cep Centrum für Europäische Politik
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cepInput

No. 7 | 2023 16 May 2023

Market Instruments for a Climate-neutral Industry

An Incentive Analysis

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The goal of decarbonizing European industry requires a balancing act between climate neutrality and competitiveness, involving considerable cost uncertainty. Under such conditions, regulation can only be successful if it views transformation as an investment project. With the Temporary Crisis and Transition Framework, the EU has given the Member States greater scope for stimulating private investments through public support. Two innovative market-based instruments are at the centre of the debate: Carbon Contracts for Difference and green lead markets. This cepInput examines their economic interaction and quantifies the magnitude of the expected costs and risks using the example of the steel industry.

Key points:

- Carbon Contracts for Difference are an effective and cost-efficient instrument for promoting investment when awarded on a competitive basis. To limit government risks and maintain openness to technology, they should be limited to their core purpose of CO_2 price hedging.
- Certification of low-emission products is an important complement to supply-side subsidies. Quota requirements for procurement should be established preferably only in combination with carbon contracts in order to limit the burden on cost-sensitive steel customers. Such a mix of instruments contributes to a balanced distribution of costs and risks between state and private stakeholders, which will increase acceptance in the long term.
- The design of both instruments should be strictly aligned with the emission target and otherwise be as non-discriminatory as possible regarding the current technology mix of producers, in order to avoid the emergence of new monopolistic market structures.

Table of Contents

1 Background **3**
2 Current situation **4**
3 Market instruments for an accelerated decarbonization **5**
3.1 Overview of political influencing factors 5
3.2 Detailed analysis CCfDs 8
3.3 Detailed analysis of green lead markets 11
3.4 Comparative analysis 14
4 Impact analysis for the steel industry **17**
4.1 Methodology and data 17
4.2 Technologies and cost patterns 21
4.3 Policy scenarios 23
4.4 Simulation results 24
4.4.1 CCfDs 24
4.4.2 Green lead markets 27
4.4.3 Comparison CO_2 mitigation costs 30
4.5 Discussion 32
5 Conclusion **33**
6 Appendix **35**

Table of Figures

Figure 1: Overview of political instruments relevant to the industrial transformation 6
Figure 2: Different instruments for investment support 7
Figure 3: Evolution of support under a CCfD 9
Figure 4: Stylized revenue profile of investment projects under different support regimes 15
Figure 5: Risks for different stakeholder groups 16
Figure 6: Process steps of the H_2-DRI-technology 22
Figure 7: Comparison of projected unit costs of crude steel production by technology 23
Figure 8: Simulation of introduction of CCfDs – Impact on revenues and expenses 25
Figure 9: Simulation of introduction of CCfDs – Composition of CO_2 contract price 26
Figure 10: Price range for H_2-DRI-steel on green lead markets 28
Figure 11: Linkage between CO_2 contract price and market price for H_2-DRI-steel 29
Figure 12: Comparison of policy mix by CO_2 mitigation costs 30
Figure 13: CO_2 mitigation costs in expectation and in a downside risk scenario 31

1 Background

Europe's industry faces a difficult balancing act in the coming years. It must implement the climate policy driven transition to new low-emission technologies at high speed, while at the same time defending its competitive position on the world markets against rivals benefiting from state support. In the current intense debate on how the development of European production capacities in the field of new green industries can succeed, there is therefore one thing that must not be overlooked: the management of decarbonizing the existing industrial base. This is particularly true for emission-intensive basic industries such as glass, steel or cement where not only is the pressure to transform at its greatest, but also, due to their exposed position in European value chains, where the economic stakes are high. The technologies required for the transformation are established and widely available. The decisive hurdle at the economic level lies in the question of investment incentives, and thus the economic viability of low-emission production methods.

With its recent agreement on the reform of emissions allowance trading, the European Union has set a course for greater scarcity in the emissions budget for industry and the energy sector, and thus presumably also for rising CO_2 prices.[1] To ensure that emission reductions are not achieved at the expense of production losses, however, more is needed than just measures to make conventional technologies more expensive. The European Commission has also recognized this by granting the Member States more flexibility in supporting industries under pressure to transform, among other things, with the Temporary Crisis and Transition Framework.[2] The decisive factor will be the extent to which the Member States use this latitude for intelligent support. Traditional instruments such as investment subsidies are reaching their limits in the current environment. They cannot cushion the regulatory uncertainty about the CO_2 price signal and long-term private hedging is not an option in view of the regulatory uncertainties. Transformation pressures have therefore recently spawned innovation at the policy level as well, in the form of new market-based instruments designed to allow investors to offload some of the existing risks onto the state or private stakeholders. However, apart from a few pilot programs, the effects of these instruments have not yet been tested in practice.

This cepInput examines the economic impact of two instruments under discussion: Carbon Contracts for Difference and quota-based green lead markets. We analyse their economic mechanics and the role of design variants both in terms of the conceptual theory and empirically, on the basis of scenarios for the steel industry. Our contribution to the current debate is, on the one hand, to shed light on the consequences of existing uncertainty about the cost burden of these instruments, not only with respect to the CO_2 price, but also with respect to energy prices, which are also essential for the transformation. And, on the other hand, we want to shed light on the expected impact on the distribution of costs between the actors directly affected (as far as they can be mapped), which will have consequences for the macroeconomic effects and the acceptance of the measures. In this way, we hope to contribute to an honest discussion about the opportunities and risks of these instruments for the transformation and preservation of industrial value creation in Europe.

[1] European Parliament (2022). Climate change: Deal on a more ambitious Emissions Trading System (ETS). Press Release, 19.12.2022.

[2] European Commission (2023). State aid: Commission adopts Temporary Crisis and Transition Framework to further support transition towards net-zero economy. Press Release, 09.03.2023.

2 Current situation

The distribution of Europe's greenhouse gas (GHG) emissions, resulting from economic activity by economic sector, paints a clear picture. Energy supply and industry are by far the largest emitters year after year, accounting for more than half (53%) of cross-sector GHG emissions in the EU-27 in 2021.[3] However, a significant difference can be seen in the trend over time. While the energy supply sector has been able to reduce its emissions particularly sharply compared to other sectors (-35% compared to 2011), emissions from industry fell only below average (-10%) over the same period. The reason lies in the different technology paths. The gradual substitution of fossil fuels by renewables has succeeded in significantly reducing the CO_2 intensity of the electricity supply in Europe as a whole, although temporary setbacks such as the most recent in 2022 cannot be ruled out. Industry, on the other hand, has so far only completed a small part of the technology transition and is still dependent on the supply of carbon-containing compounds in key value-added production stages. GHG emissions result both from their use as energy sources (fuel) and as raw and auxiliary materials (process emissions in the course of industrial processing).

However, there are wide variations between industrial sectors. Table 1 shows the distribution of sector-specific emissions as defined by the European Environment Agency. According to this, three sectors are currently particularly significant for industry's GHG emissions: the chemical industry[4], the mineral industry and iron/steel production. These production sectors together accounted for about 60% of industrial GHG emissions in the EU-27 in 2019. In all of these sectors, process emissions play an important role in addition to emissions from the combustion of fossil materials. The major impact of these sectors on the GHG balance is not only due to their high level of economic activity: they also produce significantly more emissions than the rest of industry (see Table 1) as a proportion of Gross Value Added. At the same time, it must be acknowledged that, in recent years, all three sectors have been more successful than the industrial average, in percentage terms, in their efforts to reduce their emissions contribution. However, the savings achieved in this regard (a total of -22% in industry over the period 2005-2019) are still a long way off the EU's updated medium-term targets: in 2030, according to the latest trilogue agreements on the Fit for 55 package, an emissions reduction of -62% compared to 2005 must be achieved by the energy and energy-intensive industry sectors included in the current EU ETS.[5] In the long term, the goal of climate neutrality by 2050 enshrined in the EU Climate Change Act also means a reduction in net emissions to almost zero for industrial manufacturing, unless unexpectedly high overall economic investments are made by then in negative emission technologies such as carbon capture from biomass or direct air capture.[6]

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3 Eurostat (2023a). Air emissions accounts by NACE Rev. 2 activity. Eurostat Database.

4 Including Petrochemicals

5 See European Parliament (2022).

6 Tsiropoulos, I., Nijs, W., Tarvydas, D., & Ruiz, P. (2020). Towards net-zero emissions in the EU energy system by 2050. Insights from Scenarios in Line with the 2030 and 2050 ambitions of the European Green Deal. Technical Report Joint Research Centre (JRC), European Union.

Table 1: Industrial GHG emissions in the EU-27

	Sector					
	Chemical industry	Mineral industry	Iron and Steel	Non-ferrous metals	Other industries	Total industries
GHG emissions 2019 (in MT CO_2-Equiv.)						
Energetic emissions	65.80	84.75	78.03	9.36	190.99	428.93
Process emissions	56.61	104.97	67.16	8.13	106.47	343.33
Total emissions	**122.41**	**189.72**	**145.20**	**17.48**	**297.46**	**772.26**
Change GHG emissions 2005-2019 (%)						
Energetic emissions	-22.07%	-31.09%	-25.63%	-18.72%	-17.98%	-22.95%
Process emissions	-51.70%	-22.24%	-23.46%	-43.13%	30.28%	-21.24%
Total emissions	**-39.29%**	**-26.46%**	**-24.64%**	**-32.24%**	**-5.44%**	**-22.20%**
Gross Value Added 2019 (in bn EUR)	179.83	72.66	40.48	24.32	2316.18	2633.48
Emission intensity 2019 (T CO_2 / TEUR)	**0.68**	**2.61**	**3.59**	**0.72**	**0.13**	**0.29**

Sources: EEU (2023)[7]; Eurostat (2023b)[8]; own aggregations.

3 Market instruments for an accelerated decarbonization

3.1 Overview of political influencing factors

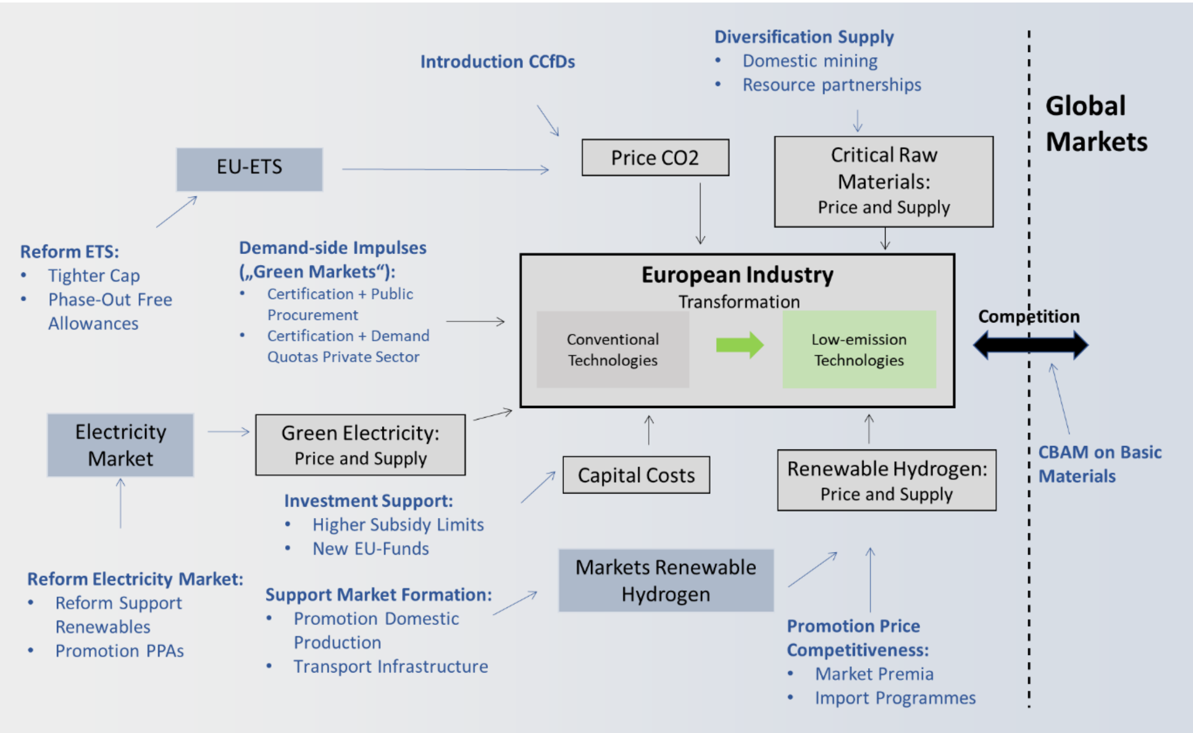
The green transformation of European industry is taking place in a complex regulatory environment. The incentives for switching to low-emission production technologies are influenced by a bundle of political instruments at the EU and Member State level. This is not just about target-related support measures, it also concerns fundamental decisions about the future structure of markets. From the point of view of an industry, not only are its own sales markets relevant, but also the markets relating to essential inputs for low-emission production methods. In many sectors, this primarily concerns the electricity market (electrification) but in the medium term the market for adequately trained skilled workers will also be relevant and thus areas such as labour market and education policy, where competencies in Europe are located at the national level.[9] In industries where complete electrification would be technologically impossible or too cost-intensive (especially parts of the chemical and steel industries), the development of a market for green hydrogen is also an important factor.[10] At the same time, regulatory conditions in non-EU countries carry significant importance for export-oriented European industry, especially in the areas of competition and climate policy.

Figure 1 provides an overview of policy measures currently under discussion, or in the legislative process, at European level that are relevant to the costs of industrial transformation. Some of these measures are aimed directly at increasing the profitability of investments in technology change by providing government investment subsidies, reducing the prices of essential inputs or improving their availability, or making conventional technologies more expensive. Some of them act indirectly by influencing the design of current or future (hydrogen) markets. The individual measures should not be looked at in isolation but in the way they interact with each other. Such interaction may be intended by the regulating body. A current example of this is the coupling of the introduction of a carbon border adjustment mechanism (CBAM) to the phase-out of the free allocation of emission allowances in the

7 EEU (2023). Greenhouse gas emissions by source sector. European Environmental Agency.
8 Eurostat (2023b). Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E). Eurostat.
9 Lankhuizen, M., Diodato, D., Weterings, A., Ivanova, O., & Thissen, M. (2022). Identifying labour market bottlenecks in the energy transition: a combined IO-matching analysis. Economic Systems Research, 1-26
10 Wolf, A. (2022). How green hydrogen will make Europe more independent. cepInput No. 6 / 2022.

