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LETTER

So you want to build a BECCS plant: the patchwork policy context for bioelectricity with carbon capture and storage in Europe

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Abstract

Bioenergy and Carbon Capture and Storage (BECCS) could produce baseload electricity with reduced net emissionsor even negative emissions—net atmospheric drawdown of CO_2—through the permanent storage of captured biogenic CO_2, but large-scale deployment remains pending. BECCS is a complex system, combining large-scale biomass sourcing, energy production, and transport and storage of CO_2, each subject to a different selection of regulatory frameworks. A BECCS installation also has competing goals; (i) producing and selling energy in a financially viable manner, (ii) providing credible and efficient net removals while minimising other environmental impacts. Navigating these conflicting goals to realize sustainable and economically feasible development of BECCS plants, requires a coherent policy environment. This paper offers a stock-take of the current EU regulatory landscape encountered by potential BECCS facilities, providing recommendations to facilitate BECCS upscaling. Reviewing 19 policies relevant to (parts of) the BECCS system, including legislation in force and under development, non-binding communications and funding mechanisms, assessing whether these policies facilitate or hinder BECCS development. In doing so, we identified a lack of a standardised definition of negative emissions, as well as insufficient clarity on the approach to system boundaries selection to use in emission accounting, sustainability criteria and accounting of upstream emissions for biowastes and residues. Furthermore, clarity regarding the long-term valuation of different types of negative emissions is missing and with it, policies that can enable long-term price stability to allow increased costs of generation practices. We conclude that BECCS is subject to a complex regulatory landscape with limited internalisation of climate value. Financial considerations at plant level as well as competition for biomass have implications for reaching EU climate targets, including the proposed 2040 target of a net-zero power sector with 4–34 Mtpa of BECCS. High-ambition BECCS targets may not be realistic under current regulatory conditions and constrained biomass supply.

1. Introduction

In 2019, 34% of anthropogenic GHG emissions originated from the energy supply sector (IPCC 2023), with fossil fuels as the main energy source in most world regions (Altawell *et al* 2021). Decarbonising the power sector is a necessary component of limiting global warming to 1.5 °C (IPCC 2023) but remains an ongoing challenge due to high costs, market uncertainty, and intermittency of existing renewables (IEA 2021). Furthermore, to maintain a climate neutral society, any residual greenhouse gas emissions must be balanced by removals of greenhouse gases from the atmosphere. Both of these challenges—a decarbonized power sector and a net neutral society—are ambitions of the EU, as part of their 2050 climate neutrality strategy (European Commission 2018). One option to provide both renewable power and carbon dioxide removal (CDR) is bioelectricity with carbon capture and storage (BECCS), where biomass is combusted to generate electricity and the produced biogenic CO_2 is captured and permanently stored, resulting in net atmospheric drawdown of CO_2 (Alvarado Cummings *et al* forthcoming, IPCC 2018, Tanzer *et al* 2021).

BECCS can offer a range of benefits. It contributes to the goals of the climate-neutrality in 2050 in two ways; reducing emissions from power generation, and providing carbon removals to balance emissions in hard-to-abate sectors (Regulation 2021/1119). BECCS development aligns with EU renewable energy targets of a 42,5% share by 2030 (Directive 2018/2001) and with the goal of reducing air pollution and black carbon caused by combusting unabated fossil or biofuels (European Commission 2021). The EU has signalled its desire for a robust carbon dioxide removals sector (Regulations 2021/1119, 2024/1735, 2024/3012), including BECCS (European Commission 2024a, Regulation 2024/3012), mediated by market incentives for reducing point-source emissions (Directives 2003/87/EC, 2018/2001), CO_2 transport and storage (Regulation 2021/1119), removals (Regulation 2024/3012), and biomass use (European Commission (2021a), Directives 2003/87/EC). Indeed, as part of their proposed scenarios for a net-zero electricity sector, the European Commission envisions between 4–34 Mt of carbon dioxide removals (CDR) from bioenergy with carbon capture and storage per year by 2040[3], reaching 37–58 Mt/year by 2050 (European Commission 2024a).

However, large-scale BECCS systems combine the complexities of bulk biomass sourcing, energy production, CO_2 capture, and transport and storage of CO_2, and face a host of implementation challenges (IEA 2023). BECCS requires large quantities of biomass, and with land resources already strained by increasing demand for food, feed and fibre, as well as the need for greater areas of protected nature and increased forest carbon stocks via reducing fellings (EU's Biodiversity Strategy and Forest Strategy: European Commission 2020, European Commission 2021a), this could conflict with the LULUCF goal of increasing land sector net removals to −310 Mt CO_2eq/year by 2030 (Regulation 2018/841). Sustainable biomass sourcing therefore requires vigilant accounting practices to manage potential impacts on i.a. land availability, carbon stocks, biodiversity and water use (IPCC 2023), necessitating traceability and data availability on feedstock sourcing. Furthermore, the emphasis on high-value uses of biomass decreases biomass availability for bioenergy applications such as BECCS but stimulates the use of residues for energy purposes. Land and water protection requirements of the Nature Restoration Law (NRL) may also limit potential siting of CO_2 transport and storage. CO_2 transport and injection infrastructure to carry the captured CO_2—sometimes across country borders —for secure geologic storage is not yet available (Global CCS Institute 2024). Furthermore, determining whether net removals occur, carbon accounting requires clear and consistent guidelines to comprehensively account for GHG fluxes throughout the BECCS value chain (Quiggin 2021), which is at odds with the timebound and site-specific nature of facility and national greenhouse gas reporting (Tanzer *et al* 2022).

Carbon capture and storage can be applied to a multitude of bioenergy systems, including electricity, but also, e.g., municipal solid waste (MSW) incineration, combined heat and power for residential energy, high temperature heat for industry and production of (advanced) biofuels, collectively called BECCS or bioCCS. However, in this paper, we solely focus on BECCS consisting of bioelectricity with CCS. Bioelectricity in this paper is considered the industrial production of electricity from non-primary biomass.

Deployment of large-scale BECCS also drastically lags behind policy targets (Martin-Roberts *et al* 2021, Wang *et al* 2021). Both the use of biomass in the energy sector and carbon capture and storage (CCS[4]) have been complicated by regulatory uncertainty and inconsistent incentives (Fridahl *et al* 2020, Yeung *et al* 2024). Efforts to realise BECCS are seen in demonstration projects, e.g., by Drax in North Yorkshire (DRAX 2018, DRAX 2022), and Stockholm Exergi in Sweden (BECCS Stockholm 2024), as well as EU and national funding calls. In Denmark, the first round of the CCUS subsidy scheme, released in May 2023, granted funds to a project to capture 0.4 Mt of CO_2 per year at two biomass-fired power stations for dedicated storage (Ørsted 2023). However, large-scale CCS projects have a history of failure, including the majority of large-scale projects announced between 2000–2021 (Martin-Roberts *et al* 2021, Wang *et al* 2021). As a result, at the time of writing, globally, no bioelectricity plants capture CO_2. Only three power plants in the world use CCS, capturing 1.45 Mtpa of fossil CO_2, of which only 0.15 Mtpa is sent to dedicated storage (Global CCS Institute 2023). The EU

[3] To put this in perspective, 99.9% of current carbon dioxide removal activity are high-reversal-risk removals through pre-existing land-sector practices, for example, managed forestry (2 $GtCO_2$/yr). Only 0.1% (0.002 $GtCO_2$/yr) of carbon removal consists of novel, and potentially permanent, removal techniques such as BECCS (Smith *et al* 2024).

