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Scaling Up Carbon Removals

Support Schemes for an Efficient Path To "Net-Zero"

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In the long term, limiting global warming to a tolerable level not only requires a significant reduction in greenhouse gas emissions but also the widespread use of technologies that remove existing CO_2 from the atmosphere. To ensure their availability in the future, infant removal technologies must start to be commercialized and scaled today, without undermining decarbonization incentives. A combination of high upfront costs, missing market incentives and infrastructure bottlenecks threatens to inhibit the investments needed for their timely ramp-up. Against this backdrop, the EU has intensified its efforts to support CO_2 removal projects, including a proposal for a dedicated funding program financed by revenues from the Emissions Trading Scheme (ETS). This cepStudy analyses the economic impacts of different support measures from an industrial economics perspective, accounting for its interplay with decarbonization investments.

- The scheme for ETS-based carbon removal credits proposed by the Commission is a step towards market integration but threatens to cause additional net emissions and lacks clarity how funds are allocated.
- In comparison to subsidy-based support, clean-up certificates do not place a direct financial burden on taxpayers and have the potential for positive net effects on the EU's carbon footprint. However, if learning processes are essential for future cost reductions, allowing for delayed emission compensation may render clean-up certificates unattractive, thereby hindering technology adoption and jeopardizing long-term cost-effectiveness.
- A combined use of direct cost subsidies and clean-up certificates mutually improves the effectiveness of the two instruments. In addition, it achieves a fairer distribution of the cost and risk burden of scaling carbon removals between the public and industrial emitters.
- To solve chicken-and-egg problems and foster competition among future CO_2-based supply chains, investor-level support must be complemented by market promotion. This should include EU-wide rules for the development and operation of CO_2 pipeline and storage infrastructure as well as opening up EU market platforms to small stakeholders.

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1 Background

The increasing competitive pressure on European industries has shifted the focus to cost efficiency in the climate policy debate. A cost-minimizing path to "net-zero" requires exploiting the development potential of all technologies that can improve the EU's greenhouse gas (GHG) emission balance. In the long-run, climate scientists and economists agree that this will include a substantial adoption of negative emission technologies (NETs), i.e. technologies that reduce instead of raise the presence of GHG in the atmosphere. Findings of the Intergovernmental Panel on Climate Change (IPCC) see comprehensive carbon removals as indispensable for limiting global warming to 1.5°C. Specifically, carbon removals are needed to accelerate the reduction of net emission levels, and counterbalance remaining residual emission in a future state of climate neutrality.[1]

Recently, carbon removals have also become an integral part of EU climate policies. In its communication concerning the 2040 climate goal, the Commission assigned a prominent role to carbon removals in the next decade. Carbon removal capacity shall be scaled to a level of about 280 million tonnes of CO_2 per year in 2040.[2] This will include both a strengthening of natural carbon sinks and the development of engineered removal technologies. However, adoption especially of the latter class of technologies is still in its infancy, with only modest growth perspectives in the short-term. This is mainly due to a combination of high present costs and significant future revenue uncertainty. Coordination problems in creating CO_2 capture, transport and storage technologies cause investment restraint. The missing recognition of NETs in the EU'S Emissions Trading Scheme (ETS) prevents CO_2 prices from becoming market signals for removals. The potential for strong learning externalities in technology adoption implies that frontrunners are not sufficiently rewarded for their contribution to future cost reductions. The joint result of these different forms of market failure is an adoption speed that is too low in welfare perspective, justifying dedicated public support.

The Commission has started to acknowledge this need as expressed in its Industrial Carbon Management Strategy.[3] However, apart from access to general EU Green Deal funding channels and project streamlining rules, there exists no dedicated EU support instrument for scaling carbon removals yet. As part of its proposal for a revision of the ETS Directive, the Commission has for the first time proposed a dedicated funding instrument.[4] However, it is still unclear how such an instrument will affect decarbonization and through what mechanism the funding will be allocated. This study investigates the potential impact of different support instruments currently under discussion and derives some policy recommendations. It does so within the framework of an industrial economics model, allowing to study the interplay of carbon removals with competition intensity, firm heterogeneity and clean investment incentives. In this way, it makes a contribution to linking the climate-focused discussion of NETs with industrial policies and the current competitiveness debate. The results demonstrate that the design of support schemes makes a substantial difference, both in terms of the cost efficiency and the climate effects of carbon removal deployment.

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1 IPCC (2023). Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

2 European Commission (2024a). Securing our future Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society. COM/2024/63 final.

3 European Commission (2024b). Towards an ambitious Industrial Carbon Management for the EU. COM/2024/62 final

4 European Commission (2026a). Proposal for a Directive of the European Parliament and the Council amending Directive 2003/87/EC and Decision (EU) 2015/1814 as regards driving competitiveness and cost-effective decarbonization. COM/2026/616 final.

2 Portfolio of Negative Emission Technologies (NETs)

2.1 Natural Solutions

Natural forms of NETs are usually summarized by the term “carbon farming”. In its broadest sense, carbon farming refers to all land management practices aimed at reducing greenhouse gas (GHG) emissions and/or increasing carbon storage in organic matter. In terms of sectors, this primarily concerns agriculture and forestry. A study commissioned by the European Parliament distinguishes between five areas of carbon farming measures: the management of peatlands, agroforestry measures, measures to increase carbon sequestration in soils, measures in the area of livestock farming, and improved soil nutrient management.[5]

The diversity of these measures makes it difficult to compare their climate-related effectiveness. Significant differences can arise not only in the average duration of the carbon sequestration achieved, but also in its vulnerability to external disturbances. Due to interconnections within the ecosystem, reductions in one area can trigger unexpected additional emissions elsewhere. In the case of carbon sequestration in soils, capacity limits must also be taken into account. Furthermore, maintaining the desired effect generally requires a long-term commitment.[6] This is a key difference from climate protection measures in other sectors: a one-time reduction in emissions from energy generation or industrial production leads to a lasting improvement in the greenhouse gas balance. Added to this are data collection challenges: agricultural emissions are dynamic, spatially heterogeneous, and difficult to measure. Focusing solely on CO_2 is often insufficient here, given the significance of methane (livestock) and nitrous oxide (fertilizer management) as greenhouse gases in agriculture. In addition to the impact on GHG emissions, potential side effects must also be taken into account in the life cycle assessment. For example, it has been shown that carbon farming practices can yield additional benefits, including improved soil quality, increased ecological resilience, and greater biodiversity.[7]

2.2 Engineered Solutions

2.2.1 Bioenergy with Carbon Capture and Storage (BioCCS)

Technologies that rely on the development of artificial capture and storage processes for atmospheric CO_2 have been at the forefront of the debate in recent years. One of these technologies is the use of bioenergy in combination with carbon capture and storage (BioCCS). Carbon is removed from the atmosphere as the biomass grows. The harvested solid biomass can be burned directly. The CO_2 released during the combustion is captured using established industrial technologies and stored geologically. Alternatively, the harvested biomass can be converted into gaseous or liquid fuels by means of fermentation or digestion, with the CO_2 gained as a by-product being captured and stored.[8] In this way, a negative greenhouse gas balance can be achieved for the overall process. One critical point is the origin of the biomass. If specific energy-rich plants are cultivated for this purpose (e.g., rapeseed, maize), the CO_2 emissions generated during cultivation and harvesting can worsen the greenhouse gas

[5] McDonald, H. Frelih-Larsen, A., Lóránt, A., Duin, L., Andersen, S.P., Costa, G., Bradley, H. (2021). Carbon farming – making agriculture fit for 2030. Study requested by the ENVI committee of the European Parliament. November 2021.

[6] Thamo, T., & Pannell, D. J. (2016). Challenges in developing effective policy for soil carbon sequestration: perspectives on additionality, leakage, and permanence. Climate Policy, 16(8), 973-992.

[7] Baumber, A., Waters, C., Cross, R., Metternicht, G., & Simpson, M. (2020). Carbon farming for resilient rangelands: people, paddocks and policy. The Rangeland Journal, 42(5), 293-307.

[8] Consoli, C. (2019). Bioenergy and carbon capture and storage. Global CCS Institute.

balance of the overall process. Additional negative effects can result from direct and indirect forms of land use change associated with cultivation (e.g., competition with food production, loss of biodiversity).[9] The assessment is different for biomass in the form of residuals such as plant residues and biogenic household waste. Their incineration in the context of BioCCS does not generate additional negative land use effects, and also contributes to better energy recovery from organic waste, in addition to achieving negative emissions. However, if the use of additional arable land is to be avoided, there are limits to the expansion of BioCCS capacities in terms of resources. For example, Rosa et al. (2021) estimate a maximum annual capture potential of 200 million tonnes of CO_2 for Europe, assuming the exclusive use of residual biogenic sources. Accordingly, only a few European countries can cover their long-term carbon removal needs exclusively via BioCCS.[10]

2.2.2 Direct Air Carbon Capture and Storage (DACCS)

In addition to indirect forms of CO_2 extraction, methods of Direct Air Capture using artificial systems and subsequent geological storage (DACCS) have also been developed. the artificial form of carbon removal using DACCS requires significantly less land[11] and water and therefore has a much smaller direct impact on local ecosystems.[12] Ambient air is fed via large fans through a separator containing a chemical CO_2 sorbent. This can be a liquid or a solid sorbent. If a liquid sorbent (e.g. sodium hydroxide, potassium hydroxide) is used, the liquid is then heated to more than 800 degrees Celsius to separate the CO_2 as a gas. When using a solid sorbent (e.g., amine materials, ionic membranes), only heating to 85-120 degrees Celsius is required for separation, as a weaker chemical bond is formed between the CO_2 and the sorbent.[13] However, the technologies with liquid sorbents are technologically more mature. A general challenge for DACCS is the low concentration of CO_2 in the ambient air. This implies high energy and material costs for the capture of concentrated CO_2.[14] Finally, potential environmental risks can also arise from pollutants as by-products in the production of sorbents.[15]

2.2.3 Other Technologies

Several other technologies for the artificial removal of CO_2 from atmosphere have been investigated over the past decade, but have not yet resulted in major commercial projects. Some consist of a manipulation of biological and geological processes. These include, for example, the increased cultivation of CO_2-absorbing phytoplankton in the oceans through the introduction of nutrients (ocean fertilization).[16] Another approach in this direction is the acceleration of geological weathering processes through the application of CO_2-binding silicate rock, e.g., on arable land (enhanced weathering).[17] The

[9] Hanssen, S. V., Daioglou, V., Steinmann, Z. J. N., Doelman, J. C., Van Vuuren, D. P., & Huijbregts, M. A. J. (2020). The climate change mitigation potential of bioenergy with carbon capture and storage. Nature Climate Change, 10(11), 1023-1029.

[10] Rosa, L., Sanchez, D. L., & Mazzotti, M. (2021). Assessment of carbon dioxide removal potential via BECCS in a carbon-neutral Europe. Energy & Environmental Science, 14(5), 3086-3097.

[11] Based on literature results, Realmonte et al. (2019) estimate the land use of a BECCS power plant to lie between 270 and 1636 m^2 per tonne CO_2 per year, while the land use of a DACCS plant with liquid sorbent is estimated at 1.5 m^2/tCO_2/year.

[12] Realmonte, G., Drouet, L., Gambhir, A., Glynn, J., Hawkes, A., Köberle, A. C., & Tavoni, M. (2019). An inter-model assessment of the role of direct air capture in deep mitigation pathways. Nature communications, 10(1), 3277.

[13] Gambhir, A., & Tavoni, M. (2019). Direct air carbon capture and sequestration: how it works and how it could contribute to climate-change mitigation. One Earth, 1(4), 405-409.

[14] Ozkan, M., Nayak, S. P., Ruiz, A. D., & Jiang, W. (2022). Current status and pillars of direct air capture technologies. Iscience.

[15] See Realmonte et al. (2019).

[16] Strong, A., Chisholm, S., Miller, C., & Cullen, J. (2009). Ocean fertilization: time to move on. Nature, 461(7262), 347-348.

[17] Hartmann, J., West, A. J., Renforth, P., Köhler, P., De La Rocha, C. L., Wolf-Gladrow, D. A., ... & Scheffran, J. (2013). Enhanced chemical weathering as a geoengineering strategy to reduce atmospheric carbon dioxide, supply nutrients, and mitigate ocean acidification. Reviews of Geophysics, 51(2), 113-149.

environmental consequences of the interaction of these methods with natural processes are complex and not yet fully understood, entailing significant environmental risk. Many researchers also see great potential in the role of biochar as a carbon sink, a result of the pyrolysis of biomass. Besides storing carbon, its use in agricultural can have additional environmental and agronomic benefits.[18] In all cases, the lack of experience with industry-scale applications and difficulties in measuring the net climate impact of the technologies represent barriers to adoption.

