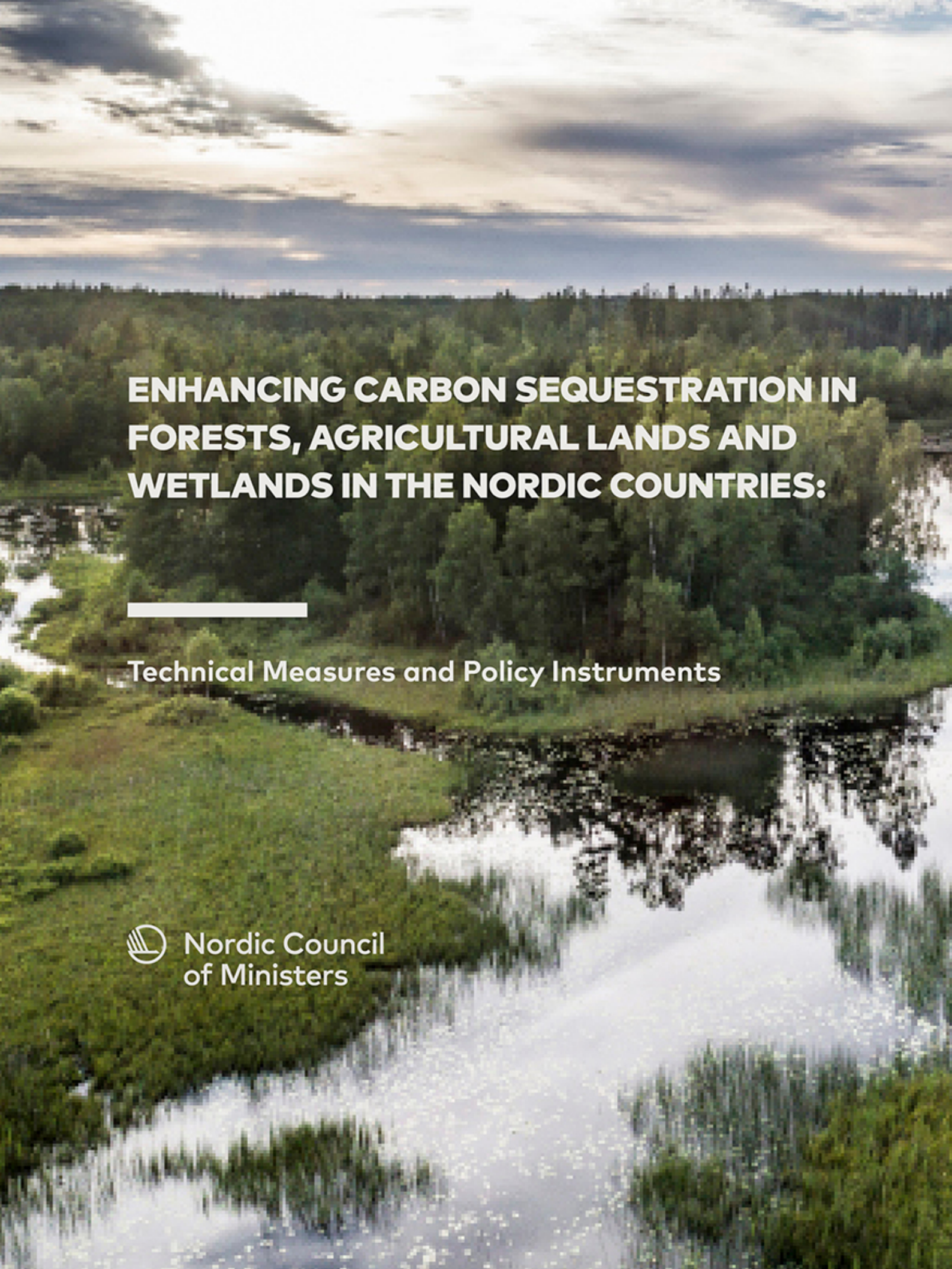




ENHANCING CARBON SEQUESTRATION IN FORESTS, AGRICULTURAL LANDS AND WETLANDS IN THE NORDIC COUNTRIES:

Technical Measures and Policy Instruments



**Nordic Council
of Ministers**

Enhancing Carbon Sequestration in Forests, Agricultural Lands and Wetlands in the Nordic Countries:

Technical Measures and Policy Instruments

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This publication is also available online in a web-accessible version at <https://pub.norden.org/temanord2021-537>.

Foreword

The work to prepare this report has been commissioned by the Nordic Working Group for Environment and Economy (NME) and funded by the Nordic Council of Ministers. The report synthesizes reviews of existing knowledge and practices on two important aspects pertaining to managing carbon sinks in agricultural land, forest and wetland. The first aspect concerns technical measures and existing policy instruments that are relevant for climate mitigation in the LULUCF sector in the Nordic region drawing insights from three countries – Denmark, Finland and Sweden. The second aspect relates to alternative instruments that have potential to be adopted as part of the strategies to further enhance climate mitigation in agricultural land, forest and wetlands in the Nordic countries.

The report is a result of a collaborative team effort. The team consists of Doan Nainggolan (Aarhus University - AU, Denmark), Johanna Pohjola (Finnish Environment Institute – SYKE, Finland), Louise Martinsen (AU), Steen Gyldenkærne (AU), Katarina Elofsson (AU; formerly with Södertörn University, Sweden) and Berit Hasler (AU).

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We hope that this report can inform further development of climate policy instruments to support efficient and integrated strategies for augmenting carbon sequestration and emission reduction in the LULUCF sector in the Nordic region.

Roskilde, August 2021

On behalf of the team,

Doan Nainggolan

Summary

This report presents the findings from a study comparing technical measures and policy instruments for enhancing land-based climate mitigation in three Nordic countries, namely Denmark, Finland and Sweden. The overarching aim of the project is to synthesize existing knowledge concerning how enhanced sequestration and reduced emissions of carbon in forest, agricultural areas and wetlands can contribute to climate policy. The study focuses on the Land Use, Land Use Change, and Forestry (LULUCF) sector, and provides an overview of a selection of measures and policy instruments currently used in the three countries, and assesses whether there is additional potential for increasing the use of these measures. In addition, we identify potential new policy instruments, not yet applied in the Nordic context, which can be relevant to include in future climate mitigation strategies.

Policy instruments are designed with an ultimate goal to encourage activities, such as the adoption of land-use and/or management practices that result in either net carbon sequestration or net carbon emission reduction, within the LULUCF sector. The report contains a brief introduction to policy instrument typology, and reviews factors which are important to consider when evaluating the potential of a new policy instrument. This review highlights the importance of ensuring the additionality, permanence of initiatives, and avoidance of leakage. Failure to address these factors implies that the actual, net climate effect will be less than anticipated. Similarly, the importance of paying due respect to transaction costs is emphasized, as it is important to ensure that the total cost does not end up exceeding total benefits. Risks related to the unpredictability of nature and climate, and to instrument design are also discussed. Furthermore, the importance and complexity of addressing risk is made evident. Finally, the review also highlights the potential benefits associated with designing policy instruments that take into account possible synergies between different policy goals, and the benefits that may be associated with instruments that address heterogeneity of costs and effects across space and time, and across different actors/landowners. Thus, adopting a long-term perspective, and acknowledging heterogeneity, it may be possible to increase the overall cost efficiency of a policy instrument.

To date, a range of land based measures, generating beneficial effects on carbon sequestration or emission reduction, do exist and are being implemented in the Nordic countries, albeit the degree of implementation varies across the countries. These measures include for example initiatives related to reducing emissions from organic soils (e.g. termination of crop production on organic soils), energy crop cultivation, afforestation, and management of existing forests. However, the present review reveals that it is only for a minor subset of the measures that the implementation is explicitly targeted at climate mitigation. This indicates scope for further exploiting the potential of cost-effective land based measures for climate mitigation in the Nordic region. For most measures, the potential positive effect in terms of climate impact is acknowledged as a secondary effect, but it seems that the focus on climate impact is increasing. Thus, there already seems to be a widespread recognition of the fact that the adoption of a more holistic perspective

may increase the cost efficiency of environmental and climate regulation.

The review suggests that the use of all implemented measures but one, namely reduced tillage, could be increased to enhance carbon sequestration and/or reduce GHG emissions from the LULUCF sector. For the measure set-aside of agricultural land it may however be noted that the relative desirability of the measure in terms of climate mitigation to some extent is limited by the fact that the effect is only temporary. The magnitude of the climate effect varies significantly across measures, but the effect of a given measure is also in many cases seen to vary significantly depending on where and how the measure is implemented. The two measures with the largest effects are withdrawal of organic soils from agricultural production and measures for GHG reduction in cultivated peatland. The effects of the other reviewed measures are significantly lower. This could suggest that they are less relevant, but this need not be the case as the measures could be cost-efficient in some locations but not in others. All else equal, costs will be higher for measures involving withdrawal of land from production than for less invasive measures. Accordingly, less effective measures, which allow production to continue, may be the best option in areas where the land production value is high, while measures requiring withdrawal of land from production may primarily be relevant in areas where the land production value is low.

Overall there does not seem to be very much variation in terms of policy instruments underlying the implementation of existing land based measures. The policy instruments are predominantly subsidies and regulation (command and control), although voluntary implementation is also seen for some of the measures. Thus, there seems to be ample scope for expanding the policy instrument portfolio, thereby potentially increasing the cost effectiveness of land-based climate mitigation.

Five potentially relevant new policy instruments are identified and discussed; common for all is that they are economic instruments, which have the potential to contribute to the cost efficiency of climate mitigation. Also common for all is that there are significant challenges, especially in relation to verification and monitoring (e.g., of the magnitude of the sequestration or emission reduction effects), that need to be overcome before the instruments can be implemented in practice.

One set of potentially relevant instruments focus on carbon sequestration through forest management, which has been considered a low-cost mitigation option. Both tax/subsidy schemes and carbon rent schemes have been discussed in the literature as policy instruments to incentivize forest owners to increase carbon sequestration in their forests. Existing modelling studies indicate that forest owners' harvest decisions, and hence the carbon sequestration effects, are identical under both types of instruments and the magnitude of the effects increase with increasing carbon prices. In implementing the instruments, it is important to define a baseline in order to pay forest owners only for additional carbon sequestration. Also, it is equally important to implement incentive mechanisms internationally in order to prevent carbon leakage resulting from increased imports when the instrument is only binding unilaterally in one or a few countries.

Another instrument relates to the creation of markets for land-based carbon sequestration. At present, LULUCF is not included under EU ETS and given the

various challenges such as the risk of impermanence, the incorporation of LULUCF into EU ETS in the near future seems to be less probable. An alternative solution is to develop a system specifically designed for trading carbon sequestered from the LULUCF sector. Although the performance of such schemes has not yet been analysed empirically for the EU, one can note that the establishment of a trading scheme would create incentives for land-based carbon sequestration activities and could potentially increase the overall efficiency of climate mitigation, while challenges related to uncertainty, reversibility and high transaction costs need to be addressed. Their realization will require close collaborations not only between the Nordic countries but also with other EU countries. In the meantime, trading can still take place following the EU flexibility rules which allow Member States to buy and sell net LULUCF carbon removals. However, detailed guidance and examples of how this kind of trading takes place in practice remains lacking.

Most of existing instruments are predominantly practice-based. In situations with information asymmetries regarding the likely effects of the practice, it may however be more efficient to employ result-based instruments where results in this context refer to the expected sequestration and/or emission reduction effects. There are several examples of result-based instruments being used in practice (e.g. Peatland Code in the UK, Carbon labelling/certification in France), and important advantages of the approach are that it provides flexibility and incentivizes innovation. Also, land-use contracts using reverse auctions could offer incentives that are based on results/performances. It has been used in other countries (e.g., Australia, UK), and important advantages of the approach are that it has the potential to both minimize transaction costs and capture spatial heterogeneity. The result-based instruments and the reverse auction contracts form policy instruments that potentially can be implemented by the government and are applicable to a wide range of measures including afforestation and wetland management. These types of economic instruments are expected to be cost effective although no empirical studies on their cost-effectiveness are available to date.

There are also potential economic instruments where the demand for governments' direct contribution or intervention would be less intensive. For example, tailored private insurance schemes, provided through market mechanisms, can provide a potentially relevant new mechanism that may serve to stimulate the adoption of climate smart agricultural practices. The idea is that insurance may provide an economic incentive to engage in climate friendly practices that might otherwise be considered too risky. Government support to help establish the market for this type of insurance may be necessary for example through contribution towards insurance premiums. Another market driven instrument can be activated through a link between actors across a supply chain of land-based productions for example through retailers providing economic incentive for farmers to adopt soil conservation measures which in turn contribute to enhancement of agricultural soil carbon sinks.