EU Emissions Trading Scheme (EU ETS).[11] However, it can also be triggered unintentionally by the interaction of decisions on different markets, e.g. when decisions on future electricity market design influence the availability of renewable energy for the electrolytic production of hydrogen. The fact that the shift to green technologies involves very long-term investment decisions, which are also subject to a natural time lag given different investment cycles, increases the importance of timing when it comes to effectiveness. The synchronization of regulatory measures - both in terms of timing and between the political levels (EU, Member States) - thus plays a decisive role for the political impetus given to the transformation to climate neutrality.

Figure 1: Overview of political instruments relevant to the industrial transformation



Source: own representation

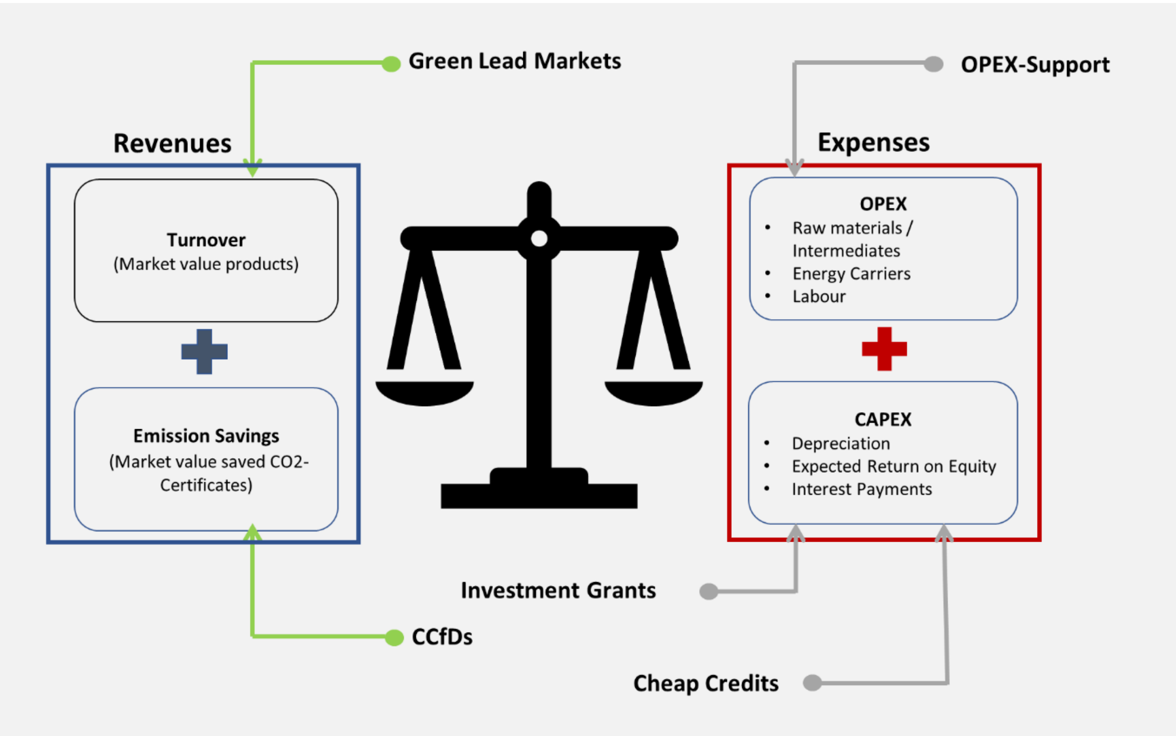
When assessing the economic impact of a particular policy mix, the investor perspective is essential. Only if the investment in low-emission technologies represents a profitable asset from the perspective of the capital markets can the change in technology succeed without a loss of value in the economy's total capital stock. Policy measures must first therefore be examined to determine whether they will contribute to market profitability, both in terms of the expected operating surpluses and the capital costs incurred in financing them. This does not mean that political decisions should be geared to maximizing the return on investment, i.e. that net present value should be assigned something like a welfare function. From a systemic perspective, such an approach would not be very targeted, if only because the economic interests of investors at different stages of industrial supply chains are not always congruent, and a higher return for investors at one stage may come at the expense of the competitiveness of upstream or downstream industries. The guiding principle for the welfare analysis should in fact be how to bring about sufficient profitability of the investments essential for the overall

[11] Menner, M.; Reichert, G. (2022). Fit for 55 – EU-Emission Trading Scheme (EU ETS 1) for industry and energy. cepAnalyse Nr. 5/2022.

economic transformation at the lowest possible social cost. In other words, it is about minimizing the social costs of the path taken towards climate neutrality.

In this paper, we focus on two innovative instruments that, if appropriately designed, could contribute to achieving such a path: Carbon Contracts for Difference (CCfDs) and green lead markets. What they have in common is that they both represent an important building block in the research debate as well as in the industrial policy considerations of the EU (e.g. in the Green Deal Industrial Plan[12]). Both are currently still in the conceptualization or early test phase, which makes a more intensive analysis appropriate at this point in time. Moreover, both are innovative in their economic functionality, as the investment decision parameters which they address are different to those addressed by conventional instruments used in investment promotion. Figure 2 illustrates this with a view to the characteristic factors influencing the return on an investment in low-emission technologies. As we will explain in more detail later, they can be combined with each other and with other instruments, which makes them additionally interesting as building blocks for a broader mix of instruments. In the following report, we therefore devote a detailed economic analysis to them, first qualitatively with regard to their general design features and then quantitatively using the steel industry as an example.

Figure 2: Different instruments for investment support



Source: own representation

12 European Commission (2023a). The Green Deal Industrial Plan: putting Europe's net-zero industry in the lead. COM (2023) 62 final.

3.2 Detailed analysis CCfDs

An important factor in calculating the return on investments in low-emission technologies is the CO_2 price. By switching to lower-carbon production methods, companies save costs associated with emission allowances. This applies regardless of whether emission allowances were purchased at auction, acquired on the secondary market or allocated to companies free of charge. This is because even in the case of allowances received free of charge, the sales option always represents a revenue potential and thus defines the opportunity costs per tonne of CO_2 emissions caused. Assumptions about the future development of the CO_2 price on the EU ETS - and its possible range - thus significantly influences the investment calculation and do so in two ways: on the one hand with regard to the average expected returns, and on the other hand with regard to their volatility. The latter variable affects the investor risk and thus the cost of capital to be borne on the market. In principle, it is the task of forward markets to mitigate such price risks by means of offsetting long-term contracts. In the area of ETS allowances, corresponding products (futures, put/call options) have also become established in standardized forms.[13] However, the time horizon of these contracts is limited to days and months, or in exceptional cases to a few years. The industry's transformation decisions, on the other hand, involve a capital commitment over a period of ten, twenty or more years.

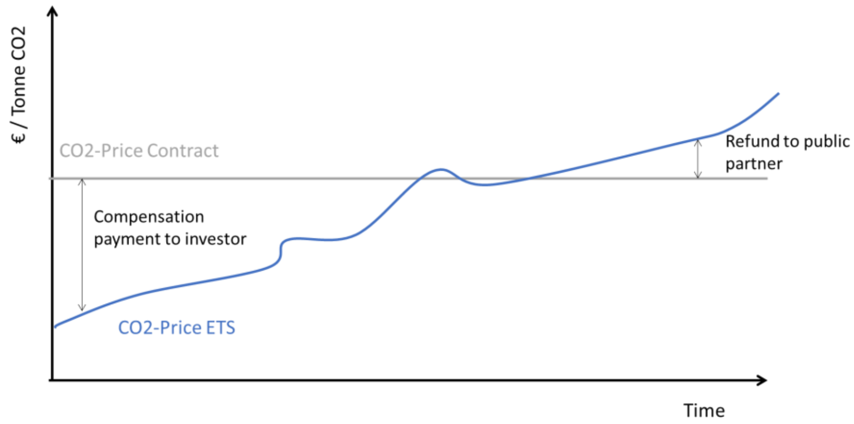
A major reason for the insufficiency of forward contracts is the politically induced risk.[14] The CO_2 price on the EU ETS is not determined purely technologically by the abatement costs of the companies, but also as a result of the politically established framework conditions, in particular with regard to the development of the annual allowance issue quantities (cap) and the future design of accompanying stabilization mechanisms (market stability reserve). Due to its organization into trading periods, there is medium-term but not long-term certainty about the regulatory path. In addition, there is the risk of future discretionary regulatory intervention in the event of unexpected price developments or crisis situations. Such a price risk, which depends on many parameters and is massively influenced by social and macroeconomic factors, is difficult for market players to manage. And even if private hedging partners were to be found, the high premium they would pay on the market would in turn be a major cost barrier for the investing industry.

The idea behind CCfDs is therefore to let the state step in as an alternative hedging partner. Their economic calculation corresponds to that of a forward contract on emission allowances. In the contract, a fixed CO_2 price is agreed between the private player investing in low-emission technologies and the state, which is valid for a fixed period. If the allowance price on the EU ETS is below this level, the private player benefits; if it is above, the state benefits. Unlike standard forward contracts, however, the benefits are not realized in the form of payments only at the end of the contract. Instead, periodic payments are made between the contracting parties over the term of the contract, corresponding to the difference between the contract price and the market price at the time. If the market price for CO_2 rises over time, the private player can expect to receive more revenue from the contract in the early phase, and the government in the later phase (see Figure 3).

[13] EEX (2023). Produktüberblick Emissionsberechtigungen. European Energy Exchange, Leizpig.

[14] Richstein, J. (2017). Project-Based Carbon Contracts: A Way to Finance Innovative Low-Carbon Investments (No. 1714). DIW Berlin, German Institute for Economic Research.

Figure 3: Evolution of support under a CCfD



Source: own representation based on dena (2022).[15]

This is the key difference to a traditional government operating subsidy: CCfDs provide an inherent repayment mechanism for subsidies. This avoids the emergence of windfall profits and can reduce the government budget burden in the long term. Because this mechanism is tied to market performance, it does not pose a risk from the private stakeholder's perspective: Repayments are due only if a favourable price development reduces the need for subsidies. **As a result, the economic value of the CO_2 emissions saved by the investment is secured for the investor. The security gained in terms of investment returns is reflected in falling capital costs: the expected net present value of the investment increases.**

Depending on how they are structured, CCfDs can provide further incentives that go beyond the pure insurance aspect. For example, the current discussion favours a model that fully offsets the difference in total costs that currently still exists between conventional and low-emission technologies. To this end, the contractually agreed CO_2 price is not based on the current or expected future market price level for CO_2 but is set high enough that the expected return from the transition to low-emission technologies will be just sufficient to compensate for the higher operating and capital costs at the present value of the investment. If such a so-called **"green premium"** is included, the CCfD will at the same time become an instrument for compensating for technologically induced differences in production costs. **Such an arrangement has several advantages. First, it defines a single economic incentive lever for overcoming various forms of investment barriers. Second, this incentive lever is targeted because it directly addresses the fundamental goal of transformation policy: the reduction of greenhouse gas emissions.** The greater the CO_2-saving effect of an investment, the higher the value of the hedge and thus the greater the incentive effect of the CCfD. At the same time, a restriction to certain technologies is not a requirement; technology neutrality can basically be maintained in such a funding scheme.

One practical difficulty may be the information requirements that arise when determining an appropriate contract price, especially with regard to the cost structure of the various technologies. Contrary to what the most recent report by the Scientific Advisory Board of the German Federal Ministry for Economic Affairs and Climate suggests, however, these requirements are by no means

[15] dena (2022). Tech for Net Zero Allianz: CCfD zur Skalierung von Klimatechnologien in Deutschland. Deutsche Energie-Agentur.

imposed one-sidedly on the state.[16] If CCfDs are awarded to investors by way of competitive tendering, the real cost structures should be revealed in the bid prices of the investors. The "green premium" thus results from the market. Uncertainty about the future cost degression of low-emission technologies cannot be eliminated because this is partly determined by technology. Depending on the actual development of productivity, an appropriately selected "green premium" may prove to be too high or too low ex post. The same uncertainty is in principle inherent in all unsecured forms of investment in new technologies. And CCfDs in their basic form deliberately do not represent an assumption of risk by society: only the CO_2 price is secured by the state; the technological risk of unit cost development remains with the investor.

Another design element discussed in this context is the possibility of indexing the contractual CO_2 price based on the prices of key production inputs for the low-emission technologies.[17] In the event of rising (falling) input prices over time, the contractual CO_2 price is to be automatically adjusted upwards (downwards). The idea here is additionally to hedge price risks in the area of operating costs via the CCfDs. This may also be effective for increasing investment incentives but makes the hedging less precise. The extent to which the state (and thus the general public) provides insurance for investment projects in climate-friendly technologies then no longer depends solely on the climate impact as a societal target, but also on project-specific input intensities for which decentralized hedging options may exist. It would be particularly problematic to ignore such price signals in the case of scarce energy sources such as electricity. The effect on price of future changes in the supply situation would no longer have a steering effect on decarbonization projects, which tend to be electricity intensive. The technological neutrality of the instrument would also be lost with such indexing. Future technologies that rely on the substitution of increasingly expensive inputs would initially not be able to exploit their cost advantage on the market.