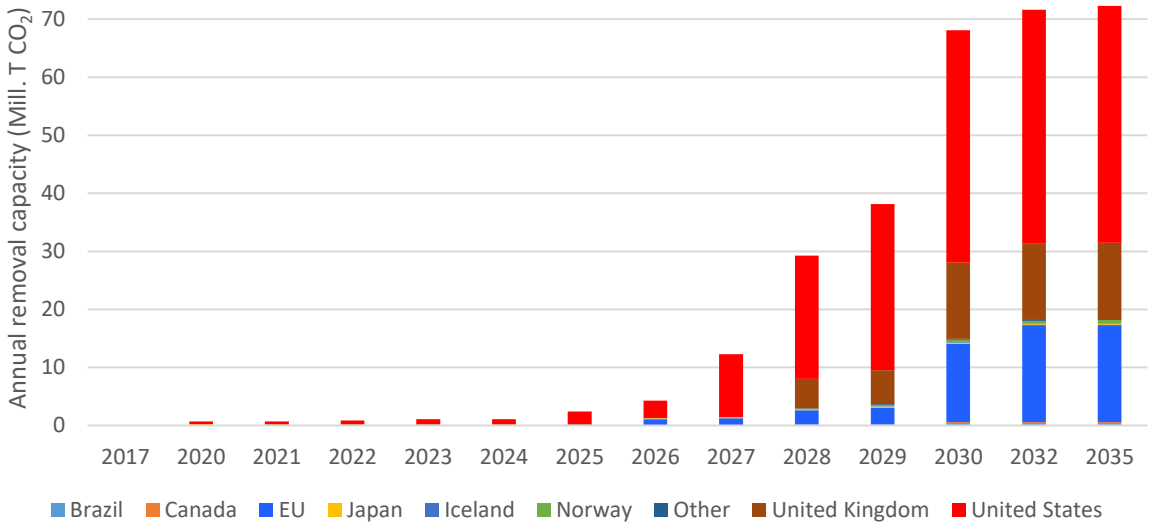
3 Economics of Carbon Removals

3.1 Deployment Perspective

Capacity-building of engineered NETs is still in its infancy. At the global level, the IEA estimates for March 2026 a total operational capacity of engineered NETs of 2.5 million tonnes of CO_2 per year[19], which is equivalent to only 0.005% of the global gross GHG emissions in 2025[20]. At the same time, the existing capacities are geographically heavily concentrated. About 90% of the operational capacity is located in the USA. In Europe, the company Climeworks has been the frontrunner of implementing engineered carbon removal solutions. Climeworks Orca in Iceland was the first commercial DACCS project to go into operation in 2021.[21] Inside the EU, the first large-scale carbon removal project will be located at Ørsted in Denmark and is planned to begin operation in 2027, with a medium-term capacity of 400,000 tonnes of CO_2 per year. It captures biogenic CO_2 from straw- and woodchip-fired power stations and ships it to Norway to be permanently stored in a saline aquifer under the seabed of the North Sea.[22] For the end of the current decade, current project plans foresee a strong increase in investment dynamic (see Figure 1). The US is continuing to lead the way but the EU and the UK are increasingly catching up. For the EU, a timely realization of current project plans will result in an operational capacity of 13.4 million tonnes by 2030. Much of this expected growth will however depend on the realization of a single megaproject, the transition to biomass use and subsequent storage of biogenic CO_2 at the RWE Eemshaven power plant (Netherlands).[23] Other significant projects are focused on the Nordic Member States Denmark and Sweden.

[18] Lehmann, J., Cowie, A., Masiello, C. A., Kammann, C., Woolf, D., Amonette, J. E., ... & Whitman, T. (2021). Biochar in climate change mitigation. Nature geoscience, 14(12), 883-892.
[19] IEA (2026). CCUS Projects Database. International Energy Agency.
[20] European Commission (2026b). EDGAR - Emissions Database for Global Atmospheric Research.
[21] Climeworks (2026). Orca: the first large-scale plant. Climeworks AG.
[22] Ørsted (2026). Carbon capture and storage.
[23] RWE (2023). RWE's BECCUS project to play crucial role in climate-neutral Dutch energy system through emission reduction and carbon removal.

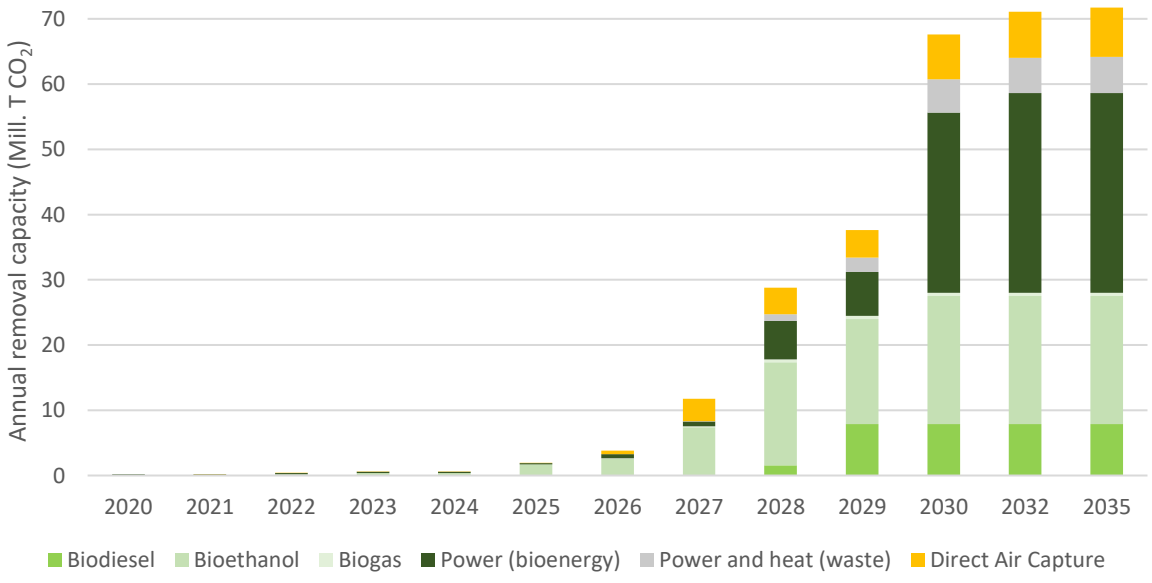
Figure 1: Global development of existing or planned carbon removal capacities by country/region



Source: IEA (2026); own calculations

In terms of removal technology, frontrunner projects predominantly rely on forms of BioCCS (see Figure 2). This is explicable by its higher technology maturity level and more favorable economics compared to direct air capture (see below). Solutions mainly consist of endowing existing bioenergy production facilities or biomass-fired power plants with carbon capture equipment. Currently, bioethanol plants are the most common object of BioCCS application. In the medium-term, current project plans continue to foresee an important role for bioethanol, but biomass-based power generation will increase in relevance. Moreover, DACCS is expected to slowly gain momentum. However, in the first half of the next decade, it will still be a much less frequent technology than BioCCS.

Figure 2: Global development of existing or planned carbon removal capacities by sector



Source: IEA (2026); own calculations

3.2 Investment Barriers

Investments in carbon removal capacities differ significantly from industrial carbon capture in terms of their revenue and cost profiles. In contrast to emissions abatement the removal process itself does not yet generate any direct economic returns (e.g. through the sale of surplus emissions allowances). Instead, the revenue potential depends on the market value of the captured CO_2. This can lie in its use as an industrial feedstock or in the certification of long-term storage and the sale of such certificates. Both types of markets are currently still in the development phase. Markets for voluntary carbon offsets have experienced significant growth at a global level in recent years. However, due to the lack of uniform global standards, current market platforms are characterized by strong price fluctuations, low transparency and strong fragmentation,[24] which entails high sales and revenue risks.

The costs of carbon removal are highly technology-dependent. The extent to which DACCS or BioCCS will prevail as the leading technology will be largely determined by the differences in the cost structure. These reveal clear trade-offs. A key cost advantage of BioCCS is that it is based on a combination of already established technologies: the combustion, fermentation or digestion of biomass and the subsequent application of industrial carbon capture technologies. The higher technological readiness compared to DACCS facilitates upscaling and also allows for a more flexible construction of plants depending on the individual sales opportunities for the bioenergy obtained. A further advantage of this setup is the fact that the bioenergy produced provides a second direct source of revenue, which can also be used to diversify CO_2 market price risks. In direct terms, BioCCS plants are therefore net energy suppliers and their activities help to reduce the scarcity problem for renewable energies. However, if the energy expenditure for cultivation and harvesting of the biomass is included, this advantage is reduced.[25] There are also limits to this form of climate technology in terms of the capacity of suitable land. When bioenergy is obtained from food and fodder crops, there is also competition for land with the food sector. Currently, around 20% of bioenergy in Europe (in energy units) is obtained from agricultural sources. The industry association expects this proportion to increase significantly in the future in connection with the growth of the bioenergy market.[26] This can result in new economic dependencies. Simulations show that a significant build-up of BECSS capacities can lead to strong price correlations between carbon and agricultural markets. A long-term rise in the price of CO_2 can thus be reflected in rising food prices.[27] For an appropriate assessment of the climate impact, greenhouse gas emissions from the production of biomass that are not recorded in the EU-ETS should also be taken into account (as far as measurable), for example in connection with fertilizer use (N_2O emissions) or the long-term carbon footprint of direct or indirect land use changes. This in turn increases the costs of carbon accounting and monitoring. Moreover, biogenic carbon compounds cannot (yet) replace fossil fuels in all industrial applications.

Like BioCCS, DACCS can lead to genuine negative emissions, but avoids the food competition resulting from the use of biomass. Land consumption is also significantly lower with comparable capacity. The CO_2 net-balance of the process is also much easier to measure, as there is no need to account for a

[24] Dawes, A., McGeady, C., Majkut, J. (2023). Voluntary carbon markets: A review of global initiatives and evolving models. CSIS Brief. Center for Strategic & International Studies.

[25] Creutzig, F., Breyer, C., Hilaire, J., Minx, J., Peters, G. P., & Socolow, R. (2019). The mutual dependence of negative emission technologies and energy systems. Energy & Environmental Science, 12(6), 1805-1817.

[26] Bioenergy Europe (2021). Bioenergy Europe Statistical Report 2021 Biomass Supply.

[27] Muratori, M., Calvin, K., Wise, M., Kyle, P., & Edmonds, J. (2016). Global economic consequences of deploying bioenergy with carbon capture and storage (BECCS). Environmental Research Letters, 11(9), 095004.

variety of agricultural carbon sources and sinks in the calculations. However, the lower level of maturity compared to other capture technologies still stands in the way of a rapid roll-out.[28] This applies first and foremost to the high energy consumption, a consequence of the low concentration of CO_2 in the atmosphere. It not only affects the economic viability of the technology, but also potentially has a massive impact on its carbon footprint, depending on the electricity mix.[29] In addition to the high direct energy requirement for filtering and concentrating CO_2, the availability of sorbents also poses a problem of scarcity in the long term. They are produced at a high energy intensity and have so far been partly obtained as by-products. A strong increase in demand triggered by DACCS could change this role and thus lead to market disruptions and a further surge in energy use for such chemicals.[30] At the same time, however, the comparatively low maturity of DACCS technologies offers the prospect of particularly strong learning curve effects to reduce input intensities in the future.[31]

From a welfare perspective, these specific features result in additional sources of market failure for NETs compared to industrial carbon capture. In addition to chicken-and-egg problems in infrastructure investment, this involves positive climate externalities from removal activity. Unlike emissions avoidance through industrial CCS, this externality is not already internalized via the EU-ETS. A future growing market for carbon removal certificates could provide such internalization. However, its formation will depend heavily on very uncertain parameters such as the development of demand and the willingness to pay for the corresponding certificates. The possession of carbon removal certificates only represents a value for companies if they can use them as a positive signal to their customers or partners in the supply chain. A sufficient market volume will thus only be achieved if consumers have strong sustainability preferences and trust in the reliability of NET technologies. Finally, the learning effects that result from the increasing operation of NET facilities also represent a form of externality. This is because investors in individual facilities do not consider the positive knowledge effects of their accumulation of operating experience for the industry as a whole, unless they result in private income streams (patenting revenues etc.). This is particularly relevant for DACCS technologies, given their currently still low maturity level.

[28] Breyer, C., Fasihi, M., Bajamundi, C., & Creutzig, F. (2019). Direct air capture of CO2: a key technology for ambitious climate change mitigation. Joule, 3(9), 2053-2057.

[29] Terlouw, T., Treyer, K., Bauer, C., & Mazzotti, M. (2021). Life cycle assessment of direct air carbon capture and storage with low-carbon energy sources. Environmental Science & Technology, 55(16), 11397-11411.

[30] See Realmonte et al. (2019).

[31] Lackner, K. S., & Azarabadi, H. (2021). Buying down the cost of direct air capture. Industrial & engineering chemistry research, 60(22), 8196-8208.