[4] Carbon capture and storage (CCS) is a process by which carbon dioxide (CO2) from industrial installations is separated before it is released into the atmosphere, then transported to a long-term storage location (IPCC, 2021).

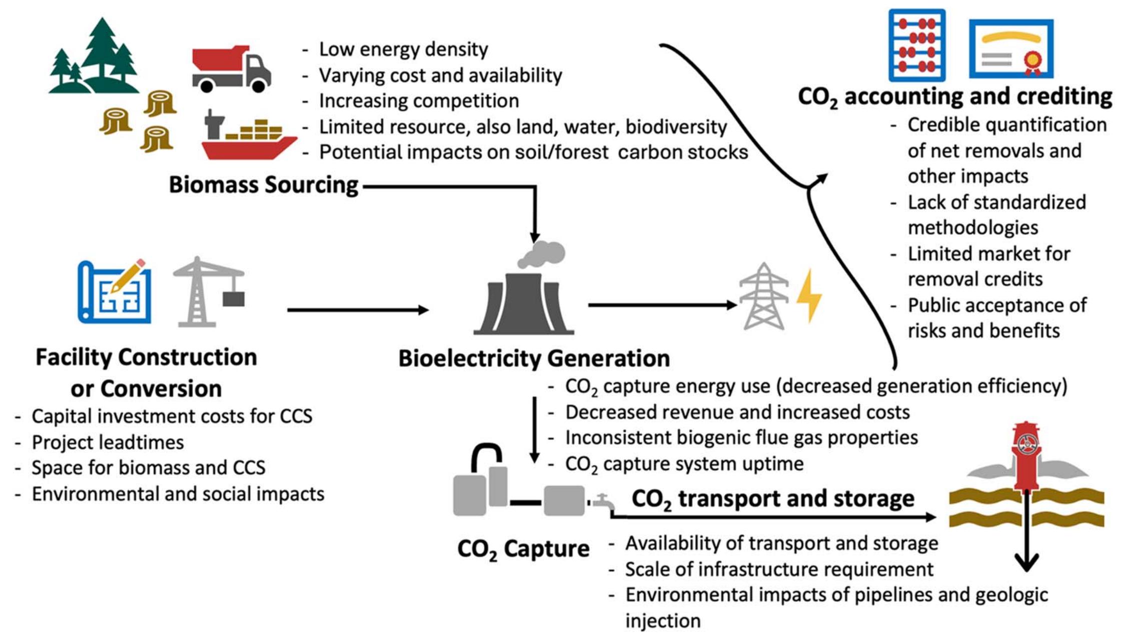

Figure 1. Key implementation challenges in BECCS systems.

BECCS projects currently under construction or in development represent a potential of 4.2 Mtpa of CO_2 captured by 2027 (Global CCS Institute 2023). Yet, if all existing solid biomass bioelectricity facilities in the EU, , were retrofitted with CCS, that alone could be enough to reach the amount of removals envisioned by the European Commission for 2040[5].

Few market incentives for businesses to engage with BECCS exist to outweigh the complexities, challenges and costs of BECCS (Torvanger 2019), particularly in the face of uncertain electricity market conditions (IEA 2023a). Achieving large-scale market-mediated BECCS in the EU within the next fifteen years crucially relies on a coherent policy environment to facilitate and incentivise sustainable and economically feasible construction and operation of BECSS plants. A comprehensive overview of the policy environment affecting BECCS in the EU currently does not exist. Therefore, this paper offers a stock-take of the current EU regulatory landscape encountered by potential BECCS facilities and provides recommendations to facilitate sustainable upscaling of BECCS.

2. The BECCS system

Large scale biomass sourcing, the production of bioelectricity and the capture, transport, and storage of CO_2 are all commercialised technologies. Coupling these components into a BECCS system creates the potential for high removal efficiencies (Chiquier *et al* 2022) with low-risk, monitorable, and permanent carbon storage (Tanzer *et al* 2022). However, each component of a BECCS system faces different implementation challenges and costs (figure 1). Adding further complexity, a BECCS installation has two competing goals. One, as a power market participant, a BECCS plant must produce and sell electricity in a financially viable manner. Two, as a climate change mitigation activity, BECCS must provide credible and efficient net removals while minimising other environmental impacts. In this chapter, we briefly evaluate the challenges (prospective) BECCS installations face while trying to balance these goals. In the following chapter, we assess how the current policy landscape facilitates or hinders these goals.

2.1. Maintain financial viability

Adding carbon capture to an existing or new-planned energy generation facility demands substantial upfront investment (Roussanaly *et al* 2021, Zetterberg *et al* 2021). Post-combustion capture, e.g., typically requires an absorption column to separate CO_2 from flue gas, a stripper and reboiler to separate captured CO_2 from the

[5] Assuming production of solid biomass bioelectricity in 2023 (87.6 TWh) operated at an efficiency of 36%, using biomass with an average energy content of 18 GJ/dry tonne and a carbon content of 50% dry matter, this would represent 89 Mtpa of combustion CO_2. Conservatively, if there are 20% losses during captured, transport, and storage, and a further 20% penalty of supply chain emissions, net removals could still exceed 50 Mtpa. However, the small size and geographic disparateness of many of these installations (IEA Bioenergy, n.d.) reduces the financial and logistic feasibility of converting all of them to BECCS.

solvent, as well as piping, storage tanks, pumps, and heat exchangers. Compressors to prepare CO_2 for transport, flue gas pre-treatment to reduce contaminants, and additional boilers, buildings, or land may also be required. Depending on the configuration, capital costs for CO_2 capture may increase total plant costs by 40%–90% (Rubin *et al* 2015). Capital expenditure and viability of investment is further influenced by administrative burden—e.g., permitting requirements, impact and risk assessments, legal disputes—which carry both direct costs for labour and processing, as well as indirect costs that can arise from delayed projects.