Regardless of their specific form, CCfDs constitute state aid. They therefore require separate approval by the EU and must be examined for compatibility with the internal market. At the beginning of 2022, the European Commission published new guidelines on how it will examine future aid measures in the field of energy, environmental protection and climate change, for compatibility with the internal market.[18] CCfDs are explicitly mentioned as a potentially useful form of support. If they mainly serve to cover additional operational costs, the Member State must prove that their introduction will lead to "more environmentally friendly operating decisions". So far, the EU has not set any concrete positive requirements for the design of CCfDs. In Germany, the federal government is currently drawing up a national program. This is to be based on a new funding guideline, a draft of which is already available. In principle, both capital and operating costs are to be eligible for funding under CCfDs. As a minimum requirement, the technical feasibility of a GHG emission reduction of at least 95%, compared to a conventional reference technology, should be fulfilled. In addition, however, the funding cost efficiency will also be included as a key criterion in the award decision. In addition, it should also be possible to dynamically index energy carrier costs, i.e. price indexing for energy inputs, in the funding

[16] BMWK (2023a). Transformation zu einer klimaneutralen Industrie: Grüne Leitmärkte und Klimaschutzverträge. Gutachten des Wissenschaftlichen Beirats beim Bundesministerium für Wirtschaft und Klimaschutz (BMWK).

[17] See BMWK (2023a).

[18] European Commission (2022). Guidelines on State aid for climate, environmental protection and energy 2022. Communication from the Commission. 2022/C 80/01.

calls. After public criticism[19] the announced requirements have been clarified to the effect that the awarding of contracts is to be carried out in a competitive manner, i.e. on the basis of auctions.[20]

3.3 Detailed analysis of green lead markets

An alternative (or supplement) to cost-side subsidy instruments is government stimulus to strengthen revenues for green technologies. If the switch to low-emission production methods were to be a purely process-based innovation, i.e. not linked to innovative product properties, there would be hardly any scope for passing on the costs of the switch via higher sales prices. This is especially true for pioneering technologies with long investment cycles: Market prices will continue to be determined by the cost structures of conventional technologies for some time to come. In order to achieve cost recovery in these cases even without external support, measures are being discussed that aim to facilitate the exploitation of climate friendliness as an asset on the market. The basis for this is public certification of products manufactured with low emissions. Their climate friendliness is thus made transparent as a signal to market participants. The basic regulatory requirements for this are in place in Europe: the EU has many years of experience in the implementation of environmental certificates since the introduction of the EU Ecolabel in 1992.[21]

Two factors are crucial for the effectiveness of voluntary climate labels: trust and willingness to pay. Consumers of certified products must be able to have confidence in the climate friendliness signalled. Tough certification criteria and a reliable monitoring system reduce the incentive for producers to cheat.[22] Under these conditions, certificates can develop a guiding effect with requirements becoming a point of orientation for all suppliers in the decarbonization of their processes and thus defining a new technology standard. The prerequisite is the widespread existence of an increased willingness to pay for green products, which allows producers to refinance the costs of the technology change as early as possible in the conversion phase.

Since the scope for setting prices for intermediate products typically depends heavily on the extent to which industrial consumers can pass on higher prices to their customers, the behaviour of the end consumers is ultimately always the decisive factor. According to empirical research, their willingness to pay a "green premium" varies greatly between products and population groups.[23] In addition to personal attitudes toward environmental and climate protection, the signal effect of a purchase decision can also play a role: In addition to higher social status, the purchase of expensive climate-friendly goods also signals a commitment to pro-social values and a general willingness to cooperate, which increases the opportunities for participation in social interaction. For the marketability of green products, it is therefore very important to make the certification as clearly visible to the outside world as possible.[24] In general, the chances of implementing an adequate premium should also be better for technologies whose products form a smaller proportion in value terms of the end products into which

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[19] Handelsblatt (2023). Habeck krempelt Subventionsregeln zur klimagerechten Transformation der Industrie um.

[20] BMWK (2023b). Richtlinie zur Förderung von klimaneutralen Produktionsverfahren in der Industrie durch Klimaschutzverträge. Draft (accessed on 04.04.2023). Bundesministerium für Wirtschaft und Klimaschutz.

[21] European Commission (2023b). What is the EU Ecolabel?

[22] Hamilton, S. F., & Zilberman, D. (2006). Green markets, eco-certification, and equilibrium fraud. Journal of environmental economics and management, 52(3), 627-644.

[23] Wei, S., Ang, T., & Jancenelle, V. E. (2018). Willingness to pay more for green products: The interplay of consumer characteristics and customer participation. Journal of Retailing and Consumer Services, 45, 230-238.

[24] Berger, J. (2019). Signaling can increase consumers' willingness to pay for green products. Theoretical model and experimental evidence. Journal of consumer behaviour, 18(3), 233-246.

they are incorporated. The necessary cost compensation is thus distributed over more products and end users, and the necessary degree of willingness to pay per end user is lower. This speaks in favour of the effectiveness of certification, especially in the area of industrial raw materials.

However, certification systems alone are unlikely to provide the necessary impetus for investment activity at the pace set by the climate targets. This is because the level of investment in green technologies requires clear sales forecasts. This is particularly true for those technologies where major economies of scale require early scaling. For this reason, various considerations have been voiced about supplementing certification with government acceptance requirements. One immediate starting point is public procurement. For example, the expected contribution to climate neutrality could be defined as a binding quality criterion with a certain minimum weight for public procurement. At the European level, this is the approach taken by the European Commission in its draft Net Zero Industry Act.[25] However, it remains uncertain what de facto relevance such a criterion will have in the actual award decision, especially compared to the contract price. Other proposals therefore aim at a quota system, whereby a minimum share of products certified as low emission must be included in public procurement over a certain period of time. This would result in a formally clearly defined sales potential. In order to further expand this potential in line with the ambitious targets, it is being discussed whether corresponding quota requirements should also be extended to procurement in the private sector.[26]

The direct effect of such a quota system is artificial market segmentation. Products that are homogeneous in terms of their utilization characteristics are differentiated into conventional and "green" submarkets according to their form of production. The aim is to enforce a green premium in the form of a price difference between the two submarkets. This is achieved by protecting the users of green technologies from the pricing power of conventional technologies through the quota system: buyers will have no possibility of substitution regarding the amount of the specified minimum share. In competitively organized sub-markets, if all arbitrage possibilities are exploited, a price difference, corresponding to the cost difference between green and conventional technologies, should settle into a stable situation in the medium term.[27] **The advantages of this automatism of market forces are obvious. State actors do not need to know the actual cost difference, since it is revealed by the market itself. Changes in its level over time (e.g., as a result of electricity price trends) do not require regulatory correction, since they are balanced out by adjustments to the price difference on the market.** Moreover, this sort of support mechanism does not require direct additional government spending.

Nevertheless, it remains an artificially created market, whose design is not comparable with existing allowance-based markets such as the EU ETS. While the latter market aims at internalizing negative climate externalities by transforming them into a marketable asset, green lead markets do not create additional space for trade. They merely force market actors to artificially differentiate products in already existing markets for private goods. With this coercion comes considerable additional leverage

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25 European Commission (2023c). Proposal for a Regulation of the European Parliament and of the Council on establishing a framework of measures for strengthening Europe's net-zero technology products manufacturing ecosystem (Net Zero Industry Act). COM/2023/161 final.

26 Joas, F., Witecka, W., Lenck, T., Peter, F., Seiler, F., Samadi, S., ... & Yilmaz, Y. (2020). Klimaneutrale Industrie: Schlüsseltechnologien und Politikoptionen für Stahl, Chemie und Zement; Studie Agora Energiewende.

27 See BMWK (2023a).

for the regulator, which could trigger the emergence of inefficiencies and undesirable side-effects. This applies both to the establishment of certification criteria and to the minimum green quota.

For example, if certification criteria are defined very narrowly in terms of the selection of eligible technologies, there is a risk that the transition phase will unintentionally give competitive advantages to suppliers who are already following the accepted technology path. Such suppliers could expect excess returns on the green lead markets, at least in the initial phase. In the longer term, there is also a danger that such excess returns could solidify into permanent monopoly situations, especially if economies of scale are involved. The danger is particularly great in cases where markets are already organized on oligopolistic lines and/or suppliers differ significantly in their choice of technology. The choice of minimum quota to be fulfilled is similarly sensitive. If quotas are chosen very ambitiously in the initial phase, there is a risk that the development of production capacities will not be able to keep pace with the demand generated, even with economically favourable incentives. This would result in very high prices for customers.

The basic problem of green lead markets in this context is the **technologically induced delay in market reactions on the supply side**. The length of investment cycles in industrial technologies implies that supply cannot react immediately to price incentives, as is the case in financial markets. Thus, a competitive equilibrium that balances out existing cost differences will only emerge in green lead markets in the longer term, and only if the regulator enables the development of competitive structures by carefully selected requirements along the way. An essential prerequisite for this is detailed knowledge of the structure and technology options on the markets concerned. The general information requirements for the regulating authority cannot therefore be regarded as fundamentally lower for this instrument than for alternative support measures.

In addition, from a dynamic perspective, there is the danger of preventing future technological progress. Certification criteria could be formulated in such a way that they unintentionally exclude alternative technology options that could achieve the same climate protection contribution with less resource input. Since the spectrum of potential future technologies is unknown at the present time, certification can only be guaranteed if it is based solely on proven emission reductions as the key performance indicator. However, this could lead to increased monitoring work. Nor is the avoidance of state budget burdens an unconditional advantage of green lead markets since this means that the consumers will have to bear the costs of subsidies through higher prices. This could jeopardize the price competitiveness of downstream industries, especially if they face strong international competition. It could also prove counterproductive in terms of climate policy. On the one hand, the cost burden could lead to fewer funds being available for investment in decarbonization of the downstream segment. On the other hand, the effectiveness of complementary measures, such as Carbon Border Adjustments, which rely on making conventional technologies a more expensive incentive, could suffer as a result of higher prices for low-emission products.

Conceptually, however, it makes sense to combine green lead markets with CCfDs. If lead markets can be organized competitively at an early stage, the danger of double subsidization is avoided by the market mechanism This means that a higher contractually fixed CO_2 price would then lead to lower price premiums on the markets for low-emission products because a larger proportion of the cost disadvantage is already compensated for by the CCfDs. This balancing effect can also at least mitigate the societal damage of possible planning errors in the pricing and dimensioning of CCfDs. On the other hand, there is also a risk of distortion if the criteria for certification and for access to CCfDs are not sufficiently coordinated. For example, if certain certified technologies were excluded from future CCfDs, a roll-out of such contracts would also affect these technologies in the form of a price devaluation, without them being able to benefit in return from the hedging of CO_2 prices.[28] In order to maintain technology neutrality as far as possible even under these conditions, criteria should be limited to the expected contributions to the goal of emission reduction.

3.4 Comparative analysis

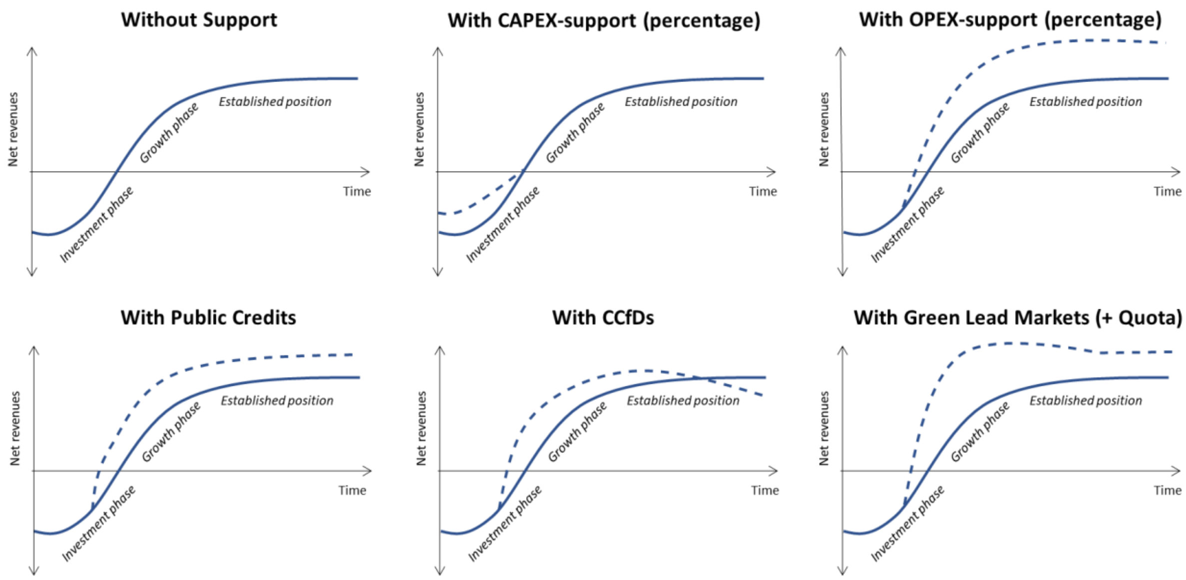
The aforementioned funding instruments aim to help cover the additional costs of investment in low-emission technologies in various ways. This is associated with different concepts of the role of the state. Basically, four different (non-exclusive) state functions can be identified in the measures currently under discussion:

1. **The state as cost bearer:** part of the additional costs compared to conventional technologies is covered directly by the state budget which directly improves the return prospects for private investors. This applies to classic subsidy instruments such as state investment and operating subsidies. But it also includes tax concessions dependent on the volume of investment, like those in the U.S. Inflation Reduction Act, since the state forgoes revenue and thus increases the net return for private equity investors.
2. **The state as risk bearer:** Part of the risks associated with the investment is assumed by the state budget without a customary market remuneration being demanded. This improves the risk-return profile from the point of view of private investors and thus helps to reduce the capital costs of private financing. Such a takeover may be associated with an injection of state capital (subsidized state loans) or may not (state guarantees for private loans). CCfDs represent an innovation in this respect because in their basic form they do not address the general revenue risk but only the risk associated with a specific revenue component (the CO_2 price).
3. **The state as "market-maker":** By certifying low-emission products or technologies, the state wants to create new markets that ensure compensation for the additional costs of the investment by private market participants. The state budget is not directly involved in cost recovery, but additional state expenditure may arise in connection with the establishment of certification systems and the resulting need for monitoring. The impact on private revenue profiles depends to a large extent on whether, and if so in what form, certification is accompanied by government purchase requirements for low-emission products (see Section 3.3).
4. **The state as an intermediary:** The state itself becomes an intermediate buyer of low-emission products. It procures these from producers at cost-covering prices and sells them on to end users in line with their willingness to pay. The monetary discrepancy, which is to be expected at least in the initial phase, is not compensated for by the forces of supply and demand but is covered from the state budget. This can be seen as the most radical form of intervention, since here the state not only ensures direct cost recovery but also creates sales channels. So far, such a model has only been discussed for the promotion of energy sources such as green hydrogen, not for industrial products.[29]

[28] See Joas et al. (2020).
[29] EPICO / KAS / Guidehouse (2023). Design options for a European Hydrogen Bank. Report EPICO Klimainnovation / Konrad-Adenauer-Stiftung / Guidehouse Germany.

