta C_{APEX,t}$ and $\Delta C_{OPEX,t}$ represent CAPEX and OPEX differences between the CCfD project and the price-setting conventional reference technology, while $\Delta E_{CO2,planned,t}$ stands for the respective difference in emissions, i.e., specific mitigated emissions through the employment of the project in the defined system boundaries (see below). Indices t refer to a period of time under consideration, e.g., a year, since cost differences vary over time subject to volatilities of the constituting prices, or changes to the production. The incremental OPEX costs $\Delta C_{OPEX,t}$ [Euro] are made up of various cost factors, and can be considered as a linear combination of price parameters p_i and input parameters d_i for the project and of price parameters p_j and input parameters d_j for the reference, respectively:

$$\Delta C_{OPEX,t} = \sum_{i}^{n} d_i \times p_i - \sum_{j}^{m} d_j \times p_j \quad (2)$$

These cost factors and parameters are sector- or process specific. Price fluctuations of important input factors can substantially impact incremental costs. To cover such risks, the contract price can be adjusted dynamically to account for the volatilities of selected price parameters (see Figure 1, and discussion below). Thereby the CCfD payout is adjusted to cope for changes in incremental costs which avoids over- and underfunding.

Effective CO_2 price

Generally, the effective CO_2 price can be defined as the difference between CO_2 revenues and costs of the novel process, divided by emissions reductions. It could thus incorporate CO_2

4. Nationally, there is e.g. the German programme "Decarbonisation of industry" available for investment support. Moreover, the Dutch SDE++ programme can be mentioned here. At EU level, the innovation fund provides investment and innovation support. The EU Invest Programme is a further programme that enables support for companies within European Union's Recovery Plan for Europe.

prices specific for materials producers that are, e.g., reached by international standards and agreements and thus implicitly included in material prices. However, such agreements are currently not in place. Materials (which are nearly homogenous commodities) are traded internationally and carbon cost pass-through to consumers is limited. To avoid carbon leakage, the EU ETS contains a carbon leakage provision in the form of free allocation of European Union Allowances (EUAs). Cost pass-through and free allocation impact the effective CO_2 price which projects are exposed to.

For simplicity of the analysis, we assume here that in all cases the European conventional processes are price setting, and thus their carbon cost and revenue differences to the novel process need to be considered. Gross revenue stems from the free allocation of EUAs according to the Delegated Regulation (EU) 2019/331. Gross costs can be attributed to the obligation to surrender EUAs according to the actual emissions caused, as defined by the rules of the monitoring, reporting and verification regulation.

The effective CO_2 price can therefore be written as the differences of gross revenues and costs for the project and its reference, divided by the emission reduction realized:

$$p_{CO2-effective,t} = p_{EUA}\frac{(E_{Reference} - A_{Reference,t}) + (A_{Project,t} - E_{Project,t})}{\Delta E_{CO2,realized,t}} \quad (3)$$

In eq. 3, p_{EUA} is the CO_2 market price, $E_{project,t}$ stands for emissions, and. $A_{project,t}$ for the free allocation. Regularly, $p_{CO2\text{-}effective}$ as defined here should be positive, representing a revenue for the project, as. $E_{Reference} > E_{Project,t}$ and free allocation in the reference covers at most all reference emissions. Importantly, this definition allows to distinguish between CO_2 revenues from cost-pass through to material prices (here assumed to be $p_{EUA}(E_{Reference\text{ -}}A_{Reference})$ as the conventional process is price setting), and from the net sales of free allocation of the low-carbon process ($p_{EUA}(E_{project,t\text{ –}}A_{project,t})$).

CCfD payout

From the viewpoint of the CCfD-contract, the contract is at-the-money when the effective CO_2 price $p_{CO2\text{-}effective,t}$ (eq. 3) equals the contract price $p_{CCfD,\,t}$ (eq. 1). Then, the CCfD payout. $p_{CCfD,\,t}$ (eq. 4) becomes zero or even negative in the case regulatory net revenues exceed the contract price. This would imply a reversed payment obligation, i.e., a payment from the industrial contract partner to the government.