In conclusion, the implementation of land-based measures that is intentionally driven by climate mitigation objectives and the policy instruments to incentivize such implementations in the Nordic countries appear to be limited. This suggests a considerable potential for further enhancement of carbon sequestration and emission reduction from the land-based sector in the Nordic region. In the same vein, there is a wide range of alternative economic policy instruments that can potentially be deployed by the government. While some instruments are based on insights from

analytical models (e.g., carbon rent and subsidy/tax combination as two potential instruments for existing forests), others have actually been implemented outside the Nordic region (e.g., performance based schemes and land use contracts based on reverse auction mechanism). Furthermore, studies and implementations from elsewhere offer insights regarding strategies to address key challenges that affect the efficiency of land-based carbon sequestration/emission reduction. For example, risk of impermanence can be addressed by setting a long-term project duration, conducting regular monitoring and verification, and imposing a risk buffer (reserving a percentage of eligible carbon credits to buffer any deviation from the anticipated sequestration/emission reduction). Nevertheless, other aspects remain understudied, for example, synergies and trade-offs with other environmental/societal objectives (such as food production, biodiversity, etc) resulting from the actual implementation of the different economic policy instruments. An overview of land managers/owners' likely responses to the different economic instruments, which in turn affect the uptake of schemes and hence the cost-effectiveness, is also currently lacking. This highlights opportunities for follow up research to support the goal to incentivize and augment climate mitigation in the LULUCF sector in the Nordic region.

Sammendrag

Denne rapport præsenterer resultaterne fra et studie, der sammenligner tekniske tiltag og reguleringsinstrumenter til at fremme landbaserede reduktioner i udledningen af klimagasser i tre nordiske lande, nærmere betegnet Danmark, Finland og Sverige. Det overordnede formål med projektet er at syntetisere eksisterende viden om, hvordan øget kulstofbinding og reducerede emissioner i skove, vådområder og landbrugsjorde kan bidrage til at reducere klimaforandringer. Undersøgelsen fokuserer på sektoren LULUCF (Land Use, Land Use Change, and Forestry; arealanvendelse, ændringer i arealanvendelse og skovbrug), og giver et overblik over et udvalg af tiltag og reguleringsinstrumenter, der i øjeblikket anvendes i de tre lande. Det vurderes, om der er yderligere potentiale for at øge brugen af disse allerede anvendte tiltag og instrumenter. Derudover identificeres potentielle nye reguleringsinstrumenter, der endnu ikke er anvendt i de nordiske lande, men som kan være relevante at inkludere i den fremtidige klimaindsats.

Det ultimative mål med de forskellige reguleringsinstrumenter er at tilskynde aktiviteter, der enten øger bindingen af kulstof eller reducerer emissionen af drivhusgasser fra LULUCF sektoren. Rapporten indeholder en kort introduktion til forskellige typer reguleringsinstrumenter, samt en gennemgang af faktorer, som er relevante at inddrage i evalueringen af potentialet af nye reguleringsinstrumenter. I gennemgangen fremhæves vigtigheden af at sikre, at de klimagevinster, der opnås, er både permanente og additive i forhold til baseline situationen, samt at lækage udgås. Hvis disse aspekter ikke adresseres tilstrækkeligt, vil den reelle klimagevinst være mindre end forventet. Ligeledes fremhæves vigtigheden af at være opmærksom på størrelsen af transaktionsomkostningerne, da det er vigtigt at sikre sig, at de totale omkostninger ikke ender med at overstige værdien af de samlede gevinster. Risici – både i forhold til den uforudsigelige karakter af natur og klima og i forhold til design af reguleringsinstrumenterne – diskuteres også, og kompleksiteten og vigtigheden af at adressere de forskellige risikoaspekter tydeliggøres. Endelig viser gennemgangen også de potentielle gevinster, der kan være forbundet med at designe reguleringsinstrumenter, så der tages højde for eventuelle synergier mellem forskellige målsætninger, og de fordele, der kan være ved reguleringsinstrumenter, som adresserer både rumlig og tidsmæssig heterogenitet i relation til gevinster og omkostninger, samt på tværs af forskellige interessenter. Hvis der anlægges et langsigtet perspektiv, og hvis heterogenitet adresseres, kan der således være potentiale for at øge den samlede omkostningseffektivitet af reguleringsinstrumenter.

I de nordiske lande er der på nuværende tidspunkt allerede implementeret en række landbaserede tiltag med positive effekter i forhold til kulstofbinding og/eller reduktion af emissioner, men omfanget af implementering varierer på tværs af de 3 lande. Tiltagene omfatter blandt andet initiativer relateret til reduktion af emissioner fra organiske jorde (f.eks. udtagning af organiske jorde fra omdrift), dyrkning af energiafgrøder, skovrejsning og ændret forvaltning af eksisterende skove. Gennemgangen viser imidlertid, at det kun er for en mindre delmængde af tiltagene, at den nuværende implementering er direkte målrettet klima. Dette indikerer, at

landbaserede tiltag repræsenterer et uudnyttet potentiale for omkostningseffektive klimaindsatser i Norden. For de fleste tiltag er der dog opmærksomhed omkring den potentielle positive klimaeffekt, og det virker som om, at fokus i stigende grad rettes mod klima som en specifik sekundær effekt. Således synes der allerede at være en udbredt erkendelse af, at omkostningseffektiviteten af miljø- og klimareguleringen kan øges, hvis der anlægges en holistisk tilgang til reguleringen.

Gennemgangen indikerer at alle eksisterende tiltag på nær reduceret jordbearbejdning, også repræsenterer potentielt relevante tiltag i forhold til den fremtidige indsats for enten at øge kulstofbindingen eller reducere emissionerne af klimagasser fra LULUCF sektoren. For udtagning af landbrugsjord bemærkes det dog, at den relative værdi af tiltaget i forhold til klima til en vis grad begrænses af det faktum, at effekten kun er midlertidig. Størrelsen af klimaeffekten varierer betydeligt på tværs af de forskellige tiltag, men effekten af et givent tiltag ses også i mange tilfælde at variere betydeligt afhængigt af, hvor og hvordan foranstaltningen implementeres.

De to tiltag med størst effekt er udtagning af organogene jorde og drivhusgasreducerende tiltag på dyrkede tørvejorde. Effekten af de andre analyserede tiltag er betydeligt lavere. Dette kunne tolkes som, at disse tiltag er mindre relevante, men det er ikke nødvendigvis tilfældet, idet omkostningseffektiviteten af tiltag kan variere fra sted til sted.

Alt andet lige, så vil omkostningerne for tiltag, der indebærer udtagning af jord i omdrift, være højere end omkostningerne for mindre indgribende tiltag. Derfor kan mindre effektive tiltag, der er compatible med fortsat omdrift, være den bedste løsning i områder hvor den landbrugsmæssig produktionsværdi er høj, hvorimod tiltag, der indebærer udtagning af jord fra omdrift, primært kan være relevante i områder, hvor den landbrugsmæssige produktionsværdi er lav.

Overordnet set synes der ikke at være den store variation i den nuværende anvendelse af reguleringsinstrumenter i forhold til den landbaserede klimaindsats. De reguleringsinstrumenter, der er anvendt i implementeringen af eksisterende tiltag, er hovedsageligt subsidier og regler (påbud, forbud) om end der også for nogle tiltag ses eksempler på frivillig implementering. Der synes derfor at være rige muligheder for at udvide porteføljen af reguleringsinstrumenter, og derigennem potentielt øge omkostningseffektiviteten af den landbaserede klimaindsats.

Fem potentielt relevante nye reguleringsinstrumenter identificeres og diskuteres; fælles for disse er, at de er økonomiske instrumenter, der potentielt kan bidrage til at øge omkostningseffektiviteten af klimaindsatsen. Fælles for alle er imidlertid også, at der er betydelige udfordringer, særligt i forhold til verifikation og overvågning (f.eks. af størrelsen af kulstofbindings - eller emissionsreduktionseffekter), der skal adresseres, før instrumenterne kan implementeres i praksis.

Et sæt potentielt relevante instrumenter fokuserer på øget kulstofbinding i skove via ændringer i forvaltningspraksis, som betragtes som et billigt klimatag. Både skatte- og subsidieordninger diskuteres i litteraturen som reguleringsinstrumenter, der kan tilskynde skovejere til at øge kulstofbinding i deres skove. Resultaterne af eksisterende modelleringsstudier viser, at skovejernes hugstbeslutninger, som er afgørende for, hvor meget kulstof der bindes i skovene, er identiske under begge typer instrumenter, og at størrelsen af effekterne stiger med stigende kulstofpriser.

Ved implementeringen af instrumenterne er det vigtigt, at der defineres et retvisende grundscenarie, så det sikres, at skovejne kun modtager betaling for den kulstofbinding, der ligger ud over grundscenariet. Derudover er det også vigtigt, at incitamentsmekanismerne implementeres internationalt, så der ikke opstår lækager som følge af øget import, hvilket kan være resultatet, hvis et instrument kun implementeres i ét eller få lande.

Et andet instrument fokuserer på skabelsen af markeder for landbaseret kulstofbinding. På nuværende tidspunkt er LULUCF ikke inkluderet i EU ETS, og med reference til de udfordringer der er i forhold til håndtering af eksempelvis spørgsmålet om permanens, så fremstår det ikke sandsynligt, at LULUCF vil blive indlemmet i EU ETS systemet inden for den nærmeste fremtid. En alternativ løsning er at udvikle et system, der er specielt designet til handel med kulstof, der bindes i LULUCF-sektoren. Der er endnu ikke gennemført empiriske analyser af potentialet for et sådant system på EU niveau, men det forventes, at det vil kunne skabe incitamenter til øget landbaseret kulstofbinding. Dermed vil det potentielt kunne bidrage til at øge den samlede effektivitet af klimaindsatsen, men inden det kan blive en realitet er der en række udfordringer i forhold til usikkerhed, reversibilitet og høje transaktionsomkostninger, der skal løses. Derudover bemærkes det, at en forudsætning for skabelsen af et sådant marked er, at det sker i et tæt samarbejde, ikke blot mellem de nordiske lande, men på tværs af EU. Indtil der bliver udviklet et marked for LULUCF sektoren kan handel stadig finde sted i henhold til EU's fleksibilitetsregler, der giver medlemsstaterne mulighed for at købe og sælge netto-reduktioner af klimagas udledninger i LULUCF-sektoren. Der mangler dog for nuværende detaljeret vejledning for, og eksempler på, hvordan denne form for handel kan foregå i praksis.

De fleste af de eksisterende instrumenter er overvejende praksisbaserede. I situationer hvor der er informationsasymmetrier med hensyn til de sandsynlige effekter af tiltag, kan det dog være mere effektivt at anvende resultatbaserede instrumenter. I denne sammenhæng kan "resultater" repræsenteres ved de forventede bindings- og / eller emissionsreduktionseffekter. Der er flere eksempler på, at resultatbaserede instrumenter anvendes i praksis (f.eks. Peatland Code i Storbritannien og kulstofmærkning/certificering i Frankrig), og væsentlige fordele ved fremgangsmåden er, at den giver fleksibilitet og tilskynder til innovation. Arealanvendelseskontrakter baseret på omvendte auktioner, kan give incitamenter baseret på faktiske resultater / præstationer. Denne tilgang er blevet brugt i andre lande (f.eks. Australien og Storbritannien), og væsentlige fordele ved tilgangen er, at den har potentialet til både at minimere transaktionsomkostninger og adressere rumlig heterogenitet. Resultatbaserede instrumenter og omvendte auktionskontrakter udgør reguleringsinstrumenter, der potentielt kan implementeres af staten, og de vil kunne anvendes i forhold til en række tiltag, herunder skovrejsning og forvaltning af vådområder. Disse typer økonomiske instrumenter forventes at være omkostningseffektive, om end der for nuværende ikke eksisterer empiriske undersøgelser af deres omkostningseffektivitet i praksis.

Der er også potentielle økonomiske instrumenter, hvor behovet for direkte statslig finansiering eller indgriben er mindre udtalt. Et eksempel er skræddersyede private forsikringsordninger, leveret via markeds mekanismer, som potentielt kan stimulere indførslen af klimasmarte landbrugspraksisser. Tanken er, at en forsikringsordning

kan give landmænd et økonomisk incitament til at overgå til mere klimavenlige praksisser, som uden det ekstra incitament ville blive betragtet som værende for risikable. I etableringsfasen af denne type forsikring kan det være nødvendigt med statsstøtte, f.eks. i form af bidrag til forsikringspræmier. Et andet markedsdrevet instrument kan aktiveres ved at forbinde aktører på tværs af forsyningskæder for land- eller skovbrugsprodukter; f.eks. ved at detailkæder giver landmænd økonomisk incitament til at omlægge deres drift i mere klimavenlig retning.

