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Quantifying and Deploying Responsible Negative Emissions in Climate Resilient Pathways

Quantitative survey of commercialisation mechanisms

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Executive Summary

Current deployment of Negative Emissions Technologies and Practices (NETPs) is supported by a wide range of incentive mechanisms, many of which (such as direct government financing for the demonstration of commercial-scale NETP projects) are ill-suited to large-scale commercialisation. In this report we survey the mechanisms already encouraging negative emissions in Europe and globally, together with an estimate of what different mechanisms appear to be paying per tonne of CO_2 removal, and how those costs are currently distributed.

A second component of this report will be a literature survey of the commercialisation mechanisms proposed in the academic literature and in draft and actual legislation, both in and outside Europe, together with an assessment of their likely impact on energy costs, carbon intensive industries or fiscal revenues.

Finally, mechanisms that are relevant to European policy are analysed by evaluating projected costs per tonne of CO_2 of each commercialisation mechanisms, as well as the size of the potential financial resource supporting each mechanism and the likely evolution of costs as scale-up in 2030 and 2050. Further analysis is conducted to understand the financial flows between governments and the private sector to NETPs via commercialisation mechanisms.

Survey of Operational and Proposed Mechanisms

Our review finds the cost of NETPs generally exceeds the amount that is recoverable in today's markets. The majority of mechanisms currently in operation are under resourced and pay too little to enable a balanced portfolio of NETPs that could support hard-to-abate sectors move to net zero. While not primarily motivated by CO_2 removal, mechanisms tend to support established afforestation and soil carbon sequestration methods. Although carbon capture and storage (CCS) is covered in some schemes, the incentives they provide are inadequate and, in some cases, not available to Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Carbon Capture and Storage (DACCS), known as engineered removals.

Notably, outside of California, there are no current examples of a coordinated portfolio of mechanisms which attempt to achieve a balance between engineered and land-based NETPs options. Existing mechanisms explicitly focused on carbon removal are geographically concentrated in the UK, USA (mostly California) and New Zealand. The majority of proposed mechanisms have not been quantified or consider their potential impact on energy costs, carbon intensive industries or fiscal revenues. A key assumption of most proposed mechanisms is the inclusion of NETPs in carbon markets.

In this analysis, mechanisms are categorised on a scale between fully market-based or dependant on fiscal incentives. Market-based mechanisms encompass those in which polluters pay the direct cost of adhering to a regulation, standard or participate in a carbon market. Market-based incentive mechanisms consist of incentives within market-based mechanisms that target a policy outcome which is not achievable without state support. Fiscal incentives consist of subsidy and tax credit mechanisms. We find market-based mechanisms pay between €1/tCO_2 and €166/tCO_2, market-based incentives pay between €10/tCO_2 and €28/tCO_2 and fiscal incentives pay between €0.6/tCO_2 and €54/tCO_2. For market-based mechanisms and incentives the price may be both the price of removal and reduction.

Analysis of Mechanisms

We assumed that the cost of engineered removals could in some way be offset by the Emissions Trading Scheme (ETS) price through a market-based mechanism, although we do not necessarily assume NETPs are integrated into the EU ETS. The land sink was assumed to be managed through a combination of carbon farming results-based payments, forestry strategy payments or a similar subsidy regime to calculate the financial resources required for each mechanism type.

In 2030, mechanisms to scale NETPs could require financial resources of between €4.8 and €6.7 billion annually, which may rise to between €9.8 and €30 billion annually by 2050. Governments contribute the majority of financial resources in all scenarios in 2030, but the market surpasses them by 2050 due to the EU ETS price exceeding the cost of removals. By 2050 engineered removals make up the vast majority of financial resource requirements across scenarios. Payments to land-based removals are expected to be reasonably consistent over time, as our estimates show the land sink could be at 80% of its potential by 2030, ensuring that agricultural emissions are offset to reach the sectors net zero target by 2035.

The primary variables between scenarios and the level of financial resource include variations in non-CO_2 emissions from agriculture, the availability of the land sink for carbon removal, and the restrictions of biomass demand additions. Europe currently does not provide incentives directly for NETPs, by 2030 government incentives for BECCS and DACCS could be €50\t$CO_2$ and €95\t$CO_2$ respectively, with the private sector contributing an equivalent to the EU ETS price of €85\t$CO_2$ towards the cost of engineered removals. We also propose a mechanism known as a “European Removals Fund” which works in parallel to the EU ETS to scale engineered removals through a reverse auction process.

Key Policy Relevant Messages

The analysis of this report concludes that mechanisms which incentivise the scale up of NETPs to match Europe’s net zero target do not exist. Outside of Europe, mechanisms generally do not pay enough to incentivise investment in DACCS and BECCS but there are important lessons to be learned from their operation to date. It is worth noting that mechanisms from different regions may not match the risk preferences of European investors and capital markets [1]. It may be that European investors prefer greater certainty of returns over profit maximising, relative to their American counterparts e.g. Contract for Difference (CfD) versus tax credits.

The European Union raises and disburses large amounts of money to achieve certain outcomes. Europe's ETS and CAP are two well-established mechanisms, both of which have been proposed for reform in order to provide an EU-wide approach to carbon removal incentives [2–5]. The analysis in this report provides insights into how each mechanism could be reformed to incentivise a limited portfolio of NETPs, from full integration to parallel mechanisms.

In addition to price signals, NETPs will likely need market-based incentives. A number of examples of market-based incentives are reviewed in this report. For Europe, the survey of proposed mechanisms found a carbon CfD to be the most commonly suggested mechanism for BECCS and subsidy type payments are more likely for land NETPs.

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Introduction

Negative emissions technologies and practices (NETPs) are an essential part of most scenarios for achieving the Paris Agreement goal of limiting warming to below 2°C, and all scenarios for limiting warming below 1.5 °C [6]. NETPs serve two main purposes: 1) compensating for temporary carbon budget over shoot, and 2) offsetting remaining emissions from three 'hard-to-abate' sectors: aviation, agriculture, and industry [7]. NETPs will require policies, incentives, regulation, standards and commercialisation mechanisms (hereafter "mechanisms") that effectively scale negative emissions to support net zero targets [3]. The degree to which current and proposed mechanisms will contribute to achieving net zero targets is unclear. This report is the first to survey commercialisation mechanisms globally in order to catalogue their current cost and scale, as well as the financial resources required to support such mechanisms in Europe in 2030 and 2050. We only consider commercialisation mechanisms which can support a portfolio or sequence of NETP projects. Voluntary carbon markets[1] and non-scalable mechanisms including funds for trials, research and innovation are not considered.

Bioenergy with Carbon Capture and Storage (BECCS) and Direct Air Carbon Capture and Storage (DACCS), known as engineered removals, are expected to be the two key NETPs options (in terms of tCO_2 removed in globally), complemented by smaller, yet vital, deployment of land-based and ocean-based NETPs[2] [9]. There are numerous impediments to the NETPs market reaching its required size and quality. Firstly, the level of uncertainty on permanence (length of storage) and the amount of CO_2 removal[3] of certain NETPs. Secondly, the costs, particularly for immature NETPs, can be high and uncertain. For example, enhanced weathering has large uncertainties around cost (£39-£390 per tCO_2) and there are possible environmental impacts and natural capital benefits not yet known. Finally, socio economic developments can also significantly affect the role and importance of NETPs in mitigation scenarios and this is likely to impact the development of the market [7]. The diversity of risk by each NETP type mean the development of the NETPs can be supported further by portfolio-based risk management approaches [10].

Mechanisms which support NETPs can operate on a scale between fully market-based or dependant on fiscal incentives. Market-based mechanisms focus on a polluter or supplier of fossil fuels pays principle that includes carbon markets and prices and regulations and standards. Market-based incentive mechanisms can operate in the middle of the scale by providing fiscal incentives within an already functioning market-based mechanism. In a market-based incentive mechanism the polluter pays principle ideally still applies but the state can help compensate NETP operators for insufficient returns or participate in the market. Subsidy and tax credit mechanisms are the purest form of fiscal incentives in which the state contributes a significant amount to the cost of developing and operating the NETPs rather than the direct polluter.

[1] Voluntary carbon markets are unlikely to provide sufficient price stability or the environmental integrity to offset residual emissions.

[2] Ecosystems restoration, afforestation, reforestation, improved forest management, enhancing soil carbon sequestration, biochar, enhanced weathering, ocean alkalinisation and ocean fertilisation.

[3] Accounting for emissions in afforestation is largely established, although monitoring can be difficult for all nature-based solutions. Challenges with BECCS and DACCS can be more administrative. For example, is it the forest's native country or BECCS plant's native country or the CO_2 storage facilities native country which claims the negative emissions. Land and soil-based NETPs, such as biochar, present the greatest challenge as both the t/CO_2 that can be removed and the storage permanence are uncertain. Enhanced weathering may depend on rainfall, temperature, soil type, and so on [88].

European Policy Context:

The EU's Land Use, Forestry, and Agriculture Regulation proposes a target for carbon removal by natural sinks of 310 million tonnes of CO_2e emissions by 2030. Increasing the target is expected to support the Land Use, Forestry, and Agriculture sector to reach net-zero emissions by 2035 [3]. By moving agriculture from the Effort-Sharing Regulation to the LULUCF Regulation, agricultural sector emissions could be limited to as much as the EU land sink removes. Land-based NETPs may need to be allocated to the agricultural sector until 2036. Sectors outside of agriculture are unlikely to be able to use land-based NETPs to meet emission reduction targets. European Commission modelling scenarios to reach net zero expect engineered removals to sequester and geologically store between 6MtCO_2e and 178MtCO_2e by 2050 [13].

The European Union raises and disburses large amounts of money to achieve certain outcomes. The EU Emission Trading Scheme (ETS) aims to reduce emission through a market which sells allowances on CO_2 emissions, known as EUAs, that increases the cost of carbon-intensive activity in the energy, industrial and aviation sectors. Selling EUAs generates income for member states that can be used to support green polices but also general government spending. Europe's Carbon Capture and Storage (CCS) directive allows for allowances not to be surrendered if point source emissions are verifiability captured, transported and permanently stored, fossil-based CCS is not a NETP. A majority of the EU budget, raised from contributions by member states, is allocated to incentives for agricultural land management practices and production currently managed through a subsidy scheme known as the Common Agricultural Policy (CAP). There is currently no direct regulatory incentive or mechanism in place in the EU, with the direct intent of, sufficiently scaling up engineered removals or increasing the land sink to meet the bloc's net zero targets.

EU ETS reform has been suggested as a potential mechanisms to scale up NETPs, but would likely be limited to NETPs which capture and permanently store carbon i.e., BECCS and DACCS [4,5]. The European Commission has already included carbon farming[4] in its recommendations to the Member States' CAP Strategic Plans and set out a forestry strategy which is expected to plant 3 billion trees by 2030 [2,14]. The European Green Deal specifies that 40% of the CAP budget will be climate-relevant [15]. In combination with forestry payments, CAP payments could be expanded or altered from a payment based mostly on agricultural output to results-based carbon farming payments for land-based NETPs. Europe's RED II directive includes GHG calculation rules that factor in carbon capture use/storage as well as soil carbon accumulation. Although these components do not get a direct financial reward, they are included so that bio-energy/biofuel pathways to meet minimum GHG performance thresholds, which are needed to get access to markets and associated support schemes. The EU also plans to launch a certification scheme for carbon dioxide removal [16].