From the investor's point of view, the various government roles are also accompanied by various payment patterns over the course of an investment. Figure 4 shows characteristic profiles of net payments for different subsidy instruments in a stylized form. The price of CO_2 allowances is assumed to increase over time. An initial investment phase should typically be followed by a growth phase with increasing sales of low-emission products until this form of production has become firmly established on the market. In this context, a common feature in the application of CCfDs and green lead markets may become apparent. While the focus of support for conventional instruments is either in the investment phase (investment subsidies) or in the entire period thereafter (operating cost subsidies, low-interest loans), the focus of the two innovative instruments is first on the growth phase. In the case of CCfDs, this is due to the fact that with rising CO_2 prices the government subsidy per unit produced increasingly melts away and may eventually become negative (as shown in the figure). In the case of quota-based lead markets, the growth phase for companies that invest early is associated with the prospect of surpluses in the emerging green markets, which should gradually melt away as market entry grows. It also follows that, in the case of these instruments, changes in macroeconomic conditions, especially in the area of capital market interest rates, have a very sensitive effect on the profitability of investments, especially in the growth phase.

Figure 4: Stylized revenue profile of investment projects under different support regimes

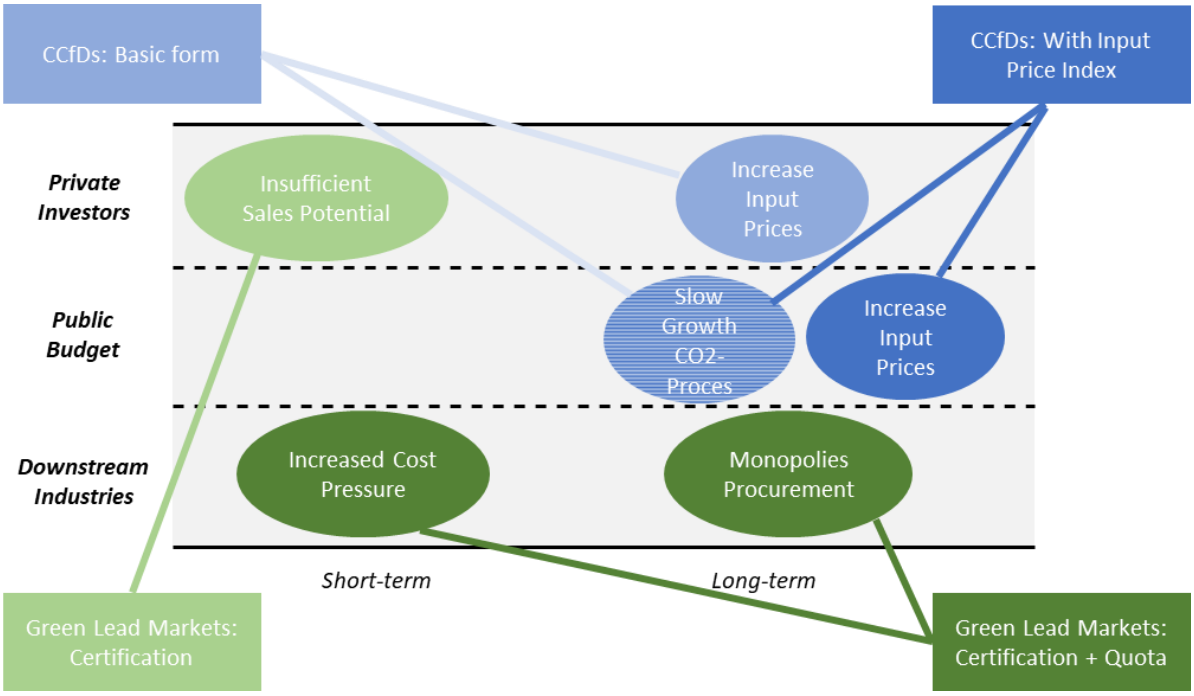


Source: own representation. Dotted lines: Support effect.

The above presentation does not yet say anything about the degree of uncertainty associated with the payment flows. The funding instruments also differ in their impact on the risk profile. Figure 5 identifies specific risks for individual stakeholder groups in connection with the introduction of CCfDs or green lead markets, differentiated according to the design variants already discussed. From the perspective of the state budget, CCfDs are associated with the risk of an insufficient future increase in the CO_2 price. In this case, the state remains a net donor under the contracts. In its basic form, i.e., if only the CO_2 price is contractually hedged, the risk of rising input prices remains with the investors in low-emission technology. If, on the other hand, a contractual indexation of these prices is agreed, this risk is also transferred to the state budget. Finally, green lead markets with quota requirements make it possible to pass on rising input prices to the buyers of low-emission products, i.e. the downstream industry. Quota requirements also create specific procurement risks for this group of stakeholders.

Their procurement costs could increase in the short term, if quotas are not defined prudently enough, as a result of high margins of scarcity for early adopters of low-emission technologies. In the long term, on this basis, there is a risk of the creation of new monopoly situations on the procurement side, and thus a perpetuation of high procurement prices. A waiver of quota requirements would eliminate this risk. In this case, however, the risk of insufficient sales potential for low-emission products remains at the investor level.

Figure 5: Risks for different stakeholder groups



Source: own representation

In view of these trade-offs, a final evaluation of these support instruments must go beyond purely qualitative criteria. The quantitative scope of the subsidy requirements (e.g. the level of the contractually fixed CO_2 price) and their interaction with the economic framework conditions are decisive for their impact. Effectiveness or targeting alone are therefore not sufficient evaluation criteria. The decisive question is rather at what (overall economic) cost can the desired effect on investment activity be realized. The CO_2 reduction costs, i.e. the social costs incurred per tonne of avoided CO_2 emissions, are the relevant indicator for this. Previous studies have been limited to a comparison of the average anticipated costs. For an evaluation, however, their distribution is also relevant, both with regard to the degree of uncertainty and the distribution of the cost burden between groups of actors. Such analyses can only be performed on the actual object itself. In the following Section, we use the transformation in the steel industry as an important application example.

4 Impact analysis for the steel industry

4.1 Methodology and data

In evaluating policy options for accelerated decarbonization, the production of crude steel is a good example, for several reasons. Firstly, the European steel industry is currently still very greenhouse gas intensive compared to other sectors (see Section 2.1). A switch to low-emission technologies in steel production can thus make a significant direct contribution to reducing overall economic greenhouse gas emissions. Secondly, crude steel as a basic material is the starting point for a large number of industrial value chains in Europe. The level of CO_2 reduction costs associated with individual policy options thus has considerable macroeconomic relevance for the competitiveness of European industry, and thus for prosperity and jobs. And third, precisely because of its macroeconomic relevance, a technology shift in the steel industry can also provide strong impetus for the decarbonization of upstream and downstream stages in the supply chains, as well as for securing sales channels for renewable energy. In the context of hydrogen-based direct reduction technology, the latter primarily concerns the development of markets for renewable hydrogen in Europe (see Section 4.2).

The methodological framework for the following analysis is the intuitive economic model developed by Richstein & Neuhoff (2022).[30] It maps the effects of regulatory incentive instruments on the returns from investments in production capacities for low-emission crude steel production. The starting point is the classic net present value approach: The net return on the investment project is recorded as the difference between discounted cash inflows and outflows from the project over the period of the capital commitment. The discount rate reflects not only the general risk-free market interest rate but also a project-specific risk premium. The project risk is thus explicitly captured in the model, allowing the effects of incentive instruments on the risk-related capital cost to be evaluated. Changes in project risk are specifically modelled via adjustments in the financing mix between equity and debt, i.e. higher risk implies the need for more equity-based financing, which increases the total capital cost of the investment.

The technology scenario considered is the switch from conventional crude steel production, based on the blast furnace route, to the low-emission H_2 direct reduction process (H_2-DRI) (see the following Section for more detailed descriptions of the technologies). The revenue and cost components of the low-emission technology in the model correspond to the generally typical breakdown (see Figure 2 in Section 3.1). The revenues consist of income from the sale of low-emission crude steel and the market value of the CO_2 emissions saved. Costs are divided into operating and capital costs. For simplified analytical presentation, all revenues and costs are expressed in annualized form and per tonne of crude steel produced. The net present value of the investment is therefore zero if the sum of the annualized returns equals the sum of the annualized costs.

With the model used by Richstein & Neuhoff (2022), uncertainty exists only with regard to the future development of the prices of crude steel and CO_2. The future price of crude steel is in part determined endogenously. It is assumed that the international markets for crude steel are competitive and that the cost structure of conventional production technology will continue to determine prices over the

[30] Richstein, J. C., & Neuhoff, K. (2022). Carbon contracts-for-difference: How to de-risk innovative investments for a low-carbon industry?. Iscience, 25(8), 104700.

next few years. As a consequence, the average expected price (expected value) of crude steel is the price which leads to a capital value of zero for investments in conventional technology (i.e. eliminates excess returns). The minimum price is the price at which the operating surpluses can at least still cover the cost of debt, i.e. a no-bankruptcy condition is maintained. On this basis, an equal distribution of crude steel prices is assumed, reflecting the uncertainty about demand and macroeconomic factors in price formation. The price of CO_2 is determined purely exogenously via a (empirically not further substantiated) uniform distribution, which reflects the uncertainty about the development of allowance prices on the EU ETS. The model configured in this way was used by Richstein & Neuhoff (2022) to explain the relationship between expectations regarding the market price of CO_2 and the level of the CO_2 price to be guaranteed in CCfDs.

We add some new real-world aspects to the model for our purpose. First, we shed light on the consequences of uncertainty not only in terms of revenues, but also in terms of operating costs. The considered alternative production process of H_2-based direct reduction (H_2-DRI) is characterized at the operational level by two key cost parameters: the future prices of electricity and hydrogen. Analogous to the approach for the CO_2 price, we model the investors' uncertainty about the price developments as exogenous probability distributions in each case (with uniform distributions as a distribution family). In addition to providing more realism, this also allows us to analyse the consequences of input price indexation of CCfDs (see Section 3.2). Second, in addition to CCfDs, we also investigate the effects of the introduction of green lead markets induced by certification and predefined procurement quotas (see Section 3.3). The assumption regarding the pricing of low-emission crude steel is modified for this scenario (see the following Section). Third, we consider the interaction with conventional forms of government investment support (investment subsidies, operating cost subsidies, favourable government loans). Fourth, we differentiate the analysis of CO_2 mitigation costs based on expected value and downside risk, as well as on distribution among investors, government, and downstream industry as the actor groups potentially affected. Fifth, we calibrate the costs and underlying probability distributions in the model on the basis of data from recent studies in order to generate a realistic picture of the amount of abatement costs per tonne of crude steel that can be expected based on current information.

On the data side - also as a consequence of the high relevance of the steel industry described above - we can draw on the results of some recent studies on the cost structure of the H2-DRI. These naturally differ in some details of the technological setup. This relates, for example, to the fundamental question of whether the electrolysis process carried out to produce the hydrogen used is integrated into the production process investigated (i.e. the electrolyser is part of the production plant set up) or whether the hydrogen is procured off-site from external sources. In practice, both variants are likely to play a role in the future, depending on the availability of a local hydrogen infrastructure. In our analysis, we focus on the case of external hydrogen sourcing, which also demonstrates the consequences of H_2 supply costs for the decarbonization of the steel industry. Further differences between the studies lie in detailed assumptions about the necessity and intensity of the use of various inputs, e.g., the extent to which fossil fuels will still be needed in small quantities for carbon enrichment by way of direct reduction. We abstract from these detailed discussions by only explicitly modelling the central reduction agents and energy sources (Conventional generation: coking coal, injection coal; H_2-DRI: electricity, hydrogen) and the remaining part of the operating costs are included as a fixed residual. This residual is taken as the average of the results from the study selection. Following Agora

Energiewende et al. (2021)[31] values for the quantity parameters were likewise determined as average values from the study selection.

The probability distributions for the future price development of inputs are also calibrated on this basis. The projections for 2030, which can be found in the study selection, serve as a temporal reference. In each case, we use the highest and lowest forecast values as limits for the applied uniform distributions. Finally, we follow Richstein & Neuhoff (2022) in determining the cost of equity and debt capital. They have adopted these values from an empirical investigation based on the CAPM-approach by Damodaran (2023)[32] specifically for the European steel industry.[33] We use the values shown on the Damodaran homepage after the latest data update (2023). Table 2 summarizes the parameters included in the model on this basis and their sources.

Firstly, in the area of input prices, it is striking that the price of electricity, and not only the predicted figure, is assumed to normalize significantly as compared with the sharp rises in industrial electricity prices in Europe since 2022.[34] In fact, all the recent studies cited assume a return to lower price levels in the medium term as a benchmark scenario. The reason becomes obvious if one looks more closely at the overall costs: at the current price level, the transformation technologies considered are very far from profitability, and adequate government investment support would thus be extremely costly. Stabilization of the industrial electricity price thus becomes a precondition for industry-specific support services.[35] Another striking feature is the wide range in the price of hydrogen. This reflects the current high degree of uncertainty in the development of a European hydrogen economy. Cost-relevant open questions here are, in particular, how the relationship between domestic supply and imports will develop, and in what time frame the development of a transport infrastructure and the exploitation of economies of scale in production will succeed.[36]

[31] Agora Energiewende / FutureCamp / Wuppertal Institut / Ecologic Institut (2021). Klimaschutzverträge für die Industrietransformation. Analyse zur Stahlbranche.