4 Support Strategies

4.1 EU Support

4.1.1 Current Framework

Short-term EU policies on carbon removals are focused on carbon farming. For 2030, the EU has set a binding target of 310 million tonnes of CO_2 equivalents for land use, land-use change, and forestry (LULUCF) removals.[32] For artificial carbon removals, there exist only a modest short-term goal of 5 million tonnes of CO_2 removals by 2030.[33] However, their comprehensive use is considered an essential prerequisite for reaching the 2040 EU climate goal of a 90% economy-wide reduction in net greenhouse gas emissions relative to 1990. For this purpose, carbon removal capacity shall be scaled to a level of about 280 million tonnes of CO_2 per year in 2040.[34]

Current EU activities of supporting the emergence carbon removal projects can be broadly categorized into market regulation, project funding and infrastructure coordination. In terms of market regulation, the EU has adopted in 2026 with the Carbon Removals and Carbon Farming (CRCF) Regulation the world's first legally binding technical standard for permanent carbon removals. It defines the criteria for recognizing and certifying permanent carbon removals based on three technologies: DACCS, BioCCS and biochar production. To obtain European certification, removal projects must fulfil four criteria summarized by the acronym "Qu.A.L.ITY": quantification of net-climate benefits, additionality with respect to existing legal minimum requirements, long-term storage of removed carbon and sustainability with respect to additional environmental goals in areas like biodiversity or water management. [35] For the practical certification process, the EU has established guidelines for independent certification bodies and compliance monitoring[36] as well as a binding measurement methodology.[37] The issued certificates shall constitute the basis for a future market for carbon removals that creates transparent removal prices and thus allows project developers to monetize carbon removals in a predictable way.

Concerning direct funding, carbon removal projects have access to the EU's general funding channels for green transformation projects, including the Innovation Fund for scaling innovative solutions[38], the Horizon Europe program[39] for research in carbon removal technologies and the announced Industrial Decarbonization Bank[40]. In addition, the EU is seeking to facilitate access to private funding sources by

[32] European Union (2023). Regulation (EU) 2023/839 of the European Parliament and of the Council of 19 April 2023 amending Regulation (EU) 2018/841 as regards the scope, simplifying the reporting and compliance rules, and setting out the targets of the Member States for 2030, and Regulation (EU) 2018/1999 as regards improvement in monitoring, reporting, tracking of progress and review.

[33] European Union (2024a). Regulation (EU) 2024/3012 of the European Parliament and of the Council of 27 November 2024 establishing a Union certification framework for permanent carbon removals, carbon farming and carbon storage in products.

[34] See European Commission (2024a).

[35] See European Union (2024a).

[36] European Union (2025). Commission Implementing Regulation (EU) 2025/2358 of 20 November 2025 laying down rules on certification schemes, certification bodies, and audits under Regulation (EU) 2024/3012 of the European Parliament and of the Council.

[37] European Union (2026). Commission Delegated Regulation (EU) 2026/285 of 3 February 2026 supplementing Regulation (EU) 2024/3012 of the European Parliament and of the Council by establishing the certification methodologies for permanent carbon removals activities.

[38] European Commission (2026c). What is the Innovation Fund?

[39] European Commission (2026d). Horizon Europe work programmes.

[40] European Commission (2025). The Clean Industrial Deal: A joint roadmap for competitiveness and decarbonization. COM/2025/85 final.

establishing a CRCF Buyers' Club. Based on the established certification framework, this club constitutes a voluntary market platform to aggregate public and private demand for certified removals and thus accelerate the emergence of transparent markets. In particular, by providing long-term offtake contracts to large-scale removal projects, it shall provide the necessary revenue security to ensure bankability of projects and thus bring them to the Final Investment Decision (FID).[41]

EU infrastructure coordination is dedicated to establish goals and standards for the development of CO_2 transport and storage infrastructure for all CCS technologies, including CO_2 obtained through removals. The main legal lever for this is the binding storage target established under the Net-Zero Industry Act (NZIA). By 2030, the annual CO_2 injection capacity of available storage shall reach a level of at least 50 million tonnes. This capacity target is coupled with a specific obligation for companies operating in oil and gas production. Depending on their shares in historical oil and gas production, they are obliged to make a pro-rata contribution to the overall capacity target. This rule reflects the eligibility of abandoned oil and gas fields as permanent CO_2 sinks. Moreover, the NZIA supports CCS projects along the whole supply chain through a recognition as strategic projects. This gives them access to streamlined permitting, including definite time limits for approval procedures.[42] For the near-term future, the Commission has announced a proposal to harmonize infrastructure planning as well as market rules and technical standards for the operation of CO_2 pipelines and storage facilities through a dedicated EU regulation.[43]

4.1.2 Proposal for ETS-based Funding

To accelerate the scaling of carbon removals and their integration into the framework of emission allowance trading, the Commission has suggested a new funding mechanism as part of its proposal for an amendment of the ETS Directive. The plan is to increase the number of emission allowances issued under the ETS-I between 2031 and 2040 by 250 million compared to what is necessary to achieve the 2040 goal. These allowances do not fall under the regular cap defined by the linear reduction factor. The revenues from auctioning these allowances do not enter the regular distribution scheme but are earmarked for funding an equivalent amount of domestic permanent carbon removal units by the Commission. Should the auction revenues turn out to be insufficient to finance such an equivalent amount, an amount of 10 million allowances from the regular cap shall be made available to the Commission to generate additional auction revenues for removal funding. Details on how funding is allocated to carbon removal projects shall be spelled out later by the Commission in the form of delegated acts.[44]

The proposed procedure can be considered an intermediate step towards a full integration of carbon removals in allowance trading, i.e. their recognition as an abatement technology in the ETS scheme. By tying project funding to ETS auction revenues, it establishes a direct connection between net revenues of removal projects and the evolution of the allowance price. Prices on the ETS thus start to become a transparent market signal for removal project developers. The procedure thus not only assists projects by providing additional funding but also by facilitating long-term revenue planning. Moreover,

41 European Commission (2026e). EU CRCF Buyers Club.
42 European Union (2024b). Regulation (EU) 2024/1735 of the European Parliament and of the Council of 13 June 2024 on establishing a framework of measures for strengthening Europe's net-zero technology manufacturing ecosystem and amending Regulation (EU) 2018/1724.
43 European Commission (2026f). 2027 Commission work programme and annexes.
44 See European Commission (2026a).

rising ETS prices represent a signal of scarcity in economically feasible abatement options, raising the need for carbon removals as an alternative way to cut net emissions. Through the price linkage, this need is directly translated into higher investment incentives for carbon removals. At the same time, by refusing the recognition of removals as an emission abatement technology in the ETS scheme, the procedure avoids the risk of a crowding-out of available decarbonization options by removal activities. Instead, the volume of carbon removals promoted remains politically controlled by the number of earmarked allowances issued.

While being risk-conscious and consistent with economic reasoning, the proposed procedure is likely to be confronted with some practical challenges. Given the currently prohibitively high unit costs and low adoption levels of artificial carbon removal technologies (see Subsection 3.2), it is unlikely that removal costs will closely converge to ETS price levels in the 2030s. Even when making use of the additional reserve of 10 million allowances, auction revenues are thus likely not to suffice for financing an equivalent amount of carbon removals. Consequently, the proposed funding process would not be climate-neutral. The level of additional removals financed would not fully compensate the additional level of gross emissions caused by issuing an extra amount of 250 million allowances. Moreover, even when being sufficient, there is a likely time inconsistency issue. Auctioning additional allowances provides firms in ETS sectors with the right to raise gross emissions immediately. Carbon removal projects can be expected to start operating only a significant time after the auctioning process. To secure bankability, project developers are likely to require knowledge on the precise level of received funding per tonne CO_2 removed before making an FID. This level is only known through the results of the aid allocation procedure, which takes place after the aid has been collected through allowance auctions. Together with the time needed for setting up and legally approving removal capacities, this results in a significant time gap between additional emissions and removals, worsening the climate balance of the scheme in intertemporal perspective.

Finally, both climate and cost efficiency of the proposed model strongly depend on the nature of the aid allocation mechanism. Defining a suitable mechanism is not trivial, as it should reward projects not only for cost efficiency, but also for the reliability and sustainability of their removal practices. Concerning the latter two criteria, the EU has already created a transparent assessment basis with its carbon removal certification framework (see Subsection 4.1.1). The definition of cost efficiency still requires methodological work. Given the prospect of future cost reductions, aid allocation should not be exclusively based on present cost comparisons but reward early adopters and acknowledge differences in development potential of technologies. Moreover, the repercussions of supporting carbon removals on the competitiveness of industries and the incentives to invest in clean production technologies need to be carefully studied.

4.2 Options for Economic Incentive Schemes

4.2.1 Investment Grants

A traditional means to reduce the substantial gap between current carbon removal costs and ETS prices is the provision of investment grants to carbon removal project developers. This reduces the CAPEX burden of capacity-building for private investors and thus a substantial part of removal costs. The fiscal risks of such a support measure can be easily limited by setting a cap on overall funding support. To ensure targeted support of the most efficient projects, a competitive allocation scheme can be easily implemented by drawing on the existing auction schemes available at the European level, e.g. the

Innovation Fund. On the downside, grants do not affect the risk profile of future revenues and costs of carbon removal business models. As discussed above, both the evolution of CO_2 prices and the speed of knowledge-related cost reductions for infant carbon removal technologies are subject to significant long-term uncertainty. This uncertainty translates into higher financing costs and thus constitutes an additional cost barrier already for present investment decisions. Moreover, as investment grants target fixed costs, they do not exert a direct influence on a project's marginal costs of removing and storing an additional tonne of CO_2. Their impact on dampening prices of carbon removal activities and scaling up competitive carbon storage markets is thus only of a limited nature.

4.2.2 Removal Premium

Alternatively, project developers can be supported by receiving fixed premium payments per tonne of carbon removed and stored. This is the most direct way of bridging the gap between removal costs and ETS prices. It immediately lowers the marginal costs of supplying carbon storage services to industries and thus contributes to scaling carbon storage markets. Depending on the size of the premium, it also provides a more or less relevant hedge against future downside risk scenarios of low ETS prices. Similar to investment grants, efficiency can be improved by allocating premium payments based on competitive auctions. Project are rewarded in the order of the lowest bids for premium payments per tonne of CO_2. The support scheme for domestic hydrogen projects established by the European Hydrogen Bank can serve as role model for this. However, the application of auctions also endogenizes the premium levels, implying that there is no full public control on the level of support provided to a certain amount of carbon removed and stored.

4.2.3 Carbon-Contracts-for-Difference (CCfDs)

In recent years, Carbon-Contracts-for-Difference (CCfDs) have emerged as a new popular tool for fully hedging investors against future CO_2 price fluctuations. In such contracts, the state guarantees individual investors a certain level of CO_2 prices for a pre-defined amount of time and conditional upon investing in low-emission technologies. The discrepancies between the contractual price and the evolution of the CO_2 price in the ETS are compensated through net payments. An initially low ETS price induces compensation payments from the state to the investor. With ETS prices growing over time, the balance will switch towards repayments from the investor to the state. In this way, investors can calculate with a locked-in long-term CO_2 price, which is usually set high enough too high to cover any OPEX- and CAPEX-related costs of the investment. In this way, when being provided to developers of carbon removal projects, CCfDs directly allow to secure project revenues that fully compensate for the initially high costs of infant removal technology. From the perspective of the state, the expectation of future repayments limits the expected long-term burden on public budgets. Similar to the previous measures, CCfDs are usually allocated through competitive tenders, with projects promoted in the order of the lowest contractual CO_2 prices required.

4.2.4 Clean-Up Certificates

Edenhofer et al. (2025) have proposed an alternative incentive scheme that is highly specific to carbon removal technology.[45] It consists of replacing a portion of regular emission allowances by clean-up certificates. These certificates grant the owner the right to emit greenhouse gases in return for the

[45] Edenhofer, O., Franks, M., Gruner, F., Kalkuhl, M., & Lessmann, K. (2025). The economics of carbon dioxide removal. Annual Review of Resource Economics, 17(1), 301-321.

commitment to finance an equivalent level of carbon removal activities at a pre-defined time in the future. In this way, emitting industrial firms obtain the possibility to extend their present emissions beyond the emission cap defined by the available number of emission allowances. Just like emission allowances, clean-up certificates are freely tradeable and their price level is determined based on willingness-to-pay. Due to arbitrage opportunities, the willingness-to-pay will be closely linked to the prices of emission allowances as well as to expectations on future carbon removal costs. Pessimistic market expectations on future progress in carbon removal technologies thus translate into lower prices of clean-up certificates. This mechanism stabilizes the uptake against changing market opinions. At the same time, the risk that technological progress turns out to be misjudged remains with the investor, affecting the firm's financing costs and creating default risk that needs to be carefully managed through collaterals. The impact of clean-up certificates on the long-term net emission balance depends on the ratio with which emission allowances are replaced by clean-up certificates, thus allowing regulators to maintain control of net emission targets.