Afslutningsvis bemærkes det, at erfaringer med implementeringen af landbaserede tiltag, der specifikt har til formål at reducere klimabelastningen, og reguleringsinstrumenter, der kan tilskynde implementeringen af sådanne tiltag, ser ud til at være begrænsede i alle de nordiske lande. Det er indikationer for, at der er et betydeligt potentiale for at øge kulstofbinding og reduktion af emissioner fra den landbaserede sektor i Norden, og der er en bred vifte af alternative økonomiske reguleringsinstrumenter, der potentielt kan anvendes af myndighederne for at realisere det uudnyttede potentiale. Det formodede potentiale for nogle af instrumenterne baseret på resultater fra analysemodeller, f.eks. for kombineret tilskud/skattesystem som reguleringsinstrument i forhold til eksisterende skove. For andre instrumenter er potentialet baseret på erfaringer fra steder uden for Norden, hvor instrumenterne er implementeret i praksis. Eksempler er de præstationsbaserede ordninger og arealanvendelseskontrakter baseret på omvendt auktion. Resultater af studier og erfaringer fra implementering andre steder giver indsigt i strategier til at tackle nogle af de centrale udfordringer, der påvirker effektiviteten af tiltag til fremme af kulstofbinding / reduktion af emissioner fra land- og skovbrug. Eksempelvis kan problemer med impermanens adresseres ved at anlægge en lang tidshorisont for projekter, gennemføre regelmæssig overvågning og verifikation og indregne en risikobuffer. Det kan foretages ved f.eks. at reservere en procentdel af støtteberettigede kulstofkreditter til dækning af en eventuel afvigelse fra den forventede effekt.

Andre aspekter relateret til den faktiske implementering af reguleringsinstrumenter så som eksempelvis synergier og/eller konflikter med andre miljømæssige/samfundsmæssige hensyn (f.eks. fødevarerproduktion og biodiversitet) synes ikke at være særligt velbelyste. Desuden mangler der viden om arealforvaltere / ejeres sandsynlige respons på forskellige økonomiske instrumenter. Denne mangel på viden er essentiel, idet denne respons er afgørende for instrumenternes succes og omkostningseffektivitet. Dette understreger relevansen af at understøtte fremtidig forskning med fokus på udvikling af omkostningseffektive klimatiltag indenfor LULUCF-sektoren i Norden.

1. Introduction

1.1. Background

The Nordic countries have a long tradition of working together and setting examples on the global scene when it comes to tackling environmental issues including climate change. At a summit in Helsinki in January 2019, prime ministers from the Nordic countries declared that "The aim of the Nordic countries is to be carbon neutral and to demonstrate leadership in the fight against global warming." The fulfilment of this ambition demands multiple strategies including land-based schemes.

Agriculture, forest, and wetlands make up a large share of land use in the Nordic region. Moreover, forestry and agriculture are important economic sectors in the Nordic countries to different extents. Managing these systems inevitably plays an integral part of the region's joint efforts to mitigate climate change.

In view of climate change, it becomes crucial to manage forest, agricultural soils and wetlands in a way that minimizes carbon release into the air and, at the same time, increase carbon sequestration in these systems. Landowners should therefore be encouraged to adopt measures that will lead to increased net uptake of carbon. To this end, understanding which policy instruments can influence landowners to adopt the aforementioned measures in a cost-efficient manner in the Nordic countries becomes crucial. There is a scope for learning from experiences through a synthesis of current knowledge on how incentive mechanisms, their associated costs and benefits as well as the implementation, vary between instruments and between countries. In this context, it may also be highly relevant to distinguish between theory and practice; thus, in some cases it may be that what is optimal seen from a theoretical point of view may not be practically feasible, e.g., due to prohibitive transaction costs such as verification and monitoring costs. Furthermore, understanding how policy instruments and measures can affect other environmental policy objectives is also of high relevance. Documenting such knowledge will highlight among other things the progress as well as challenges encountered by the Nordic countries and what gaps in knowledge and policy there are. This is important for informing future policy development and hence provides the background and the rationale to the present project.

The overarching aim of the project is to synthesize existing knowledge concerning measures and policy instruments for enhanced sequestration and reduced emissions of carbon in forest, agricultural soils and wetlands in order to contribute to national climate mitigation in the Nordic countries. To this end, the project first reviews a selection of measures that are considered among the most relevant for enhancing carbon sinks in forests, agricultural soils and wetlands. The review looks into the effects of climate mitigation measures and the policy instruments underpinning the implementation of the measures. Then, the project explores a range of potential instruments that can be introduced to support land-based strategies for enhancing carbon sinks in the Nordic region. The project focuses on three countries namely Denmark, Finland and Sweden which differ considerably in terms of the dominant land uses. Denmark represents a country with high intensity of agricultural production, while wetlands and forests are dominant in Finland and Sweden. Furthermore, Finland has a large area of peatland, which is utilized for peat harvest for energy production.

1.2. Structure of report

The remainder of the report is structured as follows:

The rest of Chapter 1 provides a brief overview of the LULUCF policy framework and presents the areal extent of the different land categories that are the focus of this report along with the associated emission levels. Chapter 2 begins with a brief introduction to a typology of policy instruments, including an overview of the general and most important advantages and disadvantages of different types of policy instruments. Factors affecting the efficiency and suitability of different policy instruments will be outlined, thus establishing a framework for the subsequent discussion of the potential for extending the use of existing policy instruments, revising existing policy instruments and for implementing new policy instruments. Throughout the chapter, previous experiences – both related to carbon sequestration and emission reduction as well as other relevant contexts – will be drawn upon, thus emphasizing the importance of acknowledging, that practical feasibility is just as important to consider as theoretical potential, when designing and implementing policy instruments.

Chapter 3 deals with measures available for increasing carbon sequestration in forests, wetlands and agricultural lands that are of relevance for Nordic countries. The chapter describes existing measures implemented in the three countries, and discusses the policy instruments used in the implementation of the measures.

Building on Chapter 2 and 3, which discuss existing policy instruments and measures in the selected three Nordic countries, and drawing on a relevant body of literature and recent practices internationally, Chapter 4 discusses a selection of new potential policy instruments for further enhancing carbon sequestration and/or emission reduction in forests, wetlands and agricultural lands in the Nordic countries. Chapter 5 sums up the findings from the previous chapters and highlights key aspects of policy relevance going forward.

1.3. EU policy framework for land-based climate mitigation

The EU 2030 climate policy framework consists of 3 pillars; the Emissions Trading System (ETS) regulating emissions from energy intensive industries, the Effort Sharing Regulation (ESR) applying to most sectors not covered by the ETS, and the LULUCF (Land Use, Land Use Change and Forest) Regulation (Romppanen, 2020). Intuitively, the latter is of utmost relevance to the scope of the present report. Together the three pillars are expected to contribute to the EU GHG emission reduction target, which was previously set to 40% reduction relative to 1990 level. In September last year, as part of the European Green Deal, EU leaders agreed to increase the target to a minimum of 55% by 2030. As to how each of the three pillars will play a role within the framework of the new target, will be elaborated by the EU Commission by June 2021¹.

In May 2018, the European Union issued Regulation (EU) 2018/841 on the inclusion of

1. https://ec.europa.eu/clima/policies/strategies/2030_en

greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework. This LULUCF Regulation concerns carbon pools in: above-ground biomass, below-ground biomass, litter, dead wood, soil organic carbon, and harvested wood products in the land accounting categories of afforested land and managed forest land. Thus, in contrast to previous EU law, where emissions from use of biomass in energy production were not accounted, the LULUCF Regulation does include biomass for energy production (https://ec.europa.eu/clima/policies/forests/lulucf_en).

At present, no specific reduction target is set for the LULUCF sector. Instead, the LULUCF regulation relies on a 'no debit rule', according to which, EU Member States, Iceland and Norway are required to ensure that accounted LULUCF emissions do not exceed LULUCF removals in the period 2021 to 2030. In relation to the 'no debit rule' it is noted that the assessment of emissions from the LULUCF sector is based on different accounting principles depending on land-use category and type of land-use change. While a net-net accounting approach is used for agricultural land (Cropland, Grassland and Wetlands), a gross-net approach is used for deforestation and afforestation, and for forest management, a Forest reference Level (FRL) approach is used. The specifics of the different accounting approaches imply that the 'no debit rule' is not equivalent to a requirement that net annual emissions from the LULUCF sector must be either zero or negative. To illustrate this, the net-net accounting principle means that if a country experiences a net loss in the base year (BY) and the same loss in the accounting year then it will not be penalized. If the same loss in the BY had been changed to a slightly lower loss, then the difference would be accounted for as a credit as the country has done something to minimize the loss. The opposite also applies; if a country has a net sink in the BY for having done something in the BY, then the country in a way is obliged to continue with the same sink in the accounting period (2021–2030) by doing something extra to avoid a penalty in the accounting period.

Looking at the EU as a whole, the LULUCF sector has been a relatively stable net sink of GHG, but looking at specific countries there is significant variation. For Denmark, the LULUCF sector is a net source of GHG emissions, mainly due to a large area with drained organic agricultural soils, which have a large emission per area. However, there seems to be an overall trend that the deficit is gradually reduced due to less drained organic soils and an increasing sink in the Danish forests. For Sweden and Finland, on the other hand, the LULUCF sector is a net-sink, and in both countries, forests represent the dominant sink. (CRF, Table 10s1, Denmark (25 May 2020), Finland (15 April 2020), Sweden (14 April 2020); downloaded from: <https://unfccc.int/ghg-inventories-annex-i-parties/2020>).

There are interlinkages between different sectors/pillars (Romppanen, 2020). Thus, within certain limits it is possible to balance emissions across different land categories, just as LULUCF credits can be used to offset emissions under the Effort Sharing Regulation (ESR) if the LULUCF sector produces accounted net removals. The degree to which emissions reductions within the LULUCF sector can be used to fulfil the reduction obligations under the Effort Sharing Regulation differs across countries. For Denmark the maximum is set to 14.6 million tonne total for the period 2021 to 2030 while for Sweden and Finland the amounts are 4.9 and 4.5 million tonnes, respectively (European Parliament, 2018). Moreover, it is also possible to transfer credits from a member state to another. Furthermore, surpluses from ESR can be used to compensate debts in LULUCF.

1.4. Land categories and emissions

The three countries in focus are of very different sizes, and the relative distribution of area between different land-use categories, is also markedly different across the three countries. Sweden and Finland are notably larger than Denmark, and while Sweden is around 30 % larger than Finland, the relative distribution of land between the different land-use categories is fairly similar. As it is seen in Table 1.1, cropland is the dominant land-use category in Denmark, while forest is the dominant land use in both Sweden and Finland. It is also relevant to note that the share of wetlands is significantly larger in Sweden and Finland than in Denmark.

Table 1.1 Area of IPCC/UNFCCC land-use categories (based on CRF tables, Table 4.1 Land Transition Matrix; <https://unfccc.int/ghg-inventories-annex-i-parties/2020>).

	Denmark		Sweden		Finland	
	1,000 ha	Pct. of total area	1,000 ha	Pct. of total area	1,000 ha	Pct. of total area
Cropland	2,817	65	2,785	6	2,490	7
Grassland	175	4	522	1	244	1
Wetland	118	3	7,385	16	6,440	19
Forest	639	15	28,198	62	21,866	65
Other (e.g. settlements)	556	13	6,239	14	2,804	8
Total area (Country)	4,306	100	45,129	100	33,843	100

In Tables 1.2 to 1.4 GHG emissions from the LULUCF sector in the three countries are presented. Emissions are presented in two different units; aggregate GHG emissions assessed in CO₂-equivalents, and CO₂-emissions. The latter refers to changes in soil carbon, plus living and dead biomass, while the former, in addition to changes in carbon, also included CH₄ and N₂O emissions.

Emissions are presented as averages for two 5-year periods; 1990 to 1994 (representing the emissions level around the base year) and 2014 to 2018 (representing recent emissions levels). The reason for comparing averages rather than specific emissions in given years is to even out year-to-year variation, which may be significant. As an example, 2018 was an atypical year (at least in Denmark) due to the very hot and dry summer, which had a negative impact on the level of GHG emissions. Thus, basing the comparison on numbers for 2018 (the most recent year for which inventories have been made) and 1990 (base year) would lead to the erroneous conclusion caused by a high loss from mineral agricultural soils (modelled estimates which take into account actual crop yield). Thus, emissions from forests have increased dramatically in the period 1990 to 2018. This, however, is not the case

as average CO₂-emissions from forest in the period has been negative (- 1,147 kt CO₂) – i.e. forests have been a net sink. The last two columns of Tables 1.2-1.4 show the percentage change in emissions between the two periods, thus indicating the trend of emissions.

Emissions are assessed both for the sector as a whole, and separately for the different LULUCF categories. Comparing across categories, it can be seen that while cropland and wetlands are generally net sources of emissions, forests and harvested wood products are generally net sinks. This difference across land-use categories, combined with the differences in the relative distribution of land across land-use categories, provides (at least partly) an explanation as to why the LULUCF sector is a net source in Denmark, while it is a net sink in Sweden and Finland.

According to current LULUCF regulation for emission accounting, only managed wetlands shall be reported. Emissions from the areas with naturally occurring wetlands (especially in Sweden and Finland, Table 1.1) are not included in emission estimates in Table 1.2 – 1.4. Here only wetlands, which have been constructed/alterd or managed since 1990 is included. Consequently, when comparing the areas in Table 1.1 with the emissions in Table 1.2 – 1.4 it can be seen that Sweden has a very large area with wetlands but almost the same level of emission as Denmark. In contrast, Finland has both a large wetland area and a large emission from wetlands. This is due to the large area where peat extraction for especially energy purposes (106,375 hectares reported in 2018) is taking place. This removal of organic matter in peat and the related CO₂ emission from the peatland is reported under wetlands in the GHG reporting and again as a CO₂-neutral emission in the energy sector. The area with peat extraction in Sweden is reported to be 11,906 ha while in Denmark it is only 300 ha.