Carbon capture also increases operating costs, primarily via the energy demand of capturing CO_2, which for commercialised amine-based post combustion CO_2 capture ranges from 2–4 MJ kg^{-1} CO_2, reducing net generation efficiency by 5%–10% (Bui *et al* 2018). Reduced net generation, along with the operating and capital costs of CCS, leads to a cost of capture for power generation of 30–200 EUR/tonne CO_2 (IEA 2020, Danaci *et al* 2021, Kearns *et al* 2021, Zetterberg *et al* 2021, GCCSI 2025), increasing electricity generation costs by as much as 50% (ZEP 2011). Furthermore, while the combustion of biomass for heat and power is a fully commercialised technology (IEA Bioenergy n.d.), with the combustion of solid biomass satisfying 5% of European electricity demand in 2022 (88 TWh) (Eurostat 2024), converting facilities from fossil to biomass may also require altering or replacing fuel handling equipment, storage, and/or boilers, particularly for bio-feedstocks with high moisture contents (Livingston *et al* 2016). Biomass feedstock costs also typically exceed fossil fuel costs, with wood pellet prices reaching double those of coal at the end of 2023 (IEA 2024, Strauss 2024).

In addition, the permanent storage of captured CO_2 in geologic formations requires steep investments to develop suitable storage sites. Co-requisite infrastructure for transportation, injection, and monitoring has historically proven cost-prohibitive, despite hundreds of research initiatives and dozens of planned projects in previous investment cycles (May 2012, MIT n.d.). Currently, only one facility in Europe injects CO_2 to dedicated storage (Global CCS Institute 2023). And while Europe has abundant storage potential (625 Gt), it is not evenly distributed between countries (Anthonsen and Christensen 2021). A cost-optimised model by the JRC suggests that a European CO_2 transport and storage network for 250 Mtpa by 2050 would pass through over 20 countries and cost 9–23 billion Euros (Tumara *et al* 2024). Nevertheless, several European CO_2 transport and storage projects are underway, including the Porthos and Aramis projects in the Netherlands and the Longship and Northern Lights projects in Norway (Global CCS Institute 2023). BECCS providers may not invest in infrastructure projects directly, but will still subject to marginal offtake costs. Marginal costs of transport and storage are highly variable, dependent on flow rates, distances, and mode of transport, with cost estimates ranging from ⟨10 to ⟩100 EUR/tonne (ZEP 2011, Global CCS Institute 2021, Smith *et al* 2021). Current estimates for the Dutch projects range from 51–72 EUR/tonne (Vink 2023).

Therefore, to maintain financial viability, a (prospective) BECCS provider must offset additional costs of carbon capture and storage as well as the higher costs of biomass fuels.

2.2. Provide credible and sustainable net removals

Negative emissions from BECCS, or other CDR activities, are the amount of carbon extracted from the atmosphere and permanently stored less all greenhouse gases emitted in the process of extracting, processing, and storing the atmospheric carbon (Tanzer and Ramírez 2019) and it is these net removals that allow BECCS to contribute to climate change mitigation. Therefore, credible quantification of greenhouse gas flows in a BECCS systems is critical to ensuring that it achieves the intended climate benefit. Insufficient accounting practices can lead to over- or under-estimation of net emissions or removals (Tanzer and Ramírez 2019). However, there is currently no standardised methodology for accounting for—or defining—negative emissions. Variations in the system boundaries of approaches used for BECCS assessment across standards and studies introduce uncertainty and affect societal acceptance of BECCS (Fajardy *et al* 2021) and can impact how industries and organisations interpret and comply with the environmental requirements.

Even when net removals are credibly quantified, large-scale BECCS is still subject to a number of social and environmental risks. While the knowledge to safely inject and monitor CO_2 in geologic formations exists (IPCC 2005), concerns remain about the permanence of subsurface CO_2 storage, e.g., potential leaks caused by seismic activity (Smit *et al* 2014), underlying the necessity of thorough pre-development characterisation of storage sites. Alignment on CO_2 transport specifications is also crucial, such as standardised impurity allowances, to minimise the risk of pipeline corrosion (IPCC 2005, ISO 2024). Furthermore, increasing demand for biomass for electricity and other fossil fuel replacement applications may lead to adverse effects on biodiversity, ecosystem climate resilience, soils, and water, such as by increased production intensity or residue removal (Giuntoli 2022), and therefore requires vigilant sourcing. Growing biomass use in Europe has been accompanied by both increasing biomass imports as well as a growing discrepancy in the EU's wood balance, with reported biomass use exceeding reported biomass supply by 11% in 2017, up from 8% in 2009 (Cazzaniga *et al* 2021). These aspects may also influence public perception and support of negative emissions realized through BECCS, which is affected by concerns for biomass use trade-offs (Bellamy *et al* 2019, Ugarte-Lucas and Jacobsen 2024).

From the perspective of a (prospective) BECCS provider, the lack of standardized quantification guidelines and methodologies creates a barrier both to determining the magnitude of their potential contribution to climate change mitigation as well as how to identify and mitigate other environmental and social risks. Without credible quantification, there is also limited pathways to market recognition or societal acceptance of carbon removal via BECCS.

3. Regulation impact assessment

A BECCS plant faces substantial logistical and technological challenges, incurring increased costs and economic risk compared to a typical power plant. This section evaluates whether, and how, current EU policy addresses the hurdles to BECCS deployment identified above, while also balancing other policy goals. The policy files evaluated are listed in table 1 and are addressed per BECCS implementation component (figure 1); facility construction and conversion, biomass sourcing, bioelectricity generation with CO_2 capture, CO_2 transport and storage, and carbon accounting and crediting. The regulation comprising the Common Agricultural Policy, while relevant to the production of biomass, has been excluded as its specific coverage and incentive design are set by member states and therefore is not holistically treatable on the EU level.

3.1. Policy effects on facility construction and conversion

In the EU, average commissioning times for renewable energy have been increasing, due to growing project size, complexity and stricter regulatory requirements such as environmental assessment reporting and sustainability standards (Gumber *et al* 2024). In particular, the Environmental Impact Assessment (EIA, Directive 2011/92/EU) process required for large-scale (>300MW) projects includes an average of 18 procedural steps, including screening, scoping and public participation, reporting, expert validation, and post-project monitoring (Schumacher 2017). While these steps are necessary to reduce environmental risks, they are a major contributor to long permitting timelines, which increase costs and risk of project failure. In recognition of these negative impacts, multiple policy files (table 2) include mandates to reduce permitting timelines for renewable energy and 'net zero strategic projects', typically to within 18 months, including the Net Zero Industry Act (NZIA) (Regulation 2024/1735), the Renewable Energy Directive (RED) (Directives 2018/2001, 2023/2413), and the Commission Recommendation on Power Purchase Agreements (Recommendation 2022/822). The NZIA also mandates that member states expedite dispute resolution for projects identified as 'net zero strategic projects', in which they could choose to include BECCS, thus reducing impacts and costs associated with delayed project development.

To mitigate the financial risks of BECCS capital investments for early adopters, EU-level funds are available. The Innovation Fund, financed through ETS allowances, allocates €4 billion to decarbonization projects, including BECCS (European Commission n.d.-c), while Horizon Europe offers €15 million specifically for DACCS and BECCS innovation (European Commission 2024b). Furthermore, as a compromise between different sustainability goals, RED exempts BECCS from the mandated restrictions on funding for wood-based bioelectricity plants. It also recognizes the energy penalty required for CCS and allows BECCS with efficiencies below 36%, which is the requirement for non-abated bioelectricity generation above 100 MW (Directive 2018/2001).