The contract price and the effective CO_2 price are defined as specific quantities, per tonne of CO_2 mitigated. To establish the actual absolute payout for a specific period, the sum of the two must be multiplied by the realized specific emission reductions (per tonne of product) and the produced product quantity covered by the contract. The CCfD payout price $p_{CCfD,\,t}$ [Euro] can therefore be written as:

$$P_{CCfD,t} = (p_{CCfD,t} - p_{CO2-effective,t})\Delta E_{CO2,realized,t}\, q_{CCfD,t} \quad (4)$$

The production quantity considered for the payout, $q_{CCfD,\,t}$ refers to the system boundaries defined in the contract. The volume of $q_{CCfD,\,t}$ may differ from the absolute production volume of the CCfD project installations if a share of the production is excluded from additional funding due to other policies, e.g., demand quotas for green basic materials. Furthermore, it is also possible that the part of production volume marketed directly by the producing companies as "green" on the market is excluded from support by a CCfD instrument. This important issue for the design of the CCfD instrument is discussed further below.

SYSTEM BOUNDARIES, BASELINE AND PROJECT EMISSIONS

System boundaries can be determined consistent to those used for EU ETS installations[5], which allows companies and the CCfD implementing agency to refer to data collected for EU ETS purposes within the existing monitoring, reporting and verification (MRV) procedures, instead of adding additional data collection effort (Richstein, 2017). Principally, system boundaries can also be determined wider than the EU ETS and cover emissions along the value chain, e.g., downstream emissions as employed within the EU Innovation Fund (European Commission, 2022). However, for the starting phase of CCfD programmes, we recommend consistence with the EU ETS since this makes reporting and comparability of project proposals easier.

For the determination of **avoided emissions**, $\Delta_{ECO2,t.}$, **Baseline or reference emissions** need to be established. This can be done based on historical data of the installation replaced by the low-carbon project or based on EU ETS benchmarks. Since the approach based on individual historical emissions disadvantages companies that already have comparably low emissions, we recommend benchmarks to determine baseline emissions. For cases where not only one specific benchmark for the product exists, e.g., for the steel industry, the CCfD framework needs to outline which emission reference to apply (or, how to combine different ETS benchmarks to derive a reference). This should be the route with lowest production cost (leaving costs for CO_2 emissions aside).

EU ETS benchmarks change over time, and are subject to regulatory changes, as currently discussed in the framework of the Fit for 55 package (European Commission, 2021). For calculating **avoided emissions**, $\Delta E_{CO2,t.}$ the benchmark at the time of contract conclusion should be fixed to determine baseline emissions. In contrast, when calculating **effective CO_2-prices** of the project and of the reference installation, i.e., $p_{CO2\text{-}effective,t}$ as described above (eq. 3), the benchmarks determining free allocation and hence the CO_2-revenues should be dynamically adjusted for. By doing so, the CCfD payout adapts to the changing regulatory framework.

Project emissions have to be estimated ex-ante by the applicant for the calculation of the contract price. Ex-post verified emissions as reported for the EU ETS are used to determine the final payment.

REFERENCE AND PROJECT COSTS TO DETERMINE INCREMENTAL COSTS

Incremental costs are defined as the OPEX (and, if the programme shall include it, also CAPEX) cost differences per ton of product, $\Delta C_{OPEX,}$, depending on the cost structures for the reference process and the project, respectively. While for the reference, the values of the input parameters (e.g., amount of

5. Rules for delimitation of installations are given in the context of free allocation in Commission delegated regulation (EU) 2019/331 and the associated guidelines.