Table 1.2 Emissions from LULUCF sector in Denmark (CRF Tables; Table 10s1 and Table 10s2).

	Average 1990–1994	Average 1990–1994	Average 2014–2018	Average 2014–2018	Change (%): Average (1990–1994) to average (2014–2018)	Change (%): Average (1990–1994) to average (2014–2018)
	CO ₂ -eq (kt)	CO ₂ (kt)	CO ₂ -eq (kt)	CO ₂ (kt)	CO ₂ -eq (kt)	CO ₂ (kt)
Land use, land-use change and forestry (total)	5,979.52	5,694.04	4,797.05	4,464.49	-19.78	-21.59
Forest land	-546.29	-579.52	-511.29	-564.45	6.41	2.60
Cropland	4,935.41	4,775.97	3,796.08	3,656.29	-23.08	-23.44
Grassland	1,511.58	1,427.68	1,388.12	1,318.38	-8.17	-7.66
Wetlands	93.69	85.62	98.85	41.68	5.51	-51.33
Settlements	24.83	23.99	174.80	162.10	604.01	575.80
Other land	-	-	-	-	-	-
Harvested wood products	-39.70	-39.70	-149.51	-149.51	-276.64	-276.64
Other	-	-	-	-	-	-

Table 1.3 Emissions from LULUCF sector in Sweden (CRF Tables; Table 10s1 and Table 10s2).

	Average 1990–1994	Average 1990–1994	Average 2014–2018	Average 2014–2018	Change (%): Average (1990–1994) to average (2014–2018)	Change (%): Average (1990–1994) to average (2014–2018)
	CO2-eq (kt)	CO2 (kt)	CO2-eq (kt)	CO2 (kt)	CO2-eq (kt)	CO2 (kt)
Land use, land-use change and forestry (total)	-32,509.18	-34,245.59	-42,572.47	-44,254.81	-30.96	-29.23
Forest land	-34,693.22	-36,135.14	-43,057.22	-44,387.43	-24.11	-22.84
Cropland	4,071.96	3,850.47	3,823.51	3,617.69	-6.10	-6.05
Grassland	-44.44	-54.23	-115.81	-127.95	-160.63	-135.93
Wetlands	84.71	78.51	214.23	204.57	152.90	160.56
Settlements	2,726.21	2,673.34	3,206.94	3,085.58	17.63	15.42
Other land	44.25	44.25	-1.90	-1.90	-104.30	-104.30
Harvested wood products	-4,702.79	-4,702.79	-6,645.37	-6,645.37	-41.31	-41.31
Other	-	-	-	-	-	-

Table 1.4 Emissions from LULUCF sector in Finland (CRF Tables; Table 10s1 and Table 10s2).

	Average 1990–1994	Average 1990–1994	Average 2014–2018	Average 2014–2018	Change (%): Average (1990–1994) to average (2014–2018)	Change (%): Average (1990–1994) to average (2014–2018)
	CO2-eq (kt)	CO2 (kt)	CO2-eq (kt)	CO2 (kt)	CO2-eq (kt)	CO2 (kt)
Land use, land-use change and forestry (total)	-19,763.88	-23,392.94	-16,883.16	-19,691.96	14.58	15.82
Forest land	-25,654.78	-29,139.68	-24,950.86	-27,551.87	2.74	5.45
Cropland	5,415.83	5,409.92	7,779.73	7,772.04	43.65	43.66
Grassland	859.92	859.29	706.41	705.61	-17.85	-17.88
Wetlands	1,608.03	1,485.35	2,239.13	2,064.24	39.25	38.97
Settlements	968.01	954.54	972.00	949.47	0.41	-0.53
Other land	-	-	-	-	-	-
Harvested wood products	-2,962.36	-2,962.36	-3,631.45	-3,631.45	-22.59	-22.59
Other	-	-	-	-	-	-

To assess the relative importance of the LULUCF sector on total emissions in the three countries, LULUCF emissions can be compared to total national emissions. In Denmark, total CO₂-equivalent emissions in 2018 were 54,536.3 kt (incl. LULUCF), and net emissions from the LULUCF sector were 6,593.56 kt, implying that around 12 % of total net emissions could be attributed to the LULUCF sector. In this connection, though, it may be noted that 2018 was an atypical year; thus, seen over the period 2013 to 2018, the average Danish LULUCF emissions were significantly lower, namely 4,312 kt. Seen over an even longer period, the share of total emissions attributable to the LULUCF sector has varied between 0 and 14 % (most recent NIR). In Sweden, total CO₂-equivalent emissions (incl. LULUCF) in 2018 were 9,785.28 kt while net emissions from the LULUCF sector were -41,993.96; thus, had it not been for the LULUCF sector, total Swedish GHG emissions would have been 5 times higher. In Finland, total CO₂-equivalent emissions in 2018 were 46,091.24 kt (incl. LULUCF) while net emissions from the LULUCF sector were -10,267.82; implying that total national emissions would have been approximately 20 % higher had it not been for the LULUCF sector.

1.5. Scope and limitations

Many measures have either a direct or an indirect effect on the amount of GHG emissions from forests, wetlands and agricultural lands, and including all such measures is not feasible within the scope of the present study. Hence, the focus of the report is on measures that affect the emissions from forests, wetlands and agricultural lands, which fall within the LULUCF sector.

CH₄ and N₂O emissions from animals and fertilizers are reported in the agricultural sector in the GHG reporting and not included in the LULUCF sector. Organic matter from animal manure applied to the soil has a positive impact on the carbon stock in the agricultural soils. However, it should be remembered that if animals did not exist, the produced feed in the fields would have been returned to the soil to be degraded and not first brought to the animals for a primary degradation in the animals before the remaining organic matter is returned to the fields. The overall effect on the soil carbon stock is therefore limited if we assume that the same crops were grown regardless of the animal digestion. Applying fertilisers that contain nitrogen to the field leads to N₂O emission. On the other hand, as the plant growth in agricultural fields is normally restricted by nitrogen deficit, application of nitrogen gives higher yield and hence a higher input of organic matter to the soils compared to a situation without nitrogen input. Consequently, nitrogen application has a large impact on the soil C in the short term as the termination of fertilization would result in an immediate decline in soil C in cultivated agricultural land.

Table 1.5 shows, based on 2018 emission inventory, the magnitude of CO₂ emissions from LULUCF compared with the total emissions from LULUCF and the individual land-use categories. While some variations across countries and land-use categories are evident, overall it seems that CO₂ is the dominant GHG in the LULUCF sector, thus supporting the reasonability of the scope of the present project. The low share of CO₂ from wetlands in Denmark, accounting for only half of the total emission, is as earlier mentioned due to the fact that peat extraction emitting CO₂ for energy is large in Finland and Sweden.

Table 1.5 CO₂ emissions from LULUCF compared to total GHG emissions from LULUCF for 2018.

	Denmark		Sweden		Finland	
	CO2 emission (kt)	Total emission in CO2-eq (kt)	CO2 emission (kt)	Total emission in CO2-eq (kt)	CO2 emission (kt)	Total emission in CO2-eq (kt)
LULUCF total	6251.09	6593.56	-43740.48	-41993.96	-13057.36	-10267.82
Forest land	348.72	402.19	-44,805.16	-43,418.76	-20,067.02	-17,484.15
Cropland	4,442.98	4,586.01	3,833.63	4,037.01	8,055.59	8,062.74
Grassland	1,389.19	1,463.49	-125.60	-113.26	728.18	728.98
Wetlands	52.61	110.01	230.47	241.75	1,923.65	2,098.86
Harvested wood products	- 162.13	- 162.13	- 5,702.33	- 5,702.33	- 4,417.01	- 4,417.01

2. Policy instruments

2.1. A brief typology of policy instruments for enhancing terrestrial carbon sinks

In the context of land-use-based carbon sequestration or GHG emission reduction that requires management actions by private agents (agricultural land or forest owners and/or managers), which is the focus of the present report, the ultimate goal of the different policy instruments would be to encourage activities that result in net carbon sequestration or carbon emission reduction for an extended period of time if not indefinitely. It has been emphasized in the literature that when designing policy instrument for carbon sequestration in terrestrial sinks, it is important to address temporal dimension (e.g., from the case of forest in van Kooten et al., 1995).

Many typologies of policy instruments exist. Nevertheless, pertaining to the purpose of this report, policy instruments can be divided into 4 overall distinct types; economic, voluntary, information based or command-and-control based. This is the conventional strict distinction between policy instrument types, but it must be recognized that some instruments span several of these categories, e.g. by mixing economic subsidies with information or mixes of optional and mandatory implementation. Such combinations might be used to incentivize farmers to undertake actions voluntarily, and if the voluntary actions are not implemented then economic incentives are instigated. In a way, the policy mixes may prove to be necessary in order to appeal to different target groups as farmers or land managers' responses are not necessarily homogenous to different policy instruments.

In principle, the aims of economic and voluntary instruments entail 1) rewarding (i.e. providing incentive for) land-use activities that lead to removal of carbon from the atmosphere and storage in the terrestrial sink as well as those preventing emission, and 2) assigning/creating disincentive for activities causing release of carbon from terrestrial sinks into the atmosphere. The incentive provision in both of these two categories can be either *result/output based* (i.e. proportional to the amount of carbon sequestered or avoided from being released) or *input/practice based* (i.e. compliance to a selection of required interventions/activities).

In practice, economic instruments can take the form of contracts and subsidies, marketable allowances and/or emission taxes (Richards, 2004). *Contracts and subsidies* are policy instruments where activities for carbon sink protection or expansion are funded by the government while the private party (landowners) carries out and has control over the details of the activities. One variant of these is the *output-based approach* where landowners are paid a fixed money amount (subsidies) per ton of carbon sequestered or a negotiated price (contracts) for a given sequestration target but then the landowners have total control over activities that they implement to meet the target. The other variant is the *input-based approach* where government pays landowners to implement a selection of sequestration practices (e.g. forest management practices, specified fallow activities).

Marketable allowances and taxes refer to policy instruments where private parties

subjected to the instruments have to pay for the cost of carbon abatement while at the same time having control over the choice/details of the mitigation activities. It is worth noting that the application of tradable allowances and taxes on carbon emission reduction and sequestration directly enforced on to land-use-based activities remains limited. One potential application is the provision of payment (incentive) in the form of tax credit or deduction to private parties involved (landowners) in return for undertaking activities that increase carbon sequestration and/or prevent shrinkage of carbon sinks. Another potential application, which has received growing attention in the literature, is to have a system that allows private landowners to earn carbon credits from their land-use activities for carbon sequestration and subsequently the possibility to trade these credits through a government's carbon offset program or through a cap and trade market system. However, at present, the European Emission Trading System does not cover land-based measures.

The implementation of land-use-based carbon sequestration or emission reduction might be encouraged by mandatory requirements (command-and-control). Under *command and control/regulation*, private party bears the cost of mitigation while the locus of discretion rests on the government where it controls and specifies private mitigation activities through a set of regulations and rules.

Examples of the different types of policy instrument will be provided in chapter 3 and 4.

2.2. Factors affecting relevance and efficiency

Many factors affect the efficiency and relevance of a given policy instrument in a specific situation. Some of the factors apply to regulation in general, while others are generic to specific instruments or relate to the measure being implemented. Some others depend on the specific spatial or geographical context. In this section, the different factors will be discussed in order to create a framework for the subsequent identification of policy instruments relevant for enhancing carbon sequestration in forests, wetlands and agricultural land. However, it is important to note that, while a combination of these different aspects represents what should be ideally considered, the degree of the application varies across policy instruments depending on the availability of information about the corresponding instruments.

2.2.1. Additionality

The criterion of additionality refers to the requirement, that a policy instrument – to be efficient – has to have an effect when compared to a baseline, where it is not implemented. In the context of carbon abatement, this means that the abatement induced by the implementation of a given measure needs to be additional to the abatement that would have taken place had the measure not been implemented. Additionality is important in relation to establishing the cost effectiveness of a policy; thus, it is a prerequisite for ensuring an efficient allocation of the resources allocated to abatement (World Bank, 2016). Additionality may also be important in relation to the environmental integrity of a policy, as failure to meet the criterion means that the net environmental effect is lower than expected.

Failure to meet the additionality criterion means that resources are spent on reducing emissions that would have been reduced in any case; thus, it is basically equivalent to paying for nothing.

In a perfect world with full information, ensuring additionality would be fairly straightforward. In reality, however, it may be difficult due to e.g. uncertainty about establishing the correct baseline against which to assess additionality and information asymmetries between principle (regulator) and agent (landowners). How to address additionality depends on the specific context, and the options will be discussed in relation to each of the policy instruments deemed relevant for increasing carbon sequestration in forests, wetlands and agricultural soils.