3.2. Policy effects on biomass sourcing

Multiple EU regulations provide sustainability criteria for biomass sourcing relevant to BECCS, most notably the RED and the Regulation on Deforestation-free Products (EUDR, under development, Regulation 2023/1115), as seen in table 3. RED requires that bioenergy use must result in a minimum of 70% emissions savings compared to fossil energy (80% after 2030) to be counted as renewable energy and thus be eligible for accreditation and support reserved for renewables. It provides EU-wide guardrail criteria for biomass sustainability, restricting harvests of forest biomass in areas with significant carbon stocks and biodiversity, with guidelines for sustainable forest management practices, clear-cuts and deadwood extraction. It also emphasises a 'cascading' principle for biomass use, prioritising the use of higher-quality biomass for high-quality purposes and thus restricts the use of wood as bioenergy feedstock. The use of biomass for carbon dioxide removal purposes is currently not considered by the cascading ranking.

The EUDR is intended to further safeguard biomass sourcing against multiple environmental impacts by excluding feedstock from deforested areas, focusing on commodities with high deforestation risk (soybeans, beef, palm oil, wood, cocoa, coffee and rubber). Operators using covered commodities as feedstock must prove that the feedstock originates from land that has not been deforested or degraded after December 31, 2020,

Table 1. Policy files considered in this study and their goals.

Abbreviation	Name	Goal
Binding Legislation (in force unless otherwise noted)		
ECL	Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 ('European Climate Law')	Reduce EU contribution to climate change via a binding target for union-wide net climate neutrality where all remaining greenhouse gas emissions are compensated by removals.
RED	Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources ('Renewable Energy Directive', Directives 2018/2001, 2023/2413)	Reduce EU emissions via binding targets for renewable energy production and provides standardised criteria for carbon accounting of renewable energy provision, including biomass.
EUDR	Regulation (Eu) 2023/1115 Of The European Parliament And Of The Council of 31 May 2023 on the making available on the Union market and the export from the Union of certain commodities and products associated with deforestation and forest degradation and repealing Regulation (EU) No 995/2010 ('EU Deforestation Regulation', Regulation 2023/1115)	Guarantee that the products EU citizens consume do not contribute to deforestation or forest degradation worldwide.
NZIA	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. ('Net Zero Industry Act', Regulation 2024/1735)	Scale up the manufacturing of clean technologies in the EU.
CCSD	Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide and amending Council Directive 85/337/EEC, European Parliament and Council Directives 2000/60/EC, 2001/80/EC, 2004/35/EC, 2006/12/EC, 2008/1/EC and Regulation (EC) No 1013/2006 ('CCS Directive', Directive 2009/31/EC)	Ensure the safe geological storage of CO_2 with a framework for environmental impact assessment, long-term financing and liability.
ETS	Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a system for greenhouse gas emission allowance trading within the Union and amending Council Directive 96/61/EC ('Emission Trading Scheme', Directive 2003/87/EC and amendments)	Bring overall EU emissions down while generating revenues to finance the green transition and allowing market forces to determine where reductions occur.
LULUCF	Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU (Regulation 2018/841)	Enhance governance, promote transparency, and strengthen the link between climate mitigation and environmental protection measures.
CRCF (Provisional)	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 (Regulation 2024/3012)	Facilitate investment in innovative carbon removal technologies, as well as sustainable carbon farming solutions, while addressing greenwashing.
EIA	Directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment ('Environmental Impact Assessment Directive', Directive 2011/92/EU)	Guarantee environmental protection and transparency with regard to the decision-making process for several public and private projects.
GCD (Proposal)	Green Claims Directive—Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on substantiation and communication of explicit environmental claims (Green Claims Directive) (adopted proposal) (Directive 2023/0085)	Prevent companies from making misleading claims about environmental merits of their products and services.
NRL	Regulation (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration and amending Regulation (EU) 2022/869)	Implement effective area-based restoration measures.

Table 1. (Continued.)

Abbreviation	Name	Goal
POLL	Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial and livestock rearing emissions (integrated pollution prevention and control)	Prevent and control pollution arising from industrial activities.
Non-Binding Communications		
PPA	Commission Recommendation on speeding up permit-granting procedures for renewable energy projects and facilitating power purchase agreements (Recommendation 2022/822)	Speed up permit-granting procedures for renewable energy projects and facilitating power purchase agreements.
FORS	Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: New EU Forest Strategy For 2030 (European Commission 2021a)	Ensure resilient forest ecosystems and enable forests to deliver on their multifunctional role.
ZPC	Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: Pathway To A Healthy Planet For All EU Action Plan: 'Towards Zero Pollution For Air, Water And Soil' (European Commission 2021)	Monitor, report, prevent and remedy air, water, soil and consumer products pollution.
BIOS	Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions: EU Biodiversity Strategy For 2030 Bringing Nature Back Into Our Lives (European Commission 2020)	Tackle the main causes of biodiversity loss; land- and sea-use changes, the overexploitation of biological resources, climate change, pollution and invasive alien species.
Funding Mechanisms		
HEF	Horizon Europe (European Commission n.d.-b)	Promote scientific collaboration and generate new knowledge and technologies.
IF	Innovation Fund (European Commission n.d.-c)	Foster competitive market solutions to decarbonise European industry and support its transition to climate neutrality.
CEF	Connecting Europe Facility (European Commission n. d.-a)	Support the development of high performing, sustainable and efficiently interconnected trans-European networks in the fields of transport, energy and digital services.

tracing all biomass to individual plots. In particular, the EUDR is relevant to wood-based BECCS[6], with 71% of bioenergy in the EU based on forest biomass in 2021 (Bioenergy Europe 2023). The EUDR does not apply to most agricultural-residue based BECCS (e.g., sugarcane bagasse). Sustainability criteria for the sourcing of biomass, as outlined in the RED III and EUDR, are key tools to safeguard sustainability of BECCS supply chains. A key difference between the EUDR and RED methodology, is that RED allows for mass-balance approach to feedstock traceability, while the EUDR explicitly prohibits mixing of deforestation-free goods with goods of unknown origin or non-deforestation-free goods at any point in the supply-chain.

The EU provisional agreement on Carbon Removal Certification Framework (CRCF) will govern the generation of carbon removal and emission reduction certificates of various NETs, and mentions the need for sustainable sourcing of biomass, aligned to the RED, but also imposing additional sustainability criteria. On a territorial level, the EU Regulation on Land Use, Land-Use Change and Forestry (LULUCF) ensures that member states report greenhouse gas emissions and removals related to land use changes and forestry, setting binding net carbon removal targets for the land use sector, which limit the availability of biomass both on the level of preventing undue land use change and maintaining specific carbon stock levels. The LULUCF target, paired with the land protection mandate of the NRL, leads a tension with supplying sustainable biomass within the EU. It should be noted that while multiple policy files give attention to the sustainability of biomass supply chains, fossil fuel supply chains see no such restrictions.