5 Policy Evaluation

5.1 Model Setup

To analyse the impact of different support options on investment incentives and mitigation outcomes, a theoretical model of optimal decision-making is constructed. Unlike existing approaches that mostly consider the optimality problem through the lenses of a fictional social planner, the focus is here on investment incentives for individual firms in ETS industries.

The model rests on the competition framework developed by Melitz (2003)[46]. The decision-making unit is a profit-maximizing firm i that produces a quantity Q_i of a good that is sold on a market characterized by monopolistic competition and heterogeneous firms. By default, the good is produced using a conventional, fossil-based technology. Production causes input (material, energy labour) costs. These are modelled as the expenditures for one aggregate production factor, which both covers a variable and a fixed cost component (F) and serves as the numeraire in the model. Variable unit costs are assumed to be represented by the constant firm-specific parameter θ_i, implying that the production technology is characterized by increasing returns to scale. Firm differences in θ_i reflect basic productivity differences. Production also involves emission costs, with constant GHG emission intensities (ε) per unit of input used and emission prices (P^{CO2}) determined on a market for emission allowances.

Before choosing its production quantity, each firm makes two basic investment decisions. Firstly, it decides whether to switch to an existing alternative climate-neutral production technology. The switch affects the whole production process and is thus a binary yes/no decision. Switching occurs instantly and involves a rise in fixed costs($F^{Clean} > F^{Fossil}$), reflecting the costs of technology replacement. As another consequence of a switch, the emission intensity and thus the emission costs drop to zero. Secondly, if the firm opts against a technology switch, it considers investing in future carbon removal capacities. Specifically, it decides about the share α of its GHG emissions that is covered by carbon removals. Removals are assumed to be fully acknowledged as emission compensation, i.e. reduce the firm's need to buy emission allowances. Carbon removals involve costs that rise more than proportional in α, reflecting the increasing spatial restrictions of forming a large-scale CO_2 transport and

[46] Melitz, M. J. (2003). The impact of trade on intra-industry reallocations and aggregate industry productivity. econometrica, 71(6), 1695-1725.

storage network. Decisions on the level of a are made by maximizing the following net benefits function V^{Rem} per unit output produced, with ω as a basic removal cost parameter:

$$V^{Rem} = \varepsilon \cdot P^{CO2} \cdot a - \frac{\omega}{2} \cdot a^2, \tag{1}$$

$$a_{opt} = min. \left\{ \frac{\varepsilon \cdot P^{CO2}}{\omega}; 1 \right\}. \tag{2}$$

For an inner solution, this results in the following net benefit from carbon removal activity:

$$V^{Rem^*} = \frac{(\varepsilon \cdot P^{CO2})^2}{2 \cdot \omega}. \tag{3}$$

The demand side is modelled by a representative consumer, whose consumption preferences for the different goods sold is characterized by a standard CES utility function, with an elasticity of substitution between different products of $\sigma > 1$. On this basis, the technology-dependent profit-maximizing production decision of each firm can be determined. The technology switch decision is then made based on a direct comparison of potential profits under the climate-neutral and the fossil production technology, taking the economic effects of carbon removals into account in the latter case. The results of this comparison depend on the firm-specific productivity level θ_i. Firms with higher productivity benefit more from switching to the climate-neutral technology, as they earn higher operating profits that are needed to cover the additional fixed costs. Therefore, a minimum productivity level θ^{Clean} can be determined above which a firm will decide to decarbonize its production. At the same time, as in the standard Melitz framework, another cut-off level $\theta^{Entry} \leq \theta^{Clean}$ exists that reflect the minimum productivity level needed to make positive profits under any of the two technologies, i.e. a basic market entry condition. The two cut-off levels jointly characterize the resulting market distribution of firms and technologies. Their ratio expresses the following meaningful relationship (see Appendix for mathematical derivation):

$$\frac{\theta^{Clean}}{\theta^{Entry}} = \left(\frac{F^{Clean} - F^{Fossil}}{F^{Fossil}} \right)^{\frac{1}{\sigma-1}} \cdot \left(\frac{1}{\left(1 + \varepsilon \cdot P^{CO2} - V^{Rem^*}\right)^{\sigma-1} - 1} \right)^{\frac{1}{\sigma-1}}. \tag{4}$$

Hence, all else being equal, with carbon removal technology becoming more efficient ($V^{Rem^*} \uparrow$), this ratio will rise, i.e. a larger share of firms active on the market will abstain from switching to clean technologies and instead reduce their emission costs by investing in compensating carbon removal activities. At the same time, an isolated increase in V^{Rem^*} also raises the absolute cut-off level θ^{Clean} but lowers θ^{Entry} (see Appendix). Hence, the availability and cost efficiency of carbon removal technologies both influences the dissemination of clean technologies and the overall productivity distribution of firms on the market. Another consequence is that the role of the carbon price becomes more complex, as it affects the returns to decarbonization and carbon removals in the same direction.

In the subsequent policy analysis, the response of the key model variables θ^{Clean} and θ^{Entry} to different policy support measures for carbon removals will be investigated based on numerical model simulations. To this end, as is standard in the literature, the overall productivity distribution of potential market entrants is assumed to follow a Pareto distribution, whose distribution function is defined as:

$$G(\theta) = 1 - \left(\frac{\theta_{min}}{\theta}\right)^{k}, \tag{5}$$

with k as a parameter reflecting the extent of productivity heterogeneity.

Based on this productivity distribution, the share of active firms switching to the clean technology S^{Clean} can be derived from the ratio of productivity cut-off levels in a simple manner:

$$S^{Clean} = \left(\frac{\theta^{Clean}}{\theta^{Entry}}\right)^{-k}. \tag{6}$$

5.2 Policy Scenarios

The policy scenarios aim to mimic some of the policy alternatives qualitatively discussed in Section 4.2. Firstly, direct financial support to carbon removals in the form of cost subsidies ($Subs$) is expressed as a percentage compensation s of removal costs. This leads to the following adjusted value function for carbon removal activity, with s as the percentage subsidy:

$$V_{Subs}^{Rem} = \varepsilon \cdot P^{CO2} \cdot a - (1 - s) \cdot \frac{\omega}{2} \cdot a^2. \tag{7}$$

The second policy scenario consists of providing firms with a CCfD when engaging in carbon removal activities ($CCfD$). It is modelled as public support payments that equal the level of compensated gross emissions times a percentage mark-up u on the carbon price. As a consequence, the CCfD both directly affects the value of carbon removal activity and the ratio of productivity cut-off levels. The mark-up level is scaled to incentivize a specific political target rate a^{pol} for carbon removals:

$$V_{CCfD}^{Rem} = (1 + u) \cdot \varepsilon \cdot P^{CO2} \cdot a - \frac{\omega}{2} \cdot a^2, \tag{8}$$

$$u = max\left\{\left(\frac{a^{pol} \cdot \omega}{\varepsilon \cdot P^{CO2}}\right) - 1; 0\right\}. \tag{9}$$

Finally, a third policy scenario consists of offering clean-up certificates to firms (CUC). These certificates grant firms the right to shift carbon removals to a time where the technology has become more mature and hence cost efficient. In this one period setup, this is modelled as a percentage discount $\delta < 1$ on the cost parameter ω, reflecting the extent of expected future learning effects. Unlike the previous measures, clean-up certificates need to be acquired and thus involve additional costs for firms. This is modelled as a fixed replacement ratio between emission allowances and clean-up certificates. This results in the following adjusted net benefit function, with r^{CUC} as the replacement ratio, i.e. the number of emission allowances firms need to surrender to obtain one clean-up certificate, and b as the share of gross emissions compensated through future carbon removal activities:

$$V_{CUC}^{Rem} = \varepsilon \cdot P^{CO2} \cdot (a + b) - r^{CUC} \cdot \varepsilon \cdot P^{CO2} \cdot b - \frac{\omega}{2} \cdot a^2 - \frac{\delta \cdot \omega}{2} \cdot b^2. \tag{10}$$

By affecting the net benefits from carbon removal activity, the policy measures also exert an influence on clean investment choices and the productivity distribution of firms surviving on the market. Consequently, in a general equilibrium perspective, they also influence the level of the carbon price through their impact on the demand for emission allowances. This, in turn, could cause further feedback effects

on public financing opportunities of carbon removal support. In the following, these channels are analysed step by step. In comparing policy impacts, specific attention will be given to the sensitivity of results to technology costs and competition intensity on output markets.

5.3 Model Calibration

The model is calibrated to the projected situation of the EU27 in the year 2030. The sector considered is total manufacturing. Consequently, all model parameters are chosen or calibrated based on properties of the EU27 manufacturing sectors. Two of the basic parameters of the Melitz model, the elasticity of substitution and the shape parameter of the pareto distribution, are pre-specified based on literature estimates. Their baseline values are adopted from econometric estimates by Bernard et al. (2003)[47] and Balistreri et al. (2011)[48]. As part of a sensitivity analysis, these values will be varied to demonstrate the role of competition intensity and firm heterogeneity for carbon removal adoption and its welfare consequences.

Other parameter values are calibrated based on macroeconomic data and forecasts. Total factor endowment is calculated to replicate the total production value of EU manufacturing in 2024.[49] The share of firms using the clean technology in the support-free state is determined based on the 2030 industrial electrification target of the EU Clean Industrial Deal strategy[50], reflecting the dominant role of electricity-based technologies in decarbonizing industrial production.[51] The emission intensity of the fossil technology in the model is determined as the ratio of industrial GHG emission projections by the EEA for a scenario reflecting the current EU Policy mix ("Mix55""-Scenario)[52] to the production value of fossil-based firms, using the Eurostat data on gross production values. The cost parameter of the carbon removal technology is determined based on the previous information and the expected ratio of carbon removals to gross emissions in the support-free state. It is calculated as expected EU removal capacity in 2030 based on the EU's Sustainable Carbon Cycles Strategy[53] divided by the EEA emission projection. Finally, the ratio of fixed costs of clean and fossil production is calibrated to reproduce the share of firms using the clean technology in the support-free state. All baseline parameter values and their sources are reported in the Appendix.

47 Bernard, A. B., Eaton, J., Jensen, J. B., & Kortum, S. (2003). Plants and productivity in international trade. American economic review, 93(4), 1268-1290.

48 Balistreri, E. J., Hillberry, R. H., & Rutherford, T. F. (2011). Structural estimation and solution of international trade models with heterogeneous firms. Journal of international Economics, 83(2), 95-108.

49 Eurostat (2026). Annual detailed enterprise statistics for industry.

50 European Commission (2025). The Clean Industrial Deal: A joint roadmap for competitiveness and decarbonization, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions.

51 Wolf, A. (2026). Priorities for an EU electrification action plan. cepInput No.5/2026.

52 EEA (2025). EU Greenhouse Gas Emissions: Sectorial progress towards 2030. European Environmental Agency.

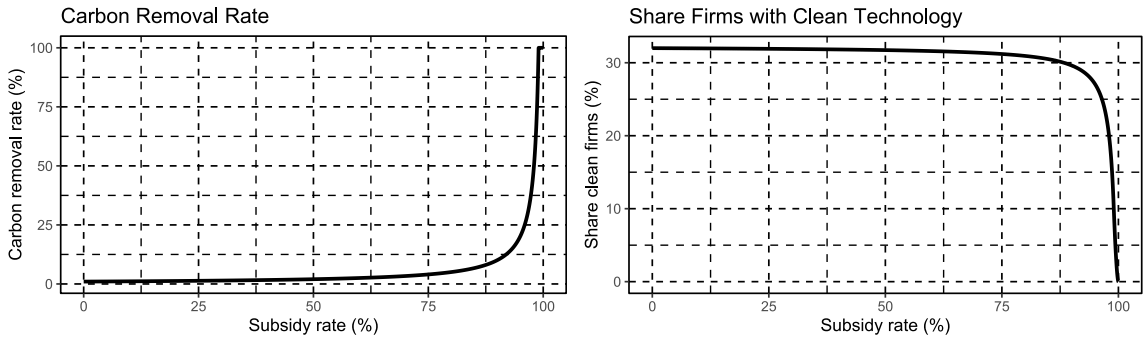
53 European Commission (2021). Sustainable Carbon Cycles. Communication from the Commission to the European Parliament and the Council.

5.4 Analysis of Policy Effects

5.4.1 Exogenous Carbon Prices

The analysis starts with the case of a partial equilibrium setup with all policy variables considered fixed. This also concerns the carbon price, whose economic interpretation thus equals that of a carbon unit tax. Firstly, the policy scenario $Subs$ is investigated. Figure 3 shows the impact of a direct percentage cost compensation ("direct cost subsidy") on the share of firms switching to the clean technology and the share of gross emissions compensated by carbon removals. It demonstrates a highly non-linear relationship between support levels and removal activity. Low to medium support levels only manage to incentivize additional carbon removal activity to a very limited degree. Only if support reaches a range of around 80% of removal costs, removals begin to take off and converge to full emission compensation for support close to 100%. This reflects the strong economic constraints for creating a substantial level of carbon removal capacity.