Findings and Paper Structure:

We find that globally, there are limited examples of mechanisms which explicitly incentivise the deployment of NETPs. Operational market-based mechanisms pay between €1/tCO_2 and €166/tCO_2, market-based incentives pay between €10/tCO_2 and €28/tCO_2 and fiscal incentives pay between €0.6/tCO_2 and €54/tCO_2. While not primarily motivated by CO_2 removal, mechanisms tend to support established afforestation and soil carbon sequestration methods. Although carbon capture and storage (CCS) is covered in some schemes, the incentives they provide are inadequate and, in some cases, not available to BECCS and DACCS. Notably, outside of California, there are no current examples of a coordinated portfolio of mechanisms which attempt to achieve a balance

[4] Agricultural methods aimed at sequestering atmospheric carbon into the soil.

between engineered and land-based NETPs options. Existing mechanisms explicitly focused on carbon removal are geographically concentrated in the UK, USA (mostly California) and New Zealand. Finally, we consider the financial resources and amount mechanisms could need to pay in 2030 and 2050 under the EU 1.5 Tech and 1.5 Life scenarios. In 2030 the financial resource required could be between €4.8 and €6.7 billion annually, which may rise to between €9.8 and €30 billion annually by 2050.

The remainder of this report proceeds as follows: the next section introduces a survey of commercialisation pathways for NETPs. Section 2 introduces the data set, estimates the model parameters, and presents our estimates of the financial resources required to support mechanisms as well as what each mechanism could pay. Section 3 provides a discussion and conclusion of the analysis, with policy relevant findings.

1 Survey of Operational and Proposed Mechanisms

This section provides a survey of existing and proposed mechanisms to support NETPs, with estimates of each mechanism's payment per tonne of CO_2 removal, scale and the distribution of costs. Table 1 provides an overview NETP mechanisms both in Europe and abroad. The review approach, workings and sources for each mechanism estimate can be found in section 4.1 of the appendix, including prices in their base currency.

Table 1 Quantitative overview of operational mechanisms

Mechanism	Type	Region	NETPS	Distribution of Cost	Scale ($MtCO_2$)	Price ($/tCO_2$)
Countryside Stewardship Scheme (CSS)	Grant	UK	Forestry	Fiscal	-	€0.6-€1.2
Woodland Carbon Fund (WCF)	Grant	UK	Forestry	Fiscal	-	€23-€28
Woodland Carbon Code (WCC)	Market	UK	Forestry	Market	11	€8-€23
Woodland Carbon Guarantee (WCG)	Grant	UK	Forestry	Fiscal	2 - 3	€20-€28
Emissions Reductions Fund (ERF)	Grant	Australia	Forestry, Soil	Fiscal & Market	138	€10
One Billion Trees Fund (1BTF)	Grant	New Zealand	Forestry	Fiscal	-	€2-€6
Conservation Reserve Program (CRP)	Grant	USA	Forestry, Soil	Fiscal	12 - 15	€54
CDFA Healthy Soils Program (HSP)	Market	USA	Soil	Fiscal	0.1	-
45Q tax credit	Credit	USA	CCS**	Fiscal	75	€31-€44
California Cap and Trade (C&T)	Market	USA	Forestry	Market	80	*€20
New Zealand ETS	Market	New Zealand	Forestry	Market	9	€19
Sowing Life (SL)	Grant	Mexico	Forestry	Fiscal	400 - 600	€5-€7
Low-Carbon Fuel Standard (LCFS)	Market	USA	DAC	Market	38 incl avoidance	€107-€166
Label Bas Carbone (LBS)	Market	France	Forestry	Market	-	-
Registro de Huella de Carbono (RHC)	Market	Spain	Forestry	Market	0.12	€25
Klik foundation (KF)	Market	Switzerland	Forestry	Market	10	€88
Colombia's Carbon Tax (CCT)	Market	Colombia	Forestry	Market	4	*€4
China CCER Certificates (CCER)	Market	China	Forestry	Market	3	*€5
Québec Cap-and-Trade System (QC)	Market	Canada	Forestry	Market	-	*€20
Kazakhstan ETS (KE)	Market	Kazakhstan	Forestry	Market	-	*€1
SDE++	Market	Netherlands	CCS**	Fiscal & Market	2.5	-

*Mechanism market carbon or ETS price – NETPs may receive a lower price.
** Not a NETP but could reduce the cost of and in future iterations include BECCS or DACCS
Prices and scale as of 26/11/2021

1.1 Operational Fiscal Mechanisms

Section 1.1 provides a brief overview of the operational fiscal mechanisms, which are highly dependent on government support and funding, identified in Table 1. The majority of mechanisms covered in section 1.1 are not explicitly or primarily motivated by CO_2 or forests being a NETP.

The Countryside Stewardship Scheme (CSS), Woodland Carbon Fund (WCF), and Woodland Carbon Guarantee (WCG) are UK based-grants to fund land-based NETPs. Environmental improvements are funded by the CSS through a variety of activities, including afforestation and soil management. The CSS does not directly pay for carbon sequestration, and payments are made per hectare [17]. New carbon-sequestering productive woodlands can be directly funded by the WCF. This includes the cost of tree planting as well as the costs of protective measures such as tree guards, fencing, and gates [18]. WCG allows landowners to sell captured carbon from their forests to the government in the form of verified credits called Woodland Carbon Units (WCUs) for a guaranteed price every 5 or 10 years up to 2055/56 [19,20]. The guaranteed price is agreed through an auction. At year 5 and year 15 the UK Accreditation Service checks if the predicted or actual carbon sequestration is materially correct [21]. Other land-based NETPs could be incentivised through the proposed Environmental Land Management Scheme (ELMS). Similar to CSS, ELMS may fund some forms of soil carbon sequestration and habitat restoration, biochar and enhanced weathering could be incorporated [22].

Conservation Reserve Program (CRP) is a longstanding US government scheme which pays farmers, through voluntary participation, to convert certain agriculturally used croplands to vegetative cover. Farmers can plant new grasses, shrubs, and trees that improve water quality, prevent soil erosion, and increase wildlife habitat. Annual rental payments, cost-share assistance (up to 50%) and financial incentives (additional 20% of soil rental rate) can be provided through contracts which last between 10 and 15 years. The Climate-Smart Practice Incentive is a new scheme under the CRP to increase sequestration through trees and permanent grasses, development of wildlife habitat and wetland restoration, it is not clear how prices will be set. Estimates suggest the program mitigates more than 12 million metric tonnes of carbon dioxide equivalent (CO_2e). CRP aims to enrol an additional 4 million acres into the program by 2023, equivalent to an additional 3 million metric tonnes of CO_2e in sequestration [24].

New Zealand's One Billion Trees Fund provides either direct grants to landowners or partnership funding to support tree planting or sustainable land management. The NZ$240-million-dollar fund aims to incentivise doubling the current tree planting rate to reach one billion trees by 2028. Direct grants are paid on a per hectare basis with set targeted grant rates [25].

Mexico's US$3.4 billion Sowing Life tree-planting initiative is intended to help meet climate goals with synergistic aims to support the country's efforts to reduce poverty and inequality. The program is currently paying around 420,000 farmers 4,500 pesos (about US$213) a month to plant trees, according to the government. The programme is expected to reforest one million hectares of land and plant one billion plants by the end of 2021 [26].

Section 45Q of the US tax code provides a tax credit to power plants and industrial facilities that capture and store carbon dioxide that would otherwise be emitted into the atmosphere (26 U.S.C. § 45Q). The tax credits cover geological CO_2 storage in general and so are applicable to both BECCS and DACCS [27]. The credit is tied to the amount of CO_2 captured, and goes directly to the entity doing the capture (i.e., the owner of the capture facility). Once captured, the facility can choose to permanently store the CO_2 in deep saline formations or provide it to companies that will use it in the production of goods ranging from plastics, concrete, other commercial materials, and enhanced oil recovery (EOR). In the latest revamp of the tax code, facilities can receive US$50/t$CO_2$

for permanent geological storage and US$35/t$CO_2$ for use in EOR or other products by 2026, up from US$32/t$CO_2$ and US$20/t$CO_2$ respectively. The taxpayer has to repay the tax credit (credit recapture) to the Treasury if the carbon dioxide ceases to be captured, disposed of, or used in a qualifying manner (i.e., if it escapes into the atmosphere) [28]. Proposed reforms, aimed at supporting DAC, include increasing the credit for CCS to between $85/t$CO_2$ and $175/t$CO_2$, making the credit permanent and offering a direct payment option [29]. Sanchez et al (2018) analyse the CO_2 capture opportunities for existing ethanol biorefineries in the United States at different levels of financial support from sequestration credits (e.g. the 45Q) and abatement credits (see LCFS section 2.1) [30]. They find that a $60/tCO2 sequestration credit may result in the sequestration of 30 Mt of CO_2 and 6,900 km of pipeline infrastructure across the United States, while a $90/t$CO_2$ carbon abatement credit might incentivise the reduction of 38 Mt of CO_2. Edwards and Celia (2018) propose the use of direct government financing in addition to the 45Q tax credit to reduce the costs of carbon capture utilisation and storage (CCUS) [31]. Government financing options, creating a lower cost of capital, for 50 percent and 100 percent of CCUS pipelines cost were examined, potentially capturing an additional 19 to 30 million tonnes of CO_2 profitably each year.

1.2 Operational Market-Based Mechanisms

Section 1.2 describes operational market-based mechanisms identified in the survey and listed in Table 1. Market-based mechanisms create markets, standards or regulations within markets where polluters pay for their pollution or services are provided to offset those emissions. Governments can act as market participants or provide incentives to support NETPs which are not yet profitable. The majority of operational mechanisms do not pay enough to support engineered removals and are focused on afforestation as a NETP.

The Woodland Carbon Code (WCC) is a voluntary carbon standard that creates independently verified carbon units or certificates for woodland creation projects in the UK. Companies looking to offset their emissions buy WCC verified carbon certificates from project developers. The units cannot at present be used in the ETS or outside the UK (including shipping and aviation) [32]. The WCC requires 20% of issued certificates to be surrendered to a buffer managed by Scottish Forestry. The buffer provides a level of scheme-wide insurance, and can be drawn down in case of unexpected reversal [33].

Participants in the Compliance Offset Program under California's Cap-and-Trade system can offset their emissions with forest projects in the United States. Offset credits from verified afforestation projects can be converted into Air Resource Board (ARB) offset credits for use in the Cap-and-Trade Program. Compliance entities may use ARB Offset Credits to meet up to 8% of their emissions compliance obligation until 2020, 4% of their emissions compliance obligation from 2021-2025, and 6% of their emissions compliance obligation from 2026-2030 [34]. California's Healthy Soils Program (HSP) is also funded from the State's cap and trade proceeds, also known as California Climate Investments (CCI). Farm management practices that are supported can include: cover cropping, no-till, reduced-till, mulching, compost application, and conservation plantings.

Launched in 2015, Australia's Emissions Reduction Fund (ERF) provides incentives to businesses to cut the amount of greenhouse gases they create and to undertake activities that store carbon, through Australian carbon credit units (ACCUs). ACCUs can be sold to the government through a carbon abatement contract or in the secondary market as an offset [35]. The market for these offsets is not regulated and relies on private contracts. Carbon abatement contracts are secured through a competitive bidding process based on lowest cost per tCO_2. The primary form of CO_2 removal for ACCU is currently through new vegetative based practices at 138 MtCO_2 [36].

Owners of forest land created after 1989 in New Zealand can voluntarily join its ETS and receive New Zealand Units (NZU) per tCO_2 removed as their forest grows. Owners of non-exempt pre-1990 forest land are required to participate in the system and are subject to its obligations if they deforest. Landowners are incentivised to pursue afforestation under the scheme since they can sell the resulting NZUs to companies in the ETS. Owners of pre-1990 forest land received a one-off free allocation of NZUs when the NZ ETS was implemented to partially compensate for the impact of the ETS. If the forest is harvested or deforested, units must be surrendered to account for the emissions, and if the participant chooses to deregister from the scheme, NZUs equivalent to the number received must be returned. Participants are entitled to receive one NZU per tonne of removal from the destruction or export of products that embed carbon as well as for the export of hydrofluorocarbons and perfluorocarbons. Nine million NZUs were issued for forest removal activities for the 2019/2020 financial year [37].