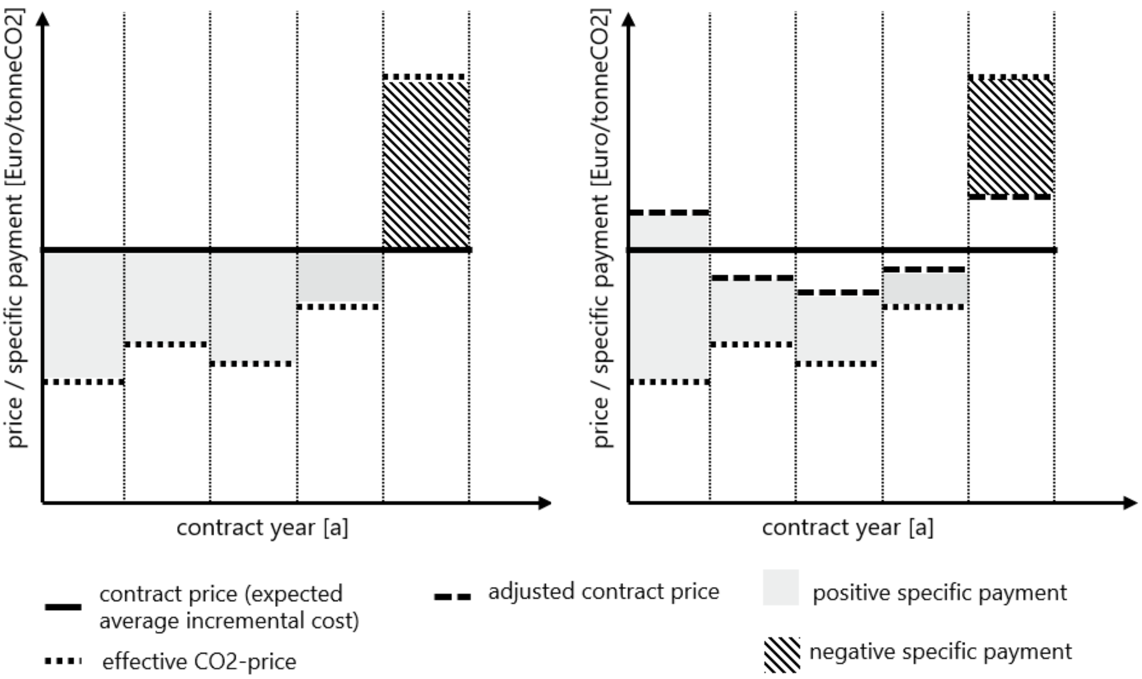

Figure 1. Specific CCfD payments with static contract price (left) and adjusted contract price over time (right), reflecting risk-hedging of volatile prices.

coke or coal needed to produce one tonne of crude steel) in the cost structure remain constant over the entire contract, they can be different for the project in each year of the contract to reflect sequential changes in the project (e.g., an increase in hydrogen usage).

Different options exist to determine those cost structures. We differentiate the following options:

1. Price and input parameters submitted by the firm
2. Standardized input parameters and prices per technology or sector
3. Input parameters submitted by the firm, but standardized prices

These options need to be seen in light of asymmetric information. The firm has best knowledge about its own costs. It also has an obvious interest to report numbers maximizing its potential CCfD payout. Submitted costs would hence need to be scrutinized. The use of standardized input parameters and prices has the downside of not fully reflecting actual costs of the firms' project or reference installations.

As an advantage, standardization reduces efforts on both sides. It also creates equal reference costs across different firms, thereby making proposals within the same sector better comparable for the awarding process. For the reference processes comprehensive knowledge is readily available, and technological developments are more or less exhausted. Therefore, plausible input parameters are relatively easy to access. For the new projects this might be different. Public knowledge about the specific cost structure of the new process is limited. Hence, we recommend standardization of input parameters for the reference, but using input parameters submitted by the firm for the new process, which, of course, must be scrutinized during the selection process. We recommend using standardized prices in project selection and standard price indices for calculating the CCfD payment. This provides an incentive for firms to aim for low input prices. Furthermore, it eliminates the risk that companies assume too low prices to win the award process for a CCfD and thereby avoids winner's curse. Based on standardized prices the incremental costs can be dynamized as described below.

DYNAMIC ADJUSTMENT OF THE CONTRACTUAL PAYMENT

In the energy intensive industry, the product price is typically determined to a very large degree by energy and raw material costs. Prices for relevant energy and material cost factors may vary substantially over time, impacting the product selling price. As long as fossil intensive production is price setting, this is a risk for a firm investing in low-carbon production since it has a different cost structure. That means, it may not equivalently benefit from, say, reduced coal prices but suffer from lower market prices. Such an increased risk limits incentives to invest in low carbon technologies if the CCfD contract price would be fixed for the complete contract duration and would result in higher necessary CCfD contract prices to incentivise investments (Richstein et al., 2021). Dynamic adjustment of the contractual payment, e.g., with a suitable indexation for relevant price parameters, addresses this issue and prevents over- or underfunding. Such indexation shifts risks from price volatility (partially) from the company to the government. Furthermore, the payment should be adjusted for price relevant impacts of regulation (changes in the ETS regime), which is realized by adjusting the effective CO_2 price (eq. 3).