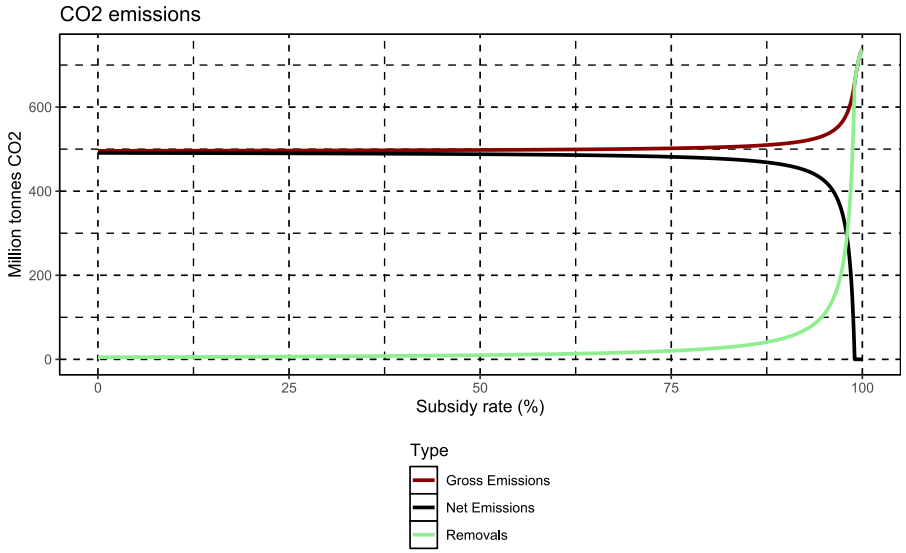
Figure 3: Partial equilibrium effects of removal subsidies – Investment Decisions



Source: own calculations

At the same time, the share of active firms switching to the clean production technology decreases with increasing carbon removal support. This is due to two effects. Firstly, due to the opportunity for a less cost-intensive compensation of emissions, the cut-off productivity level for clean investments increases, i.e. clean investments no longer pay for some firms in the medium productivity range. Secondly, for the same reason the cut-off level for market entry declines, allowing firms in the low productivity range to enter the market by applying fossil technology. Again, these effects only materialize substantially for very high levels of carbon removal support. In turn, the cut-off effects influence the overall GHG emission balance of the considered sectors. While gross emissions per unit output are rising in removal subsidies due to the increasing share of fossil-based producers, net emissions are decreasing (see Figure 4). Increased carbon removal activity thus overcompensates the undesired clean investment restraint.

Figure 4: Partial equilibrium effects of removal subsidies – Emissions



Source: own calculations

However, this result cannot be directly transferred to the EU situation of flexible carbon prices determined through allowance trading. Firstly, total emissions are politically fixed by the number of emission allowances made available to firms. Positive net effects of carbon removal activities on the emission balance can thus only be realized in conjunction with a cut of allowance supply. Secondly, by lowering abatement costs, a decline in removal costs should have a depressing effect on the ETS price. This should particularly affect the competition situation of firms in the low productivity range. Finally, the need to finance public removal support can require a redirection of public revenues from ETS auctions, which has welfare implications for households.

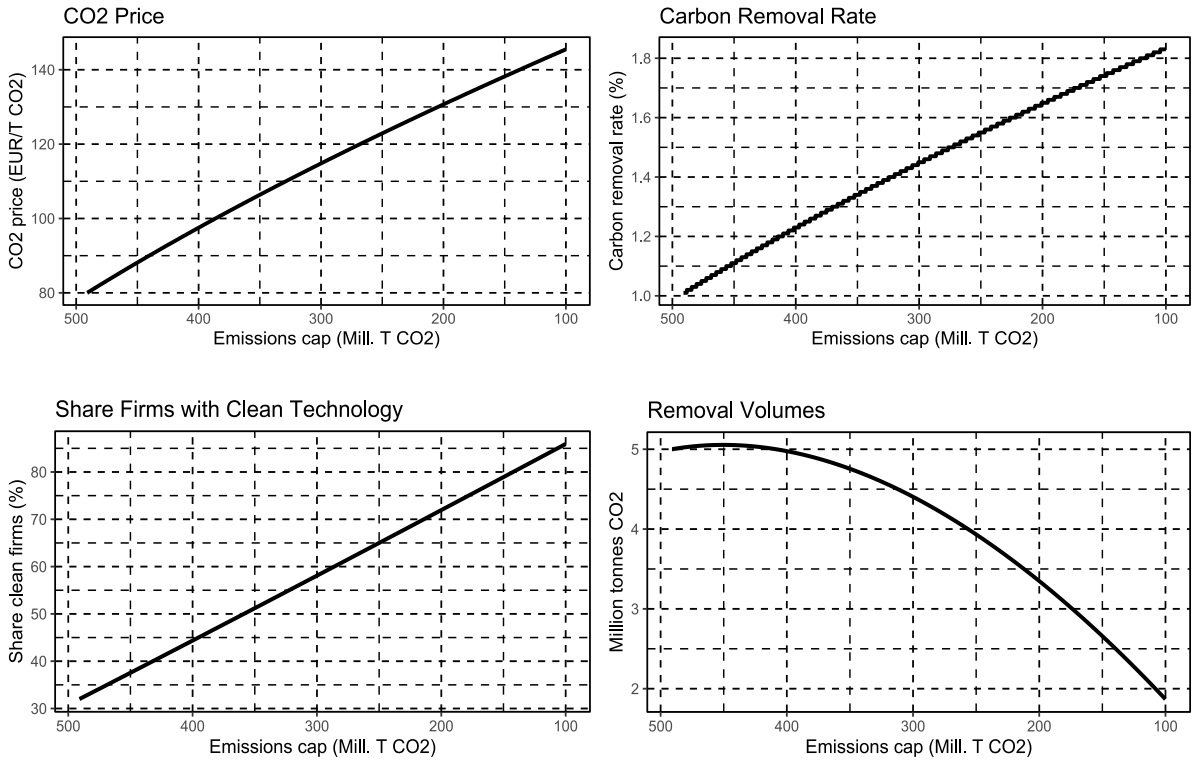
5.4.2 Endogenous Carbon Prices

In the following, the scope of the simulation model is extended by assuming the level of the carbon price to be determined endogenously on a market for emission allowances. In accordance with the EU-ETS, supply on this market is fixed by political emission goals. Allowance demand by manufacturing firms is the combined result of decarbonization decisions, carbon removal investments by fossil-based producing firms and total firm activity on the product market. As part of a general equilibrium perspective, support payments from carbon removals are financed by ETS auction revenues. The remaining net revenues from auctions are distributed to the representative consumer.

First, Figure 5 shows benchmark results for a scenario with full integration of carbon removals in emissions trading but without dedicated public removal support. As to be expected, reduced availability of emission allowances causes upward pressure on carbon prices that induces more and more firms across the productivity spectrum to engage in emission abatement. Abatement happens in two forms, depending on the productivity level of the respective firms. For firms close to the previous clean tech cut-off level, lower allowance supply creates incentives to switch to the clean technology. Firms with productivity levels far below the clean tech cut-off will instead respond by intensifying carbon removal activities. Carbon removal rates of fossil-based producers monotonically increase with decreasing emission caps, but only very slowly and are not predicted to exceed a level of 2%. Consequently, gross

emissions are predicted to decline unequivocally with reduced allowance volumes, while carbon removal volumes follow an inversely U-shaped path and finally converge to zero.

Figure 5: General equilibrium effects of changes in the emissions cap

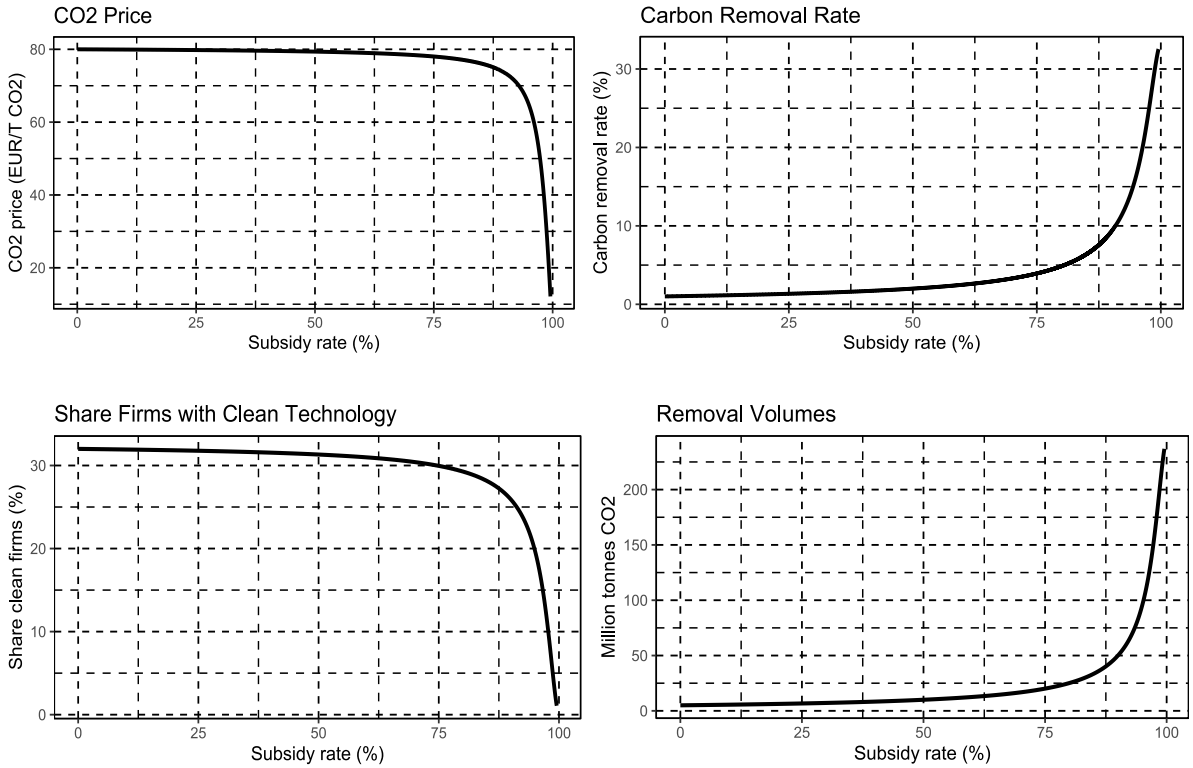


Source: own calculations

Under these conditions, carbon removal technologies are merely a transitory phenomenon. They are only used as an abatement instrument as long as carbon prices are not high enough to make paying the investments costs of clean production technologies worthwhile. On the upside, this implies that fears of carbon removal technologies causing the economy to remain stock in a fossil world seem exaggerated. On the downside, it implies that under the framework of an ambitious allowance trading regime development perspectives of infant carbon removal technologies are limited.

As a second exercise, Figure 6 shows how the direct removal cost subsidy discussed in the previous subsection performs under the conditions of the general equilibrium framework. For a given level of emissions cap, raising the subsidy level causes not only an increase of removal rates but also a demand-induced decline of the carbon price. This, in turn, limits the incentive effect of the subsidy. Moreover, due to the rigorousness of the cap, the incentive effect is fully offset by an increase in gross emissions caused by reduced clean investment activity. Removal subsidies unavoidably cause a crowding-out of clean production technologies by depressing the carbon price. The effects of subsidies on the consumer's real income are less clearcut. On the one hand, the reduced carbon price both directly and indirectly (by reducing market entry costs and thus raising the number of product varieties) lowers the consumer price index. On the other hand, nominal transfer income is reduced due to lower auction revenues and subsidy payments redirected to carbon removal activities. The simulation results indicate that the latter effect dominates under this parameter setup: real income declines with higher subsidy levels.