2.2.2. Leakage

Leakage refers to the situation where emission reductions in one context result in emission increases in another context, implying that the effect of the regulation is rather one of moving emissions from one place to another instead of actually reducing emissions. As practically all regulatory interventions are associated with costs (deadweight losses and transaction costs), it is evident that leakage hampers the efficiency of regulatory instruments. The risk of leakage is often discussed in relation to national regulation of heavy industrial production, but it is equally relevant in relation to e.g. production of biomass for energy production.

2.2.3. Permanence

For many land-use-related climate measures, permanence is an important issue to address when determining which policy instrument to use, and how it should be designed. Thus, a prerequisite for realizing the anticipated effect of many measures, e.g. afforestation and recreation of wetlands on organic soils, is that the land use change is maintained either indefinitely or at least over a long period of time. Moreover, it may also be important to ensure that the land is managed a certain way in order to maximise the climate effect over time.

2.2.4. Transaction costs

Focus may often be on the direct costs of implementing a specific measure, but it is also important to acknowledge the transaction costs associated with implementing a given measure. Hence, it is important to ensure that the scheme – in order to address e.g. additionality, co-benefits and permanence – do not end up being so complex that the costs associated with administration and monitoring get so large that the measure no longer represents a cost-effective means to climate mitigation.

2.2.5. Heterogeneity

The effect of climate mitigation measures will in most cases depend on the specific conditions of the geographical location where the measure is implemented. Differences in e.g. climate and soil types have an important impact on the expected effect of implementing a given measure, just as they may also affect the size of the opportunity costs associated with changing the land use. Thus, there is likely to be spatial variation in both the costs and effects of carbon sequestration or emission reduction measures, and ideally this needs to be reflected in the design of policy

instruments in order to ensure that measures are implemented efficiently.

In addition to spatial heterogeneity, it is also important to acknowledge the heterogeneity of agents (landowners). Several studies have shown that actors are often motivated by a range of factors, and accordingly focusing solely on providing economic incentives may not be a viable approach, as this fails to address the likely heterogeneity of preferences across agents.

2.2.6. Side effects

Just as measures targeted at e.g. reducing nutrient leakages may have an effect on the climate, measures targeted at climate mitigation may also have environmental side-effects. Therefore, in the design of policy instruments it is important to address the potential side-effects (positive as well as negative) associated with a given measure. By doing so it may be possible to take advantage of potential synergies between different effects thereby increasing the overall efficiency of environmental policies, while also avoiding the potential efficiency loss associated with implementing policies that may fix one problem, but aggravate other problems in the process. Sometimes, of course, it may be necessary to make trade-offs between different objectives, but it is important that the trade-offs are acknowledged and included in the decision-making process in order to ensure that likely trade-offs are reflected in a well-founded weighing of the associated costs and benefits.

In recent years there has been growing interest in both scientific and policy domains with regard to the importance and urgency of addressing coherence between multiple environmental policy objectives. A number of studies at different spatial scales has supported this and demonstrated that, up to a certain degree, policy synergies can be achieved and are economically feasible. A study by Gren and Säll (2015), though not exclusively addressing land-use-based measures, shows that jointly managing targets on both nutrient and GHG emissions are more cost effective than individual management of targets. This however requires the following two conditions: 1) the measures being implemented in abating pollutant are complementary and 2) the same source emits multiple pollutants. The study pointed that multi-target management results in 11% reduction in total costs compared with single target management.

Konrad et al. (2017) used spatially explicit data from the Limfjorden catchment in Denmark for economic evaluation of the optimal agricultural land-use patterns for delivering three environmental objectives: climate regulation, water quality improvement, and food provisioning. Findings from their analysis show synergistic effects between climate and water regulation services but trade-offs between these regulating services and food provisioning. In other words, while land-use change as a policy strategy to enhance one regulating service leads to positive spill-over effect on the other regulating service, this choice of strategy comes at the expense of lower food production. Moreover, the findings indicate that a policy strategy targeting both climate and water regulation services are more superior in terms of cost efficiency compared to sequential targeting strategies. The analysis furthermore highlights that spatial characteristics of catchments are an important determinant for the variation of the effects of selected policy strategies.

Nainggolan et al. (2018) further developed the BALTCOST model (Hasler et al., 2014), a cost-minimisation model, to assess different policy scenarios for implementing land-based measures in the Baltic Sea region by taking into account

the spatial heterogeneity between different catchments across the region. Among the key findings, the model results show that a policy scenario specifically targeted on water quality management can deliver climate change mitigation co-benefits equivalent to 2.3% of the 2005 emission level (from agriculture and waste water combined) for the entirety of the Baltic Sea region. Furthermore, the model results show that a joint policy scenario simultaneously tackling water quality and climate change can produce further climate change mitigation benefit (i.e. up to 5.4%) at a marginal cost that is comparable to mitigation costs reported by other studies for efficient technologies.

2.2.7. Risk

Practically all land-use-related measures are associated with some degree of risk, many of them related to the unpredictability of nature and climate. Afforestation may be devastated by storm damage; catch crops may fail to establish due to either heavy rains or droughts. Such events may imply that the anticipated climate effects are not realized, and it is important that such risks are addressed in the design of policy instruments. If the agent carries all the risk it may be difficult to get the agent to enter into voluntary schemes, on the other hand, if the principal carries all the risk there may be no incentive for the agents to minimise risks. Risk needs to be identified and addressed specifically, e.g. by the introduction of insurance schemes. Targeting of schemes, e.g. practice versus performance-based schemes, may also to some extent be an option for addressing risk.

Risk is also linked to the instruments. A command and control regulation might stipulate exactly the kind of output expected, thereby reducing the risk of not attaining the expected result. On the contrary, an economic instrument introduces more flexibility to the agents, which may be associated with a larger risk for unfulfillment of the expected output, unless the economic instrument is linked to result-based indicators.

2.2.8. Data availability

Data and knowledge pertaining to the climate effects of land-use measures per se do not determine the relevance of a policy instrument for land-based carbon sequestration or emission reduction. However, the availability of accurate data is important for the operationalization of a policy instrument including for the purposes of verification and monitoring of the mitigation effects expected from the implementation of land-use measures specified under a given policy instrument.

3. Land-use measures for enhancing carbon sinks in the three Nordic countries and the associated policy instruments

Policy instruments act as incentives for agents, e.g. farmers and forest owners and managers to implement measures. As mentioned, some instruments (the economic and voluntary) provide flexible incentives for the agents to make choices of which (if any) measures to implement in order to contribute to the desired change, while mandatory command and control often specify the measures to be implemented directly. It is worth noting that the flexibility regarding the choice of measures and the application intensity, offered in economic incentives, holds only in result-based schemes. However, this is not the case when economic incentives are for action/practice-based schemes where farmers/landowners are required to implement specific measures, e.g. subsidy schemes for specific measures such as set aside land. Nevertheless, there could also be a case where landowners/managers are incentivized by the magnitude of results/outputs (i.e. the amount of carbon sequestration and/or emission reduction) tied to specific actions i.e. the implementation of specified land-based measures.

As the focus of the project is on land-based carbon management, the report deals with land-use-related measures. Management practices and changes in land use may have either positive or negative impacts on carbon sequestration, and accordingly measures may either be targeted at increasing sequestration or reducing emission.

That changes in land use and land management practices play an important role in relation to climate mitigation is not new, but during the past years increasing focus has been put on formalizing the contribution required by the sector. In this chapter, we review a number of land-use measures that have been subject to scientific and policy interests for the potential effects on increased sequestration or reduced emission of carbon.

The reviewed measures do not represent an exhaustive list of all potentially relevant measures related to land use and/or land management. They only represent a subset of measures, where the choice has been made based on the extent of their use and their potential to contribute to carbon sequestration in the Nordic region. The measures reviewed in the following sections are:

- Reducing GHG emissions from organic soils (wetlands/peatlands)
- Energy crops
- Afforestation and reduced deforestation
- Reduced tillage
- Catch crops
- Set-aside (short term)
- Promoting forest productivity and health

The reviewed measures for increasing carbon sequestration in forests, wetlands/peatlands and agricultural soils are already implemented to some extent in one or more of the three considered countries. It is important to note however that the measures are not necessarily implemented with an explicit objective to improve soil carbon sequestration. In fact, for most of the measures so far, the prime target is to improve biodiversity or water environment, while climate is either not mentioned or only represents a secondary target. This observation that one measure may affect the provision of not only one but several ecosystem services simultaneously highlights an important aspect in relation to carbon sequestration policies, namely the potential synergies and trade-offs there may be between different targets. This issue is discussed in Section 2.2.6.

3.1. Reducing GHG emissions from organic soils (wetlands/peatlands)

Cultivated organic soils are an important source of GHG emissions. Targeting organic soils therefore seems to be a logical choice as one of the key land-based measures for climate mitigation. In Denmark, the focus is on taking organic soils out of production, which entails either conversion of the areas into permanent grass or restoration of the areas into their natural wetland status. According to the Danish Climate Council (Klimarådet, 2020), drainage and cultivation of organic soils are responsible for more than 50% of the total emission from cultivated agricultural areas despite the fact that organic soils occupy only 7% of the cultivated agricultural area. Rewetting all organic soils in Denmark is expected to reduce CO₂ emissions by up to approx. 4.1 million tonnes. The potential climate effect per hectare is quite large and is influenced by various factors, including whether draining continues or not (i.e. rewetting), the organic carbon content of the soil and previous land use (rotation or permanent grass). With reference to Olesen et al. (2018), see Table 3.1, the LULUCF climate effect is expected to be significant in all cases. The largest reduction is seen to come from withdrawal of land, including termination of drainage, on land with a soil organic carbon content above 12 % that previously has been in rotation. It should be noted, that the reduction estimates presented in Table 3.1 refer to Danish conditions, and that the effects may be different in Sweden and Finland. Moreover, it is noted that the estimated effects are associated with significant uncertainty implying that they should not be regarded as exact specifications of the effects; instead they should rather be interpreted as approximate indications of the magnitude of the likely effects, and as illustrations of the significant degree of variability, which depends on specific local conditions. Nevertheless, based on the UNFCCC, the emission factor for organic soils in Denmark in 2018 is higher than in Sweden and Finland. This can be seen in Table 3.2.

Table 3.1 GHG reductions within the LULUCF sector of withdrawing organic soils from agricultural production (ton CO₂-eq. per ha per year) (Olesen et al., 2018).

	Organic carbon content of soil > 12%	Organic carbon content of soil 6-12%
Drainage continued	10.97	5.28
Drainage discontinued, land in rotation	34.97	13.88
Drainage discontinued, permanent grass	24.00	8.60

Table 3.2 Reported Implied Emission Factor (IEF) for organic soils in 2018 from different countries (Source: UNFCCC.int)

	IEF, t C/ha/yr (not converted areas)		
	Forest	Cropland in rotation	Permanent Grass
Denmark ^a	1.29	7.59	5.66
Belgium	NO	10.00	1.89
Finland	0.19	6.49	3.50
Netherlands	0.93	3.59	4.12
Sweden	0.35	6.22	1.70
Germany	2.57	8.10	6.75
United Kingdom	- 0.66	5.00	0.25
IPCC, default ^b	2.60	7.90	6.10

^aThe average IEF for Denmark include 6–12% OC and >= 12% OC areas for Cropland and Grassland.

^bfully drained EF for temperate areas (IPCC, 2014)

A GIS overlay between the most recent map of Danish organic soils and agricultural fields reported by the Danish farmers to the Danish Agricultural Agency shows that approximately 171,000 hectares of organic soils (> 6 % organic carbon) are cultivated. However, the actual potential of the measure is likely to be less than the total area (Olesen et al., 2018). Some of the areas are used for producing high value crops (e.g. carrots and potatoes) and implementing the measure in such areas is likely to be prohibitively costly. Besides, in many cases rewetting of the organic soils on one spot will affect the surrounding agricultural fields and make them too wet for crop growing too. Consequently, the cost of setting aside organic soils may increase to compensate for the effect on the mineral soils.

In Sweden, organic soils are predominantly found on Wetlands (7.4 million ha), Forest land (4.1 million ha) and Cropland (0.1 million ha). The latest National Inventory Report for Sweden highlighted that drained organic soils on Forest land and Cropland were the primary emitters within the LULUCF sector (Swedish Environmental Protection Agency, 2021). Forest land and Cropland respectively

account for 85% and 11% of the total 1.2 million ha drained organic soils in Sweden.

According to a review by Kløve et al. (2017), management options to reduce emissions from drained, cultivated peat soils in the Nordic region are varied, including rewetting, which may prove infeasible in some areas due to for example landscape topography. Furthermore, Kløve et al. (2017) suggest that the selection of best management options should consider both local environmental characteristics and socio-economic needs.

Since 1990, the Swedish state has financed the rewetting of drained organic soil. Between 1990 and 2019, approximately 150 ha of drained organic soils on Forest land have been rewetted, which contributed to an accumulated emission reduction of approximately 9.5 kton for the 20-year period. However, the actual figure may be much larger².