Therefore, it needs to be defined which cost factors should be dynamically adjusted and how. Adjustment should be done only where relevant. Omitting factors that are irrelevant for incremental costs from dynamization avoids undue burdens in contract administration.

In some cases, it might be advantageous to foresee an opt-out clause from standardized prices (either ex-ante or ex-post in the operational phase). A case in point would be a firm contracting a long-term purchase agreement for green hydrogen to produce green low-carbon steel. This creates a positive trickle-down effect fostering market development for green hydrogen and potentially even further to green power production needed to feed the electrolyser. An opt-out would allow companies to enter such long-term purchase agreements for green power or green hydrogen and therefore create co-benefits for downstream market development. In turn, companies surrender dynamization of a cost factor which they decide to manage on their own and have an individual price parameter fixed in the CCfD. However, it needs to be considered that an ex-post opt-out clause provides an option for a company, which they would only exercise if beneficial.

To differentiate between cost factors which should and should not be considered in the cost structures, or dynamically adjusted or not, we suggest a three-fold classification:

- Cost factors for which demand parameters do not vary substantially between reference technology and low carbon production, i.e., where the specific demand is quite similar[6]. These cost factors have no big impact on the emission abatement costs, since they do not play a relevant role in determining incremental costs. Hence, they could be omitted from the CCfD.
- Cost factors that impact incremental costs, but that can be easily fixed ex-ante at the point of contractual agreement and do not vary significantly over time. These cost factors should be included when determining the CCfD contract price, but they should not be adjusted dynamically, i.e., their value would be kept constant for the contract duration.
- Cost factors with a relevant and fluctuating impact on incremental costs[7]. These cost factors should be dynamically adjusted for since they are relevant for abatement cost and cannot easily be fixed ex-ante.

The classification of cost factors must be done for each technology or production process. This should be realized by the authority administering the CCfD instrument based on analyses of historical incremental costs' evolvement. Once the factors for dynamization are selected, a suitable adjustment mechanism must be found. One option would be an ex-post cost-review and adjustment of the contractual payment according to reported project operational costs. However, such an approach leads to reporting requirements for firm specific operational data. This does not only come with substantial administrative effort but is also prone to problems concerning confidentiality. Furthermore, payment based on actual firm-specific costs eliminates the incentives for the firm to produce efficiently altogether, since whatever cost it incurs (in excess of the conventional process) would be compensated.

We propose another option: **Index-based adjustment** of the contract price. This requires suitable price indices for those cost factors that shall be dynamized. The following aspects should be considered:

- The market on which the price used for the index is set should be, at best, competitive to avoid financing monopolistic mark-ups.
- The price needs to be transparent and the index available with only moderate time delay.
- The index needs to be suitable for the cost factor to be dynamized, i.e., it should adequately reflect the commodity used and the actual price movements

Such an index-based dynamization leaves efficiency incentives at least partly intact since firms are not compensated for whatever high costs (exceeding the index evolvement) they might incur. But it still substantially reduces the risk of unforeseen price developments for the firm. On the one hand this is positive for project development and may reduce CCfD contract prices. On the other hand, firms are usually well placed to take certain market risks by themselves and can use, e.g., long term green power purchase agreements to manage their risk from electricity purchases. This could in turn be a relevant factor for market development of (green) electricity.

For many relatively standardized inputs price indices are available and published by national statistical institutions. In Germany e.g., the Federal statistical office of Germany (DESTATIS) publishes long-term time series on the development of energy prices. These include import prices for hard coal, oil and natural gas, producer prices for lignite and several electricity prices for stylized demand situations. EUROSTAT as the EU's statistical office offers data on product and energy price evolvement for EU member states. DESTATIS publishes yearly data on several products used for industrial purposes such as lime for use in blast furnace, lime for cement production or oxygen (Destatis, 2022b).