[32] Damodaran, A. (2023). Costs of capital by industry sector – Europe. Online-Dataset. Update: January 5, 2023.

[33] The implicit assumption, as explained by Richstein & Neuhoff (2022), is that in the future the risk pattern (i.e. correlation of individual project risk with overall market portfolio risk) will behave for H_2 DRI projects in the same way as for the current (conventional) steel production studied by Damodaran (2023). This does not need to be the case, given that decarbonization processes are taking place simultaneously in other industries. In the case of an industry-wide electrification trend, for example, the correlation with the market could well increase. However, concrete assumptions in this direction would currently still fall into the realm of pure speculation and are also not of central importance for our purpose.

[34] Eurostat (2022). Electricity price statistics. Eurostat Database.

[35] The extent to which this requires adjustments in electricity market design or government capping of end-user prices requires a separate analysis and is not the subject of this paper.

[36] Wolf, A. (2023). Establishing hydrogen hubs in Europe. cepInput No.1/2023.

Table 2: Overview model parameters

Parameter	Value	Unit	Source(s)
Technology-specific: Conventional production (Blast furnace route)			
Investment need (brownfield)	170.00	Euro / Tonne Crude steel	Average of Vogl et al. (2018)[37]; Agora Energiewende et al. (2021)
Coking coal: Quantity	0.48	Tonnes / Tonne Crude steel	Average of Sprecher et al. (2019)[38]; Agora Energiewende et al. (2021); LBST (2022)[39]; Bertelsmann Stiftung (2023)[40]
Coking coal: Price (Maximum)	143.00	Euro / Tonne Coking Coal	Agora Energiewende et al. (2021)
Coking coal: Price (Minimum)	95.60	Euro / Tonne Coking coal	Sprecher et al. (2019)
Coal dust: Quantity	0.17	Tonnes / Tonne Crude steel	Average of Sprecher et al. (2019); Agora Energiewende et al. (2021); LBST (2022); Bertelsmann Stiftung (2023)
Coal dust: Price (Maximum)	110.00	Euro / Tonne Coal dust	Agora Energiewende et al. (2021)
Coal dust: Price (Minimum)	110.00	Euro / Tonne Coal dust	Agora Energiewende et al. (2021)
Residual OPEX*	307.62	Euro / Tonne Crude steel	Average of Sprecher et al. (2019); Agora Energiewende et al. (2021); LBST (2022); Bertelsmann Stiftung (2023)
THG-emissions (CO_2-Equiv.)	1.77	Tonnes / Tonne Crude steel	Average of Vogl et al. (2018); Agora Energiewende et al. (2021); LBST (2022); Bertelsmann Stiftung (2023)
Technology-specific: H_2-DRI			
Investment need	440.00	Euro / Tonne Crude steel	Average of Vogl et al. (2018); Agora Energiewende et al. (2021); EPRS (2021)[41]
Electricity: Quantity	0.79	MWh / Tonne Crude steel	Average of Agora Energiewende et al. (2021); LBST (2022); Bertelsmann Stiftung (2023)
Electricity: Price (Maximum)	124.00	Euro / MWh Electricity	Bertelsmann Stiftung (2023)
Electricity: Price (Minimum)	60.00	Euro / MWh Electricity	Agora Energiewende et al. (2021)
Hydrogen: Quantity	48.46	kg / Tonne Crude steel	Average of Agora Energiewende et al. (2021); LBST (2022); Bertelsmann Stiftung (2023)
Hydrogen: Price (Maximum)	6.60	Euro / kg Hydrogen	Agora Energiewende (2021)
Hydrogen: Price (Minimum)	3.00	Euro / kg Hydrogen	Aurora Energy Research (2021)[42]
Residual OPEX*	373.45	Euro / Tonne Crude steel	Average of Agora Energiewende et al. (2021); Bertelsmann Stiftung (2023)
THG-emissions (CO2-Equiv.)	0.12	Tonnes / Tonne Crude steel	Average of Agora Energiewende et al. (2021); LBST (2022); Bertelsmann Stiftung (2023)
General			
CO_2: Price (Maximum)	161.00	Euro / Tonne CO_2	Ariadne / Enerdata (2022)[43]
CO_2: Price (Minimum)	100.00	Euro / Tonne CO_2	IETA / pwc (2022)[44]
Capital costs: Equity	12.32	%	Damodaran (2023)
Capital costs: Debt	6.57	%	Damodaran (2023)
Risk-free interest rate	3.88	%	Damodaran (2023)
Depreciation period	20	Years	Vogl et al. (2018); Agora Energiewende et al. (2021)

Source: own representation. *: I.a. iron ore, alloys, labour.

[37] Vogl, V., Åhman, M., & Nilsson, L. J. (2018). Assessment of hydrogen direct reduction for fossil-free steelmaking. Journal of cleaner production, 203, 736-745.
[38] Sprecher, M., Lüngen, H.B., Stranzinger, B., Rosemann, H., Adler, W. (2019). Abwärmenutzungspotenziale in Anlagen integrierter Hütten werke der Stahlindustrie. Stahl und Eisen, 139(1), 27.
[39] LBST (2022). Emissionsfreie Stahlerzeugung. Studie im Auftrag des Deutschen Wasserstoff- und Brennstoffzellenverbandes (DWV). Ludwig Bölkow Systemtechnik GmbH.
[40] Bertelsmann Stiftung (2023). Ökonomische Evaluation klimapolitischer Instrumente – Am Beispiel der Chemie-, Zement- und Stahlindustrie.
[41] EPRS (2021). Carbon-free steel production - Cost reduction options and usage of existing gas infrastructure. Study Panel for the Future of Science and Technology. European Parliamentary Research Service.
[42] Aurora Energy Research (2021). Green hydrogen production at 2 EUR/kg in Europe requires significant cost reductions; 3 EUR/kg is more realistic over the next two decades.
[43] Ariadne / Enerdata (2022). The EU ETS price through 2030 and beyond: A closer look at drivers, models and assumptions.
[44] IETA / pwc (2022). GHG market sentiment survey. International Emissions Trading Organization / PricewaterhouseCoopers.

4.2 Technologies and cost patterns

The benchmark technology for our analysis is the currently still dominant form of **primary steel production in blast furnaces.**[45] In this so-called blast furnace route, coking coal and other aggregates (including lime) are initially fed into the furnace in addition to iron ore. Hot air is blown into the lower part of the furnace, and the oxygen reacts with the coke below to form carbon monoxide. The rising gas then binds the oxygen contained in the iron ore, leading to the desired reduction. Liquid pig iron and blast furnace slag accumulate as reaction products and are removed from the lower part of the furnace. The by-product are process gases, which can be used as an internal or external energy source. The pig iron is then converted into crude steel in converters, where the carbon contained in the pig iron is combusted.[46]

As a low-emission alternative technology, we are investigating **hydrogen-based direct reduction (H_2-DRI)** of iron ore, a technology pathway identified as particularly promising in recent studies.[47] Hydrogen is the only reducing agent used here. As the hydrogen used is produced electrolytically using only renewably generated electricity, and only renewable energy sources are used as heat sources in the reduction process, this form of steel production is virtually climate-neutral. At the same time, the high demand for green hydrogen may also represent a significant demand stimulus for the development of a European hydrogen economy. The plant technology is also largely compatible with the process of natural gas-based direct reduction, which is already used in some cases today.[48] The process is basically designed in two stages. In the first stage, iron ore is reduced in a shaft furnace to sponge iron, a porous solid intermediate product. Iron ore pellets are fed into the furnace from above for this purpose. The oxygen in the ore reacts with the reducing agent added in the middle of the shaft to form sponge iron.[49] In the second stage, the sponge iron is melted into crude steel in an electric arc furnace, often with steel scrap mixed in. An electric arc furnace is an electric melting furnace in which an electric arc is generated above the metallic charge material and the molten steel. To protect the molten products from undesirable reactions and heat loss, a slag layer is formed, for which external carbon enrichment is required. The process is not yet completely climate neutral because the added carbon is not obtained completely from biogenic sources, but it is significantly lower in emissions than the conventional blast furnace route.[50]

For the investment requirement and the resulting input costs, it makes a significant difference whether the hydrogen used is produced off-site or on-site. In the case of on-site production, the initial investment includes not only the shaft furnace and the electric arc furnace but also an electrolyser which means that hydrogen does not have to be procured externally. In this case, results relating to the cost structure are directly related to assumptions regarding the efficiency of the electrolyser used. Existing studies predominantly consider the off-site scenario and we are also going to consider this setup, as it allows us to highlight the importance of developing a hydrogen market and the associated uncertainty for the steel transformation.

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[45] According to Wirtschaftsvereinigung Stahl (2023) this route currently accounts for about 70 % of total production of crude steel in Germany, about 30 % are gained in electric arc furnaces as secondary steel from scrap.

[46] Stahlinstitut VDEh (2023). Kohlenstoffbasierte Stahlerzeugung.

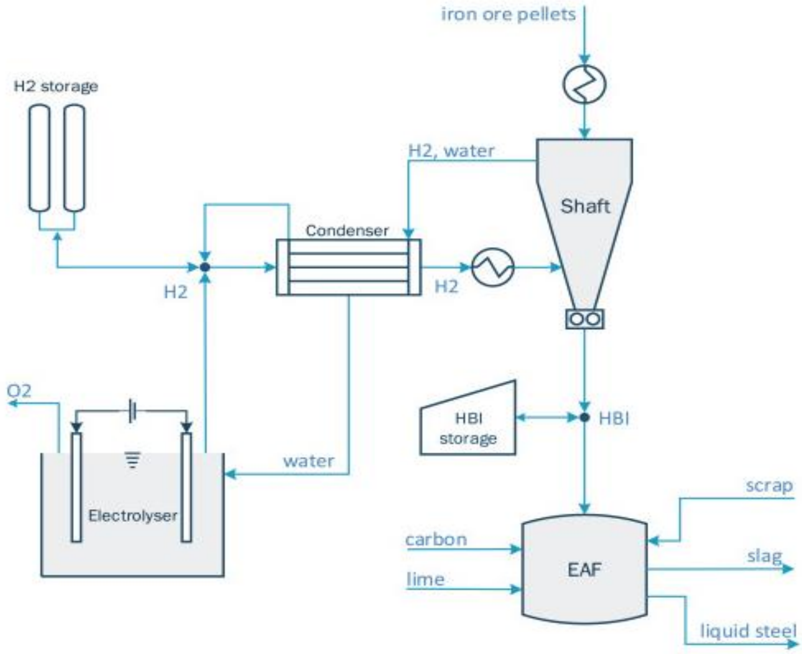
[47] Alternative low-emission technologies are the electric steel route and the combination of blast furnaces with CO_2 capture.

[48] See LBST (2022).

[49] Rechberger, K., Spanlang, A., Sasiain Conde, A., Wolfmeir, H., & Harris, C. (2020). Green hydrogen-based direct reduction for low-carbon steelmaking. Steel Research International, 91(11), 2000110.

[50] See Joas et al. (2020).

Figure 6: Process steps of the H_2-DRI-technology



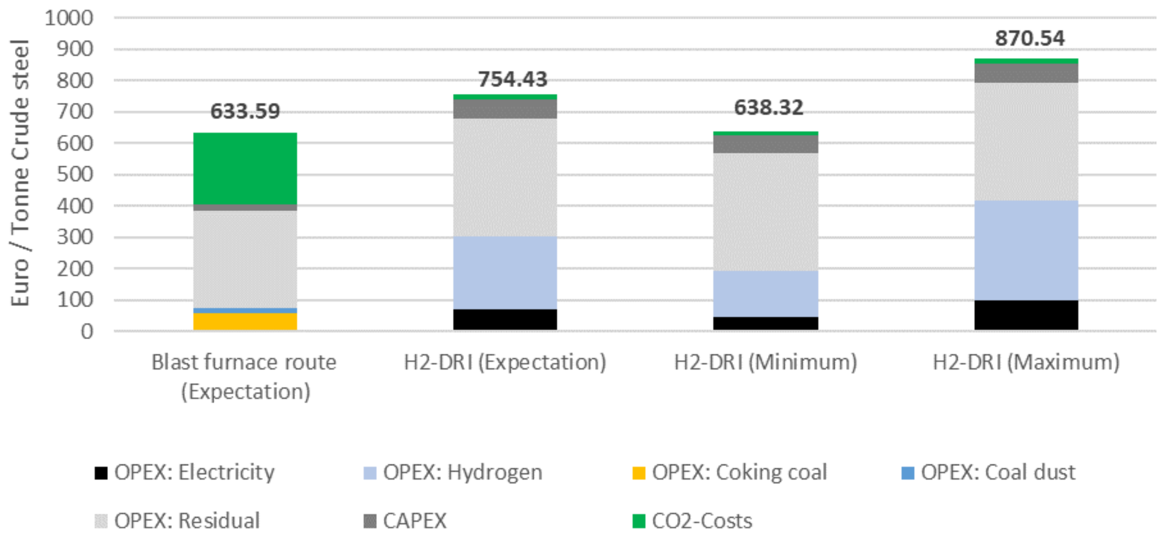
Source: Vogl et al. (2018). EAF: Electric Arc Furnace.