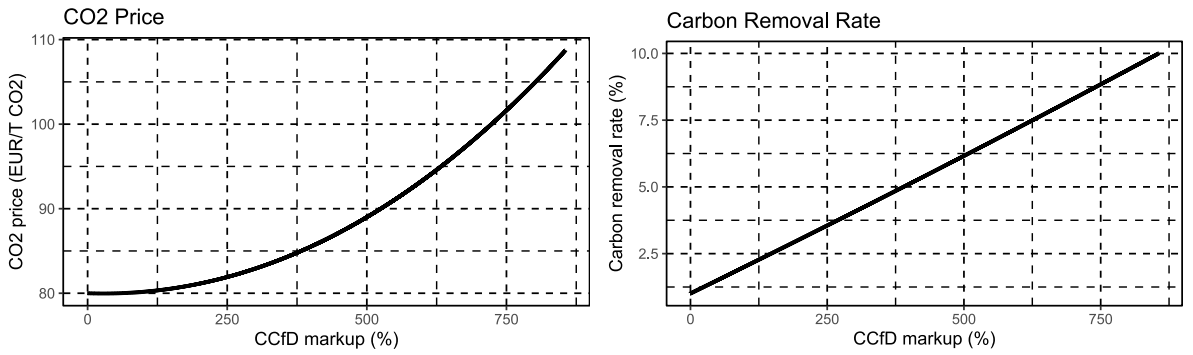
Figure 6: General equilibrium effects of removal subsidies

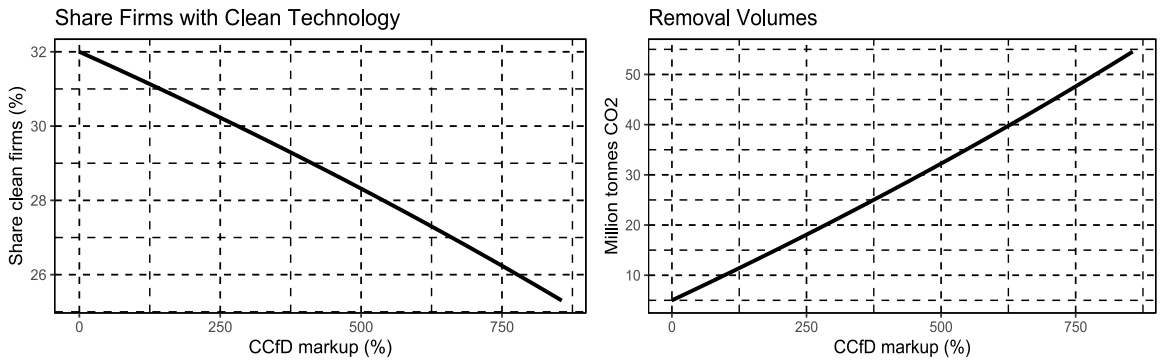


Source: own calculations

As a comparison, Figure 7 shows the same indicators in the presence of carbon removal support in the form a CCfD-based carbon price mark-up. In this scheme, public support takes the form of price-dependent payments for each tonne CO_2 removed instead of a simple percentage cost coverage. This leads to adjustment effects that are strikingly different. To incentivize high carbon removal rates among the fossil-based firms, using CCfDs requires much more financial substantial support, due to the increasing marginal costs of removals. This, in turn, results in strong disincentives regarding clean technology investments. The share of firms producing with clean technology approaches zero already for targeted carbon removal rates around 30%. Hence, the offered CCfD makes clean production even for the most productive firms no longer an attractive option. This is coupled with a rise (instead of a fall) of the carbon price and a continuous increase of absolute carbon removal volumes.

Figure 7: General equilibrium effects of CCfDs



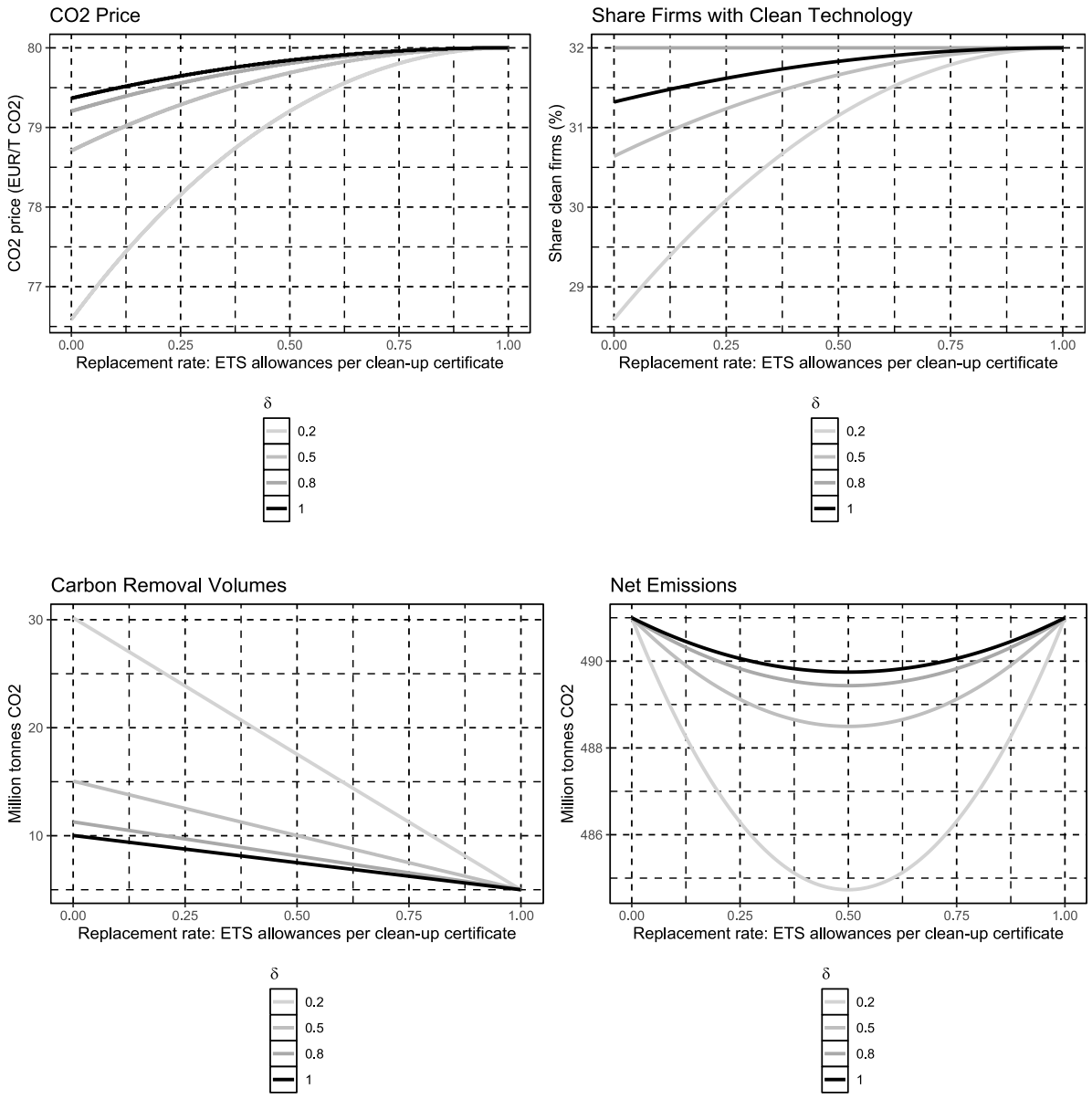


Source: own calculations

Finally, support in the form of clean-up certificates is investigated in general equilibrium perspective. Depending on the replacement ratio between allowances and clean-up certificates, firm demand for clean-up certificates has a direct effect on allowance supply. Hence, the interrelationships covered by the model now extend to interactions between the product market, the market for emission allowances and the market for clean-up certificates. Starting with the calibrated amount of emission allowances considered in the previous examples, Figure 8 shows how important model variables respond to different replacement ratios. In the absence of any expected learning effects ($\delta = 1$), additional future removal activity is very limited and only converges to the level of present removal activity for replacement ratios approaching zero, i.e. clean-up certificates becoming costless. The carbon price and hence investments in clean production technology are hardly affected even at very low replacement ratios. With some limited degree of learning ($\delta = 0.8$), future carbon removals make measurable contributions at already higher replacement ratios. However, this comes at a cost of a slight reduction in present carbon removals, caused by a negative demand effect on the allowance price. For a very steep learning curve ($\delta = 0.2$), the market repercussions become more apparent. Future carbon removals are substantial and exceed present carbon removals even at certificate replacement ratios around 0.8. As a consequence, the carbon price is expected to fall by several percent, causing a measurable decline in the share of firms opting for clean technology. However, due to the binding allowance cap, total net emissions are not increasing. On the contrary, they are decreasing, due to the partial replacement of allowances by clean-up certificates. This is a major difference to the other support instruments analysed above. Smaller replacement ratios incentivize more total removal activities but limit the scarcity effect on allowances. Consequently, comparable to the results obtained by Lessmann et al. (2026)[54] based on a macroeconomic growth model, net emissions follow a U-shaped pattern with varying replacement ratios.

[54] Lessmann, K., Gruner, F., Kalkuhl, M., & Edenhofer, O. (2026). Emissions trading with clean-up certificates: How carbon debt can increase climate ambition levels. Journal of Environmental Economics and Management, 103307.

Figure 8: General equilibrium effects of clean-up certificates



Source: own calculations

5.5 Discussion

5.5.1 Sensitivity Analysis

The imperfect competition assumption and the presence of heterogeneous firms in the model allows to assess the role of competition intensity and productivity differences in shaping the model results. Competition intensity is captured by the substitution elasticity σ. A bigger σ implies smaller product differences and thus higher price sensitivity of product demand. Table 1 shows how core model variables respond to varying σ. With shrinking levels of competitive pressure, the propensity to switch to clean production technologies declines. Firms have more leeway to pass on high carbon prices to their customers. The higher allowance demand in turn puts upward pressure on the carbon price, which results in higher returns to carbon removal activity. Consequently, for equivalent subsidy rates, a small σ boosts carbon removal volumes both by inducing more firms to stick with fossil technology and by

raising the carbon removal rate of the individual firm. High subsidies on carbon removals further amplify the role of competition, as carbon removal activities are less governed by rising marginal removal costs and more by the CO_2 price level. Hence, promoting carbon removals in an industry environment characterized by strong competition is especially difficult and requires more substantial public support. At the same time, the system-internal financing sources of removal subsidies, revenues from allowance auctions, tend to be smaller in such an environment.

Table 1: Sensitivity of subsidy effects to competition intensity

		Elasticity of substitution between products		
	Subsidy level	*σ=2.5*	*σ=3.8*	*σ=5*
Share firms with clean technology (%)	*s=0*	30%	32%	33%
	s=0.5	28%	31%	32%
	s=0.9	13%	26%	30%
Carbon price (€/T)	*s=0*	204	80	42
	s=0.5	202	79	42
	s=0.9	173	73	40
Carbon removal rate (%)	*s=0*	3%	1%	1%
	s=0.5	5%	2%	1%
	s=0.9	22%	9%	5%
Carbon removal volume (Mill. T)	*s=0*	13	5	3
	s=0.5	26	10	5
	s=0.9	137	50	26
Governmental net revenues (Bill. EUR)	*s=0*	100	39	21
	s=0.5	97	39	21
	s=0.9	-21	20	15

Source: own calculations

Moreover, the impact of the degree of firm heterogeneity can be highlighted by varying the productivity dispersion parameter *k* (see Table 2). A high *k* implies strong productivity discrepancies between firms. Firms thus differ profoundly in terms of competitiveness and clean investment rationales. The sales potential of firms at the lower end of the productivity range is severely limited. This fact depresses allowance demand and hence the carbon price. Without removal subsidies in place, carbon price repercussions on clean tech investments and carbon removal rates are nevertheless not substantial. Due to their high sales volumes, high-productivity firms still have a sufficient incentive to pay the fixed costs of the technology transition, while the productivity gap pressures low-productivity firms to compensate emissions even at low carbon prices. This changes for significant subsidy levels. By strengthening the role of the carbon price, it also magnifies the impact of productivity differences on gross emissions. Under these circumstances, higher productivity heterogeneity implies reduced clean-tech investments and more substantial overall carbon removal activity. A heterogeneous firm structure thus tends to be a supportive factor for carbon removal promotion.