Restoring wetland on agricultural organic land will also affect the surrounding land. As a result, it is suggested that the measure can lead to the removal of an equal amount of arable land on mineral soil from production (Jordbruksverket, 2012), resulting in a total loss of arable land area up to twice the size of the reestablished wetland. It could also be noted that Sweden may target abandoned agricultural lands to reduce emissions from drained organic soils (Ministry of the Environment, 2020).

In Denmark, a scheme called "Lavbundsordningen" (Organic soils scheme) has been put in place by the government, in order to support the implementation of the measure. The scheme is part of the EU Rural Development programme and offers a subsidy to cover expenses related to feasibility studies and actual implementation, and farmers can be compensated for income reductions due to termination of agricultural production. Data pertaining to the Organic soils scheme show that in the period of 2015–2019 the measure has been implemented (or is under implementation) on a total area of 1,296 ha. The total costs amount to 177.8 mDKK corresponding to 137,149 DKK/ha, of which 15% refers to feasibility study costs, while the remaining 85% represent implementation related costs. The implementation related costs include expenses for 20 years retainment, purchase/sale of land, land distribution and actual construction costs. On the land, all existing drainage systems are removed to increase the water level and an easement is laid down that the land must not be cultivated, drained, fertilized or receive pesticide applications in the future. If possible, grazing and collecting of hay is allowed. A minimum reduction of 13 ton CO₂-eq/ha must be obtained to be included in the scheme. Construction costs comprise around 20% of implementation related costs.

In addition to the "Lavbundsordningen", in the Finance Act 2019, a political agreement has been reached, allocating a total of 2.6 bn DKK for the period 2020–2029 to the withdrawal of organic soils from agricultural production, the purpose being to create climate-friendly nature³. Of the total budget, 600 mDKK is to be spent in the period 2020–2022, and approximately 42 % of the funds are to be used for a new national subsidy scheme, while 55 % will be allocated to projects to be undertaken by the Danish Nature Agency. The remaining 3 % are allocated to

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2. See: https://www.naturvardsverket.se/upload/sa-mar-miljon/statistik-a-till-o/vaxthusgaser/vaxthusgaser-utslapp-fran-markanvandning/sweden_LULUCF_art10.pdfhttps://www.naturvardsverket.se/upload/sa-mar-miljon/statistik-a-till-o/vaxthusgaser/vaxthusgaser-utslapp-fran-markanvandning/sweden_LULUCF_art10.pdf
 3. See: <https://fvm.dk/nyheder/nyhed/nyhed/600-mio-kroner-skal-over-tre-aar-forvandle-marker-til-natur-med-klimaeffekt/>

building the knowledge base regarding the measure. In total, the agreement is expected to lead to withdrawal of 15,000 ha of organic soils, and in 2030 the effect is estimated to be 0.27 mio. tonnes CO₂-eq. The scheme is a voluntary scheme, directed at private landowners, municipalities as well as foundations, and offers a one-time compensation for withdrawal of land from agricultural production. The first 3 years are considered a trial period, and the more specific details of the future scheme is to be decided before 2023, drawing on the experiences from the trial period and thereby ensuring the efficiency of the scheme. Moreover, in the Finance Act 2021, further 660 mDKK are allocated to withdrawal of organic soils from agricultural production in the period 2021–2024⁴. This new funding is expected to lead to rewetting of further 5,000 ha of agricultural land with an estimated area of organic soils of 3,000 ha, and the estimated effect is 75,000 tonnes of CO₂-eq in 2030.

In Sweden, Jordbruksverket (2012) discusses agri-environmental support as a policy instrument for restoration of wetland on organic land. The measure would carry an investment cost of SEK 150,000 per hectare of wetland and a maintenance cost of SEK 4,500 per hectare per year during the (assumed) time of maintenance, 20 years. There is also a cost to the landowner because wetlands cannot be used for cultivation. This cost is related to the opportunity cost of land. Jordbruksverket (2012) calculates this cost as the contribution margin for cereal crops, discounted over a 20-year period, resulting in a present cost of SEK 2,500 per hectare. Farmers would have to obtain a compensation covering all of these costs. Together, the measure would entail a cost of SEK 5,100 per hectare of CO₂-eq. Jordbruksverket (2012) suggests locating such wetlands with an aim to simultaneously increase biodiversity. Details in the design of the instrument are not discussed. A more recent report suggests that the potential to reduce emissions through rewetting differs widely across different organogenic soils, and re-wetting of drained peatland seems comparatively more cost-effective. In that case, the private economic cost is estimated at approximately SEK 4,000 per tonne of CO₂-equivalent (Rabinowicz & Jörgensen, 2021).

In Finland, measures to reduce GHG emissions from peatland fields (i.e. cultivated peatlands) have been identified: reducing tillage, increasing vegetation cover, keeping organic matter below water level through controlled subsurface drainage, avoiding new clearing of peatlands, and converting low-yield fields to paludiculture, wetland, forests or leaving them abandoned (Kärkkäinen et al. 2019, Lehtonen et al. 2020). Emission factors for peatland fields under different uses are presented in Figure 3.1. As the emission factors are highest for cultivation of annual and perennial crops, emissions can be reduced through land use conversion especially to paludiculture and restoration. In the final report of ILMAVA project on measures to mitigate climate change in the land use sector (Lehtonen et al., 2021), the emission impacts are evaluated for land use changes for areas of 10, 000 and 50,000 ha. For 50,000 ha, converting land from annual crops to other uses would reduce the total emissions of 8,4 Mt CO₂-eq. by 6–19 %, from perennial grasslands to other uses by 6–13 % and from abandoned land to uses with lower emissions coefficients by 0–8 %.

4. See: [Aftale om finansloven for 2021 og aftale om stimuli og grøn genopretning \(fm.dk\)](#)

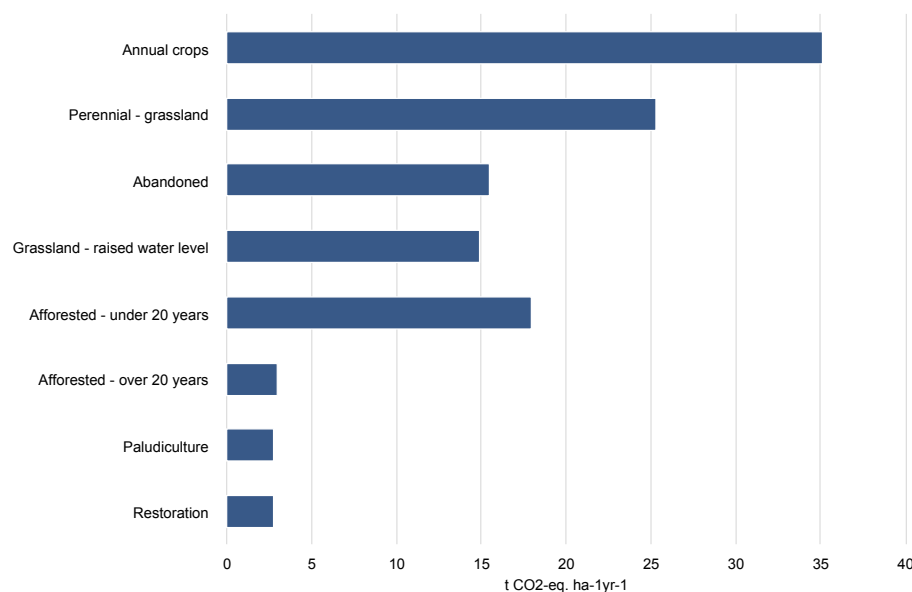


Figure 3.1 Emission factors for different uses of peatland fields in Finland. Emission factors are from Lehtonen et al. 2021, based on IPCC 2014 and Maljanen et al. 2010.

In a scenario analysis of the ILMAVA report (Lehtonen et al., 2021), expert judgement was used to specify the amounts of land converted to different uses. For example, the area converted to afforestation was assumed to be small due to the fact that afforestation of peatland field is often perceived as cumbersome, uncertain and expensive. The scenario analysis is based on the WAM1 scenario presented in Climate road map for Agriculture (Lehtonen et al., 2020). In this scenario the land is taken especially from annual planting but also from perennial planting to cultivating grass with higher water level, paludiculture, afforestation and wetland. A notable amount of land is abandoned. The annual increases in areas are presented in Table 3.3. These land use changes result in about 1.9 Mt CO₂-eq emission reductions in 2050 compared to emissions in 2020. In Table 3.3. the impacts of individual measures on total GHG emissions from peatland field and annual increases in area involved are presented for years 2035 and 2050. The highest emission reductions are associated with abandonment of fields due to the larger areas involved.

Table 3.3 GHG emissions from peatland fields (Mt. CO₂-eq. yr⁻¹) in different years if emission reduction measures were implemented one at a time and the scope of the measure was the same as in the WAM1 scenario in climate roadmap for agriculture, assuming half of the area is taken from cultivation of annual crops and half from perennial crops. In addition, the calculations assume that the total area of peatland fields will not change during the next 45 years. (Source: Lehtonen et al., 2021).

Measure (increase in area /yr)	2020	2035	2050
Increasing grassland with higher water level (633 ha/yr)	8.42	8.27 (-2%)	8.13 (-4%)
Abandonment (1900 ha/yr)	8.42	8.00 (-5%)	7.58 (-10%)
Increasing paludiculture (333 ha/yr)	8.42	8.28 (-2%)	8.14 (-3%)
Re-wetting (500 ha/yr)	8.42	8.21 (-2%)	8.01 (-5%)

The costs of emission reduction differ between measures. The costs have been evaluated to be lowest for controlled subsurface drainage (9–43 €/t CO₂-eq.), silvipaludiculture (4–9 €/t CO₂-eq.) and afforestation (14 €/t CO₂-eq.) according to Koljonen et al. (2017). Furthermore, implementing the above measures would imply notable income losses for farmers. Therefore, substantial compensation is needed to achieve the emission reductions (Lehtonen et al., 2020).

The controlled subsurface drainage is one of the measures under environmental subsidy scheme in the Rural Development Programme for 2014–2020. Subsidies are given both for investments and maintenance. The amount of investment subsidy is 40 % of the qualified costs. The subsidy for maintenance is 70 €/ha.

To promote the cultivation of grass with raised water level, Climate road map for agriculture (Lehtonen et al., 2020) proposes that the subsidy should be 200–300 €/ha to cover the maintenance costs and possible losses in income.

Abandonment, afforestation and restoration imply the loss of agricultural subsidies. These losses are suggested to be compensated in Climate road map. In the case of restoration, it is suggested that the compensation should cover the loss of subsidies and costs of restoration. They suggest annually reducing compensation for 10 years starting from 400 €/ha, maintenance cost of 200–300 €/ha and full compensation of restoration costs of 700–3000 €/ha. Temporary compensation is also proposed to remove peatland fields with low-productivity from use by abandonment. Compensation is also needed for afforestation to partly cover subsidy losses and costs of afforestation. The costs of planting might be even 2000 €/ha as the afforestation of peatlands is challenging.

In addition, reduction in subsidies for uses with high emissions coefficients is suggested in the Climate road map for agriculture (Lehtonen et al., 2020). Subsidies for annual planting with high emissions per hectare should be reduced while subsidies for areas with perennial plants could be slightly increased. However, the more ambitious scenario does not involve a higher subsidy for continuous cultivation. Currently, this measure is part of the environmental subsidy scheme with a subsidy of 50 €/ha.

The measures included in the current Energy and Climate Strategy (Koljonen et al. 2017) and Government Report on Medium-Term Climate Change Plan for 2030 (KAISU, 2017) are controlled subsurface drainage, paludiculture and silvipaludiculture, afforestation and continuous perennial grasslands on organic soils. In the following, we present the expected emission reductions as in these strategy reports, emissions for agricultural and LULUCF sectors are presented separately. However, both of these strategies will be updated in 2021 by utilising e.g. ILMAVA report. For continuous perennial grasslands on organic soils, the expected emission reductions are 0.07 Mt CO₂-eq./year in the agricultural sector and 0.32 Mt CO₂-eq./year in the LULUCF-sector for year 2030. For raising the ground water table through controlled subsurface drainage, the emissions reductions are reported to be 0.14 Mt CO₂-eq. in the agricultural sector and 0.43 Mt CO₂-eq. in the LULUCF-sector in year 2030. Estimated emission reduction for afforestation are 0.23 Mt CO₂-eq. in agricultural sector and 0.26 CO₂-eq. in LULUCF-sector and for silvipaludiculture 0.01 Mt CO₂-eq. and 0.13 CO₂-eq. correspondingly.

The impacts of the above-mentioned measures on other environmental factors are discussed in Lehtonen et al. (2020). The measure 'Continuous perennial grasslands' reduces the nutrient loads and increases the biodiversity. The impact of controlled subsurface drainage on nutrient loads is diverse as raising the groundwater table level might decrease the current loads but the possible need for increased fertilization would have the opposite impact. The immediate impact of afforestation is increased nutrient load while in the long term the loads are in the lower level. Both controlled subsurface drainage and afforestation have diverse impacts on biodiversity.