3.3. Policy effects on bioelectricity generation with CO_2 capture

The operation of BECCS plants to produce power and removals is subject to a number of regulations that may influence operation costs (table 4), although none provide direct cost support. In particular, the NZIA aims to

[6] Wood residues such as sawdust and wood chips are also subject to the EUDR.

address barriers to scaling up negative emission technologies within the EU by creating market access and conditions conducive to attracting investment, potentially leading to increased purchase agreements. However, corresponding incentives for BECCS provision are missing from the Emission Trading Scheme (ETS), which currently regulates only fossil CO_2 emissions (and excludes removals). As a result, the ETS motivates a shift to full-biomass power plants but provides no incentive to capture biogenic emissions. The CRCF does mandate the European Commission to investigate the integration of CRCF removal credits into the ETS in 2026, which may lead to indirect inclusion of BECCS into the trading system.

Some EU funds are available to support the production of negative emission power, including the Innovation Fund and Horizon Europe, whose investment can support the construction of early-adopter BECCS plant and speed technological learning, which could reduce future operating costs. However, these funds themselves do not provide support or value for the cost of capturing and storing biogenic CO_2. Motivated by EU targets, member states have also set up support schemes for bioenergy (Wu and Pfenninger 2023) and for BECCS in the case of Denmark (Danish Energy Agency 2024), though national schemes are outside of the scope of this paper.

3.4. Policy effects on CO_2 transport and storage

Projects developing CO_2 transport and storage are subject to the CCS Directive (table 5), which mandates that CO_2 transport and storage installations are subject to the EIA and ETS regulations. The extensive characterization and permitting process creates long project timelines, requiring detailed geological data and pre-construction investments to ensure safe and reliable injection and storage are possible. Moreover, the need for bilateral agreements for transboundary transportation of CO_2 (as established by the London Protocol) complicates regulatory alignment and can extend the timelines further (Lockwood and Bertels 2022), although several bilateral agreements are already in place (Global CCS Institute 2023a). The CCS Directive emphasises the importance of minimising the introduction of additional chemical substances into CO_2 flows to mitigate risks of corrosion and contamination, ensuring the integrity of transport chains and storage sites (Directive 2009/31/EC). The rigorous risk reduction requirements of the CCSD makes the CO_2 storage development target set by the NZIA at 50 Mt year^{-1} in 2030 and 300 Mt year^{-1} by 2050 (Regulation 2024/1735) ambitious, highlighting the need for a centralised infrastructure for CO_2 transportation that is open and non-discriminatory, enabling efficient and reliable movement of CO_2 to geological formations.

In alignment with this, CCS projects have been recognized as a Project of Common Interest (PCI) within the EU (Regulation 2022/869), allowing them access to funding via the Connecting Europe Facility (CEF) fund (European Commission n.d.-a). An expansion of PCI CCS could allow Europe's cross-border CO_2 networks to materialise, addressing the 'chicken-and-egg' problem of matching CO_2 captured rates with storage availability, though BECCS operators will compete will fossil CO_2 sources for transport and storage bandwidth. Additional funding tracks for CCS for development projects exists within the Innovation Fund and Horizon Europe, including an HEF call specifically targeting BECCS systems.

3.5. Policy effects on carbon accounting and carbon removal credits

Carbon accounting in the REDIII, CRCF, and the LULUCF regulations all take different approaches for measuring removals as they occur in a BECCS system. The LULUCF is concerned with annual fluxes of carbon in the EU region, with a current target for carbon uptake of biomass to exceed biomass harvests by 2030, as defined by the national reference levels. The LULUCF does define removal, but in the context of the land sector, as uptake of carbon by sinks (i.e., forest, soils). In contrast, the RED methodology is focused on estimating emission reduction of specific use cases of biomass compared to a fossil benchmark, and requires the consideration of life cycle emission savings, including both reductions, increased land-based carbon storage, and permanent removals on equal footing, with waste biomass assumed to be 'burden-free' until the point of collection, to allow actors to receive financial support or other benefits of being considered 'renewable'. The CRCF similarly considers project-based lifecycle emissions but focuses on net removal, not reduction from a baseline, with the goal of commodifying the quantification itself into 'removal credits', further divided 'between permanent removals, carbon farming, and carbon stored in products. No use case for the credits is provided by the CRCF (table 6). The CRCF also mandates that the carbon removal operator, to whom the removal credits are assigned, is liable for monitoring and rectifying any reversals of the removal, such as via the leakage of stored CO_2. However, this is potentially contradictory with the CCS directive, which assigns this liability to the CO_2 storage operators.

None of these accounting mechanisms provides BECCS operators with remuneration for the net removals they produce alongside their generated electricity. Currently, this is available only via the unregulated voluntary carbon market, where consumers and companies purchase credits for emission avoidance, reduction, and removals that are typically used to 'offset' their greenhouse gas emissions, leading to criticism of greenwashing

Table 2. Impact of EU policies on BECCS facility construction and conversion relative to other bioenergy installations, other renewable energy providers, and large scale industry and infrastructure construction.

Policy	Content	Impact on BECCS operator	Contribution to other policy goals
EIA	Requires that an environmental impact assessment is carried out for large construction projects .	**Burdens proportionate to other large-scale industry and infrastructure construction projects**. Creates administrative burden and increases permitting time.	Protects environment and human health.
NZIA 15.3; NRL 6.1	Projects of 'overriding public interest', including 'Net zero strategic projects' can be exempted from the requirement that no less damaging alternatives are available.	**Favors renewable energy providers including BECCS**, if member states deem a BECCS plant to be a 'net zero strategic project'.	Prioritises energy transition over the protection and restoration of nature.
NZIA 6.1, 6.4	Mandates member states to decrease lead time of permitting for renewable energy projects, electronic submission of application (6.4), and single point of contact (6.1).	**Favors renewable energy providers, including BECCS**. Reduces administrative burden.	Prioritises deployment of renewable energy to increase.
RED 15.1	Mandates member states to streamline administrative procedures, rules, and charges for renewable energy plants and distribution networks, and the producers of biobased and non-biobased renewable fuels.	**Favors renewable energy providers, including BECCS**. Reduces administrative burden.	Prioritises deployment of renewable energy.
RED (3d(b)	BECCS is exempted from requirements of minimum generation efficiency and of a ban on wood use in bioenergy otherwise required to receive cost support.	**Favors BECCS**, above other bioenergy installations. Note that as the energy demand of CCS reduces a plant's net power output, the same generation efficiency standard would have disproportionately burdened BECCS.	
IF, HEF	Funding calls to support research and development projects that cover parts of the BECCS chain (IF: CCS, Renewable Energy) or are potentially BECCS specific (HEF: BECCS/DACCS, HORIZON-CL5-2024-D3-02-12).	**Favors funding priorities, including BECCS**. Provides a limited amount of dedicated funding that can speed technological learning and establish early commercialisation of BECCS technology.	Speed technological research and innovation to meet policy goals such as the clean energy transition.