However, the available index is not in each case suitable. For electricity e.g., actual electricity prices paid by energy intensive industry, that benefits from certain privileges concerning electricity taxes and levies, are typically lower than the statistical average price for the entire industrial sector (cf. e.g. Zerwawy et al., 2020).

In some cases, no suitable indices seem to exist. In the case of DRI pellets, for example, this can be attributed to an oligopolistic market structure. For green hydrogen, there simply is no developed market yet. In those cases, it must be scrutinized whether one of the available indices can be used as a proxy. This can be a pragmatic and sensible solution if it can be reasonably assumed that the price development of the proxy and the price of the actual good run more or less in parallel. Green hydrogen is an example for this: since green hydrogen will be produced via electrolysis using green electricity, its production cost will very likely develop in parallel to the price for green electricity. Lack of suitable indices may be a further argument to leave out certain factors from index-based dynamization and instead require applicants to submit price estimates and long-term contracts.

6. The demand for calcium carbonate in cement production might be a good example, when comparing a conventional production process with an Oxyfuel/CCS production process, as the specific raw material input per unit of cement should be roughly the same.

7. The use of green hydrogen and electricity in DRI-steel production, compared to blast-furnace basic-oxygen-furnace steelmaking is an obvious example.

OPTIONS TO DEAL WITH THE DIRECT MARKETING OPTION

CCfD contracting companies might also be interested in directly marketing products as "green" to their customers, charging a premium above market price. As this represents potential additional revenues, the question arises how to treat this in a CCfD funding scheme. A range of different options can be thought of, which come along with specific trade-offs.

In principle, five options seem to exist:

1. Prohibiting the use of a green label, i.e., no direct marketing is allowed
2. Allowing direct marketing, but not considering additional revenues in the scheme
3. Considering green sales as additional revenue stream
4. Excluding green sales from supported quantity of product sales $(q_{CCfD,t})$ –unrestricted optionality
5. Excluding green sales from supported quantity of product sales. $(q_{CCfD,t})$–restricted optionality

First option: Prohibiting green marketing means for the products they would be labelled as "grey" on the market, i.e., indistinguishable from the conventional products. The reasoning behind this is the idea of a ban of a double marketing of a valuable good which has already been subsidized, as, e.g., in force for the German renewable energies act (EEG). However, without a distinction between green and grey products on the market, green lead markets are at least not fostered. The state itself, as the "owner" of the green product property, might step in as market actor and sell the green product property. Questions regarding the implementation (price setting, bidding process, …) arise, but shall not be discussed here.

Second option: Allowing direct marketing of "green" products without further considering potential additional revenues at all in the CCfD regime is the administratively easiest option. Further, it can be argued that companies price in expected revenues in a competitive bidding process. To which degree this takes place depends on the market value expectations of the companies, their respective risk tolerance, and their expectation of competition. However, if competition is limited and green margins are expected to be significant, regulators may want to reduce the necessary funding streams (or increase expected paybacks) by considering green sales in the payout function of the contract (eq. 4), either by Option 3 or 4. Moreover, if green product revenues are not subtracted, market power of CCfD-companies concerning the green product can be foreseen to be rather low, as customers can always refer to the CCfD-funding. This leads to the expectation of rather low-priced green products, which in turn might cause market distortions relative to other options to mitigate emissions, e.g., options to avoid and substitute primary production.

Third option: For subtraction of green revenues the regulator needs to determine the green margin either by an estimation ex-ante, or via ex-post auditing, and then subtract associated green revenues from the contract price. The ex-ante estimation of revenues can be challenging but is administratively easy to implement. It risks, however, to either lead to losses for companies if green margins do not materialise or to significant windfall profits, in case the margin was underestimated. It may further reduce attraction to participate in the CCfD regime in the first place. The ex-post determination of the green margin is both administratively and conceptually challenging, due to the heterogeneity of final products.