Several research projects exist to analyse effective ways to reduce emission from fields in organic soils. A project called 'Novel soil management practices – key for sustainable bio economy and climate change mitigation (SOMPA)' develops ecologically and economically sound methods to manage organic soil fields and forests while simultaneously mitigating climate change. SOMPA is a large multidisciplinary project with five organizations and it is funded by the Strategic Research Council of the Academy of Finland. Another project 'Economically sound alternatives for treatment of the peatland fields with deep layers' (RATU) co-develops with farmers, advisors and researchers the solutions for climate friendly agriculture in peatland fields. The project investigates how to use existing peatland fields effectively, identifies solutions to reduce new clearing of peatland fields for cultivation, and applies best practices to reduce emissions. The duration of the project is 2019–2021.

3.2. Energy crops

Energy crops as a measure to increase soil carbon involves the conversion from conventional crop production to production of perennial crops such as willow and poplar. The increase in soil C following conversion primarily occurs in the top 10 cm of the soil. Thus, Georgiadis et al. (2017) find that there is a significant difference in soil C content between soils under short-rotation woody crops such as willow and poplar and soils under cropland when looking at the top 25 cm (the plough layer). Looking at the 0–100 cm layer, however, they do not find any overall differences in the C content of soils under cropland and soils under short-rotation woody crops.

In addition to affecting soil carbon sequestration, the conversion also affects GHG emissions from the agricultural sector in other respects; through changes in the level of N-fertilization, ammonia emissions, N-leaching, and fossil fuel use in agricultural machinery (Olesen et al., 2018). Extending the scope beyond the agricultural sector, production of energy crops may also entail significant reductions in GHG emissions from the energy production sector. The magnitude of this substitution effect depends on which fuel is substituted, but it is suggested to be much greater than the effect from carbon sequestration⁵.

Based on a number of generalised assumptions Olesen et al. (2018) estimates the total average GHG effect within the agricultural sector of converting from single year crops to perennial energy crops, such as willow or poplar, to be 1,376 kg CO₂-eq/ha/year, of which 660 kg CO₂-eq/ha/year can be attributed to increases in soil C.

Energy crops are already grown in Denmark; in 2019 the area with willow was approximately 4,900 ha, and in addition to this there was 3,300 ha with poplar. Olesen et al. (2018) suggest that there is a potential for increasing the area with energy crops by 100,000 ha by 2030. However, the realization of the suggested potential does not seem realistic considering the rather small area at present. In a recent report from the Danish Climate Council (Klimarådet, 2020) a more realistic scenario of 25,000 ha is used; this potential is assessed with reference to an overall scenario, where 100,000 of agricultural land is taken out of rotation. Of these 100,000 ha, 25 % is used for energy crops, and another 25 % is used for permanent grass, while the remaining 50 % is allocated to afforestation.

Energy crops are also grown in Sweden; in 2019 the area with poplar and willow was about 8,700 ha (SCB, 2019), but there is suggested to be a potential for increasing the area grown with energy crops. Meanwhile, in Finland, the area of green grass canary covers 3.000 ha with a decreasing trend. The national peat company VAPO established a program with farmers to produce green grass canary for energy production in the early 2000's. Due to the technical problems and low energy density, green grass canary could not compete with peat and wood-based fuels. New contracts were not established after 2011 and the last contracts were terminated by 2016. In a more ambitious scenario (WAM2) of Climate road map for agriculture (Lehtonen et al., 2020), cultivation of green grass canary in peatlands is suggested as one option to reduce emissions. Green grass canary could be used as litter although the markets should be developed.

There are currently no policy instruments in Denmark specifically targeted at increasing the production of energy crops. However, energy crops can be used to fulfill the Environmental Focus Area requirement, and as an alternative to the requirements for mandatory catch crops and catch crop requirements related to the use of organic fertiliser, which needs to be met in order for farmers to be eligible to receive agricultural support. Thus, in a sense, production of energy crops may be seen as being subsidized, although in a quite indirect way, and not in a way that rewards farmers for producing energy crops but rather in a way that allows farmers to avoid being penalized (i.e. losing support). Moreover, it is noteworthy that the Environmental Focus Area and catch crop requirements are imposed with a view to protect and improve biodiversity⁶ and protect the environment, but not with a view to enhancing soil C sequestration. Previously farmers could apply for a subsidy for

5. See e.g.: https://ec.europa.eu/clima/sites/clima/files/eccp/second/docs/finalreport_agricsoils_en.pdf
6. https://lbst.dk/fileadmin/user_upload/NaturErhverv/Filer/Tilskud/Arealtilskud/Direkte_stoette_-_grundbetaling_mm/2020/Vejledning_om_groen_stoette_2020.pdf

producing energy crops, but this subsidy scheme has been discontinued, and currently farmers lack economic incentive to engage in the production of energy crops such as willow and poplar⁷.

In Sweden farmers can get a subsidy for planting and fencing when planting energy crops on farmland. Also, energy crop cultivation is eligible for farm support, thus giving equal status to energy crops and conventional agricultural crops.

3.3. Afforestation and reduced deforestation

Afforestation is often mentioned as an important measure to mitigate climate change. The effect of forests in terms of GHG emissions varies depending on many factors, one of the most important being the way the forest is managed.

Felby et al. (2018) discuss the GHG effect of untouched forests versus production forest and find that production forests are preferable from a climate perspective. While the net annual GHG effect of untouched forests is zero in the long run⁸, the net effect of production forest can be positive both in the short and in the long run. The net effect of a given forest area, however, will vary over the life of the forest. Under optimal conditions, the maximum amount of C stored in one hectare of Danish forest is equivalent to approximately 1,510 tonnes of CO₂ and of these 840 tonnes are stored in the trees while 670 tonnes are stored in dead wood, decaying plant material and in the soil (Felby et al., 2018). In this regard, it is important to note, that while the net annual GHG effect of untouched forest will be zero in the long run, this does not mean that the climate effect is zero. Thus, the large amount of carbon stored in the forest implies that the forest represents significant value due to its carbon storage capacity.

Johansen et al. (2019) discuss the effect of afforestation on soil organic carbon. Based on comparisons of soil inventories in cropland and forests, and assuming a transition period of 100 years, afforestation is estimated to lead to an increase in soil organic carbon of 0.21ton C/ha/year. The estimate, however, is not deemed sufficiently representative and documented to be included in the FRL (Forest Reference Level). For forests remaining forests evidence suggests that there will be no significant change in soil organic carbon; this suggests that reforestation will not entail increases in soil C. For comparison, estimates of carbon sequestration following afforestation of agricultural land presented in Klimarådet (2020) suggests that the climate effect of afforestation is 4.1 tonnes CO₂-eq/ha/year, and it is noted that the effect can potentially be increased through targeted management.

At present, approximately 14.8 % of Denmark is covered by forest, but the long-term goal is that somewhere between 20 and 25% of Denmark should be covered by forest landscapes⁹ by the end of the 21st century. As significant increases in the forest area are already planned, the additional potential for using afforestation as a measure to reduce GHG emissions is likely to be limited, as land is a scarce resource. However, with reference to the planned increase in forest area, future reductions in

7. See: Landbrugsavisen, 11. Maj 2019; <https://landbrugsavisen.dk/avis/energiagrøder-parkerer-kulstof-i-jorden>

8. There is an upper limit to how much C can be stored in forests, and when this limit is reached, an equilibrium will occur, where the decay of the trees will be equal to their growth.

9. It should be noted that forests and forest landscapes are not synonymous terms; forest landscape is a more inclusive term, also including more open areas of the forest and the border between forests and the open land (Miljø- og Fødevarerministeriet, 2018:14).

GHG reductions through afforestation can be expected. How large the forest related reductions will be is dependent on where the forest is planted, the type of forest (i.e. choice of tree species) and how it is managed. This emphasizes the relevance of adopting a broad and holistic perspective when designing policies rather than focusing narrowly on a single issue. By considering e.g. climate, biodiversity and N-leaching jointly, and explicitly considering spatial differences between different areas (e.g. in terms of N-leaching risk, biodiversity hotspots and suitability for forest production) it may be possible to optimize the sum of environmental benefits compared to a situation where the focus is on one goal, and where other effects are just considered as side-effects.

In both Sweden and Finland, the share of land covered by forest is significantly higher than in Denmark; in Sweden it is approximately 62 % while it is 65 % in Finland. Still, there may be potential for increasing the forested area through afforestation.

In Denmark, there are two subsidies directed at forests; one is a subsidy for afforestation on private land, the other is a subsidy for setting forest areas aside as "untouched forest". None of the subsidies are motivated by climate, but as both initiatives may have an impact on the soil carbon, they are nevertheless considered relevant to mention here.

The subsidy for afforestation on private land is targeted at reducing N-leaching in order to fulfil the targets specified in the Water Framework Directive, but is likely to have an additional positive effect on carbon sequestration. The subsidy for untouched forest is to support biodiversity; the effect of this initiative on soil carbon is less certain, thus compared to production forest it may serve to reduce the long-term climate reduction potential of the forest. It may be noted that not all afforestation initiatives are subsidized; accordingly, an analysis of afforestation initiatives in the period 1990--2012 revealed that 70% of the afforestation had not been subsidized. The advantage of not applying for subsidy is, that it then – in most cases – is possible to avoid forest reserve restrictions; such restrictions imply that once the forest has been established the area has to remain forest forever. In this connection it may be noted that around 85 % of Danish forests are subjected forest reserve restrictions (in Danish "Fredskovpligt") preventing deforestation and ensuring that forests are managed sustainably, as defined in the Danish Forestry Act. The forest reserve restrictions were introduced almost 200 years ago with the purpose of ensuring future timber supply¹⁰.

In addition to the afforestation subsidy, the Danish Government has launched a new initiative, a Climate Forest Fund¹¹. The primary purpose of the fund is to promote afforestation and withdrawal of organic soils from rotation but the focus is also on synergies related to e.g. the water environment and biodiversity. The bill was passed in December 2020¹², and the fund is expected to be operational by the end of 2020. The fund is granted a starting capital of 100 mio. DKK, while future financing is expected to come from donations/investments from private individuals and businesses, who in turn receive a number of CO₂-certificates, which can be used in e.g. businesses' voluntary climate accounts and in reports to e.g. Carbon Disclosure

10. See: https://natureindenmark.lex.dk/Danmarks_skove_and_fredskovspligten-og-tilsyn/

11. See: <https://kefm.dk/aktuelt/nyheder/2020/sep/danskernes-klima-skovfond-vil-nedbringe-co2-og-give-mere-natur>

12. See: <https://www.retsinformation.dk/eli/lt/2020/2186>

Project. The certificates cannot, however, be exchanged for EU ETS quotas.

In Finland, enhancing afforestation is included as a climate measure for the LULUCF sector in government programme. The Act on Temporary Support for Afforestation is scheduled to enter into force at the beginning of 2021, and subsidy could be applied for from the Forest Center from the beginning of March 2021. Subsidy is granted for afforestation of wasteland/abandoned land, such as set-aside areas and former peat production areas. Areas under active farming are not to be afforested under the subsidy, so the aid would be conditional on no agricultural subsidies being granted to the arable sector after 2019. When granting the subsidy, biodiversity, the rural landscape, water management and planning constraints are also considered.

Afforestation subsidy would be granted to private landowners. The subsidy¹³ would consist of a flat-rate compensation as well as a management fee, each based on an average calculated cost per hectare. It is proposed that if forest is established on agricultural land, subsidy would be 2000 € per hectare for peatland and 1500 € for mineral soil. In the case of peat production land, the subsidy would be 1500 € per hectare if afforestation is performed as planting and 1000 € in the case of seedling. The management fee is proposed to be 900 € per hectare, paid in the second and eighth year after afforestation. The subsidy is conditional on no previous funding for afforestation of the same sector. The aim is to create a permanent forest area, so afforestation support would not be granted for growing willow or Christmas trees, for example. The obligation to maintain the afforested area and the obligation to preserve it as forest land would last for ten years.

The potential area of wasteland to be afforested was estimated at about 118,000 hectares, according to the assessment using spatial data by Tapio Oy, a Finnish company that offers advisory and consulting services related to forest management. The potential areas are mainly located in northern part of Finland.