(Streck 2021). However, the proposed Green Claims Directive is designed to combat greenwashing. The proposed regulation mandates careful substantiation of any net-zero targets or carbon neutrality claims, including clear differentiation between offsets and emissions reductions and requires detailed information about their reliance on specific processes. Furthermore, the proposed Green Claims Directive introduces legal obligations and potential penalties for non-compliance. While the directive aims to protect consumers, it may inadvertently hinder investment in and marketing of carbon removal technologies such as BECCS if they remain reliant on the VCM for recouping the costs of generating net removals.

No government procurement scheme for removal credits certified by the CRCF exists, though European Commission mandate to investigate the integration of CRCF credits into the ETS could lead to an ETS-internal offset mechanism as available allowances decrease. Direct or indirect integration of negative emissions (from BECCS) into a compulsory carbon market, or public procurement of standardised removal credits to reach national net emission targets, could provide more stable financial prospects to BECCS providers. However, this may risk reduced efforts in emission reductions (McLaren *et al* 2019), if removals are allowed to be fungible with emission reduction, particularly if non-permanent removal credits are also integrated.

4. Discussion

Reducing atmospheric concentration of greenhouse gases, and environmental sustainability more broadly, is a public good and will not be provided by an unregulated market. Just as government intervention is necessary to internalise the costs of negative externalities into market actors' balance sheets (e.g., via bans of harmful substances, carbon taxation, and the polluter-pays-principle), market provision of public goods, such as

Table 3. Impact of EU policies on biomass sourcing for BECCS.

Policy	Content	Impact on BECCS operator	Contribution to other policy goals
RED 30.4	Allows the use of third-party certification schemes for demonstrating compliance with greenhouse gas savings and other sustainability requirements.	**Favors bioenergy producers, including BECCS**, by reducing administrative burden of biomass user by allowing outsourcing of compliance checks.	Ensuring domestic and imported biomass meets minimum sustainability criteria.
RED	Life cycle emissions of biogenic wastes are zero-rated prior to collection.	**Favors waste biomass users, including BECCS**, by reducing administrative burden of data collection and impact allocation.	
RED 29.3-5	Prohibits the use of agricultural biomass from land with high biodiversity value or high carbon stock, or peatlands for bioenergy purposes.	**Burdens bioenergy producers, including BEECS**, by reducing available sources of biomass for bioenergy.	Supports the preservation of biodiverse ecosystems and land-based carbon stocks.
RED 29.6	Requires that internationally sourced forest biomass follows sustainable forestry practices, evidenced by local governance structures or project-based risk assessment.	**Burdens bioenergy producers, including BECCS**, by reducing accessible sources of biomass for bioenergy.	Supports the resilience and multi-functionality of forest ecosystems globally
RED 29.7	Requires that internationally sourced forest biomass comes from countries party to the Paris Agreement and whose LULUCF net emissions are neutral or negative.	**Burdens bioenergy producers, including BECCS**, by reducing accessible sources of biomass for bioenergy.	Supports the resilience and multi-functionality of forest ecosystems globally
EUDR	Requires that biomass suppliers demonstrate that relevant biomass products (including wood) comply with anti-deforestation criteria via documentation, analysis, risk assessment, risk mitigation procedures.	**Burdens wood and other relevant biomass importers, including BECCS**, by increasing administrative burden for biomass suppliers and importing buyers, and potentially reducing accessible sources of biomass.	Supports the resilience and multi-functionality of forest ecosystems globally
CRCF 8.3	Requires that CDR certification methodologies promote ecosystem biodiversity, contribute to food security, and avoid land speculation and unsustainable use of biomass.	**Burdens removal options, including BECCS**, but beyond biomass use covered by the RED as it exceeds RED requirements.	Supports the preservation of biodiverse ecosystems, land-based carbon stocks, and reliable food supply
NRL	Mandates the protection of 20% of European land area and ecosystems.	**Burdens other biomass users, including BECCS**, by reducing accessible sources of biomass.	Supports the preservation of biodiverse ecosystems and land-based carbon stocks.

removals, requires the internalisation of that value for market actors. Market-based climate policy therefore has two primary levers to adjust the price, and thereby the supply and demand, of market-provided goods and services. One, discouraging harmful activities via the internalisation of climate costs, e.g., taxation, takeback requirements, and public reporting requirements. Two, encouraging beneficial activities, via the internalisation of climate value via, e.g., subsidies, price support, purchasing agreements, or tradable credits for impact reduction. Therefore, to effectively provide the public good of CDR, policy to regulate climate mitigation technologies must also provide clarity on definitions, accounting methods, and sustainability safeguarding (Sudana 2016). Climate policy can also shape markets by mandating behaviour via bans and standards or by increasing or decreasing barriers to market participation (e.g., permitting processes, providing information, standardized definitions). Our review provides a stock-take of the EU policy environment, highlighting barriers and facilitating factors to BECCS development.

Our policy review shows that no EU policy currently in force addresses the costs and values of BECCS in a holistic manner. However, several existing policies do impact BECCS system components, e.g., infrastructure development, biomass sourcing, electricity generation, and CO_2 transport and storage, and removals accounting. While some policies create enabling conditions for BECCS projects, via decreasing permitting timelines and providing financial support for capital costs of BECCS projects, including CO_2 transport and storage infrastructure, these are typically part of larger efforts to accelerate renewable energy and carbon management initiatives. In a rare instance of direct acknowledgement of BECCS value, the RED exempts BECCS plants from requirements for electricity efficiency and biomass types, required of other bioelectricity plants, to receive member state funding. Otherwise, limited options for internalisation of the climate value of BECCS exist. The ETS incentivises the use of sustainable biomass via zero-rating their biogenic emissions, but the climate

Table 4. Impact of EU policies on bioelectricity generation with CO_2 capture relative to other bioelectricity and bioenergy providers and fossil-fuel generation.