Fourth option: The reduction of supported product quantities, can be implemented unrestricted or restricted. Unrestricted direct marketing would give companies full flexibility to decide in each CCfD-period (year) to sell any quantity of their production from CCfD-funded projects freely on the market, while the residual production quantity remains in the CCfD-regime. If implemented in a way that the CCfD-company reports ex-post the quantities which have been sold directly on the market, the CCfD becomes a pure risk hedging instrument for the contracting companies. This can be also called "complete optionality". As the additional green product revenues must be completely subtracted from CCfD revenues, the market power of CCfD-companies relative to their customers is significant: the customers cannot refer back to the CCfD-funding. The specific CCfD-payment sets a price floor for the value of the green product, sending clear price signals to the market. However, this option also has its trade-offs. With complete optionality in each CCfD-period, the companies can avoid paybacks completely by marketing the complete production quantity freely in times of negative CCfD cash flows, and the CCfD is effectively turned into a put option.

Fifth option: If complete optionality as discussed above is not considered as favourable or feasible, different provisions within the CCfD contracts can be thought of to restrict that optionality. For example, a certain share of the CCfD-production could be excluded from direct marketing ex-ante in the contract; this would be rather simple, but also quite arbitrary. Another option would be to restrict the share of direct marketing during the payback period to the share of direct marketing reached before (when the company received payments). This could be operationalized through a production-quantity weighted average. This should incentivise direct marketing during the phase of positive CCfD payments, as it lowers the potential paybacks for the companies. On the other hand, higher shares of direct marketing during times of positive CCfD payments reduces the total funding needed for a CCfD program, as the revenues are subtracted from CCfD funding. A disincentive this design option might have could be shifting quantities to other, non-CCfD production capacities, if available.

ELEMENTS AND OPTIONS FOR A TENDER AND SELECTION PROCESS

It is common practice to disburse funding such as through CCfDs in a competitive selection process. This allows to set out certain selection criteria for applicants, which then compete on these. In the EU, the award process needs to follow EU state aid regulations for approval of the funding scheme.

The final decision on the design for a tender and selection process depends largely on the overall aim of CCfDs as a funding scheme. These aims are set as part of the political process underlying the funding scheme and can therefore not be fully anticipated here. Examples of selection criteria also mentioned by Lösch et al. (2021) for CCfDs, include those relevant for the EU Innovation Fund: greenhouse gas (GHG) avoidance, degree of innovation, scalability, project maturity and cost efficiency of the funding (European Commission 2022). For project-based CCfDs for the basic materials industries, it needs to be considered that a funding scheme will target large-scale projects.

In addition, it can be argued that the projects should support establishing green markets (see above on the direct marketing option) and aid setting up infrastructure relevant for a climate neutral economy, such as hydrogen networks or synergies between technologies (Agora Energiewende et al., 2021). McWilliams & Zachmann (2021) suggest additional emphasis on technological learning curves and possible technological cost decreases.

In addition, the selection process may make use of different stages. This has implications for the choice and design of the criteria at each stage, which can be defined as eligibility or selection criteria. The exact target variables to be addressed and incentivized by the selection procedure are political in nature. We therefore only briefly discuss certain design elements without spelling out a particular scheme, and thereby highlight features to consider in the design of the process.

One of the main criteria typically applied is **cost efficiency**. This criterion evaluates the costs of avoiding one unit of emissions. This makes it a close relative of the contract price, only aggregated over time (contract duration) in an adequate manner. The costs considered in the selection process may be designed to include the full project costs, which would then allow to award projects with the lowest total abatement costs, even when the payout considers only OPEX. The total budget available for projects always needs to be considered during the award process.

When ranking projects on cost efficiency, it needs to be considered that different technologies and sectors require different effective CO_2 prices to become competitive, i.e., with cost efficiency as sole criterion not all technologies will have a realistic chance of winning a grant, since abatement costs differ. This can be considered by ranking within sectors and specifying a certain quota of projects or budget per sector, the latter requiring good knowledge of the monetary requirements in each sector.

The overarching aim of a scheme to support decarbonisation such as CCfDs is to avoid GHG emission. This is therefore a well-suited selection criterion, which can be defined as **absolute or relative GHG avoidance**. Both measures have their drawbacks: Absolute emission avoidance will favour large projects and thereby large players, while several smaller projects in a sector could trigger more learning effects, leading to a faster and more efficient transition. If projects are ranked on relative GHG avoidance, many projects may reach the full score if all emissions are avoided, which may limit the value of the measure as a criterion.