Table 2: Sensitivity of subsidy effects to firm productivity heterogeneity

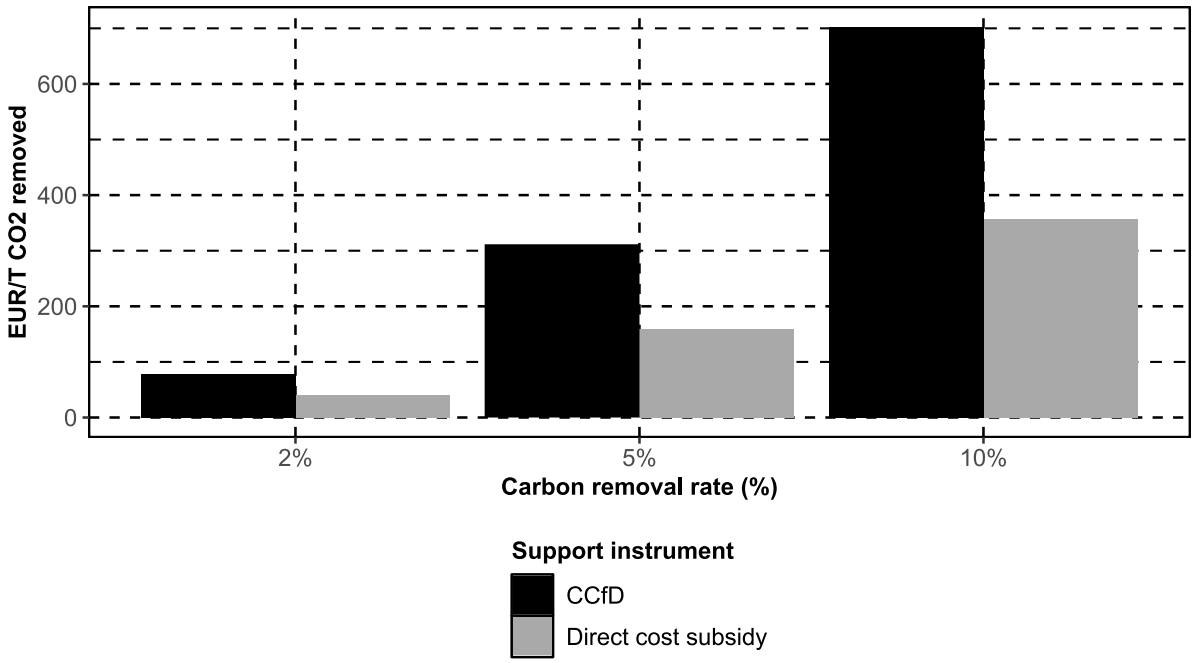
		Firm productivity heterogeneity		
	Subsidy level	*k=3*	*k=4.6*	*k=6*
Share firms with clean technology (%)	*s=0*	32%	32%	32%
	s=0.5	32%	31%	31%
	s=0.9	28%	26%	24%
Carbon price (€/T)	*s=0*	56	80	94
	s=0.5	55	79	93
	s=0.9	51	73	87
Carbon removal rate (%)	*s=0*	1%	1%	1%
	s=0.5	1%	2%	2%
	s=0.9	6%	9%	11%
Carbon removal volume (Mill. T)	*s=0*	3	5	6
	s=0.5	7	10	12
	s=0.9	34	50	61
Governmental net revenues (Bill. EUR)	*s=0*	27	39	46
	s=0.5	27	39	45
	s=0.9	17	20	19

Source: own calculations

5.5.2 Welfare Analysis

The support instruments discussed differ in the scope of their effects. Under the framework of emissions trading, direct cost subsidies and CCfDs are neutral with respect to the climate balance. Their goal is to support removal technology development as an additional emission abatement option and thus contribute to a reduction of long-term abatement costs. One indicator to compare their efficiency is the level of required public support volumes per tonne of CO_2 removed. Due to the non-linearity of removal costs, this indicator is sensitive to the removal rate (see Figure 9). For both instruments, support volumes per tonne sharply increase in the removal rate. For equivalent removal rates, required support payments are only about half as high in the case of direct cost than for CCfDs. The gap widens in absolute terms for higher removal rates. This is due to the nature of CCfDs, which foresee identical public support for every tonne of carbon removed. Hence, to motivate an expansion of carbon removal volumes to levels of high marginal removal costs requires a substantial increase in support for every single tonne. As a consequence, CCfDs are a more expensive means to incentivize large-scale carbon removal than a direct cost compensation through investment subsidies.

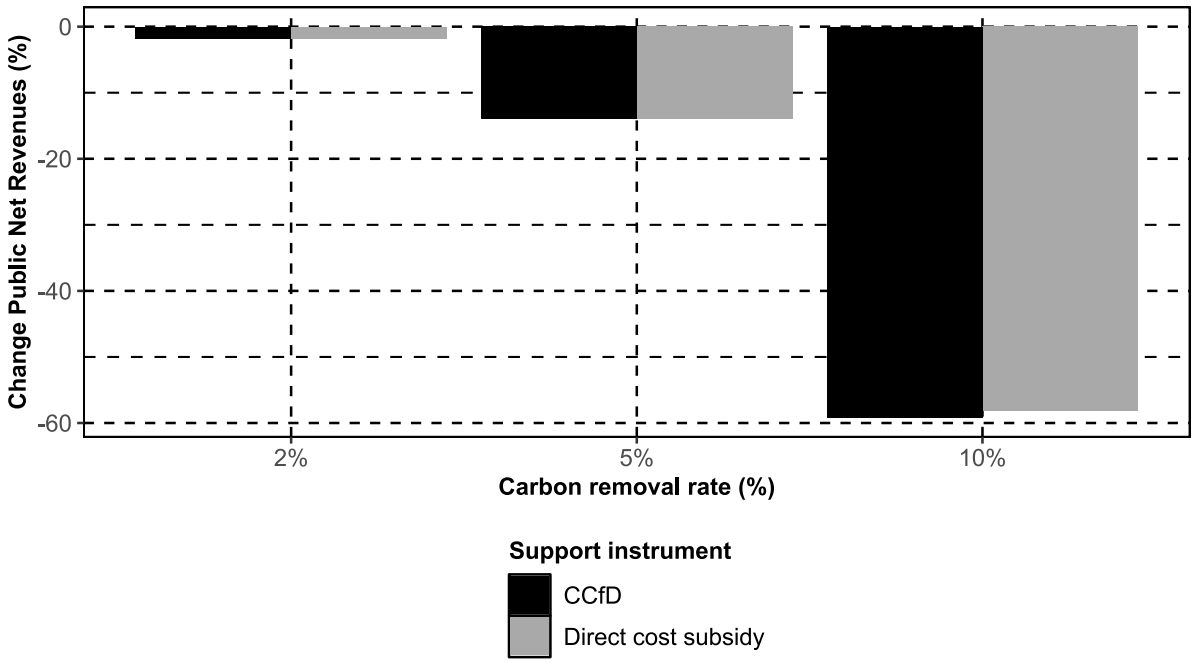
Figure 9: Comparison expenditures for removal subsidies and CCfDs per tonne CO_2 removed



Source: own calculations

However, an efficiency valuation also requires to consider the impact on the carbon price. By influencing the price level of emission allowances, carbon removal support instruments not only affect public budgets on the spending side but also on the revenue side, in the form of revenues from allowance auctions. Figure 10 shows that both instruments perform almost identically in terms of their effect on public net revenues ("climate budget"), despite the significantly higher public expenditures associated with CCfDs. This is due to the positive effect of CCfDs on the allowance price, while direct cost subsidies tend to lower the allowance price and hence auction revenues (see above). At the same time, this implies that the social burden from scaling carbon removals is distributed in different manners. With traditional subsidy payments, the financing is widely distributed among the entirety of consumers, by cutting public expenditures for other purposes. By contrast, CCfDs tend to shift a significant part of the economic burden to small, low-productivity-firms and their customers through intensifying carbon price pressure. At the same time, they require more abundant overall funding.

Figure 10: Comparison net budget effects of removal subsidies and CCfDs

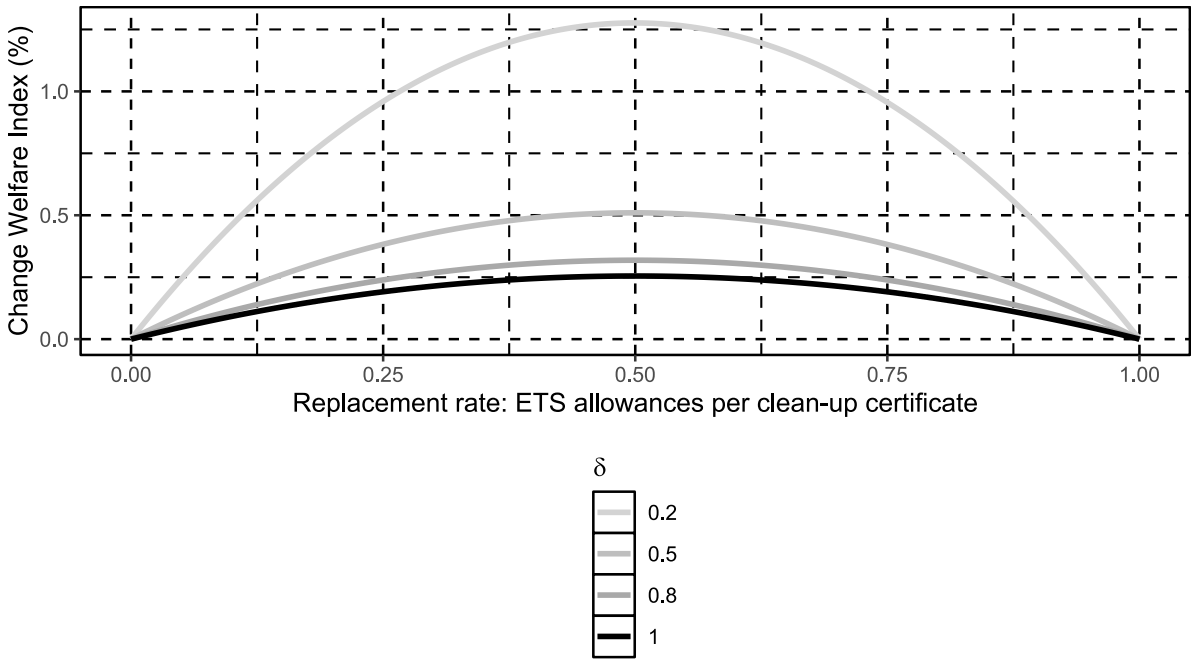


Source: own calculations

Clean-up certificates require a more sophisticated evaluation, as their impact on the emission balance is not zero. The more emission allowances that must be surrendered to obtain one clean-up certificate, the more positive the climate impact of clean-up certificates. This effect is the key channel for the welfare evaluation, as clean-up certificates do not involve direct public spending and their impact on carbon price levels is very limited (see above). In the following, the overall welfare effect is investigated by means of an additively separable social welfare function, weighing impacts on consumer purchasing power and climate damage.[55] Figure 11 shows how this welfare indicator changes with different allowance replacement ratios and assumed removal learning rates. It indicates a U-shaped relationship. Starting from a 1:1 replacement ratio, lowering the number of allowances to be surrendered raises welfare up to a certain ideal replacement ratio. This is the outcome of two opposing effects. While reducing the replacement ratio strengthens incentives for additional future carbon removals, it reduces the positive net effect of each tonne CO_2 removed on the climate balance. As to be expected, faster learning (lower δ) implies larger welfare gains from offering clean-up certificates. Moreover, further simulations show that a higher intensity of competition (higher σ) shifts the optimal replacement ratio to a slightly lower level. This is due to the higher sensitivity of firm profits to carbon prices, which strengthen the incentive effect of a more favourable replacement ratio.

[55] Formula: $W = \ln\left(\frac{I}{P}\right) - \tau \cdot E^{net}$. I: Income (including net public revenues). P: CES Consumer Price Index (featuring love-of-variety). E^{net}: Net CO_2 emissions. τ is a parameter reflecting the marginal social climate damage. As a rough estimate, it is specified as 100 EUR / T CO_2, in line with results from: Barrage, L., & Nordhaus, W. (2024). Policies, projections, and the social cost of carbon: Results from the DICE-2023 model. Proceedings of the National Academy of Sciences, 121(13).

Figure 11: Welfare effects of clean-up certificates



Source: own calculations

5.5.3 Comparative Evaluation

The above analysis has shown that there are trade-offs involved in selecting the ideal instrument to promote carbon removal. To fully grasp their extent, the limitations of the static simulation model must be taken into account. In reality, from the EU's perspective, future cost reductions resulting from learning effects are, to a certain extent, endogenous, depending on Europe's contribution to knowledge building. With endogenous learning, policy measures that more successfully support CO_2 removal in the initial phase yield additional benefits in the form of lower long-term removal costs. This argues in favour of direct cost subsidies to promote early, large-scale deployment and against clean-up certificates, which only incentivize additional removal measures in the future.

In fact, with strong endogenous learning, there is a serious risk that technology support through clean-up certificates will fail due to investor expectations and a tendency toward self-fulfilling prophecies. If, in the early stages of technology adoption, investors predominantly expect only modest investments in CO_2 removal, their expectations regarding future cost reductions will also be limited. This reduces the value of purchasing clean-up certificates today and nourishes a wait-and-see attitude. A reliance on clean-up certificates could thus slow down both current and future carbon removal activities.

A long-term welfare perspective also requires to consider the impact on green transformation decisions. Many clean industrial production technologies are still in the early stages of their technological life cycle and are therefore also subject to learning effects. Even though the proportion of companies investing in clean technologies does not directly affect the emissions balance in a cap-and-trade system, it is nonetheless a relevant factor for long-term emissions reduction costs. In this regard, the model results suggest that there are no significant differences between the policy instruments. All tend to lead to a similarly strong reduction in investments in decarbonization.