Policy	Content	Impact on BECCS operator	Contribution to other policy goals
ETS Annex 4	Biogenic CO_2 emissions are considered 'zero-rated' if they result from the combustion of biomass meeting the RED III sustainability guidelines.	**Burdens BECCS** by recognizing no value for capture of biogenic CO_2. RED-compliant bioenergy production is favored over fossil-fuel generation by their exemption from emission allowances.	Supports the reduction of fossil fuel combustion.
RED 29.10	Sets minimum life cycle greenhouse gas savings criteria for bioelectricity production (70% compared to fossil baseline, increasing to 80% in 2030).	**Favors BECCS over other bioelectricity installations**, as CO_2 captured and stored is included as a form of emissions savings in the RED emissions saving methodology.	Supports the cascading use of biomass by setting high standards for biomass use for electricity.
RED 3c(a); FORS 2.2	Financial support is not available for bioenergy produced from 'the use of saw logs, veneer logs, industrial grade roundwood, stumps'.	**Burdens forest biomass users, including BECCS**, by discouraging use of high-grade forest biomass.	Supports the cascading use of biomass and the preservation of forest carbon
RED 3d(b)	BECCS is exempted from requirements of minimum generation efficiency (36%) and of a ban on wood use in bioenergy otherwise required to receive cost support.	**Favors BECCS**, above other bioenergy installations. Note that as the energy demand of CCS reduces a plant's net power output, the same generation efficiency standard would have disproportionately burdened BECCS.	
RED 15.8	Member states are instructed to remove 'unjustified barriers' to and promote 'long-term renewable energy purchase agreements.	**Favors renewable energy providers, including BECCS**, by encouraging stable uptake of renewable energy.	Prioritizes deployment of renewable energy.
NZIA 26.7	Increased sustainability criteria for >30% (>6 GW) of electricity auctioned by each member state.	**Favors renewable energy providers, including BECCS**, by encouraging stable uptake of renewable energy.	Prioritizes deployment of renewable energy.
POLL Annex V	Provides emission limits for NO_X and SO_2 generated during stationary fuel combustion.	**Burdens bioenergy combustion installations, including BECCS**, but setting stricter limits for biomass than for peat, lignite, or coal for certain installation sizes	Protects environment and human health
IF, HEF	Funding calls to support research and development projects that include CCS (IF: renewable energy CCS, HEF: BECCS/DACCS call, HORIZON-CL5-2024-D3-02-12).	**Favors funding priorities, including BECCS**. Provides a limited amount of dedicated funding that can speed technological learning and increase availability of CO_2 transport and storage.	

change mitigation value of capturing biogenic CO_2 is currently unacknowledged. And while free allowances are no longer issued to the power sector, the value of emission reduction, such as via zero-rated biomass, as long as free allowances continue to distort ETS emission pricing. This leaves the valuation of net removals to the voluntary carbon market, which has variable standards for carbon credit quality, a fact recognized by the proposed Green Claims Directive, which may have the effect of tempering both greenwashing and demand for credible removals. The development of methodological standards for removals, including BECCS, as part of the CRCF, has the potential to provide clearer guidelines on how to define and account for net removals. However, the CRCF is a voluntary framework whose crediting protocols do not have a designated purpose and therefore does not provide a BECCS operator with remuneration for any certified credits.

Integration of negative emissions into the ETS, an option that the CRCF mandates the European Commission to explore, if focused on a limited quantity of secure (i.e., geologically stored) removals, may provide necessary financial recognition for the climate value of removals, but if poorly implemented, could lead to diminished emission reductions (Anderson and Peters 2016, Edenhofer *et al* 2023). To combat this, separate targets should be maintained for emission reductions, non-permanent carbon sequestration (e.g., through afforestation) and permanent negative emissions, to account for their different climate effects and implanting conditions, as has been proposed by Allen *et al* (2025), Koponen *et al* (2024) and Lamb *et al* (2024).

More notable hindering conditions for BECCS are those caused by uncertainties in the existing policy landscape. Ratcheting strictness of biomass sustainability requirements temper environmental risks from increasing biomass demand but may create barriers to the ambitious BECCS deployment envisioned by the

Table 5. Impact of EU policies on CO_2 transport and storage for BECCS.

Policy	Content	Impact on BECCS operator	Contribution to other policy goals
NZIA 20.1	Mandates the development of 50 Mt/year of CO_2 injection capacity by 2050	**Favors point source CO_2 operators, including BECCS**, by promoting the availability of CO2 storage.	Supports the reduction of fossil fuel emissions. Supports the continuation of carbon-based industry.
EIA	Requires that an environmental impact assessment is carried out for large construction projects, including CO_2 transport and storage	**Burdens industrial actors, including BECCS**. Creates administrative burden and increases permitting time.	Protects environment and human health
CCSD 20	Requires CCS storage operators to provide long-term financial contribution to site monitoring	**Burdens industrial actors, including BECCS**, by increasing cost of CO_2 transport and storage.	Protects environment and human health
CCSD 13, 16	Assigns liability for monitoring and leakage to the CO_2 transport and storage operator	**Burdens industrial actors, including BECCS**, by increasing costs of CO_2 transport and storage.	Protects environment and human health
CEF	Cross-border CO_2 transport projects are eligible for funding as 'Projects of Common Interest	**Favors point source CO_2 operators, including BECCS**, by incentivising increased availability of CO_2 offtake options.	Supports the reduction of fossil fuel emissions. Supports the continuation of carbon-based industry.
IF, HEF	Funding calls to support research and development projects that include CCS (IF: CCS , HEF: BECCS/DACCS call, HORIZON-CL5-2024-D3-02-12)	**Favors funding priorities, including BECCS**,. Provides a limited amount of dedicated funding that can speed technological learning and increase availability of CO_2 transport and storage	

Table 6. Impact of EU policies on CO_2 accounting and crediting for BECCS.

Policy	Content	Impact on BECCS operator	Contribution to other policy goals
CRCF 4	Sets out standardized guidelines for the quantification of permanent removals (including BECCS, carbon farming, and carbon storage in products	**Potentially favors BECCS deployment**, by acknowledging climate value of removals. However, no use cases for carbon removal credits are defined.	
CRCF	Assigns liability for monitoring removal permanence and rectifying reversal of removal to CDR operator.	**Burdens BECCS deployment** by creating an open-ended liability potentially outside of the control of the BECCS plant operator. Potentially contradictory with the designation of liability in the CCSD and ETS to the CO_2 transport and storage operator.	Reduces risks to environment and human health
GCD	Set guideline	**Potentially burdens BECCS deployment**, by increasing administrative burden and decreasing market for carbon credits. However, if market for carbon credits remain, could increase value of permanent net removals from BECCS.	Protects consumers from misleading environmental claims.

European Commission. Notably, the application of the concept of 'cascading' to BECCS is not consistently uniform across contexts. For example, in some contexts biomass is considered eligible for energy production only if no other uses are available anymore, while in other contexts residuals that cannot be used for any other purposes may be considered eligible for energy production. The biomass use hierarchy does not indicate how net removals should be valued as a use of biomass, it is unclear whether CDR is to be considered a high-quality use of biomass, or an end-of-life fate. Furthermore, comparable sustainability requirements to those placed on biomass supply chains by the RED and EUDR are absent for fossil fuel supply chains, creating an uneven playing field.

We also identified a lack of a standardised definition of removals across EU policy files, as well as inconsistent system boundaries to use in emission accounting, and a lack of clarity on selection criteria and accounting of upstream emissions for biowastes and residues. This is particularly critical to the discussion of removal use cases, e.g., if removals are to counterbalance residual emissions, their climate impact must be established to credibly equal and opposite to the intensity and duration of the warming effect of those emissions, and quantification methodologies must reasonably ensure this, while also stringently minimizing other adverse environmental impacts.