The Californian Low-Carbon Fuel Standard (LCFS) is a market-based policy that sets annual carbon intensity benchmarks on the full lifecycle emissions of transport fuels sold, supplied or offered for sale in California. LCFS allows CCS projects that reduce emissions associated with the production of transport fuels sold in California, and projects that directly capture CO_2 from the air, to generate LCFS credits. LCFS credits can then be sold for between \$122/tCO_2 and \$190/tCO_2 to buyers within the scheme which exceed their allocated carbon intensity benchmark, or in the Credit Clearance Market for up to \$200/tCO_2 at the schemes year end [38]. Permanence Certification is required to operate, which includes agreeing to monitor the project for 100 years after injection and a high likelihood (greater than 90% probability of occurrence) that over 99% of CO_2 sequester will not be re-released 100 years post-injection. To compensate for any potential CO_2 leakage from projects, 8% to 16.4% of the credits generated by CCS projects are allocated to a Buffer Account. Operators must also ringfence capital for maintenance, emergency or corrective action, and eventual project closure using a third-party financial responsibility instrument based on the cost of contracting a third party to do those services [39]. Combining the LCFS credits and 45Q tax credits is estimated to provide an incentive for any geologic CO_2 storage project equivalent to over \$200/tCO_2, at prevailing credit values [38]. To scale up DAC in the US, Rhodium propose the Section 45Q tax credit could be changed to prolong the commence-construction deadline for DAC eligibility to the end of 2030; increase the value of the credit for geologic storage to US\$180 per tonne; and lower the minimum capture and use thresholds to 10,000 tonnes per year. Rhodium expect changes to the Section 45Q Tax Credit, together with revenues from California's LCFS, to make projects break even, costing the government \$1.5 billion annually to sequester 9$MtCO_2$ by 2031 [40].

Spain’s Registro de Huella de Carbono (RHC), administered by the states Ministry of Environment, registers forestry projects sequestrating CO_2 among other services. Afforestation and reforestation in the scheme are expected to last at least 30 years. Project are listed on a public registry once approved by the Ministry of Environment, with follow up reports required every five years. Third party verification of ex-post GHG emissions is required if a buyer retires their carbon units to confirm the amount of carbon sequestered. A buffer with a fixed rate of 10% of an estimated carbon unit is also applied to projects to account for issues of permanence [41].

Label Bas-Carbone is a French mechanism administered by the Ministry for the Ecological Transition. The mechanism largely focuses on afforestation and reforestation projects but is expected to expand to other forms of sequestration including agroforestry soil carbon in agriculture, mangroves and methanization [41]. Local projects using new NETP methods can also apply to mechanism for approval. Project developers receive 1 “credit” per tCO_2 sequestered/avoided under the scheme. Credits are negotiated and traded directly between the project owner and the buyer, rather than offered on an open market. Depending on the project risk category, forestry projects must apply a 10% to 25% reduction to account for permanence. Similar to RHC projects must last for a minimum of 30 years [41].

Switzerland's state managed national offset program supports its national carbon tax in incentivising emissions reductions. Importers of motor fuels are required to offset up to 90 percent of their emissions under the Swiss CO_2 act. The KliK Foundation for Climate Protection and Carbon Offset (KliK) was established as a sector wide carbon offset grouping for suppliers of motor fuels in support of the obligation. The KliK Foundation currently funds projects that generate offset credits based on a Swiss carbon standard, including the possibility of forestry projects. Companies pay the costs that are created within the scheme through a levy placed on consumers [42]. From 2021, the KliK Foundation will act as a designated agency which will produce Internationally transferred mitigation outcomes as part of their operation [43].

The Colombian government adopted a carbon tax of approximately US$5/t$CO_2$e covering fossil fuels in 2016. Companies can avoid paying the tax by purchasing carbon offsets from projects. From 1 January 2018, projects must be located in Colombia. Accepted offsets include afforestation, improved forest management and REDD+ projects as well as agricultural and grassland management projects [41].

In China, the National Development and Reform Commission (NDRC) set the guidelines for the Chinese GHG Voluntary Emission Reduction Program's project development and clarified its working procedures in 2009 and 2012. In January 2015, the voluntary program's registry was launched, marking the official start of trading and signifying that China Certified Emission Reductions (CCERs) can be used for compliance in China's local carbon markets. The Chinese government began spot trading for China's national carbon market in 2020, and allows the use of CCERs as offset credits, which are generated or traded within the voluntary program. Forestry represents a small proportion of the scheme's activity at 2.54MtCO_2 out of a total 140MtCO_2 in emissions reductions [44]. Entities are able to use CCER certificates to offset as much as five percent of emissions by volume. A single CCER unit is able to offset 1tCO_2e, which could come from carbon sinks and methane recovery.

Kazakhstan's Emissions Trading Scheme allows for the use of domestic offsets in all economic sectors including forestry, under the legislation offset projects are expected to apply Clean Development Mechanism principles [45,46]. Project owners must submit an application to the Ministry of Ecology, Geology and Natural Resources for approval for offset credits. Ministry specific rules and IPCC methodologies are used to assess each project.

Québec has developed an offset protocol for afforestation and reforestation projects in private lands in the province, linked to their ETS, which is expected to be finalized and adopted in 2021. Up to 8% of each entity´s compliance obligation can be met by offsets [47]. Under the mechanism offsets credits which are deemed illegitimate by the regulator must be replaced by the offset project owner. An environmental integrity account is used when credits are not replaced. An automatic withholding of 3% of issued offset credits from all offset projects is used to fund the account [47].

In the Netherlands, the SDE++ mechanism provides a 15-year CfD-like subsidy support covering the cost of CCS operation above the EU ETS price. Operators can retain free allowances under the ETS. Operators of industrial facilities are exempt from Dutch carbon tax system on CO_2 that is captured and stored [48]. After 2035, the SDE++ mechanism will not provide subsidies to new industrial CCS. Support for CCS in the mechanism is limited to a maximum of 7.2 MtCO_2/year. Projects are ranked based their subsidy intensity and only projects below the cost threshold for CCS could participate in the auction. Calculating the subsidy intensity is done by taking the base rate from the application and subtracting the long-term price divided by the emission factor [48].

1.3 *Proposed Mechanisms to Create Demand*

In this sub-section, mechanisms which could increase the demand for NETPs are reviewed, the following sub-section reviews mechanisms which could increase the supply of NETPs. The vast majority of proposed mechanisms have yet to be quantified in a way that could provide comparison of costs or wider impacts (e.g., energy prices and industrial competitiveness).

Honegger & Reiner (2018) evaluate the ability of the Sustainable Development Mechanisms (SDM), part of Article 6 of the Paris Agreement, ability to support a new carbon market instrument. They propose the SDM could allow for voluntary transfers of mitigation units in return for payment of a price for each tonne of CO_2 of avoided emissions by the country that receives the units. This could then be expanded to analogously include payment of a price for each tonne of CO_2 removed. The received units might then be counted towards the buyer country's mitigation target or its climate finance pledges. This would create the flexibility to fund mitigation activities including NETPs outside of national borders in a way that they contribute to the funders' mitigation target [49].

Allen et al. (2009) proposed the concept of mandatory sequestration or more recently formalised into a mechanism known as a Carbon Take Back Obligation (CTBO) [50]. In a CTBO, producers or importers of carbon compounds must sequester/store an increasing fraction of the CO_2 produced rather than releasing it into the atmosphere (100 percent by 2050). Carbon sequestration/storage can be carried out in-house or outsourced by purchasing carbon storage units (CSUs) or contracting sequestration/storage from third parties. To reliably calculate the amount of CO_2 removed, CTBOs require a minimum accounting standard, and only NETPs that meet this standard (including permanence) should be covered by the CTBO. Similar to a carbon tax, the cost of the CTBO is passed onto fossil fuel consumers, which could increase energy prices and decrease industrial competitiveness, however there is no cost to the taxpayer. A workshop of stakeholders was used to assess a variety of CTBO designs for natural gas in the Netherlands, and the results suggested that the obligation should be mandatory and put as far up in the value chain as possible, favouring geological storage as a source of CSUs [51]. Jenkins et al (2021) find a CTBO could be comparable in cost, including economic costs, to similar ambition scenarios dominated by demand-side measures simulated by a global carbon price. In the near term, demand-side policy is required to incentivise emissions reductions before the CTBO stored fraction increases significantly enough to disincentive fossil fuel use [52].

Intertemporal instruments through a Carbon Removal Obligation (CRO) have also been proposed to incentivise the repayment of previously accrued carbon debt. Bednar et al. (2021) propose an emissions-trading scheme that provides permits for emissions consistent with a specific global-warming goal, but that allows further emissions as long as the emitter commits to removing the extra carbon later on. Within the proposed mechanism the default risk of carbon debtors is addressed by pricing atmospheric CO_2 storage through interest on carbon debt. Emitters are therefore charged for the temporary 'storage' of this carbon in the atmosphere. The authors conclude that interest payments for CRO induce substantially more ambitious near-term decarbonisation complemented by earlier and less aggressive deployment of NETPs [53]. They show that this would lead both to earlier reductions in carbon emissions (decarbonisation) and to earlier application of CO_2-removal technologies than would otherwise occur.

Under the EU ETS, operators that undertake CCS are not required to surrender allowances where emissions have been verified as captured and transported for permanent storage (Council Directive 2018/410/EC). However, emissions from using biomass for electricity generation are not covered by the EU ETS. Consequently, the incentives for CCS do not extend to BECCS. Rickels et al 2021 explore a number of design options for the inclusion of NETPs (primarily BECCS and DACCS) through a proposal for CO_2 removal credits (CRCs) in the EU ETS, focusing on the economic, legal, and political challenges of each [54]. They propose removing the mandatory link between emitting activities and the use of emissions-reducing technologies, then adjusting the unused allowance pool to assign CRCs, integrating CRCs indexed to observed prices and quantities, and procuring CRCs in advance by a yet-to-be-established regulatory authority.

1.4 Proposed Mechanisms to Create Supply

In the United States, a number of mechanisms have been proposed to expand the availability of carbon-sequestering land based NETPs. A carbon bank programme, funded by US$30 billion from the Commodity Credit Corporation, is being considered at the federal level. It would involve giving carbon credits to farmers and landowners in exchange for adopting carbon sequestration practises, which they could then sell in a cap and trade market [55]. A number of US states, including New York, Vermont, and Hawaii, have proposed soil-based sequestration mechanisms, which are generally funds in the form of grants or concessional financing [56–59]. A tax credit model for farmers who maximise carbon sequestration potential on their land is also being considered in New York [60].

Vivid Economics (2019) propose a stand-alone tax credit and a more integrated tax credit funded by a carbon levy. The 48 a/b tax code in the US provides an additional tax credit available for initial capital investment for gasification equipment, they suggest this could be adapted for capital intensive NETPs to reduce costs. The carbon levy approach consists of a four-part process: 1) Banded set of available tax credits paid for $/tCO2 of greenhouse gas removed (similar to the 45Q tax credit). 2) Additional complementary tax credit is made available for initial (capital) investment for NETPs. 3) Make tax credits tradable. Tax credits are available to tax-paying entities. Companies with large tax liabilities like supermarkets and banks could reduce their tax bill by investing in NETPs on farms etc. 4) Introduce a carbon levy to make it revenue-neutral. Levy proceeds directly used to finance NETPs tax credits [61].