The scope of emissions considered as a selection criterion can be set independently from those emissions considered in (eq. 4). However, this brings additional complexity in MRV and raises questions of ownership for the avoidance. Nevertheless, emission savings along the value chain merit consideration, at least in one of the qualitative criteria, in order to support climate neutrality comprehensively. Finally, it needs to be considered that a limited budget coupled with the criterion of cost efficiency already leads to a selection of projects achieving an overall high level of emissions reductions. GHG avoidance may thus be most suitable to identify projects best in line with long-term net-zero emissions goals.

In general, the numeric criteria could be ranked on normalized values directly, for example by normalizing all projects on cost efficiency to the most cost-efficient project, which receives a certain number of maximum points. Alternatively, projects could be awarded points depending on the position in the order of a specific criterion. The choice of the design in awarding points should consider the expected outcome of a tendering procedure, i.e., the spread of projects within and between sectors. In addition to the quantitative criteria, the selection process may be designed to feature qualitative criteria in support of the political aims of the funding scheme. These will then need an evaluation by experts with good guidance for an objective result.

Relationship of CCfDs with the evolvement of the EU ETS

In July 2021, the European Commission communicated a series of policy proposals, subsumed under the label "Fit for 55 package", aiming at meeting the bloc's 55 % reduction target for 2030. The ETS proposal, COM (2021) 551, and the CBAM (Carbon Border Adjustment Mechanism) proposal, COM (2021) 564, are of special interest regarding the design of project-based CCfDs for the industry.

The ETS proposal suggests amending the regularities concerning free allocation of EUAs. In the future, low-carbon technologies should also receive free allocations, by defining activities entitled to free allocation (Directive 2003/87/EC) technology neutral. This is intended to remove disincentives in the ETS-regime for innovative carbon-lean processes, which are currently not covered by free allocation of EUAs.

This impacts the effective CO_2 price $p_{CO2\text{-}effective,t}$ as defined in eq. 3. In case technology neutral free allocation results in equal free allocation for the CCfD-reference and the CCfD-project, i.e. $A_{Reference,t}=A_{Project,t}$, the resulting effective CO_2-price becomes equal to the EUA-price $p_{CO2\text{-}effective,t}=p_{EUA}$ in eq. 3, assuming that carbon costs resulting from allocation below the global emission average can be passed on to consumers (e.g. due to the presence of a CBAM). In that case, the carbon price signal and its incentives for low-carbon investment are not reduced by $A_{Project,t} < A_{Reference,}$ anymore. Carbon leakage protection due to free allocation is not immediately affected by this, as free allocation is still provided.

The CBAM is suggested as a new carbon leakage protection mechanism, phasing out free allocation over time. Competitiveness on international markets would not be secured any further by subsidizing emission intensive processes within the ETS-regime. The logic of securing competitiveness on the internal market is essentially reversed. To avoid distortions, a long phase-in of the CBAM is suggested. In case that process specific allocation is abandoned is already realized during the CBAM phase-in, there is no change to $p_{CO2\text{-}effective,t}$, as the CBAM phase-in affects only the absolute quantity of both allocations, but not their relation. It is thus implicitly assumed in eq. 3 that the CBAM strengthens CO_2-cost pass-through to the internal market. If the market does not absorb the full emission cost (or more so than anticipated), a different pass-through price could be considered in the CCfD (instead of p_{EUA} in eq. 3). However, as for the ex-post determination of the green margin in Option 3 above, it is both administratively and conceptually challenging to determine this difference to $p_{EUA.}$

In any case, as CCfD contract durations of ten years or more are envisioned, the contracts must be constructed in a way to fit in possible policy changes for the carbon market and carbon leakage protection. The derivation of the payment formula $P_{CCfD,t}$ (eq. 4) presented in this paper reflects this flexibility.