Figure 7 compares the cost structures of the two technology variants as (annualized) production costs per tonne of crude steel, based on the mean values of the price corridors listed in Table 2 in Section 4.1.[51] The pure production costs for H_2-DRI are therefore expected to be around 83% higher than for the conventional blast furnace route. A key characteristic of H_2-DRI is the fact that the inputs electricity and above all hydrogen make up a high proportion of the operating costs. This is not solely due to material considerations. Due to the lack of high-temperature process heat and the generation of co-product gases, compared with the blast furnace route, there is also an additional requirement for externally supplied energy.[52] The capital costs are also higher than in the conventional production process with an equivalent financing mix, solely as a result of an overall higher investment requirement. However, annualized over the assumed capital commitment period (15 years), operating costs dominate as a cost driver. Prices and availability of electricity and hydrogen thus play a key role in the competitiveness and funding requirements of this alternative steelmaking technology. Also important for the cost comparison from the investor's point of view is the development of the CO_2 price: It determines to what extent the higher production costs of H_2-DRI can be compensated by lower costs in trading with emission allowances (EU ETS). We reflect the degree of price uncertainty in the following policy scenarios.

[51] To focus on the technology-related cost differences, an equivalent financing mix in the form of an equity share of 56.7 % (see Richstein & Neuhoff (2022)) is assumed.

[52] See LBST (2022).

Figure 7: Comparison of projected unit costs of crude steel production by technology



Source: own calculations

4.3 Policy scenarios

We investigate the conditions under which the two incentive instruments discussed in general terms in Section 3 - CCfDs and quota-based lead markets - can be usefully applied in the transformation of conventional steel production methods into the H_2-DRI process. The starting point in each case is the investor perspective: The effectiveness of the instruments is measured by the extent to which they contribute to the profitability of investments in H_2-DRI plants. The concrete indicator is the net present value of the investment. The relevant question from a societal perspective is how subsidies should be designed to incentivize the necessary private investment at the lowest possible subsidy cost.

In the case of CCfDs, this corresponds to the question of what the minimum necessary level of the government-backed CO_2 price should be. The higher this CO_2 contract price, the more negative the expected payment stream from the perspective of the state budget - given the price development on the EU ETS. The minimum necessary contract price is then the price that makes the investment in H_2-DRI just as profitable for investors from a present perspective as an alternative investment with the same risk profile, i.e. just leading to an expected net present value (determined with a risk-adjusted interest rate) of zero. This is precisely the case when the sum of sales revenue (market price of crude steel) and revenue from CO_2 savings equals the sum of operating and capital costs per tonne of crude steel. However, in view of the remaining price uncertainty (steel, hydrogen, electricity), this is not the only condition. At the same time, the secured CO_2 price should be sufficient to avoid bankruptcy even in the event of a negative price scenario. This assumes that the operating surpluses in such a scenario are at least still sufficient to cover debt service. These two conditions together result in the amount of the CO_2 price to be applied and the corresponding private financing mix of the investment (equity ratio).[53]

When analysing CCfDs, we distinguish between a basic form and a form with additional price indexation (so-called dynamic contracts). While in the basic form the contractual CO_2 price is fixed

[53] See Richstein & Neuhoff (2022).

independently of the actual price development for electricity and hydrogen, in the dynamic form it is adjusted upwards and downwards according to the price development of key inputs, i.e. the associated input price risk is eliminated from the investor's perspective. This influences the conceivable negative scenario and thus leads to a lower capital cost via a more favourable financing mix (higher debt ratio).

With the introduction of quota requirements in the procurement of H_2-DRI steel, the case is fundamentally different. Here, there is no direct monetary support via the state budget; the additional costs are compensated via the lead market for low-emission steel that will form (see Section 3.3). This compensation is therefore not the direct result of government decisions but arises from market processes. Indirect influence can, however, be exerted via the decision as to which technical criteria are defined for state approval so that the steel can meet the quota requirement. The scope of the quota requirement is also essential for the additional costs incurred at the level of steel purchasers. In the policy scenarios, we examine quota-based lead markets both as a stand-alone policy option and in combination with CCfDs with different price levels. Finally, we compare the different variants with respect to the level and distribution of the estimated CO_2 mitigation costs.

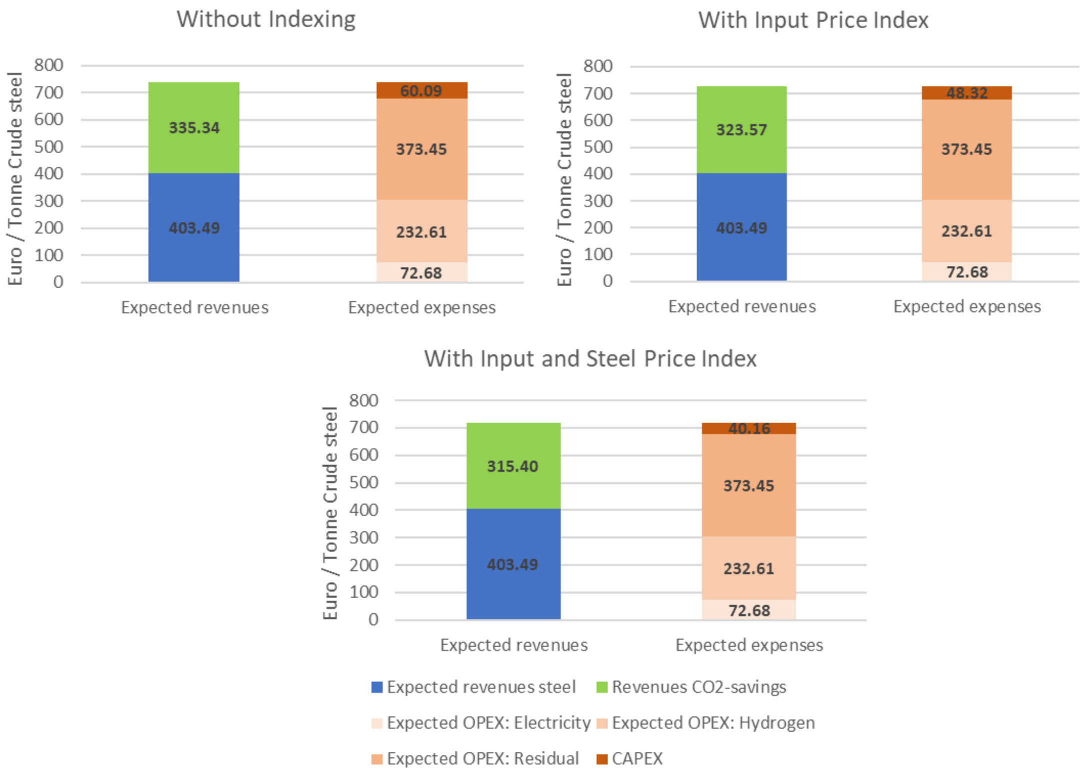
4.4 Simulation results

4.4.1 CCfDs

The introduction of CCfDs based on competitive bidding procedures should lead to contractually fixed CO_2 prices that precisely cover the expected additional costs of the H2 DRI steel route. The average return on investment generated at these prices then corresponds exactly to the alternative return achievable on the market with an equivalent residual risk. This residual risk depends crucially on the extent to which CCfDs hedge other forms of risk in addition to the CO_2 price. Extended hedging lowers the alternative return and thus the capital cost of the investment, which depresses the bid price for CO_2. The level of realized bids is also influenced by individual expectations regarding steel price trends and production inputs and is likely to fluctuate in real bidding processes depending on the situation. However, based on the data we have collected from recent studies (see Section 4.1), we can at least estimate the magnitude of expected CO_2 contract prices, provided we assume rational price expectations on the part of investors. Figure 8 plots the estimated revenue contributions of different forms of carbon offset contracts per tonne of crude steel against the estimated costs. In order to compensate for the considerable differences in operating costs (see Section 4.2), a secured return from CO_2 savings, almost equal to the level of the expected market revenues from the sale of steel, is therefore required in any event. This involves CO_2 contract prices in the order of around 200 euros per tonne, i.e. well above the range of conceivable CO_2 market prices on which the analysis is based.

The difference between contract and expected market prices for CO_2 corresponds to the green premium granted by the state to investors. If set competitively, it just compensates for the expected average additional costs (capital and operating costs) of low-emission steel production and amounts to about 73 euros per tonne of CO_2 in its basic form. Figure 9 shows that in the case of steel production, the difference in operating costs between the technologies is the dominant effect. Among these, it is in particular the expected cost of the input hydrogen (see Section 4.2) that will drive the green premium upwards. In contrast, the capital costs - and thus the risk-reducing aspect of CCfDs - play only a minor role in quantitative terms. Accordingly, the differences determined between the design scenarios presented are small. For example, a dynamic design (i.e., indexing the prices of the key inputs electricity and hydrogen) leads, as expected, to a reduction in the required CO_2 contract price compared to the basic form of pure CO_2 price hedging, but only in the amount of about 7 euros per tonne of CO_2. In the extreme case of additional indexation of the output side (steel prices), the reduction compared to the basic form is also only about 12 euros per tonne of CO_2. **In terms of the budgetary burden, an extended state assumption of risk thus only pays off to a very limited extent.**

Figure 8: Simulation of introduction of CCfDs – Impact on revenues and expenses



Source: own calculations

Figure 9: Simulation of introduction of CCfDs – Composition of CO_2 contract price

Source: own calculations

If CCfDs with corresponding pricing were applied to the transformation of the entire capital stock of the steel industry, without input price indexation, an annual crude steel production of 152.6 million tonnes in the EU-27 (estimated value for 2021) would result in a total sum of around 11.18 billion euros in premium payments per year to be borne on average by the state budgets. With indexation of input prices, this burden would decrease slightly to 10.32 billion euros per year.[54] With CO_2 market prices rising over time, the annual burden would be higher in each case at the beginning of the support period until it falls below the average after a certain time. As companies will not all invest in the switchover at the same time due to the different investment cycles, these figures should actually be regarded as an upper limit: CCfDs concluded further in the future should - assuming a positive price trend for CO_2 allowances and falling input prices (especially for hydrogen) - be associated with decreasing premiums. However, in view of the ambitious timeframe set for the transformation, the real total burden should not be dramatically lower.

Moreover, CCfDs will not be the only funding instrument for the transformation of the steel industry in the future. Thus, with regard to the government cost burden, the way in which the introduction of such contracts relates to conventional forms of investment support is also relevant. A possible complementarity arises from the different starting points: While CCfDs, as described, have as a special feature the perpetuation of the CO_2 price signal, conventional instruments are aimed solely at certain segments of the cost side. In the case of government OPEX subsidies, this affects the additional operating costs (expected or de facto for the future). Government investment subsidies reduce the capital requirements to be financed via the private market, thus helping to lower the cost of capital. Government subsidized loans (in the form of government guarantees or direct lending by public

[54] World Steel Association (2022). World Steel in Figures 2022.

institutions) in turn represent a form of government risk assumption and reduce private financing costs via the cost of capital. Figure A1 of the Appendix illustrates the impact of these instruments on the resulting CO_2 contract price (in its basic form) under competitive conditions. Accordingly, a government subsidy equal to about 10% of expected operating costs could roughly halve the expected green premium. The impact of comparable investment subsidies in percentage terms is less significant, given the lesser importance of capital costs, but is also noticeable. The same applies to government subsidized loan financing.

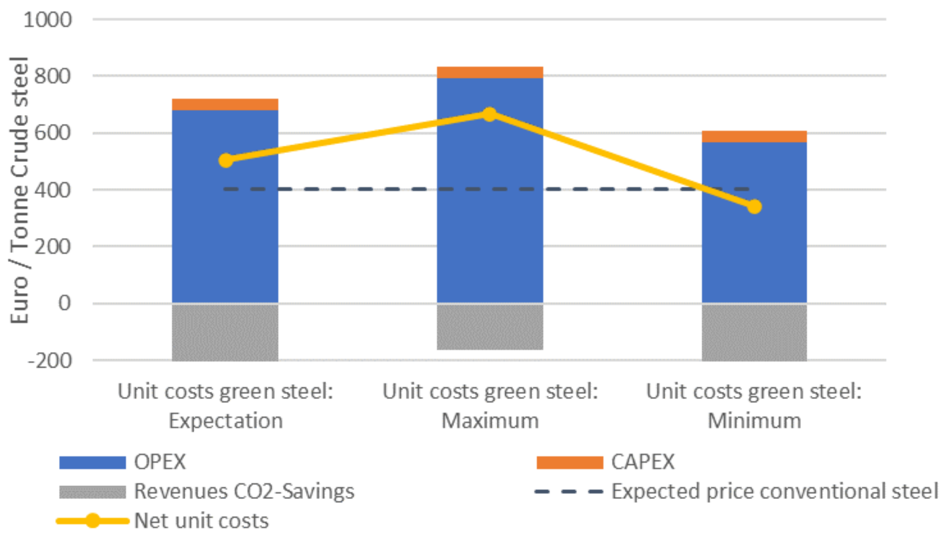
4.4.2 Green lead markets

An essential prerequisite for the development of green lead markets is that the homogeneity of conventionally produced low-emission steel is broken down from the user's perspective. If recognized certification criteria succeed in making H_2-DRI steel, or products based on such steel, transparent on the market, the additional costs of production could be compensated for by higher sales prices. The extent to which this can be achieved depends on the existence of procurement requirements. If no government requirements are imposed, the possibility of cost compensation depends solely on the free willingness of the demand side to pay a sufficient green premium. According to the cost structure on which our analysis is based, this premium would have to comprise a price premium of around 32% on average compared with conventional steel. Moreover, in such a market, there is little risk mitigation to be expected in terms of fluctuating input prices. Rising electricity prices, for example, can hardly be passed on to the buyers of H_2-DRI steel, at least in the initial phase, as sufficient conventional steel (hardly affected by electricity price increases) is available as a substitute. On the revenue side, the yield is also likely to be strongly influenced by world market fluctuations in the price of conventional steel due to the close substitution relationships.