NETPs could also be incentivised through a contract-for-difference (CfD) mechanism. The UK's contract-for-difference (CfD) auction mechanism works to stabilise the revenues of renewable energy project developers, with successful bids, by guaranteeing a strike (electricity) price that is paid when market prices fall below it, when prices exceed the strike price excess revenues are paid back to the counter party. To date, two 'biomass conversion' and three 'biomass with CHP' projects in the UK have won CfD's [62]. BECCS developers could use a CfD to secure a strike price for electricity that could incentivise investment [61]. A CfD could be tied to ETS or carbon pricing[5] for industrial BECCS and DACCS [63]. Frontier Economics argue the most effective commercialisation mechanism for BECCS combines a CfD with a fixed carbon payment ($/t$CO_2$ sequestered), rather than a regulatory asset base model, cost plus book, cap and floor or negative CO_2 obligation scheme. Carbon payments would serve as a financial incentive to sequester carbon, with a CfDs covering the cost of power generation ($/MWh) [64]. Stakeholders in a recent UK government stakeholder consultation on CCUS business models expressed a preference for a combination of a CfD and upfront capital support, with comparable business models considered to the Frontier Economics research [63].

Element Economics and Vivid Economics expand further on CfD mechanisms for BECCS [65]. They focus on two CfD commercial frameworks including an electricity price CfD (CfDe) plus Negative Emissions Payment (NEP) and

[5] A CfD strike price is agreed per tonne of CO_2 abated, based on the expected costs of building and operating the industrial carbon capture assets. The emitter partly funds the cost of capture by selling any excess free CO_2 allowances (or equivalent) and the government (through a CfD counterparty) pays the difference between the CfD strike price and a defined reference price (linked to the prevailing CO_2 allowance price) for an agreed period of time.

a standalone carbon or ETS price CfD (CfDc) for BECCS. Both the NEP and CfDc are expected to receive payments from the state to the BECCS facility, with NEPs set at £92/tCO_2 and CfDc set at £107/tCO_2. The analysis suggests that the cost of the NEP could be recovered by the state selling a NEC on the voluntary market or the operator of the BECCS plant selling a NEC at a discount (£40/tCO_2) in the voluntary market with the state making up the difference in the NEP. The report concludes that the NEP approach, unlike the CfDc, may be easier to implement in a shorter time frame because it avoids ETS adjustments and the CfDe is more familiar to investors.

The EU Innovation Fund aims to bring highly innovative technologies and industrial solutions for decarbonising Europe to the market, generally through grants and loans. Its budget comes from allocated allowances or EUAs which it can sell in the EU ETS. The scope of the Innovation Fund has been extended to allow it to provide support to projects through competitive tendering mechanisms such as CfDcs [66]. Commercial second, or third of a kind NETP projects, may benefit and be deployed as part of this development. CfDcs may raise problems for the ETS forward market, effectively reducing the need for market participants to hedge their risks leading to reduced overall liquidity and thus less efficient price-formation [67].

Cabral et al. (2019) propose a mechanism which incentivises repurposing existing coal-fired power plant fleet into BECCS. This mechanism may also have secondary benefits including displacing CO_2 emissions from coal-use and enabling a just transition, i.e., avoiding job loss and providing a supportive economic framework that does not rely on government subsidies. Negative emissions generated from capturing and storing atmospheric CO_2, from repurposed coal to BECCS plants, can be converted into negative emission credits (NECs) and auctioned to hard-to-decarbonise sectors, thus providing another revenue stream to the power plant. The analysis finds BECCS plants have a levelized cost of $70 to $100, achieved through auctioning NECs at between $90/t$CO_2$ to $135/t$CO_2$, with a sequestration potential of 9G tCO_2 [68]. Subsequent analysis has found that incentivising NETPs through NECs in the UK could mean that lower levels of carbon taxation are needed to meet the Paris Agreement, which in turn lowers electricity costs [69].

NEC mechanisms have also been analysed through value pools with an estimated worth of between £35.3bn to £36.9bn by 2050 in the UK [70]. The value pool calculates the theoretical available potential in the market for new revenues and avoided costs. Platt et al. (2018) consider BECCS focused business models (including BECCS, EOR, and CCS), Distributed Biomass focused business models for NETPs (including Decentralised Pyrolysis, Pyrolysis & Electricity, Pyrolysis and Biofuels, and Afforestation), and DAC focused business models (including DAC utilisation, storage and CCS) in their value pool analysis. In comparison to enhanced oil recovery, afforestation payments, biochar markets, and industry and commercial uses of captured carbon, the authors conclude that near energy market policy, specifically access to a carbon credit mechanism, has by far the greatest near-term potential to drive the negative emissions technologies.

The Swedish government has proposed that a system for operating support for BECCS in the form of reverse auctioning be introduced in 2022. In 2022, a first reverse auction is expected to be held, in which the operators who can supply the service at the lowest cost win the tender. The first payment will be made after storage of carbon dioxide with payment from 2026, with an annual budget of SEK 400 million per year during the period 2026 –2040 for winners of the reverse auction. This means that the Swedish government intends to invest a total of SEK 6 billion during the period 2026–2040 [71]. Zetterberg et al. (2021) consider five policy proposals for incentivising BECCS in Sweden. They suggest the government could provide guarantees for purchasing BECCS outcomes initially, similar to the auction approach. Followed by a larger quota obligation scheme or integration of BECCS into the EU ETS to scale up BECCS. They also considered a voluntary compensation scheme or international transfers of BECCS outcomes (similar to the SDM), but conclude these two approaches were too uncertain for the short term [4].

2 Analysis of Mechanisms

In this section we outline the scenarios, assumptions and methods used to calculate the amount per tonne of CO_2 sequestered each mechanism would need to pay and the financial resource to support each mechanism.

2.1 Scenarios

The European Commission' 2018 publication 'A Clean Planet for All' provides guidance on potential pathways to reach net zero emissions through three scenarios the 1.5 Tech, 1.5 Life and 1.5 Life-LB. Deliverable 8.1 concluded that these are the only scenarios available for in-depth analysis of Europe, excluding the 2020 impact assessment report. The scenarios do not predict what will happen in the future but provide three pathways for how net zero emissions in Europe could be reached by 2050. The EU Commission 2020 impact assessment concludes that in the EU the total negative emissions including the land-use change and forestry (LULUCF) sector and NETPs needs to be around 0.5 GtCO2/year by 2050, in order to enable climate neutrality [72].

Table 2 Amount Captured and Stored from 'A Clean Planet for All' – 2030 estimates and DACCS estimates are our own analysis

Amount Captured and Stored	1.5 Tech 2030 ($MtCO_2$)	1.5 Tech 2050 ($MtCO_2$)	1.5 Life 2030 ($MtCO_2$)	1.5 Life 2050 ($MtCO_2$)	1.5 Life-LB 2030 ($MtCO_2$)	1.5 Life-LB 2050 ($MtCO_2$)
BECCS	17.8	178	0.6	6	1.4	14
DACCS	6	60	3.7	37	3.9	39
Afforestation	128	160	160	200	160	200
Forest Management	160	200	208	260	232	290

Table 2 outlines the amount of CO_2 captured and stored in 2030 and 2050 by NETP type. The 'A Clean Planet for All' report does not provide estimates for the year 2030. 2030 values for BECCS and DACCS are assumed to be 10% of 2050 levels, the land sink is assumed to be 80% of 2050 levels to approximately match Europe's 2030 target. The CO_2 captured by DAC is utilised rather than geologically stored in the 1.5 Tech and Life scenarios. For the purposes of this analysis, we assume that 50 percent of CO_2 that is geologically stored through conventional point source CCS is instead captured by DACCS. Consistent with the 1.5 Tech and 1.5 Life we do not consider Biochar, Enhanced Weathering, Ocean Alkalinisation and Ocean Fertilisation, as no European modelling results are available.

In the 1.5 Life scenarios, most of the CO_2 stored underground is from fossil fuel origin and mainly captured in the industry sector. Only the 1.5 Tech scenario differs with biogenic carbon supplying the largest share of CO_2 stored in geological storage sites. The 1.5 Tech scenario requires a substantial amount of technological carbon removal to generate negative emissions (BECCS) to offset the residual emissions (in particular non-CO_2 emissions from agriculture) and reach GHG neutrality by 2050. This is contrary to the 1.5 Life and 1.5 Life-LB scenarios that reduce further non-CO2 emissions and relies on a larger land sink. The scale of removal from the land sink varies between the scenarios. In 1.5 Life scenarios, there are more dietary changes assumed, letting more land available for afforestation. This reduces the reliance on BECCS. In addition, in the 1.5 Tech scenario, more bioenergy is produced from lignocellulosic grass and short rotation coppice, and less forest land and non-productive grassland and shrub is available than in 1.5 Life scenario. The 1.5 Life-LB scenario aims to reach net zero with limitations on biomass demand increases. Thus, many assumptions impact the results, and one cannot directly conclude that increased use of BECCS would cause a trade-off with the enhancement of the land sink.

The ETS price estimate in each of the report's scenarios is €28/tonne in 2030 (significantly below the 2021 ETS price of ~€70/tonne) and €350/tonne in 2050. The EC's 'Fit for 55' package's updated estimate of €85/tonne in 2030 is used instead [73].

2.2 Costs

Providing cost estimates of various options for removing carbon from the atmosphere is challenging. Costs from the literature vary significantly, reflecting the heterogeneity in the methodologies used for their estimates. These large ranges of possible costs and uncertainties are unavoidable since most of the options for carbon removals are only at an exploratory stage and none of them are sufficiently mature for large deployment (except afforestation, reforestation and ecosystem restoration).

Table 3 Cost Estimates – 2030 and 2050 cost estimates are our own analysis

NETP	Year	Min (€/tCO_2)	Mean (€/tCO_2)	Max (€/tCO_2)
BECCS	2020	100	150	200
DACCS	2020	100	200	600
Afforestation	2020	7	25	50
Forest Management	2020	0.7	2.5	5
BECCS	2030	80	120	180
DACCS	2030	80	160	540
Afforestation	2030	6.3	20	45
Forest Management	2030	0.6	2	4.5
BECCS	2050	60	90	140
DACCS	2050	60	120	420
Afforestation	2050	4.9	15	35
Forest Management	2050	0.5	1.5	3.5

The cost estimates used in 1.5 Tech and 1.5 Life scenarios come from a comprehensive review of the current knowledge regarding NETP technologies are summarised in Table 3 [74]. According to this review, most of the NETP options could remove CO_2 from atmosphere at a cost below €200/tCO_2, in the long term and assuming a removal of the uncertainties surrounding the development and implementation of the technologies involved. The European Commission's 1.5 Tech and 1.5 Life scenarios use the same cost range assumptions as Table 3, although they do not disclose the actual cost assumption used or how costs evolve over time. We assume costs for all NETPs fall by 10 percent by 2030 and 30 percent by 2050 and use the mean cost estimate as our base case.

Each NETP option is a generalisation of a number of approaches which sequester CO_2 in a similar process, the differences in these approaches along with project characteristics create the large range in costs. Combustion BECCS, for example, can have higher costs than ethanol fermentation and cogeneration units [7]. Lower costs may be possible at plants with easy access to abundant biomass and short distances to storage sites.