For feedbacks of CCfDs on the EU ETS, CCfDs should be seen as complementary to the EU ETS. Importantly, concerns that CCfDs would weaken the EU ETS are not justified. Two cases can be distinguished: a) CCfDs are used as an innovation policy instrument to address for example the technology spill-over market failure. In this case the scale of the investment with CCfD prices high above market prices is limited and impacts thus small. b) CCfDs are used to scale up technologies that are already mature and needed for efficient transition pathways. In this case, CCfDs work as a de-risking policy that addresses regulatory uncertainty and correspond to expected CO_2 prices over the contract horizon. They merely fill a, potentially temporary, gap in the long-term hedging markets, and thus address the incomplete market challenge (also cf. Greenwald et al., 1986).

Conclusions and Outlook

CCfDs are a promising instrument to advance the decarbonisation of emissions-intensive basic materials industries. They are a transitional policy instrument that bridges the period of uncompetitiveness, until climate-friendly production processes become price-setting on the market and thus competitive with conventional, emission-intensive processes. The further regulatory development in the CO_2 market, as well as a general trend of falling prices due to green electricity and hydrogen roll-out, will determine the timeframe for which CCfDs will be necessary, and the state funds required for the instrument.

This paper discusses important elements for the design of CCfDs , and presents impacts and trade-offs of the concrete shape of these design elements and necessary assumptions associated with it. Design elements considered include: 1) the formulae for the contract price, effective CO_2-price and CCfD payout, 2) the definition of system boundaries, 3) the determination of reference and project cost to calculate incremental cost, 4) dynamization of the CCfD payout, 5) direct marketing of green products, i.e., if and how to consider a potential green premium, as well as 6) the tendering and selection process.

For example, our work shows that system boundaries may be either set concordant to the EU ETS which reduces administrative effort, or they may be set broader including emissions along the value chain since these are also very important to support climate neutrality as a whole. The formula developed and presented in this paper for considering an effective CO_2-price assumes either a complete carbon price pass-through, or a clear delimitation of the CCfD from the carbon leakage protection mechanisms employed, which ensures suitability of the CCfD instrument in times of a changing ETS-regime. Dynamization of contractual payments seems to be suitable to prevent over- or underfunding and reduce risk of price fluctuations for the company, as the hedging of relevant volatile prices is a central goal of the instrument. But it comes, for some input factors, with the risk of funding market power-based mark-ups, and disincentivising market-based hedging behaviour. Hence, we conclude that careful choice of which cost factors to dynamize, to achieve a suitable balance between benefits and costs, is required. Allowing direct marketing of the low-carbon production characteristic would be desirable to bring the "green" product to the market, i.e., to foster green lead markets. However, without subtracting the associated revenues from the CCfD payout, it may lead to market distortions detrimental for other low carbon options since prices might not reflect the real cost of low carbon production. Moreover, not subtracting additional revenues might lead to overfunding. As the discussion also shows, the implementation of the direct marketing design element also has potential consequences for the repayment mechanism of the CCfD.

As illustrated by these examples, this paper highlights the complex, and in part interdependent, design issues that a CCfD instrument raises. The choice of certain design options for the instrument is in many cases political. Beyond the aspects above, it depends on the framework for implementation of the instrument, for example: how many different sectors does it cover, and how do those differ, e.g., in terms of abatement costs? Will it be implemented at the level of a member state[8], or EU-wide?

Moreover, the paper argues that CCfDs can be seen as complementary to the EU ETS, and concerns that CCfDs would weaken the EU ETS are therefore not justified. CCfDs can be either seen as innovation policy instrument addressing the technology spill-over market failure, or as de-risking instrument to scale up mature technologies which are needed for efficient transition pathways. In the first case, CCfD impacts on the ETS market are limited as to the limited scale of investments above ETS prices, in the latter case, CCfD funding corresponds to expected CO_2-prices over the contract horizon, filling a temporarily gap to realize a pull-forward effect.

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8. Currently (February 2022), the German Ministry for Economic Affairs and Climate Action is planning to introduce a pilot programme for project-based CCfDs for the German industry (called "Klimaschutzverträge" in German) before the end of 2022. Key points on a possible design were already published in 2021. The instrument shall target steel, cement, lime and ammonia production. A central point is the requirement of an emissions reduction of at least 90 % compared to the status quo.

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