The prospects are fundamentally better if fixed quota targets (see Section 3.3) are set for (public and/or private) procurement in order to establish green lead markets. If companies in downstream production are forced to cover a certain percentage of their steel requirements by way of H_2-DRI steel, there will no longer be any possibility of substitution with steel forms below the minimum quota. The markets for conventional and low-emissivity steel are thus segmented into sub-markets by regulation. In this case, substitution as a reaction to an increase in price can only basically take place away from steel and towards other basic materials. Under these conditions, companies investing in DRI technology have significantly more opportunities to compensate for their additional costs directly on the market. A distinction must be made between short-term and medium-term potential. In the short term, quota requirements could offer frontrunners among the producers the opportunity to enforce prices on a market for green steel which, in addition to compensating for the additional costs, also include an oligopolistic profit markup. This is because the delayed reaction of the other steel producers (length of investment cycles) would mean that there would be no immediate erosion of returns as a result of market entry. In the medium term, i.e. once repercussions of market entry occur, prices should nevertheless move toward a just cost-covering level, provided the certification criteria do not promote the formation of monopolistic structures (see Section 3.3). The price difference between the two submarkets will then correspond exactly to the difference in production costs (taking into account the yield from CO_2 savings).

Under these conditions, quota-based green lead markets perform a similar hedging function for investors as CCfDs. This is because cost-side uncertainty and price fluctuations (e.g. price of hydrogen) can be compensated for on the revenue side via the market price, and in principle across all cost components. However, technological risks in the cost development of important inputs do not disappear because they are reflected in the price premium over conventional steel and are thus merely passed on to steel customers. Figure 10 gives an impression of the variability of such a surcharge depending on the cost scenarios we have considered.[55] The difference as compared to the expected price for conventional steel would reach around +25% in the expected range, and a level of +65% in the maximum range (i.e. at the upper end of the price ranges for electricity and hydrogen and the lower end for CO_2). The cost minimum, on the other hand, is even below the expected price for conventional steel, i.e. with comparatively favourable cost development, low-emission steel could already become competitive by itself in the period under consideration. Since in such a case the manufacturers of low-emission steel have the incentive to market the steel in the conventional segment, the downward price difference is limited to zero.

Figure 10: Price range for H_2-DRI-steel on green lead markets



Source: own calculations

The cost burden that these price surcharges would impose on steel users naturally varies greatly with the intensity of steel use and the individual substitution possibilities. The level set for the minimum procurement quota is also central to this issue. For end products in the form of consumer and capital goods, only a very limited additional burden should be expected on the basis of these figures. Anecdotal estimates of the additional burden can be made for the automotive industry on the basis of reference values for the average weight of a passenger car (approx. 1.4 tons[56]) and the average weight of the steel used (approx. 60%[57]). The expected price increase of 25% would lead to additional costs of around 17 euros for the production of a passenger car at a mandatory green steel quota of 20%, and 34 euros at a quota of 40%. These are very low figures in relation to selling prices. However, the situation may be different for the production sectors immediately downstream of crude steel production, i.e. metalworking and metal products. An important factor here is the significance of

[55] Due to the complete cost pass-through, the possibility of a complete debt-based financing is assumed for this scenario.
[56] MeinAuto.de (2023). Wie schwer ist ein Auto?
[57] Wissenschaft.de (2023). Aus welchen Teilen besteht ein Auto?

exports and the intensity of international competition on the respective markets. **In general, this argues in favour of a differentiated approach to the introduction of quota requirements by sector.**

The expected interactions in the case of the simultaneous introduction of quota-based lead markets and CCfDs can also be analysed with the help of this cost scheme. As described, the two instruments are substitutive in competitive design: Both can contribute to increasing investment incentives in H_2-DRI steel capacity by covering additional costs. The combined use of both instruments may nevertheless be useful to control the economic distribution effects. Figure 11 illustrates this effect by showing the expected price spectrum for low-emission steel depending on the level of a government-backed CO_2 price. Figure A2 of the Appendix presents concrete simulation results regarding the distribution of prices of low-emission steel for three different CO_2 price levels.[58] The higher the contractually agreed fixed CO_2 price, the lower the expected price level on the market for low-emission steel, as the cost-reducing effect would be passed on directly to steel customers via competition. This is tantamount to a redistribution of the social costs of government quota requirements away from the steel users concerned and towards government budgets. At the same time, the price adjustment mechanism can be used to avoid double subsidization, but this will only be fully effective if the CO_2 contract price remains within moderate limits. If it reaches a level at which overcompensation becomes likely on the cost side, producers could earn excess returns by selling low-emission steel on the regular markets.

Figure 11: Linkage between CO_2 contract price and market price for H_2-DRI-steel

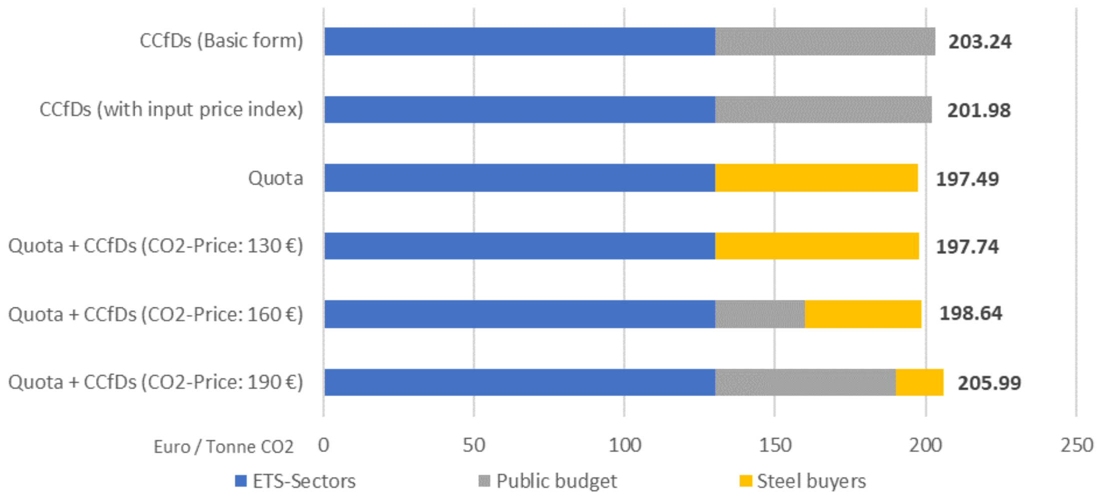
Source: own calculations

[58] These are the results of a Monte Carlo simulation (number of draws: 10000) of the price for low-emission steel based on the price distributions for electricity, hydrogen and CO_2. These are each modeled as mutually independent uniform distributions within the price corridor under consideration (see Table 2 in Section 4.1).

4.4.3 Comparison CO_2 mitigation costs

The preceding analysis has shown that, if designed in a competitive manner, both instruments are suitable for providing investment incentives for climate-friendly steel production. The main evaluation factor remains the level of costs incurred by the general public and their distribution between different groups of stakeholders. The usual indicator for this is the CO_2 abatement costs, i.e. the additional societal costs associated on average with avoiding the emission of one tonne of CO_2. In our scenario, this corresponds to the ratio of the cost difference of steel production between the DRI and blast furnace routes to the emission savings achieved. Figure 12 compares the magnitude and distribution of the average expected abatement costs for the different policy variants discussed earlier. The overall level of costs is therefore slightly higher in a variant relying purely on CCfDs than in the case of the introduction of quota-based lead markets. This is due to the increased hedging effect for investors resulting from the possibility of passing on costs in such markets. However, these differences are quantitatively insignificant because capital costs only make up a small proportion of the expected total costs (see Section 4.4.1). More striking are the differences in the distribution of costs between the groups of stakeholders. In the case of a variant relying solely on CCfDs, the share of costs exceeding the ETS price[59] is borne solely by the state budget (and thus by taxpayers); in the case of a pure quota solution, it is borne by the purchasers of the steel. A combination of both options, on the other hand, allows a more balanced distribution of costs, depending on the level of the state-guaranteed CO_2 contract price.

Figure 12: Comparison of policy mix by CO_2 mitigation costs



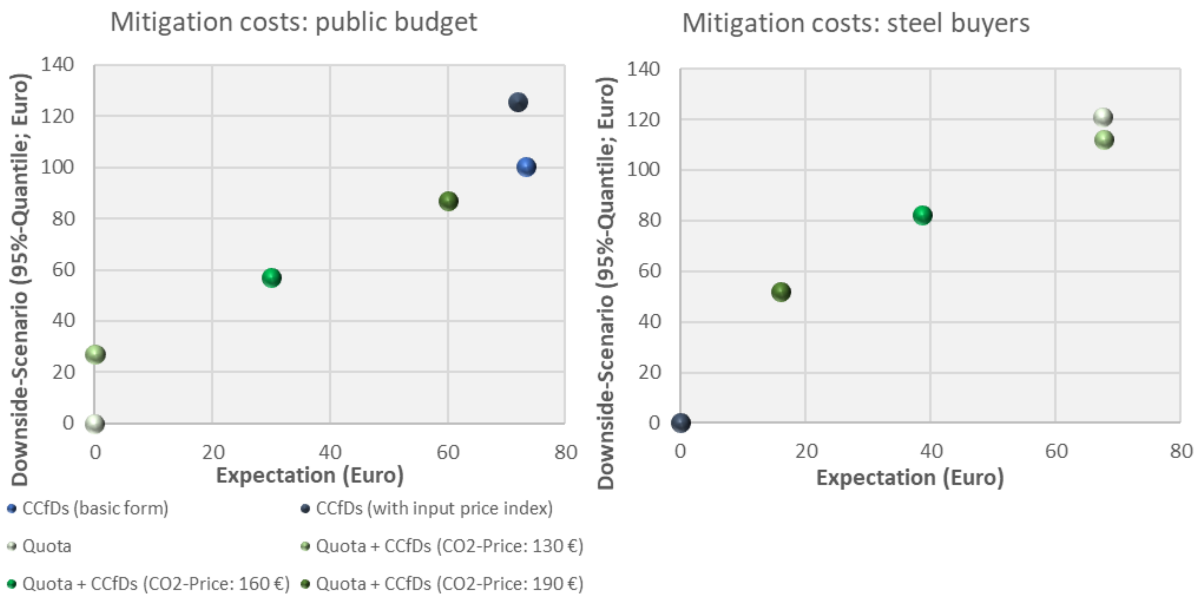
Source: own calculations

However, in view of the existing price uncertainties, a comparison of the average expected costs alone is still insufficient. Not only for investors in the steel industry, but also for other stakeholders, the effects of worst-case scenarios should be taken into account as a downside risk. Our stochastic approach also allows estimates to be made in this respect. Figure 13 compares the average expected

[59] In our analysis, we assume that the introduction of the instruments has no immediate repercussions on EU ETS pricing, as we consider the initial phase of the transformation. In the medium term, however, the triggered adjustments in the plant fleet should change the marginal abatement costs (and thus the willingness to pay for CO_2 allowances).

costs with the cost burden in a downside risk scenario[60], both from the perspective of the state budget and that of the steel buyers. From the government's perspective, supplementing CCfDs with quota regulations not only lowers costs on average but also reduces costs in the downside scenario. The reason for this is that the supplementary quota regulations make it possible to lower the CO_2 contract price, thus making scenarios involving major positive price differences from the CO_2 market price less likely. The effect on the risk disposition of steel customers is almost mirrored. A lower CO_2 contract price implies a lower secure earnings buffer against cost risks, and thus a stronger tendency to balance this by passing on higher production costs to customers via the market price for green steel. A well-designed combination of both instruments should thus allow regulators to balance both the mean costs and the risks between cost bearers, and thus avoid unilateral burdens that could damage acceptance.

Figure 13: CO_2 mitigation costs in expectation and in a downside risk scenario



Source: own calculations

It is important to note that our analysis here focuses on direct costs. Their final distribution among individual industries and ultimately among population groups depends to a large extent on price sensitivities and adjustment reactions in downstream markets. A cost burden that damages the competitiveness of downstream industries may have repercussions for tax revenues and thus for the national budget through a reduction in corporate profits, and may also burden industries not directly involved in steel supply chains through indirect demand effects. The detection of such indirect distribution effects would be the task of a dedicated macroeconomic analysis.

60 The scenario figures each correspond to the 95% quantile of the estimated cost distributions resulting from the Monte Carlo simulations described in Footnote 58. The overall cost distributions are shown in Figure A3 of the Appendix.

4.5 Discussion

Our quantitative analysis is based on the scenario of a steel industry in the initial phase of the transition to low-emission technologies, facing markets that are basically functioning in terms of their investment conditions, but with a lot of (regulatory and technological) uncertainty for the transition period. Such a scenario cannot illuminate all facets of future interaction between industrial transformation, market prices and regulatory conditions. At this point therefore an additional qualitative analysis of the significance of additional channels of impact is important.

One aspect relates to possible **interactions between cost-relevant price variables**. Unlike in our stochastic analysis, in reality the prices for electricity, hydrogen and CO_2 are not independent variables. For example, there is a positive correlation between the prices on the electricity exchange and the price of CO_2 allowances, which is empirically documented via the generation of peak-load electricity from fossil fuel technologies, and which should also have an indirect effect on the industrial end-user prices for electricity. Since, for the period of the next few years that is under consideration, these technologies will not have been completely dispensed with, this genuinely represents a risk-balancing factor. In the future, however, a positive correlation can also be expected between the price of electricity and the price of electrolytically produced hydrogen. Since both are cost parameters, this effect would tend to amplify the risk. The effects of the price correlations on the overall risk pattern thus remain to be seen.

Another aspect is the ancillary **occurrence of volume risks**. In our technology setup, this relates above all to the availability of hydrogen. Since corresponding markets for hydrogen are only just emerging, it is not yet possible to say with certainty whether a market mechanism that balances out shortages will be established in the foreseeable future. On the regulatory side, however, efforts are already being made to create more planning security through programs such as H_2-Global by means of government-coordinated long-term procurement contracts.[61]

One aspect of particular relevance with regard to CCfDs is the **future influence of CO_2 prices on the markets for conventional steel**. In our quantitative analysis, we implicitly assumed a competitive world market for steel in which prices are formed independently of European climate legislation. Whether this can be assumed for the future depends on the one hand on the success of the EU strategy of gradually motivating relevant trading partners via climate clubs to adopt comparable CO_2 pricing.[62] On the other hand, at least for intra-European steel sales, restrictions result from an implementation of the agreed CO_2 border adjustment mechanism (CBAM).[63] By increasing the price of steel imports according to emission content, a differential to the world market price level for steel could be enforced. In the planned mechanism, this would be positively dependent on the level of the ETS price for CO_2. From the investors' point of view, this correlation reinforces the importance of the CO_2 price for the expected development of earnings. CCfDs would not then cushion the entire CO_2 price-related yield risk. In such a scenario, the rapid establishment of alternative lead markets for low-emission steel would be even more important.