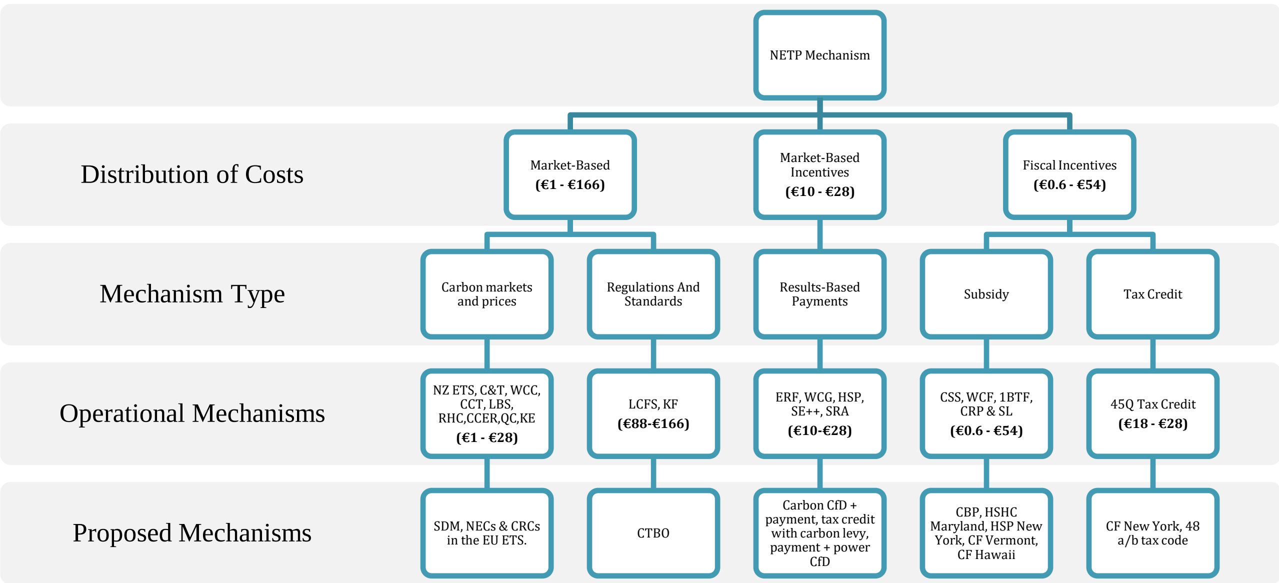
First-of a-kind plants for DACCS in Europe are likely to be more expensive than the costs assumed in Table 3, which reflect the expected average cost at scale. Climeworks' DAC plant in Switzerland is estimated to be operating at a cost of \$500/tCO_2-\$600/tCO_2 but Climeworks expects costs to fall to \$100/tCO_2 in ten years [75]. Solid sorbent approaches to DAC may be lower in cost in comparison to liquid solvent approach's, due to the difference in energy requirements for regeneration [75]. DAC plant operating costs will be influenced by the cost and source of energy they consume, emissions from energy supplied to the DAC plant would also need to be removed [7].

Afforestation cost estimates from the previously cited literature review are based on bottom-up estimates. The authors state no estimates from the Integrated Assessment Modelling (IAM) literature for 2100 were available but as more IAM estimates become available they expect upper cost estimates to move higher. The estimated lower bound cost globally was €2/tCO_2, we have opted to use the lower bound WCC price as our lowest estimate of £7/tCO_2 or €8/tCO_2 for Europe. Conserving forests as long-term sinks will still require management after the actual afforestation process, the literature review and EC report do not provide estimates for forest management costs. Assumptions from a forestry survey financial model, combined with the WCF minimum requirement of averaging two thousand trees per hectare, were used to calculate management costs instead [76]. Management costs are estimated to equate to nine percent of the costs of afforestation. This estimate is consistent with the assumed rate for Europe in the Global Timber Model with an initial cost of $1,068 per hectare and an annual cost of $93 per hectare [77]. It is not clear if weeding and replacing trees which have died are included in the latter estimate but are explicit in the former. As the land sink increases it is possible that only land with higher opportunity costs remain, increased costs of converting land could emerge. It is also possible that afforestation and particularly forest management costs rise as permanence is considered an increasingly important aspect of the commercialisation pathway for the NETP.

2.3 Categorisation of Mechanisms

A combination of carbon market, market-based incentives and subsidy mechanisms could be used to incentivise NETPs to a scale which could support Europe's net zero targets. In this section, each mechanism reviewed in section 1 is categorised by mechanism type to understand their suitability within the context of Europe's existing climate policy framework and potential impacts.

Figure 1 Categorisation of Mechanisms



Key: Countryside Stewardship Scheme (CSS), Woodland Carbon Fund (WCF), Woodland Carbon Code (WCC), Woodland Carbon Guarantee (WCG), Emissions Reductions Fund (ERF), One Billion Trees Fund (1BTF), Conservation Reserve Program (CRP), CDFA Healthy Soils Program (HSP), California Cap and Trade (C&T), New Zealand ETS, Sowing Life (SL), Low-Carbon Fuel Standard (LCFS), Label Bas Carbone (LBS), Registro de Huella de Carbono (RHC), Klik foundation (KF), Colombia's Carbon Tax (CCT), China CCER Certificates (CCER), Québec Cap-and-Trade System (QC), Kazakhstan ETS (KE), Sustainable Development Mechanism (SDM), Negative Emission Credits (NECs), Carbon Take Back Obligation (CTBO), Carbon Removal Credit (CRCs), Contract for Difference (CfD), Carbon Farming (CF), Swedish Reverse Auction (SRA).

Figure 1 generalises all of the mechanisms reviewed in section 1 into five mechanism type categories based on how costs are distributed between polluters (market-based) and governments (fiscal incentives). Mechanism types include: Carbon Markets and Prices, Regulations and Standards, Results-based Payments, Subsidy and Tax Credit. The payment range per tonne of CO_2 for each mechanism type is also included. Mechanism types may also need to ensure that cash flows from NETPs projects are predictable, consistent and have certainty to be more attractive to investors [78].

To develop NETPs to a scale aligned with reaching net zero by 2050, the EU and its member states may need to raise and disburse large sums of money through the mechanism types outlined above. Europe’s ETS, CAP and Innovation Fund are examples of large mechanisms operating today to achieve EU policy outcomes. The report's introduction outlined the subsidy-type schemes proposed in the EU forestry strategy as well as CAP reforms (including carbon farming) to expand the land sink in order to achieve a net zero European agriculture sector by 2035. National subsidy schemes are also possible, for example Germany announcing €800 million to assist in the replanting of over 440,000 acres of trees [79].

There is no operational mechanism or fund dedicated to the outcome of scaling up engineered removals in Europe. Integrating engineered removals (e.g., BECCS and DACCS) into the EU ETS is one proposed mechanism. From section 1.3, CRCs could be used as a way for operators of NETPs to earn revenue. To ensure a carbon balance one EUA would need to be equal to one CRC i.e., each tonne of CO_2 emitted would correspond to a tonne of CO_2 permanently removed. Applying a multiplier value on EUAs could be possible while the price of an EUA is below the cost of engineered removals. In the current EU ETS, facilities producing “grey” hydrogen by steam methane reforming or partial oxydation receive 6.84 EUA per tonne of hydrogen produced [66]. For illustrative purposes, using a multiplier of four EUAs (at €85/tCO_2) for each tonne of CO_2 permanently removed could make DACCS or BECCS commercially viable in 2030. The multiplier could be then be phased down to a one-to-one ratio once the cost of EUAs equals or is above the cost of engineered removals. Competitive distortions have been cited as the main concern of the multiplier approach [80]. It is also possible to implement temporary national-level mechanisms to account for the cost difference between ETS prices and engineered removals. CfDc’s, NECs,a CTBO or tax credits feature in section 1, as proposed mechanisms for Europe.

Alternatively, a 'European Removals Fund' could be established as a separate mechanism from the EU ETS. Funding for this mechanism could come from a variety of sources, including national governments, the fossil fuel industry, free allocations from the EU ETS or businesses which emit CO_2 through their activities. Similar to Sweden’s proposed reverse auction mechanism for BECCS, operators of NETPs could tender bids to the fund. One potential funding model would be that the fund is set a fixed number of allocated free allowances similar to the Innovation Fund in design. For each free allowance or EUA it receives it must permanently remove one ton of CO_2 using engineered NETPs. The difference in cost between the EUA and the cost of removal could be made up for from direct contributions from national governments or similar to a CTBO fossil fuel companies could be mandated to contribute the difference in the cost of removal to the fund. It is also possible for the fund to be independent of the EU ETS and entirely funded by national governments or fossil fuel companies. One distinct advantage of this mechanism is the fund is incentivised to accept bids from the best NETPs possible rather than purely the lowest cost NETPs, it can also build a durable portfolio of NETPs. The Norwegian NOx fund works on a similar principle. Enterprises joining the NOx Fund pay a lower fee per kg NOx to the Fund instead of paying the NOx tax to the state. Importantly, the Fund must ensure sufficient NOx reduction measures are implemented to meet the agreed reductions. If the reductions are not met, the tax is re-imposed [81]. It could be that oil and gas companies that contribute to the fund pay a smaller or no amount for CTBO credits.

Each mechanism type will have different impacts on energy costs, carbon intensive industries and fiscal revenues. Carbon markets and prices are designed to increase the costs of carbon intensive activities in a region to incentivise cleaner alternatives. It is important that the inclusion of NETPs does not distort that policy objective. Higher energy prices and cost of production for industry can be expected in carbon intensive systems. The proceeds raised by carbon markets and prices are generally allocated to government spending which can incentivise emissions reductions. The inclusion of removals in carbon markets can divert that revenue to operators of removals which reduces fiscal revenues. Regulations and standards place the obligation on the user or supplier of fossil fuels. Energy prices can increase as supplier pass the costs of NETPs on to consumers. The impact on carbon intensive industry depends on the proportion of additional costs that are passed on to consumers and the impacts on demand from cost increases. Direct fiscal impacts are unlikely, fuel prices may increase which could increase the tax revenues from fuels and fuel demand may fall which would reduce tax revenue.

Market-based and fiscal incentives can have varying degrees of impact on fiscal revenues. The use of tax revenues to support NETPs can reduce the resources available to support other policy objectives. It may also require an increase in taxes to support NETP mechanisms. Market-based incentives can have a lower impact as costs are split between the state and the market. Subsidies and tax credits can lead to governments supporting a higher proportion of the costs of NETPs relative to other mechanism types. Fiscal incentives are likely to have the lowest impact on energy prices and industry as it supports markets absorb the cost of removals, however it creates the biggest impact on fiscal revenues. Market-based incentives have a greater impact on profits and the competitiveness of carbon intensive industry, ensuring a level playing field with other carbon intensive industries globally could help mitigate those impacts and limit the impact on fiscal revenues.

2.4 Cost and Financial Resources by Mechanism Type

Payment per tonne of CO_2 for each mechanism type and their required financial resource are presented in tables 4 to 6 of this section, using assumptions from section 2.1, section 2.2 and mechanisms proposed in section 2.3.