Moreover, the impact of support instruments on the price for emission allowances is interesting in itself for at least two reasons. Firstly, it gives rise to potentially undesired distributive effects. A rising CO_2 price means that small businesses in competitive markets face particularly strong cost pressures. Under real-world conditions of imperfect capital markets, this limits their investment opportunities and can lead to them becoming permanently dependent on public subsidies for CO_2 removal or other compensatory measures in order to remain competitive ("fossil lock-in"). Secondly, if EU carbon border adjustment remains imperfect[56], a rising carbon price also exacerbates the problem of carbon leakage. From a global perspective, therefore, promoting carbon removal cannot be considered climate-neutral. In this regard, direct cost subsidies and clean-up certificates appear to be superior to CCfDs. According to the model simulations, the first two instruments lead to a decline in the price of carbon, while CCfDs are expected to cause an increase.

Table 3 summarizes the pros and cons of the three instruments in qualitative terms. Overall, the representation suggests a complementary use of different support instruments to scale carbon removals. In particular, the combination of classical investment support in the form of a direct cost subsidy with the introduction of clean-up certificates is appealing. These two instruments complement each other in several ways. Direct cost subsidies promote the early adoption of CO_2 removal measures, which accelerates the technological learning process and thus leads to cost reductions over time. This increases the value of clean-up certificates and avoids the risk of a wait-and-see attitude described above. It can also help amplify the positive climate effects of clean-up certificates, as less generous replacement ratios are needed to create incentives for purchasing clean-up certificates. At the same time, the availability of clean-up certificates reduces the required subsidy payments per tonne CO_2 removed. This provides financial relief to taxpayers and limits the risk of crowding out funding for decarbonization. If managed wisely, the combined use of both instruments thus offers the potential for more effective and efficient capacity building in the field of carbon removal in Europe.

Table 3: Summary of policy evaluation

Instrument	Effect on decarbonization incentives	Effect on EU climate balance	Contribution to learning curve
Direct Cost Subsidy	Negative	Neutral	Yes
CCfDs	Negative	Neutral	Yes
Clean-up Certificates	Negative	Potentially positive	No
	Burden on public budget	**Cost pressure on SMEs**	**Effect on carbon leakage risk**
Direct Cost Subsidy	Yes	Falling	Falling
CCfDs	Yes (substantial)	Rising	Rising
Clean-up Certificates	No	Falling	Falling

Source: own representation

[56] Wolf, A. (2025). A CBAM for Exports. cepStudy No.6/2025.

6 Policy Recommendations

6.1 Combine Public Investment Support with Clean-up Certificates

Ensuring a fast and yet sustainable scaling of carbon removal technologies suggests a combination of more direct public investment support with the introduction of clean-up certificates. Subsidies are crucial to enable early adoption and thus create the learning and scaling effects necessary for future cost efficiency. However, a support strategy solely based on subsidies is expensive, threatens to crowd-out public and private funding for decarbonization and creates no direct positive climate effect under a cap-and-trade system. If being financed by auctioning additional emission allowances, it can even lead to a higher GHG net emissions over the short-to-medium term. The introduction of clean-up certificates constitutes a way to promote long-term removals without direct fiscal costs. When being offered in exchange for surrendering emission allowances, they have the potential to reduce net emissions in the long-term. However, their attractiveness strongly depends on future cost expectations. When learning is endogenous, missing incentives for early adoption translate into pessimistic expectations on future removal costs, undermining the value of buying clean-up certificates and thus further curbing experience-based cost reductions in the medium-term. To avoid such negative self-fulfilling prophecies, incentives for future removal activity must be coupled with intensified state support for early adopters in the present. A combined use of direct cost subsidies and clean-up certificates mutually improves the effectiveness of the two instruments. In addition, it achieves a fairer distribution of the cost and risk burden of scaling carbon removals between the public and industrial emitters.

6.2 Establish Accessible Market Platforms for Private Funding

In the medium-to-long term, cost efficiency of carbon removals not only depends on scale economies but also requires sufficient competition among removal projects and technologies. Platforms for market aggregation like the CRCF Buyers' Club established by the EU represent an important tool not only for raising funds for large-scale projects but to facilitate market access for small players and those developing innovative removal solutions. The aggregation mechanism of platforms should thus be complemented with targeted incentives for small project developers on both the supply and the demand side. This could take the form of a partial public backing of collaterals needed to cover the implementation risks of projects provided with long-term offtake agreements on such platforms. The commercialization of innovative removal technologies could receive dedicated support through separate aggregation mechanisms, using tools like state-backed double auctions to compensate initial gaps between costs and carbon price levels.

6.3 Harmonize Market Rules to Create an Internal Market for Removed CO_2

In addition to EU-wide project funding, the development of cross-border markets for removed CO_2 also requires common rules for project and infrastructure development. Uniform market rules and a well-developed cross-border CO_2 pipeline network are prerequisites to achieve sufficient capacity utilization of large-scale removal and storage facilities. To this end, Member States should prioritize the acceleration of approval procedures for strategic CCS projects prescribed by the Net Zero Industry Act, e.g., by creating sufficient administrative capacities. Moreover, additional legislation is needed at EU-level to create joint rules for the development and operation of a future CO_2 pipeline infrastructure,

similar in its objectives to the recent revision of the internal gas market legislation.[57] This should include uniform quality standards for CO_2 transport (temperature, pressure, purity) and rules on the form of cross-border cooperation for future Europe-wide network planning, as well as common principles for the levying of network charges when transporting CO_2 from external sources. The common goal of all rules must be the fast development of CO_2 transport in the EU with as few barriers as possible. This creates margin for the realization of a cost-optimal pipeline geography and of scale economies in large storage reservoirs.

6.4 Engage in International Cooperation for Faster Technology Development

The need for a rapid development of removal technologies urges Europe to exploit scale economies beyond continental borders. In particular, research and knowledge cooperation with technologically advanced third countries, including the US as a frontrunner in DACCS, promises positive spillovers. By engaging in joint research and knowledge dissemination activities as well as cooperating in the development of market rules and technical standards, Europe can participate directly in future knowledge gains of countries at the technological frontier. In return, it can offer its own significant expertise in the fields of certification and basic technology research. This helps to cut removal costs faster and makes cost reductions less dependent on early domestic adoption. In turn, this lowers the long-term need for domestic subsidies and raises the attractiveness of clean-up certificates. By synchronizing abatement costs, it is also an important step towards forming a comprehensive joint climate policy regime (“climate clubs”) with partners.

7 Conclusion

High costs of emission abatement and competitiveness concerns in energy-intensive industries are motivating a search for new technologies to help the EU become climate-neutral by 2050. Technologies for the direct or indirect removal of CO_2 from the atmosphere offer significant long-term potential to offset unavoidable residual emissions. However, their timely adoption is hindered by high upfront costs and market externalities, which justify targeted policy support. The EU has recognized this need. To complement general support for CO_2 infrastructure, the Commission recently proposed a special project funding program in the form of CO_2 removal credits. While this is a step in the right direction, the proposed design may accidentally cause additional net emissions and the allocation scheme still requires clarification.

This cepStudy analyzes the economic impacts of various support mechanisms for carbon removal within the context of the established EU carbon pricing system. To highlight the role of competition, firm heterogeneity, and incentives for clean investments, carbon removal is incorporated into an industrial economics model. Direct cost subsidies are compared with CCfDs and the recently proposed clean-up certificates as policy options. The results reveal significant trade-offs between the options. Unlike direct cost subsidies and CCfDs, clean-up certificates do not place a financial burden on taxpayers and have the potential for positive net effects on the EU’s carbon footprint. However, if learning processes are essential for future cost reductions, allowing for delayed emission compensation may render clean-up certificates unattractive, thereby hindering technology adoption and jeopardizing long-term cost-effectiveness.

[57] European Council (2023). Gas package: Council and Parliament reach deal on future hydrogen and gas market. Press release, December 8 2023.

Therefore, a welfare-optimal policy strategy consists of a combination of different support instruments. In particular, the combined use of direct cost subsidies and clean-up certificates mutually improves the effectiveness of the two instruments. In addition, it achieves a fairer distribution of the cost and risk burden of scaling carbon removals between taxpayers and industrial emitters. To solve chicken-and-egg problems and enable faster scaling, investor-level support must be complemented by a strong market pull. Above all, the Commission should swiftly develop a proposal for an EU-wide legal framework with market rules and technical standards for the transport and storage of CO_2 in order to leverage economies of scale in the cross-border use of infrastructure. To ensure sufficient private financing and competition in a future EU market for captured or removed CO_2, the Commission should further expand its market aggregation platform, with a particular focus on ensuring access for small players. Finally, to strengthen the technological learning process and benefit from the momentum of foreign investment, the EU should strive to form technology partnerships at the international level that focus on CO_2 removal, including with the United States as the world's leading pioneer in removal technology.

8 Appendix

Derivation of cut-off conditions

1. Demand function for variety i:

$q_i = \left(\frac{p_i}{P}\right)^{-\sigma} \cdot \frac{I}{P}$, $\sigma > 1$, p_i: Price of variety, P: Consumer Price Index, I: Income

2. Profits of firm i with productivity coefficient θ_i:

2.1 Profits with fossil production technology:

$$\pi_{i;fossil} = p_i \cdot q_i - \left(\frac{1 + \varepsilon \cdot P^{CO2} - V^{Rem^*}}{\theta_i}\right) \cdot q_i - F^{Fossil}$$

$$\pi_{i;fossil} = \left(p_i - \left(\frac{1 + \varepsilon \cdot P^{CO2} - V^{Rem^*}}{\theta_i}\right)\right) \cdot \left(\frac{p_i}{P}\right)^{-\sigma} \cdot \frac{I}{P} - F^{Fossil}$$

Profit maximization condition: $\pi'_{i;fossil}(p_i) = 0$

$$\rightarrow\ p^*_{i;fossil} = \frac{\sigma \cdot \left(\frac{1 + \varepsilon \cdot P^{CO2} - V^{Rem^*}}{\theta_i}\right)}{\sigma - 1}$$

$$\rightarrow\ \pi^*_{i;fossil} = \frac{I \cdot P^{\sigma-1}}{\sigma} \cdot \left(\frac{\sigma}{\sigma - 1} \cdot \left(\left(\frac{1 + \varepsilon \cdot P^{CO2} - V^{Rem^*}}{\theta_i}\right)\right)\right)^{1-\sigma} - F^{Fossil}$$

Cut-off condition for market entry: $\pi^*_{i;fossil} = 0$

$$\rightarrow\ \theta^{Entry} = \left(\frac{F^{Fossil} \cdot \sigma}{I \cdot P^{\sigma-1}}\right)^{\frac{1}{\sigma-1}} \cdot \left(\frac{\sigma}{\sigma - 1}\right) \cdot \left(1 + \varepsilon \cdot P^{CO2} - V^{Rem^*}\right)$$

2.2 Profits with clean production technology:

$$\pi_{i;clean} = \left(p_i - \frac{1}{\theta_i}\right) \cdot \left(\frac{p_i}{P}\right)^{-\sigma} \cdot \frac{I}{P} - F^{Clean}$$

Cut-off condition for clean investment: $\pi^*_{i;clean} = \pi^*_{i;fossil}$

$$\rightarrow\ \theta^{Clean} = \left(\frac{F^{Clean} - F^{Fossil}}{\sigma \cdot P^{1-\sigma} \cdot I^{-1} \cdot \left(\frac{\sigma}{\sigma - 1}\right)^{1-\sigma} \cdot \left(1 - \left(1 + \varepsilon \cdot P^{CO2} - V^{Rem^*}\right)^{1-\sigma}\right)}\right)^{\frac{1}{\sigma-1}}$$

$$\rightarrow\ \frac{\theta^{Clean}}{\theta^{Entry}} = \left(\frac{F^{Clean} - F^{Fossil}}{F^{Fossil}}\right)^{\frac{1}{\sigma-1}} \cdot \left(\frac{1}{\left(1 + \varepsilon \cdot P^{CO2} - V^{Rem^*}\right)^{\sigma-1} - 1}\right)^{\frac{1}{\sigma-1}}$$

Parameters: Baseline values and data sources

Symbol	Meaning	Baseline value	Source
ε	Emission intensity production	0.01006 T CO_2 / EUR	Value of CO_2-eq. per EUR manufacturing output in EU27 2024
ω	Removal cost parameter	0.99 EUR	Calibrated to reproduce expected EU removal capacity (5 Mill. T CO_2) in 2030
F^{Clean}/F^{Fossil}	Fixed cost ratio of clean to fossil technology	1.05659	Calibrated to reproduce expected EU industrial electrification rate in 2030
σ	Elasticity of substitution between products	3.8	Bernard et al. (2003)
k	Shape parameter of productivity distribution	4.6	Balistreri et al. (2011)
E^{Cap}	Total emissions cap	496 Mill. T CO_2	EEA projection of EU industrial GHG emissions in 2030
L	Value of total labor endowment (wage: numeraire)	5,858 Bill. EUR	Calibrated to reproduce manufacturing output in EU27 2024
τ	Marginal social climate damage	100 EUR / T CO_2	Barrage & Nordhaus (2024)

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