61 BMWK (2023c). One-Stop-Shop – Wasserstoff – H2Global. Bundesministerium für Wirtschaft und Klimaschutz.
62 Nordhaus, W. (2015). Climate clubs: Overcoming free-riding in international climate policy. American Economic Review, 105(4), 1339-1370.
63 See Mennert & Reichert (2022).

One aspect of particular relevance to green lead markets is the at least temporary **risk of supply-side market power**. Depending on the specific design of certification criteria, there is a risk that certain suppliers in the emerging market for low-emission steel will gain an exclusive position due to technology-related cost advantages, enabling them to extract surplus rents via higher prices. A reduction of these rents as a result of market entry would be subject to a time lag due to the length of the investment cycles. However, the combination of quota requirements and CCfDs also provides the regulator with a means to counter this. In order to ensure sufficient competition on green lead markets from the outset, strict certification requirements could be deliberately combined with comparatively high CO_2 contract prices that make the transformation attractive to a wide range of investors even if technological adaptation costs are high. This also means that it could make sense, in the interest of the overall costs, to dispense with competitive tenders when awarding CCfDs, or at least to rely on a pay-as-bid (instead of a pay-as-clear) bidding procedure to compensate for certification-related cost advantages.

Finally, taking a long-term perspective, the aspect of **future technology development** must also be considered. No-one can say for sure, based on the current situation, what innovations can be expected in the field of steel production in the next few years, and whether the technology we are looking at for hydrogen-based direct reduction of steel will still be the ideal solution for a climate-neutral industry in 2050. This elementary technological uncertainty is not, in principle, incompatible with CCfDs or quota-based lead markets. However, it reiterates that the design of both instruments should always focus on the core aspect of climate policy, i.e. the expected contribution of an investment project to reducing greenhouse gas emissions. The addition of technology-specific hedging mechanisms not only leads to a significant redistribution of risks (see simulation results) but can also increase costs in the long term by narrowing the technology path.

5 Conclusion

The plan to decouple Europe's energy-intensive industry from fossil resources within a short period of time is a delicate balancing act in both technological and regulatory terms. The transition to new low-emission technologies must be incentivized across the board without endangering the existing industrial base as the cornerstone of Europe's prosperity. In order to stimulate sufficient private investment in an environment characterized by massive cost risks, there is also a need for innovation at the regulatory level. The challenge is to develop additional support instruments that increase the capital marketability of investments without overstimulating or diluting existing long-term CO2 price signals. This can only succeed if the scope of support is consistently aligned with society's overall goal of reducing emissions.

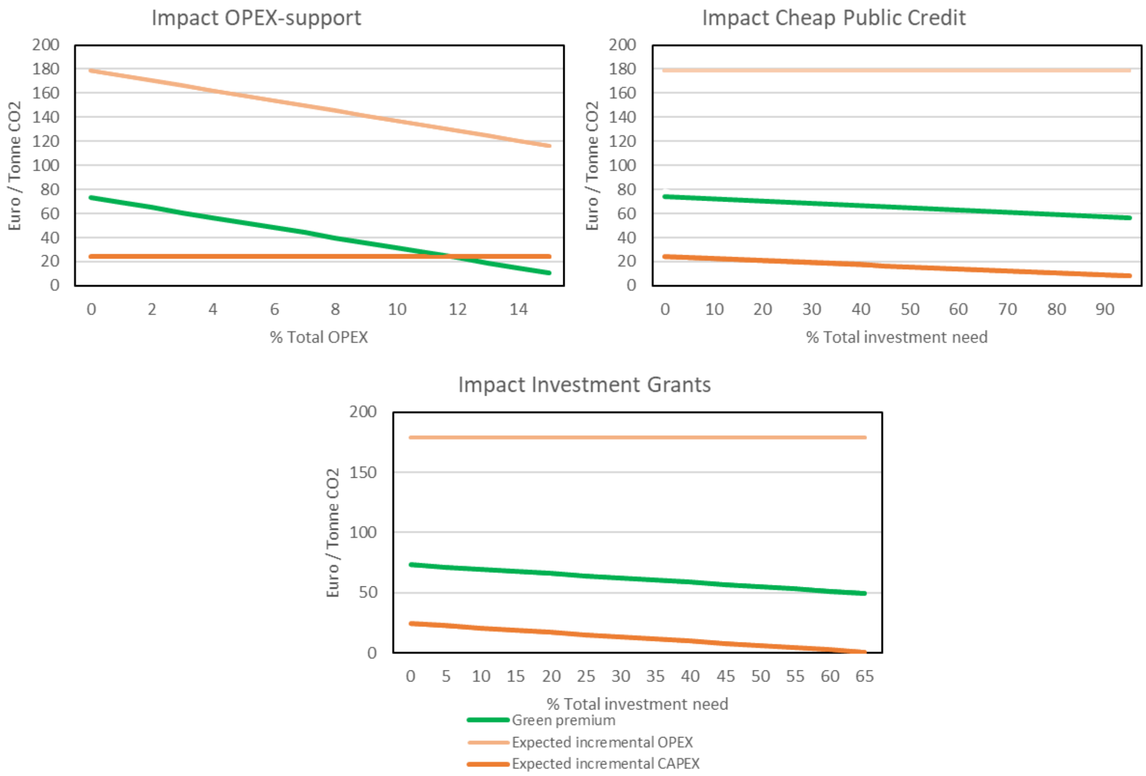
This cepInput examines the interplay between two promising incentive instruments: CCfDs and green lead markets. Both instruments have the basic principle in common that they mitigate regulation-induced revenue uncertainties and reward more entrepreneurial ambition regarding decarbonization. They can also be combined without leading to a duplication of subsidies. Their interaction via market forces makes it possible to place the decarbonization process on a broader regulatory footing. For this to happen in a targeted and cost-efficient manner, their implementation must be based on competitive principles. In the case of CCfDs, this presupposes the awarding of contracts via competitive tenders that are based on bids for the amount of the contractually secured CO_2 price. In the case of green lead markets, the main task is to define certification criteria for low-emission products in such a way that competition can be established as early as possible by the formation of new green markets, preventing the emergence of excess returns resulting from a preference for the technology of individual suppliers.

Even with an efficient design, however, the introduction of these instruments is associated with a direct burden on the general public. This is because the instruments will not make the additional costs and price risks arising from the technology disappear: they are redistributed to create incentives. For the future acceptance of these instruments, an honest debate about their opportunities and risks is therefore necessary. This cepInput makes a contribution to this by quantifying the cost risks arising from implementation, and their distribution, taking the steel industry as an example. The average burden to be expected appears acceptable in principle: A rapid introduction of CCfDs for the EU-27 steel industry would cause government spending in the order of 10-12 billion euros per year on average during the transition phase, a rather small amount compared with the total costs of the transformation. The establishment of lead markets based on predefined procurement quotas for green steel would - if prices were set competitively - also only lead to minor additional cost burdens for central downstream industries. Beyond these mean values, there are nevertheless not insignificant risks for the cost bearers of the respective instruments, which in the case of steel relate primarily to the future pricing and availability of electricity and hydrogen. Our detailed analysis of the expected risk structure shows that combining CCfDs with green lead markets also offers added value in this respect because it will enable a more balanced distribution of both the mean expected costs and the downside risks between government budgets and buyers of low-emission steel. This prevents one-sided cost burdens and contributes to social acceptance.

At the same time, the danger of overloading and diluting the instruments must be kept in mind. This applies in particular to the tendency on the part of regulators to respond to justified concerns about high energy costs by linking CCfDs to energy price developments. This would not only dilute the core principle of securing revenues from emission reductions, it would also impose additional risks on state budgets, which are considerable in view of the current high level of uncertainty on the energy markets. Technology openness could also hardly be guaranteed in such an expanded subsidy scheme, which would jeopardize the long-term cost-effectiveness of the transformation path. This illustrates that the instruments examined, for all their effectiveness in terms of investment incentives, are not all-purpose tools for coordinating the energy transition. Bringing industrial energy prices back to a competitively sustainable level, while maintaining investment incentives in renewables, remains a separate and pressing regulatory task.

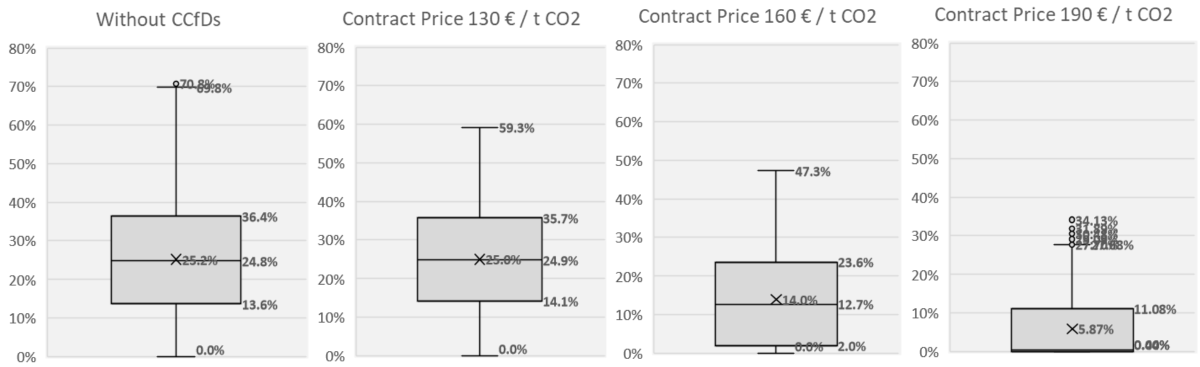
6 Appendix

Figure A 1: CO_2 contract price with conventional support instruments in place



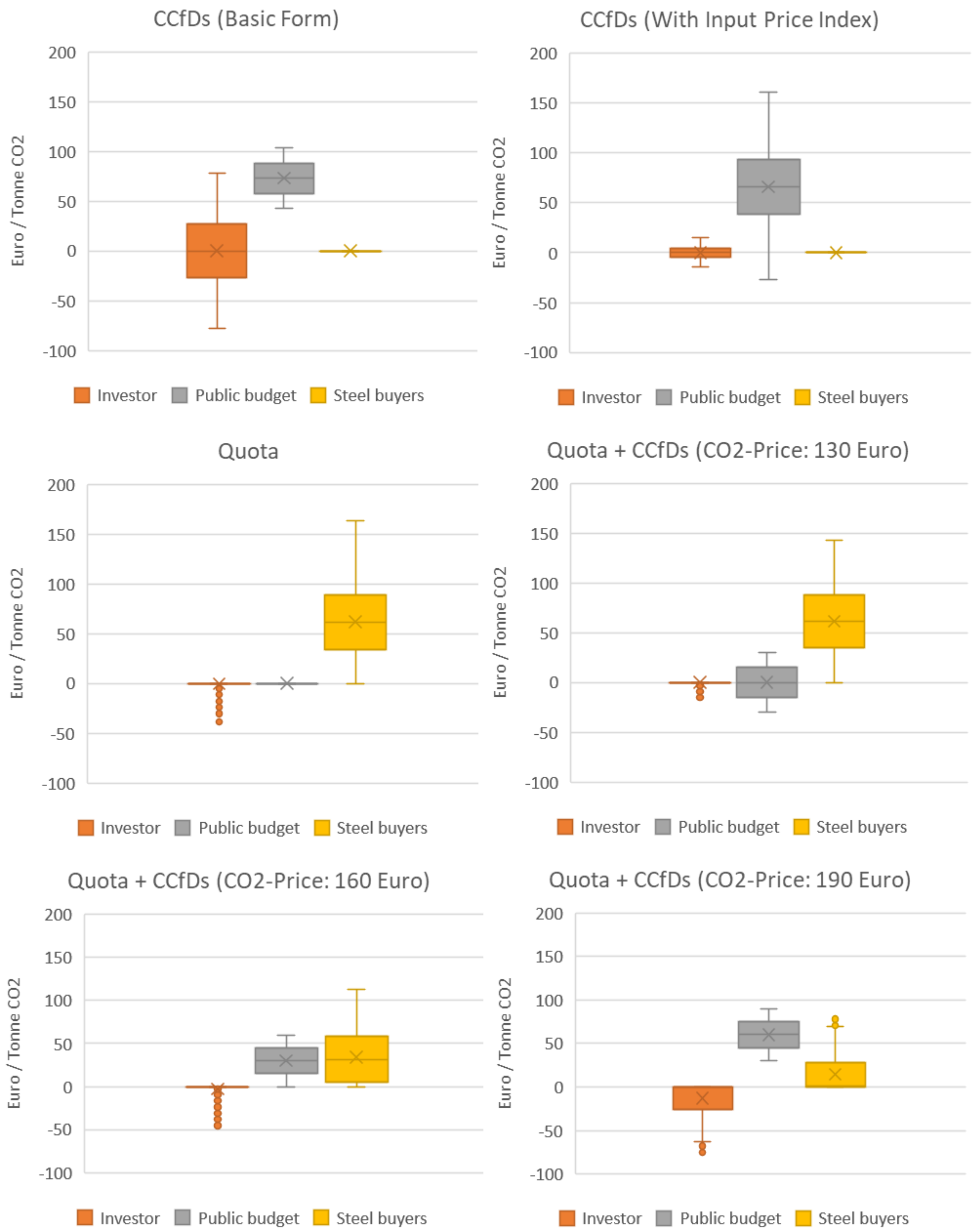
Source: own calculations

Figure A 2: Probability distributions of price surcharge on lead markets for green steel



Source: own calculations

Figure A 3: Probability distributions of CO_2 mitigation costs for different policy variants



Source: own calculations

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