Table 4 Cost and Financial Resources by Mechanism Type 1.5 Tech Scenario

Mechanism Type	NETP	Payment 2030 €/tCO_2	Payment 2050 €/tCO_2	Financial Resource 2030 (€Bln)	Financial Resource 2050 (€Bln)
Market-Based	BECCS	€85.0	€105.0	€1.5	€18.7
Market-Based	DACCS	€85.0	€140.0	€0.5	€8.4
Results-Based Payments	BECCS	€50.0	€0.0	€0.9	€0.0
Results-Based Payments	DACCS	€95.0	€0.0	€0.6	€0.0
Subsidy	Afforestation	€22.5	€17.5	€2.9	€2.8
Subsidy	Forest Management	€2.3	€1.8	€0.4	€0.4

Table 5 Cost and Financial Resources by Mechanism Type 1.5 Life Scenario

Mechanism Type	NETP	Payment 2030 €/tCO_2	Payment 2050 €/tCO_2	Financial Resource 2030 (€Bln)	Financial Resource 2050 (€Bln)
Market-Based	BECCS	€85.0	€105.0	€0.1	€0.6
Market-Based	DACCS	€85.0	€140.0	€0.3	€5.2
Results-Based Payments	BECCS	€50.0	€0.0	€0.03	€0.0
Results-Based Payments	DACCS	€95.0	€0.0	€0.4	€0.0
Subsidy	Afforestation	€22.5	€17.5	€3.6	€3.5
Subsidy	Forest Management	€2.3	€1.8	€0.5	€0.5

Table 6 Cost and Financial Resources by Mechanism Type 1.5 Life-LB Scenario

Mechanism Type	NETP	Payment 2030 €/tCO_2	Payment 2050 €/tCO_2	Financial Resource 2030 (€Bln)	Financial Resource 2050 (€Bln)
Market-Based	BECCS	€85.0	€105.0	€0.1	€1.5
Market-Based	DACCS	€85.0	€140.0	€0.3	€5.5
Results-Based Payments	BECCS	€50.0	€0.0	€0.07	€0.0
Results-Based Payments	DACCS	€95.0	€0.0	€0.4	€0.0
Subsidy	Afforestation	€22.5	€17.5	€3.6	€3.5
Subsidy	Forest Management	€2.3	€1.8	€0.5	€0.5

In Tables 4 to 6, the market-based mechanisms represent any of the variations of the ETS proposed in section 2.3. Results-based payments are determined by subtracting the difference between the cost of removal in Table 3 by the ETS price assumed in section 2.1. The ETS price is used as a proxy for what could be recoverable in the market-based mechanism in 2030 and 2050. Results-based mechanisms are expected to provide the additional monetary incentive required to develop BECCS and DACCS. Once the ETS price exceeds the cost of removal results-based payments are phased out and return a value of €0/tCO_2. The analysis in section 2.3 revealed that subsidy type mechanisms could be most common for afforestation and forest management practices. It is assumed that these subsidies cover the entire cost of removal.

In each of the three scenarios for 2030 the ETS price is assumed to be €85/tCO_2 with a top up results-based payment of €50/tCO_2 for BECCS and €95/tCO_2 for DACCS. Results-based payments for BECCS and DACCS are phased out by 2050 as the ETS price of €350/tCO_2 far exceeds the cost of removal for BECCS at €105/tCO_2 and DACCS at €140/tCO_2. In 2030, afforestation receives a €22.5/tCO_2 subsidy, while forest management receives a €2.3/tCO_2 subsidy, both of which decrease to €/17.5tCO_2 and €/1.8tCO_2 respectively by 2050. This subsidy could be administered through the CAP, a mechanism to support the forestry strategy or through national schemes. The appendix provides tables with min cost and max cost scenarios.

The financial resource required to support each mechanism will equate to the price per tonne of CO_2 removed multiplied by the aggregate amount of CO_2 the mechanism aims to capture and store. Table 4 to 6 present the financial resource required to support each NETP type by each mechanism type. Figures 2 to 7 illustrate the financial flows between governments and markets to NETPs showing the distribution of cost over time. The results show that over time, the market will provide the majority of financial flows for NETPs, while the government will provide less.

In 2030, mechanisms to scale NETPs could require financial resources of between €4.8 and €6.7 billion per annum. Governments are assumed to contribute between €3.3 and €4.1 billion per year to afforestation and forest management by 2030. Depending on the level of engineered removals, results-based payments range from €0.43 billion to €1.5 billion. In the 1.5 Tech scenario, the ETS or market-based mechanism contributes €2 billion, whereas in the 1.5 Life scenarios, it contributes €0.4 billion. BECCS and DACCS may both require financial resources of €2.4 and €1.1 billion respectively in the 1.5 Tech scenario, but because of its higher cost, DACCS may require more state support through results-based payment on a per ton of CO_2 basis. BECCS is utilised substantially less in the 1.5 Life scenarios, allowing DACCS to obtain money as the principal engineered removal.

In 2050, the financial resource required to support each mechanism could rise to €30 billion per annum in the 1.5 Tech scenario and between €9.8 and €10.9 billion in the 1.5 Life scenarios. The ETS price is expected to far exceed the cost of removal which spurs a phase out of results-based payments, setting their value to zero. Market-based mechanisms provide the majority of the financial resource, which ranges from €6 to €27 billion, while government support of afforestation, which ranges from €3.2 to €4 billion, is slightly lower due to cost reductions. In the 1.5 Tech scenario, BECCS (€18.7 billion) may require a larger financial resource than DACCS (€8.4 billion). The 1.5 Life scenario relies on DACCS, which might cost €5 billion per year.

Figure 2 Distribution of Financial Resources by Mechanism Type 1.5 Tech Scenario 2030

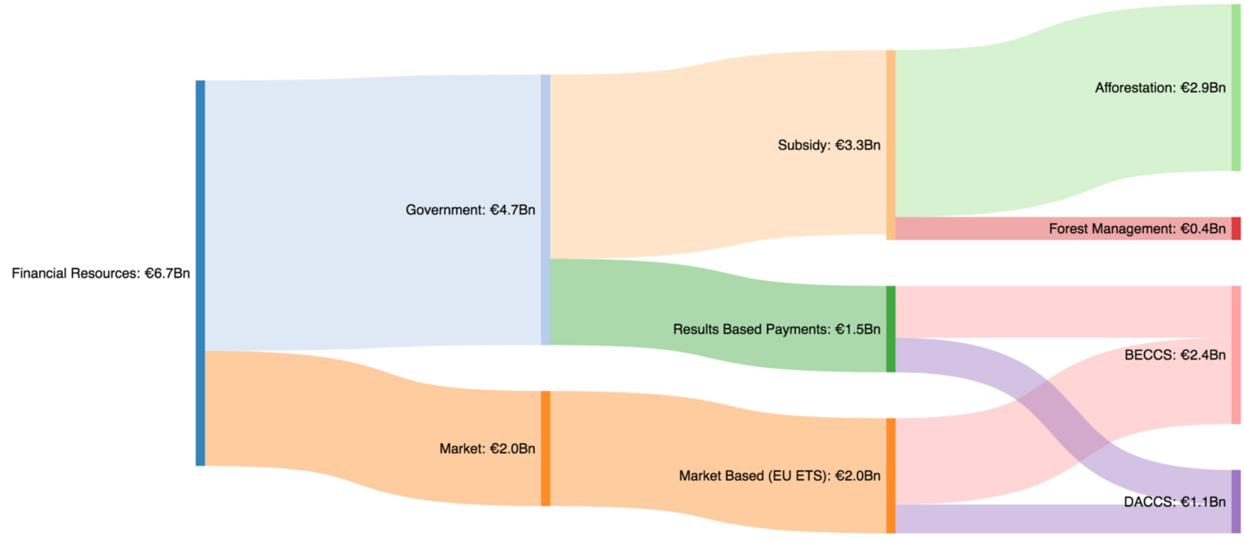


Figure 3 Distribution of Financial Resources by Mechanism Type 1.5 Tech Scenario 2050

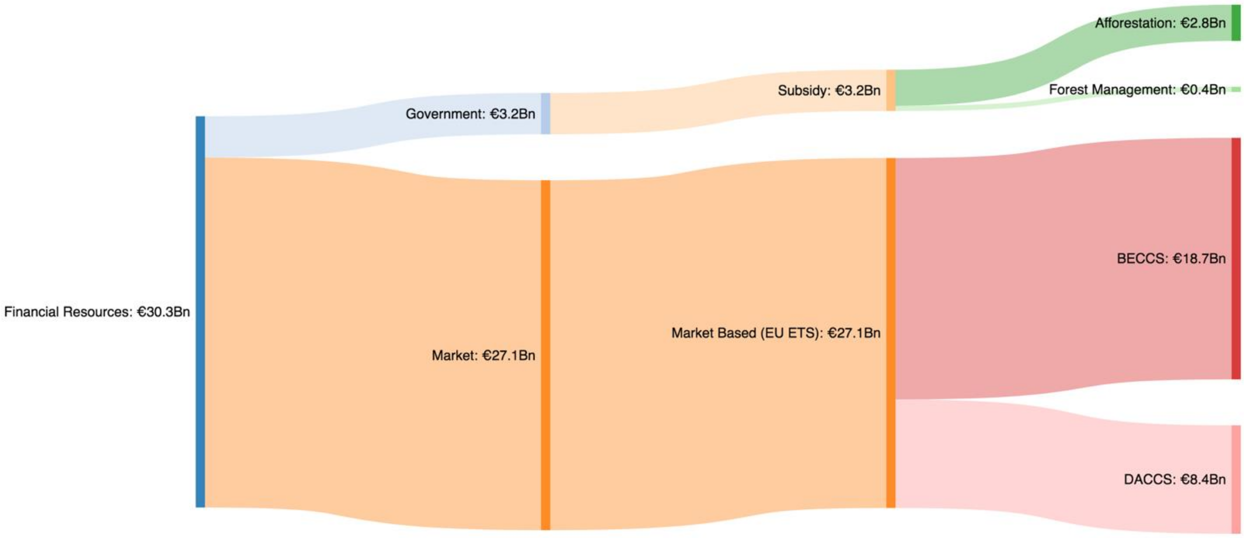


Figure 4 Distribution of Financial Resources by Mechanism Type 1.5 Life Scenario 2030

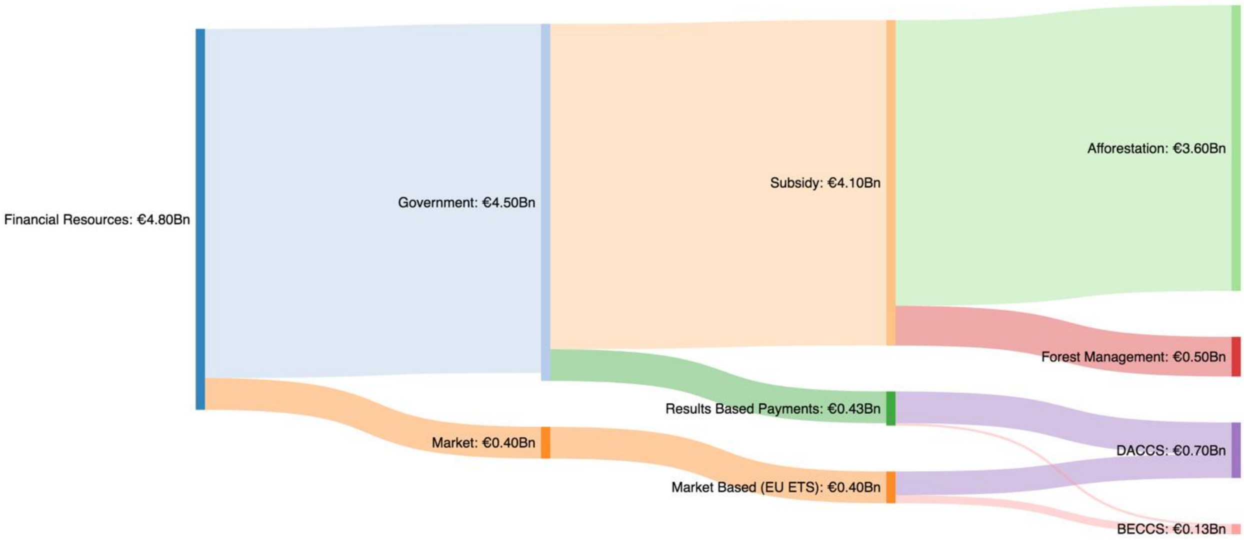


Figure 5 Distribution of Financial Resources by Mechanism Type 1.5 Life Scenario 2050