Stringent requirements must be paired with stringent guidance, user-friendly administration, and increased data sharing, since navigating the intricacies of supply chains, particularly in global markets, presents considerable challenges, which are often hindered by the absence of sustainability data and the lack of resources including time, financial resources, and subject matter expertise. This is particularly the case for deforestation-free production, where global supply chain complexities, sector expertise and satellite imagery data might be missing. However, the feedstock traceability required to report on sustainability criteria, and the exclusion of certain feedstock types and/or regions, results in higher feedstock sourcing costs, and in the case of the EUDR, currently no methodology for collecting the required information is provided (Bioenergy Europe 2023). Presently, the EUDR offers minimal guidance on how to effectively address these challenges, leaving businesses with limited direction on how to overcome these hurdles and ensuring sustainable practices and no deforestation after 2000 within their supply chains. Furthermore, as observed by previous studies (Mai-Moulin *et al* 2021), in the case of agricultural residues, REDIII lacks guidance on ensuring sustainable extraction rates and overlooks upstream process tracing and does not allocate biomass designated as waste any supply-chain emissions before the point of collection.

Our review highlights misalignment between existing and proposed policies. In particular, the promotion of carbon removals via BECCS creates a tension with the carbon removals provided via the land sector, particularly forestry. Increased demand for biomass, particularly wood, has the potential to reduce accumulation of forest carbon, cannibalising land-based removals embodied in the LULUCF target, as well as the goals of the NRL, and Forest and Biodiversity Strategies. Focusing on applying CCS to existing bioenergy plants (and other point sources of biogenic CO_2) could decrease the risk of increasing biomass demand. Increased demand also risks leakage of forest carbon impacts to outside of the EU through biomass imports, although this risk is reduced when the EUDR comes into effect. However, as the land sink is subject to higher risk of both sink saturation and sink reversals (e.g., fire, drought, pests), well-managed biomass harvests for BECCS could allow for increases in total removals, beyond those of forestry alone, though timing of benefits is sensitive to carbon debt caused by land use change and harvest methods (Field *et al* 2020, Chiquier *et al* 2022), although the risk of carbon debt is expected to be low (Alvarado Cummings *et al* forthcoming). Yet, while the anti-deforestation mandates of the EUDR and RED emphasize a concern of land carbon stocks, the quantification of land carbon is not included in the EUDR or RED. The quantification methodology of the CRCF (clause 4.1) does require that the quantification explicitly account for emissions from indirect land use change, but quantification methodologies are still pending.

Furthermore, clarity regarding the long-term valuation of different types of negative emissions is missing and with it, policies that can enable long-term price stability for more costly generation practices. Currently, the disparate development of policies—and reporting systems—to safeguard biomass sustainability and credibility of negative emissions have created a level of administrative burden that is not required for fossil-based energy providers, whose feedstock sourcing is not subject to any form of sustainability standards or reporting requirements. This is exacerbated by the split between regulations (e.g., EUDR, LULUCF), and directives (e.g., REDIII, EIA), the latter of which are implemented by individual member states, thus further increasing burden for transnational operators.

Minimising reliance on removals via deep mitigation reduction is paramount, and policy should strive foremost to disincentivize fossil fuel use. BECCS is resource intensive and requires attention across domestic and international supply chains to ensure continued availability without displacing impacts to other markets. While we should treat biomass as a critical raw material and assess its optimal application across sectors, we need to be mindful of the bottom-up decision-making process of the actors required to shift towards a bioeconomy, and the incentives provided to them by governance structures. However, as production of negative emissions may be required to reach net-zero targets, governance structures crucially need to provide incentives for (prospective) BECCS providers to deliver negative emissions as a common good.

This paper provides a first-of-its-kind policy analysis from the perspective of a potential BECCS operator in Europe to understand enabling and disabling conditions for (prospective) BECCS providers. Our observations have been validated through workshops, interviews and written reviews of practitioners, environmental NGOs and bioenergy experts.

5. Recommendations and conclusions

Policies to promote BECCS must balance the competing demands of allowing for financial viability of BECCS operations while providing credible and sustainable negative emissions, and there is a clear tension between due diligence and streamlining BECCS implementation. While no single action could hope to do so, we provide a number of recommendations.

First, **provide a clear and climate-credible definition and accounting standards for CDR across policy files** with broad system boundaries for accounting associated emissions, and clearly linked in policy files to the intended use cases for the removals. This definition should distinguish clearly between emission reductions and removals, permanent and non-permanent removals, which are currently all considered 'emissions savings' in the RED. Indeed, it is critical, as discussed above, to **maintain separate targets for reductions and removals**, including between removals to different sinks. To **clearly establish CDR in the biomass use cascade**, above unabated bioenergy, can also emphasize the value of removals. Similar to the RED requirements of minimum emission reduction, **establish a minimum CDR efficiency criteria** that require a BECCS system to meet a certain standard of net removals to gross emissions, to encourage efficient use of biomass. Clear methodologies should be provided that **reduce ambiguity by aligning biomass sourcing and emission accounting criteria between policies** without reducing overall sustainability criteria. This can improve the credibility and social acceptance of BECCS, and **reduce administrative burden, e.g. by creating a unified reporting portal** for ensuring operations compliance with different policy files, including for feedstock sourcing and emission accounting. This should also include a clarification of liability for monitoring and reversal rectification between BECCS operator and CCS storage operator. **Incentivise the capture of biogenic CO_2, particularly from existing point sources** without decreasing incentive for fossil emission reductions, such as incentivisation of via government procurement of CRCF removal credits or payments via the ETS that are not tradable with emission allowances. Focus on providing a **stable and transparent regulatory trajectory** that does not disincentivize the required long-term investments in emission abatement required by prospective BECCS providers.

Private entities providing negative emissions currently need to navigate a complex regulatory landscape that provides them of limited internalisation of the climate value. Achieving an ambitious 4–34 Mtpa of removals from BECCS by 2040 requires incorporating plant-level financial considerations into national and EU climate policy design as well as explicit prioritisation of limited sustainable biomass resources. Without clear incentives for (prospective) BECCS providers, there is significant risk of failing to achieve these removal targets in the EU. With the EU at the forefront of BECCS development ambition, failing these targets sets a bleak precedent for global roll-out of BECCS. However, credible climate benefits from removals will also require stringent accounting and monitoring practices and must not shift environmental burdens to the biomass supply chain. Indeed, the feasible scale of BECCS will be constrained by competing policy goals as well as competition for limited sustainable biomass and secure geologic CO_2 storage resources, and the EU's current BECCS ambitions may not be realistic. Therefore, the most effective CDR strategy will always be reducing the need for removals via the urgent and drastic reduction of emissions across all sectors.

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Data availability statement

All data that support the findings of this study are included within the article (and any supplementary files).

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