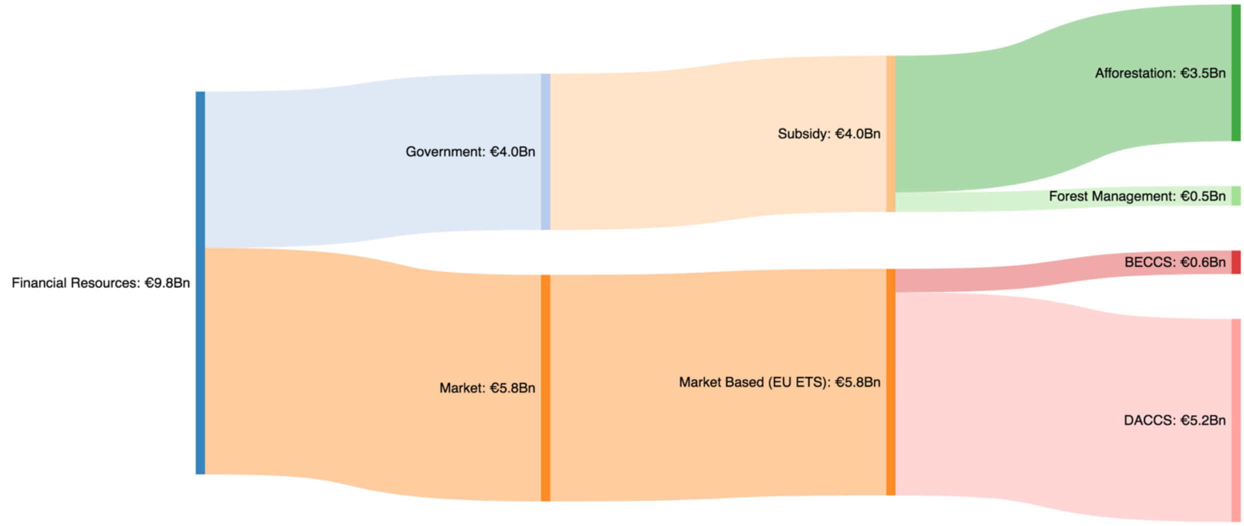


Figure 6 Distribution of Financial Resources by Mechanism Type 1.5 Life-LB Scenario 2030

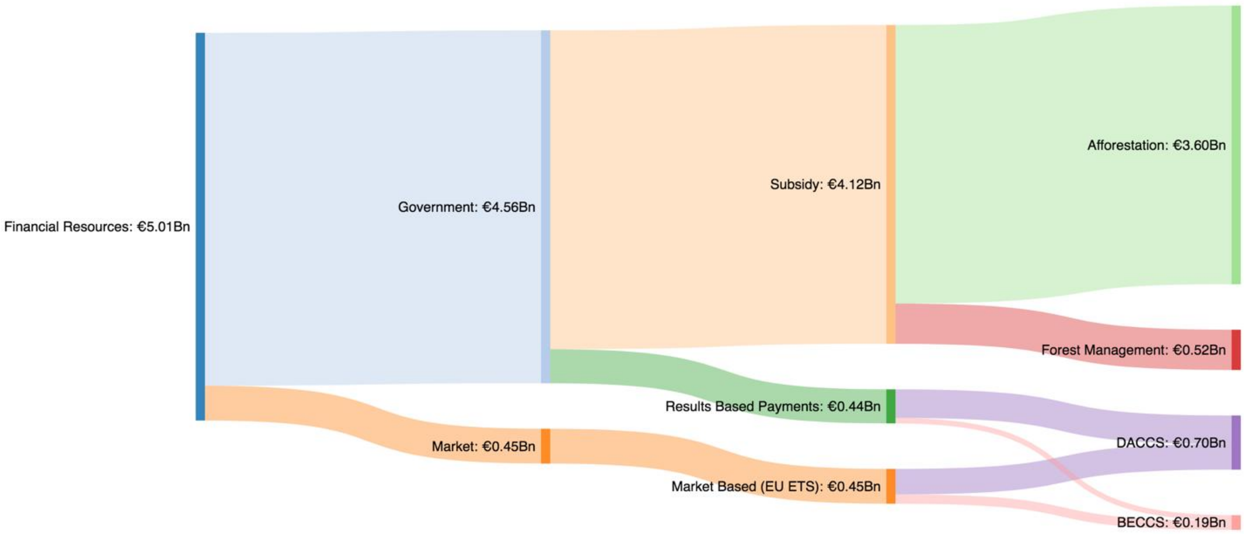
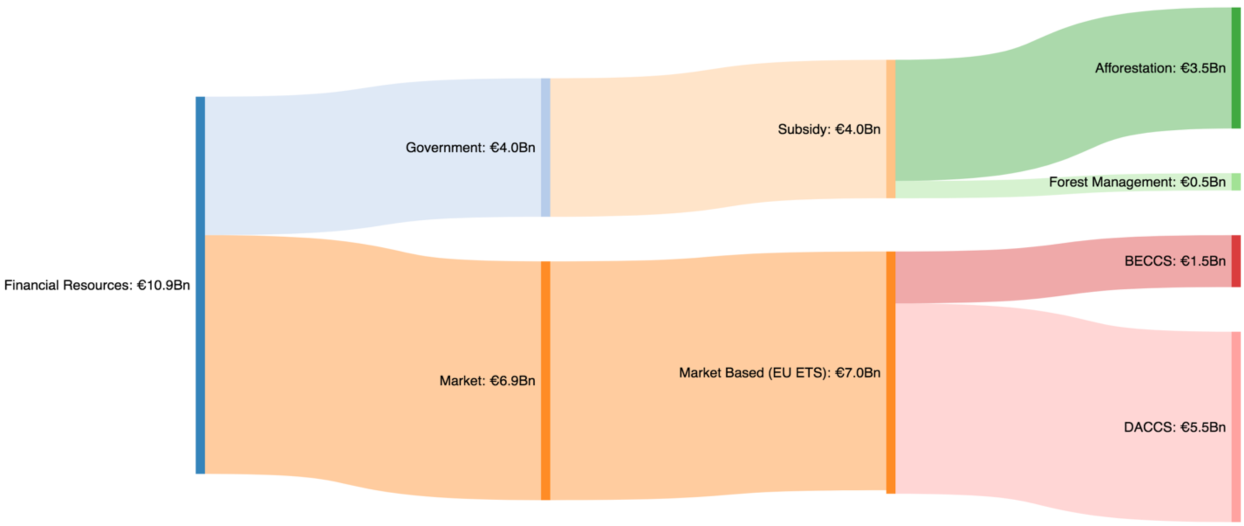


Figure 7 Distribution of Financial Resources by Mechanism Type 1.5 Life-LB Scenario 2050



Higher financial flows to BECCS in the 1.5 Tech scenario reflects biogenic carbon supplying the largest share of CO_2 stored in geological storage sites. The analysis of scenarios in section 2.1 indicates that BECCS is used to also offset non-CO2 emissions from agriculture by 2050, which may mean that its revenues aren't strictly from the hard-to-abate ETS sectors and subsidies could be lower. Non-CO_2 emissions are reduced further, from changing dietary needs, in the 1.5 Life and 1.5 Life-LB scenarios which creates less demand for removals. More land is also available for afforestation which increases the financial flows to subsidies. It isn't clear in the 1.5 Life scenarios if sufficient engineered removal capacity will be available to support the ETS sector, the land sink may not be available to issues CRCs due to issues of permanence, monitoring and verification.

A CTBO is another proposed mechanism which would create demand for NETPs in Europe and is expected to operate on a global scale. Jenkins et al. 2021 argue in their analysis that in the medium term a CTBO would be complemented with a carbon price, to support continued emission reductions [52]. Consistent with their analysis we assume a fraction of emissions are stored by 2030 and all emissions by 2050. It is possible that in 2030, oil and gas companies could contribute the cost of result-based payments rather governments. In this scenario, the incentive to reduce emissions remains for firms paying an ETS price but an increasing fraction of their emissions are stored by their suppliers. It also mitigates the impact on fiscal revenues as governments would no longer pay into the mechanism. The impact on industrial competitiveness could also be low because the costs of NETPs are spread across the supply chain. The total financial resource required in all scenarios would remain the same, however the proportion attributed to the market would increase to include the value of results-based payments. Under the CTBO, oil and gas companies could be entirely responsible for the cost of removal and hard-to-abate ETS sectors responsible for the cost of emissions reductions.

It is possible to use tax credits, instead of results-based payments, to make up the gap in income between the ETS price and cost of engineered removals. In the United States a combination of the California LCFS and 45Q tax credit are seen as complementary policies to incentivise engineered removals. A key issue of this approach is that it may not provide a high degree of certainty on returns relative to a CfD, returns would be mostly a function of the LCFS or carbon price. A higher level of uncertainty may not be acceptable to investors or they could increase the cost of capital to compensate, further increasing the cost of removal.

3 Conclusions

3.1 Conclusions

Mechanisms that support NETPs are an important part of scaling up the removal capacity required in the majority of net zero modelling scenarios. This report attempts to survey all current and proposed commercialisation mechanisms for NETPs globally. We estimate each mechanism's payment per tonne of CO_2 removed today and scale of removal, then categorise them based on how they distribute costs and risk between the public and private sectors. Each mechanism type is evaluated for its relevance to Europe, followed by a quantitative analysis of the financial resources required in terms of payment per tonne of CO_2 and total annual cost for suitable mechanisms. The results presented in this report are subject to the uncertainty inherent to the data and modelling assumptions used, which we attempted to showcase by using a number of scenarios based on different requirements of NETPs. It is possible that not all mechanisms that focus on afforestation, agricultural NETPs and conservation have been captured. Using web-based searches for mechanism is the source of this limitation, with mechanism details being published in languages outside of the search terms used.

The cost of NETPs generally exceeds the amount that is recoverable in today's markets. The majority of mechanisms currently in operation are under resourced and pay too little to enable a balanced portfolio of NETPs that could support hard-to-abate sectors move to net zero, according to the quantitative survey undertaken in this research. Mechanisms tend to promote established practices of afforestation and soil carbon sequestration and are not primarily motivated by CO_2 removal. Although carbon capture and storage (CCS) is covered in some schemes, the incentives they provide are inadequate to support BECCS and DACCS. Notably, outside of California, there are no current examples of a coordinated portfolio of mechanisms which attempt to achieve large-scale deployment of a high-quality portfolio of NETPs options. Existing mechanisms explicitly focused on carbon removal are geographically concentrated in the UK, USA (mostly California) and New Zealand.

Thereafter, all of the mechanisms were categorised by whether they were market-based or depended on fiscal incentives. We assumed that the cost of engineered removals could in some way be offset by the ETS price through a market-based mechanism, although we do not necessarily assume NETPs are integrated into the EU ETS. The land sink was assumed to be managed through a combination of carbon farming results-based payments, forestry strategy payments or a similar subsidy regime to calculate the financial resources required for each mechanism type. In 2030, mechanisms to scale NETPs could require financial resources of between €4.8 and €6.7 billion, which may rise to between €9.8 and €30 billion by 2050. Governments contribute the majority of financial resources in all scenarios in 2030, but the market surpasses them by 2050 due to the EU ETS price exceeding the cost of removals. By 2050 engineered removals make up the vast majority of financial resource requirements across scenarios. Payments to nature-based removals are expected to be reasonably consistent over time, as the land sink is expected to be at 80% of its potential by 2030, ensuring that agricultural emissions are offset to reach the sectors net zero target by 2035. The primary variables between scenarios and the level of financial resource include variations in non-CO2 emissions from agriculture, the availability of the land sink for carbon removal, and the restrictions of biomass demand additions.

3.2 Policy Relevant Findings

The analysis of this report concludes that mechanisms which incentivise the scale up of NETPs to match Europe's net zero target do not exist. Outside of Europe, mechanisms generally do not pay enough to incentivise investment in DACCS and BECCS but there are important lessons to be learned from their operation to date. It is worth noting that mechanisms from different regions may not match the risk preferences of European investors and capital markets [1]. It may be that European investors prefer greater certainty of returns over profit maximising, relative to their American counterparts e.g. Contract for Difference (CfD) versus tax credits.

The European Union raises and disburses large amounts of money to achieve certain outcomes. Europe's ETS and CAP are two well-established mechanisms, both of which have been proposed for reform in order to provide an EU-wide approach to carbon removal incentives [2–5]. The analysis in this report provides insights into how each mechanism could be reformed to incentivise a limited portfolio of NETPs, from full integration to parallel mechanisms. The ETS should continue to principally focus on emissions reductions, while the CAP should focus on its three core objectives: viable food production, sustainable natural resource management, and balanced territorial development. Although it is difficult to assess their integration into the European policy mix, mechanisms outside of the EU ETS and CAP have been proposed.

Between 2018 and 2020, Europe's ETS is estimated to have generated revenues of between €14 and €16 billion per year, with revenues predicted to rise to €100 billion by 2030 with the inclusion of new sectors and higher prices [82]. In these circumstances, the EU ETS could have the financial resources to support the required level of NETPs in some capacity. The Commission's proposal of the CAP 2021-27 budget, including an "economic recovery" envelope, amounts to €352 billion, with an expectation that 40% of the CAP budget will be climate-relevant [15]. Subsidies to reach the land sink target are estimated in this analysis to equal to below €4 billion per annum. It is possible that the CAP in combination with the forestry strategy could support land-based NETPs to ensure the agricultural sector reach's its 2035 net zero target.

In addition to price signals, NETPs will likely need results-based payments. A number of examples of results-based payment mechanisms are reviewed in this report. For Europe, the survey of proposed mechanisms found a carbon CfD to be the most commonly suggested mechanism for BECCS and subsidy type payments are more likely for land NETPs. The results in section 2 indicates that these mechanisms could be wound down once the EU ETS price exceeds the cost of removals.

3.3 Further Research

These results highlight both the importance and gap in mechanisms required to successfully scale NETPs to sufficient levels to reach Europe's net zero target. Further research could build on scenarios that consider a broader portfolio of NETPs, an uncertain carbon price and cost projections. This analysis considers a simplified integration of NETP mechanisms into established or proposed mechanisms that reduce emissions or manage land use change. It isn't clear if this is the best approach or if a more radical change could deliver stronger results, for example a CTBO approach or a CTBO ETS hybrid. More research could be done to overcome these limitations and look into the implications of more sophisticated mechanisms, as well as better understand how EU ETS or CAP reform for removals could be implemented. Further research could consider mechanisms for non-CO_2 NETPs and mechanism which can better capture the advantages and disadvantages of different NETPs.

For preparing this report, the following deliverable/s have been taken into consideration:

D#	Deliverable title	Lead Beneficiary	Type	Dissemination level	Due date (in MM)
8.1	Stocktaking of scenarios with negative emission technologies and practices - Documentation of the vision making process and initial NEGEM vision	VTT	Report	PU	18

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4 Appendix

4.1 Review Methods

To identify the literature linked to NETPs and commercialization mechanisms, a two-stage literature review was done. The first stage involved searching Google Scholar for key phrases in two categories: commercialisation mechanisms (‘commercialisation', ‘incentives', ‘policies', and ‘subsidies') and NETPs (‘negative emissions', ‘NETPs', ‘NETS', ‘greenhouse gas removal', ‘CDR', ‘CO2 removal', and ‘carbon dioxide removal'). The titles and abstracts of the returned publications were then reviewed to exclude those that were not connected to commercialisation mechanisms and NETPs. The second stage used ‘snowballing’ to identify further relevant publications which cited or were cited by the publications identified in the first stage in order to help address possible bias caused by the choice of key words [83]. Expert interviews were also conducted.

Table 7 Mechanism Assumption and Sources

Mechanism	Reported Total Funding	Reported Scale ($MtCO_2$)	Reported Scale Hectares	Reported Price ($/tCO_2$)	Reported Price Per Hectare	Estimated Scale ($MtCO_2$)	Estimated Price ($/tCO_2$)	Source
Countryside Stewardship Scheme (CSS)					£409/ha - £200/ha		£0.5 - £1	[17]
Woodland Carbon Fund (WCF)					£7,800/ha- £9,500/ha		£19.5 - £23.75	[18]
Woodland Carbon Code (WCC)		11.1		£7-£20				[84]
Woodland Carbon Guarantee (WCG)	£50 million			£17-£24		*2.94 - 2.08		[19]
Emissions Reductions Fund (ERF)		138		AU$15.99				[36]
One Billion Trees Fund (1BTF)					NZ$ 1,000/ha – NZ$ 4,000/ha		NZ$ 10-NZ$ 2.5	[25]
Conservation Reserve Program (CRP)	$1.795 billion	12.0 - 15.0			$82/acre			[23,24]
CDFA Healthy Soils Program (HSP)	$22 million	0.1						[85,86]
45Q tax credit		75		$35 -$50				[28]
California Cap and Trade (C&T)		80		$23				[87]
New Zealand ETS		9.1		NZ$ 30.83				[37]
Sowing Life (SL)	US$3.4 billion		1 million			400 - 600	US$ 5.7-US$ 8.5	[26]
Low-Carbon Fuel Standard (LCFS)		38 incl avoidance		$122-$190				[38,39]
Label Bas Carbone (LBS)								[41,42]
Registro de Huella de Carbono (RHC)		0.12		€25				[41,42]
Klik foundation (KF)		9.6		€88				[41,42]
Colombia’s Carbon Tax (CCT)		4		<$5				[41]
China CCER Certificates (CCER)		2.5		<$6				[44]

Québec Cap-and-Trade System		<$23	[47]
Kazakhstan's ETS		<$1.1	[46]
SDE++	2.5		[48]

The CSS, WCF and 1BTF operate on payments per hectare rather than per tonne of CO_2. Each mechanism discloses the amount they pay to participants of the scheme. The forestry commission estimate that a new native woodland can capture 300-400 tonnes of CO_2 equivalent per hectare by year 50. By year 100, it can capture 400-600 tonnes of CO_2 equivalent per hectare [84]. We use a central estimate of 400 tonnes of CO_2 equivalent per hectare in our analysis to calculate the value of the payment in per tonne of CO_2. Payments to the CSS are focused on managing existing land rather than tree planting, hence they are lower. The SL mechanism has a goal of achieving one million hectares of forests and a total budget of US$3.4 billion. We convert the hectarage value into tonnes of CO_2 and divide by the total budget. For WCG the scale is estimated by dividing the governments total budget of £50 million by the amount they expect to pay per tonne of CO_2. The CRP disclose that for an additional 4 million acres of land in the scheme 3 million tonnes of CO_2 are expected to be sequestered. From this we generate a rate of 0.75/tCO_2 per acre that is multiplied by CRPs average payment per acre of $82 to calculate the value of payments. For the HSP the price per tonne of CO_2 is not disclosed and the level of scale is reported as annual sequestration potential rather than the aggregate lifetime scale of each project. CCT, CCER, QC and KE do not report average prices paid for NETP type offsets so we assume the price is below the carbon price. All other prices and scale are in their reported amounts.

4.2 Cost Scenarios

Min-Cost Scenario

Table 8 Cost and Financial Resources by Mechanism Type 1.5 Tech Scenario

Mechanism Type	NETP	Payment 2030 €/tCO_2	Payment 2050 €/tCO_2	Financial Resource 2030 (€Bln)	Financial Resource 2050 (€Bln)
Market-Based	BECCS	€85.0	€70.0	€1.5	€12.5
Market-Based	DACCS	€85.0	€70.0	€0.5	€4.2
Results-Based Payments	BECCS	€5.0	€0.0	€0.1	€0.0
Results-Based Payments	DACCS	€5.0	€0.0	€0.0	€0.0
Subsidy	Afforestation	€6.3	€4.9	€0.8	€0.8
Subsidy	Forest Management	€0.6	€0.5	€0.1	€0.1

Table 9 Cost and Financial Resources by Mechanism Type 1.5 Life Scenario

Mechanism Type	NETP	Payment 2030 €/tCO_2	Payment 2050 €/tCO_2	Financial Resource 2030 (€Bln)	Financial Resource 2050 (€Bln)
Market-Based	BECCS	€85.0	€70.0	€0.1	€0.4
Market-Based	DACCS	€85.0	€70.0	€0.3	€2.6
Results-Based Payments	BECCS	€5.0	€0.0	€0.0	€0.0
Results-Based Payments	DACCS	€5.0	€0.0	€0.0	€0.0
Subsidy	Afforestation	€6.3	€4.9	€1.0	€1.0
Subsidy	Forest Management	€0.6	€0.5	€0.1	€0.1

Table 10 Cost and Financial Resources by Mechanism Type 1.5 Life-LB Scenario

Mechanism Type	NETP	Payment 2030 €/tCO_2	Payment 2050 €/tCO_2	Financial Resource 2030 (€Bln)	Financial Resource 2050 (€Bln)
Market-Based	BECCS	€85.0	€70.0	€0.1	€1.0
Market-Based	DACCS	€85.0	€70.0	€0.3	€2.7
Results-Based Payments	BECCS	€5.0	€0.0	€0.0	€0.0
Results-Based Payments	DACCS	€5.0	€0.0	€0.0	€0.0
Subsidy	Afforestation	€6.3	€4.9	€1.0	€1.0
Subsidy	Forest Management	€0.6	€0.5	€0.1	€0.1

Max-Cost Scenario

Table 11 Cost and Financial Resources by Mechanism Type 1.5 Tech Scenario

Mechanism Type	NETP	Payment 2030 €/tCO_2	Payment 2050 €/tCO_2	Financial Resource 2030 (€Bln)	Financial Resource 2050 (€Bln)
Market-Based	BECCS	€85.0	€140.0	€1.5	€24.9
Market-Based	DACCS	€85.0	€420.0	€0.5	€25.2
Results-Based Payments	BECCS	€95.0	€0.0	€1.7	€0.0
Results-Based Payments	DACCS	€455.0	€0.0	€2.7	€0.0
Subsidy	Afforestation	€45.0	€35.0	€5.8	€5.6
Subsidy	Forest Management	€4.5	€3.5	€0.7	€0.7

Table 12 Cost and Financial Resources by Mechanism Type 1.5 Life Scenario

Mechanism Type	NETP	Payment 2030 €/tCO_2	Payment 2050 €/tCO_2	Financial Resource 2030 (€Bln)	Financial Resource 2050 (€Bln)
Market-Based	BECCS	€85.0	€140.0	€0.1	€0.8
Market-Based	DACCS	€85.0	€420.0	€0.3	€15.5
Results-Based Payments	BECCS	€95.0	€0.0	€0.1	€0.0
Results-Based Payments	DACCS	€455.0	€0.0	€1.7	€0.0
Subsidy	Afforestation	€45.0	€35.0	€7.2	€7.0
Subsidy	Forest Management	€4.5	€3.5	€0.9	€0.9

Table 13 Cost and Financial Resources by Mechanism Type 1.5 Life-LB Scenario

Mechanism Type	NETP	Payment 2030 €/tCO_2	Payment 2050 €/tCO_2	Financial Resource 2030 (€Bln)	Financial Resource 2050 (€Bln)
Market-Based	BECCS	€85.0	€140.0	€0.1	€2.0
Market-Based	DACCS	€85.0	€420.0	€0.3	€16.4
Results-Based Payments	BECCS	€95.0	€0.0	€0.1	€0.0
Results-Based Payments	DACCS	€455.0	€0.0	€1.8	€0.0
Subsidy	Afforestation	€45.0	€35.0	€7.2	€7.0
Subsidy	Forest Management	€4.5	€3.5	€1.0	€1.0