The impact of the afforestation subsidy on GHG emissions was assessed by Natural Resources Institute (Luke)¹⁴. The reduction in greenhouse gas emissions from afforestation compared to previous land-use emissions is based on the increase in carbon sequestration by growing stands, reduction in emissions from soil and increase in soil carbon stock. The reduction in greenhouse gas emissions caused by afforestation varies notably (3.8-17.1 tonnes CO₂ eq./ha/yr) depending on the previous land use, land type, tree species and time period after afforestation. The largest climate benefit would be achieved by afforesting peatland-based fields and former peat production areas due to the reduction of emissions from soil. Afforestation of former agricultural land in mineral soil increases carbon sequestration by an average of 3.8 tonnes of CO₂ eq./ha/yr compared to initial land use during the first 15 years. Afforestation of former agricultural production in peatland reduces emissions by 9.8 tonnes of CO₂ eq./ha/yr and afforestation of former peat production land by 7.8 tonnes of CO₂ eq./ha/yr over the corresponding period.¹⁵

If the annual afforestation area of abandoned land in Finland were 3,000 hectares per year for the next 15 years, i.e. a total of 45,000 hectares, greenhouse gas emissions would decrease by an average of 0.1 million tonnes of CO₂ eq/year

13. <https://mmm.fi/metsat/metsatalous/metsat-ja-ilmastonmuutos/joutoalueiden-metsitys>

14. <https://mmm.fi/metsat/metsatalous/metsat-ja-ilmastonmuutos/joutoalueiden-metsitys>

15. The option to apply afforestation should be compared with the alternative of rewetting the land, as one cannot apply both measures on the same land.

compared to previous land use. If the reference period were 45 years, greenhouse gas emissions would decrease by an average of 0.2 million tonnes of CO₂ eq/year. In ILMAVA report (2021), the emission reductions are reported for areas of 90,000 ha and for the theoretical potential of 118,000 ha, in addition to 45,000 ha. For the 118,000 ha, the average annual emission reduction would be 0.25 million tonnes of CO₂ eq for the next 15 years.

In Finland, forests are still being converted into built-up area and agricultural land. The emissions from forest loss are quite high in Finland. The area involved is largest in the case of converting forests into built-up areas while GHG emissions are highest when forests in peatland are cleared for agricultural usage such as manure spreading. Efforts are made to reduce the clearing of forest into agricultural land by developing the processing and utilisation of animal manure (including the biogas programme) and planning and advisory services. With respect to built-up areas, a charge to be collected for land use changes and other possible steering instruments are being considered. According to Timonen (2020), the carbon payment related to land use change would however be an inefficient mechanism to reduce deforestation due to the administrative burden of the large number of small areas involved. Instead, strengthening the Acts on land use and buildings with a perspective of reducing deforestation is suggested to be more effective.

Afforestation and deforestation were studied in the project 'Potential of land-use measures in climate change mitigation' (MISA; Kärkkäinen et al., 2019), according to which, climate benefits from decreasing deforestation generally exceeded those from increasing afforestation in Finland. The most beneficial would be to decrease the deforestation on peatlands. Results also showed that for the low productivity agricultural land with thick peat layer, the climate benefits from afforestation valued with the price of emission trading correspond to the average land rent of agricultural land in the northern parts of Finland.

In ILMAVA project (Lehtonen et al., 2021), the potential to mitigate climate change through reducing deforestation was evaluated further by providing three additional scenarios compared to MISA scenarios. The highest annual GHG emission reductions of 0.68 Mt CO₂-eq. in 2035 and 0.86 in 2050 Mt CO₂-eq were obtained in the scenario in which clearing of peatlands is reduced the most. However, the difference in emission reduction is small compared to the scenario with equal reductions in deforestation in peatland and mineral soils. This is partly explained by the fact that emissions from built-up areas and total amounts of clearing are of the same magnitude. The notable amount of emissions is caused by removed trees in clearing and that is identical in both scenarios.

Wejberg (2020) studied whether afforestation subsidy would be a cost-effective instrument to reduce emissions from both agriculture and the LULUCF sector in Finland. The amount of afforestation subsidy required was calculated as a difference between the net present value of the fields and afforestation. The climate benefits of afforestation in thick peatlands with annual crops were greater than the amount of afforestation support required, for the areas of all ELY centres (The centre for economic development, transport and environment). Afforestation subsidy was found to be an efficient instrument for cessation of peatland cultivation, according to the net present values calculated. If perennial crops were grown on thick peatland, the cost of afforestation subsidy was higher than the climate benefits of afforestation of peatland in some ELY centres. The price of carbon applied in the

analysis was 25 €/t CO₂. At the current price of EU ETS allowances, afforestation support appeared to be a cost-effective way of reducing emissions from agriculture and the LULUCF sector.

Although production subsidies are abolished under the present Swedish Forest Act, there are some initiatives related to forestry, which may be relevant to mention here. One is a compensation scheme related to untouched/biodiversity forest¹⁶; the compensation is based on negotiation, and the scheme is targeted at improving biodiversity. Nevertheless, it may be relevant as it may affect the level of carbon sequestration. In addition to this, there is a subsidy for afforestation/rejuvenation of broadleaved forest (Ädellövskogsbruk) and for establishing forests for nature and cultural purposes (Nokås)¹⁷. The purpose of these subsidies is not climate mitigation, but nevertheless they may have an effect on the future level of carbon sequestration of the forest.

3.4. Reduced tillage

Reduced tillage comes in different versions, one being no tillage. No – or reduced – tillage is one of the three guiding principles behind conservation agriculture. The other two being permanent crop cover and varied crop rotation (never cultivating the same crop two years in a row) (SEGES, 2019). Since reduced tillage is often practiced jointly with the other principles and practices of conservation agriculture, e.g. varied crop rotation, use of catch crops and retention of straw, which all may contribute to increasing the carbon pool of the soil, it may be difficult to isolate the effect of reduced tillage on soil C (Olesen et al., 2018).

Reduced or no tillage is advocated as a climate smart agricultural practice due to its perceived positive effects in terms of climate mitigation (increase soil C) as well as climate adaptation (e.g. reduced soil erosion and improved water management). Numerous findings, however, show conflicting results regarding the carbon sequestration effect of reduced tillage, suggesting that reduced – or no – tillage may not represent as promising a climate mitigation measure as initially assumed. Meurer et al. (2018) compares the soil organic carbon content of soils across 3 different tillage intensities and finds that the SOC content is higher for intermediate tillage intensity and no tillage compared to high tillage intensity, but the effect is limited to the top soil, i.e. the top 30 cm of the soil. Similarly, Munkholm et al. (2020) report findings from studies suggesting that the effect of no-till practices primarily is a redistribution of the soil carbon content between different layers of the soil rather than an absolute increase. Meurer et al. (2018) conclude that their results indicate, that the C sequestration potential of no till cultivation practices is overvalued when neglecting deeper depths. This conclusion is supported by findings reported in Olesen et al. (2018), and is in line with the conclusion of Ogle et al. (2019), where it is suggested that no-till should primarily be perceived as an element of climate smart agriculture that can contribute to facilitating adaptation, rather than as a practice that can contribute to mitigation through carbon storage.

With reference to international meta studies and Danish field trials, Munkholm et al.

16. See: <https://jordbruksverket.se/stod/lantbruk-skogsbruk-och-tradgard/investeringar-inom-lantbruk-tradgard-rennaring-skogsbruk/miljoatgarder-i-skogen>

17. See: <https://www.skogsstyrelsen.se/aga-skog/stod-och-bidrag/adellovsstod/> and <https://www.skogsstyrelsen.se/aga-skog/stod-och-bidrag/nokas/>

(2020) note that the effect of direct sowing on soil carbon is negligible – or at least very minor – in cold and wet climates, thus suggesting the effect to be questionable under the climatic conditions prevailing in the Nordic countries. Results of recent Danish studies focusing on the C content of the top 50 cm of the soil support this conclusion, as the results of trials at two different locations covering the period 2002--2019 only come close to being significant. However, since the results are close to being significant, it is suggested that there might be an effect if the practice is continued in the long term. If there is an effect, Munkholm et al. (2020) emphasizes that the effect will be declining over time, as a new equilibrium is established (decades).

Tillage intensity can also affect N₂O emissions, but the effects are complicated, and the sign of the net-effect can either be positive or negative, and accordingly it is not possible to estimate an effect based on existing knowledge (Olesen et al., 2018). However, to consider reduced tillage as a climate mitigation measure, it may be important to also factor in the effect on N₂O emissions in order to avoid situations where the net-climate effect will be negative.

It is relevant to note that reduced tillage entails a reduction in GHG emissions due to reduced use of fuel in agricultural machinery. The reductions are estimated to be in the interval of 33–64 % depending on the more specific practices (Olesen et al., 2018).

No-till cultivation is primarily implemented in conventional agriculture, as no-till cultivation often creates good conditions for pests such as leaf fungi, slugs and grass weeds (Olesen et al., (2018). Increased presence of pests means that increased use of pesticides may be necessary if an acceptable yield needs to be maintained, and such use of pesticides is evidently not compatible with organic agricultural practices.

No-tillage cultivation practices are becoming increasingly popular among Danish farmers. From 2016 to 2018 the no-tilled area (area cultivated without ploughing and direct sowing) increased by 26 % from 253,000 to 319,000 ha, which corresponds to approximately 12 % of the total Danish agricultural area¹⁸. The conversion to reduced - or no - tillage in Denmark has been driven by farmers themselves; thus, the adoption of reduced tillage is not prescribed by any regulatory initiative, nor promoted by subsidization.

Munkholm et al. (2020) provides an overview of the prevalence of conservation agriculture in several countries including Denmark, Sweden and Finland. The overview is based on the area where direct sowing is practiced; the share of agricultural land in rotation where direct sowing is practiced amount to 2 % in Denmark, 0.7 % in Sweden and somewhere between 5.5 and 9.2 % in Finland. Thus, the practice is significantly more common in Finland than in the two other countries, but it is noted that interest in the practice is declining.

18. See e.g.: <https://www.dst.dk/da/Statistik/bagtal/2019/2019-08-26-flere-danske-landmaend-dropper-ploven>

3.5. Catch crops

Catch crops are primarily established as a means to reduce nitrogen leaching from fields, and they are established between the main crops or undersown in cereal. Catch crops have several effects on the GHG balance working in opposite directions; N₂O emissions increase, while the C storage in the soil also increases. According to Eriksen et al. (2020) the average increase in N₂O emissions across soil types is 29 kg CO₂-eq. per ha per year, while the increase in soil C is around 990 kg CO₂-eq. per ha per year.

Catch crops are already widely used in Danish agriculture, estimated at around 550000 ha (Hutchings et al., 2020). The primary aim of catch crop implementation in Denmark is to reduce N-leaching. However, there is still considered to be ample potential for increasing the area with catch crops although it is noted that the costs of using the measure are estimated to increase as certain thresholds are reached (e.g. when increased use necessitates transition from winter sown crops to spring sown crops) (Eriksen et al., (2020).

In Denmark, catch crops are implemented through four instruments. 1) Mandatory catch crops, a requirement for catch crops targeted at reducing N-leaching for all farms above 10ha¹⁹. 2) Livestock catch crops, a requirement for catch crops for farms applying more than 30 kg N per ha from animal manure or other organic fertilizer (not organic farms)²⁰. 3) Targeted catch crops, via mandatory and targeted schemes, contributing to the targeted N regulation. 4) Ecological Focus Area catch crops, the requirement for Environmental Focus Areas (EFA) (Miljøfokusområder; MFO), which constitute one of three Greening Requirements (according to the CAP 2013–2021). Here catch crops represents one of several options for fulfilling the requirement, which is a prerequisite for receiving the “green share” of the direct agricultural support, which constitutes 30% of the total direct agricultural support. It is worth noting that the fulfillment of compulsory and livestock catch crops can be met using alternative measures such as early sowing of certain winter crops, set aside areas, perennial energy crops or reduction of Nitrogen quota²¹.

In Finland there is a subsidy for establishing plant cover on arable land during winter; the subsidy is part of the Rural Development programme, and it is one among several measures for climate change mitigation and adaptation.

As in Denmark, catch crops represent one among several options for fulfilling the greening requirements – a prerequisite for being eligible to receive the general agricultural support – in Sweden. The purpose of the greening requirements is to promote biodiversity and reduce the impact of climate change. In Sweden, catch crops are also subsidized as part of an environmental subsidy scheme for fields located in nitrogen sensitive areas. The purpose of the subsidy is to reduce nitrogen leaching and phosphorus loss, and to store carbon in the fields. In Finland, a subsidy of 100 €/ha is given to catch crops as part of an environmental subsidy scheme. However, it is limited to 25 % of the area under subsidy scheme. The objectives of the subsidy are similar to those in Sweden and Denmark, while improved productivity of land is also mentioned as a benefit from catch crops. The catch crops cover an area

19. <https://lbst.dk/landbrug/efterafgroeder-og-jordbearbejdning/efterafgroeder/pligtige-efterafgroeder/#c48967>

20. <https://lbst.dk/landbrug/efterafgroeder-og-jordbearbejdning/efterafgroeder/husdyrefterafgroeder/#c47955>

21. See “Faktaark om alternativer til efterafgrøder 2021” (Facts sheet on catch crops) available at: [Efterafgrøder - Landbrugsstyrelsen \(lbst.dk\)](https://lbst.dk/landbrug/efterafgroeder-og-jordbearbejdning/efterafgroeder/pligtige-efterafgroeder/#c48967)

of over 100,000 ha, which is more than 5 % of the agricultural land. The lack of guidance on cultivation practices, weak seedling and worries that catch crop might beat the main crop have been identified as potential reasons why cultivation of catch crops has not spread more widely.

3.6. Set-aside (short term)

Changing land use from rotation to set-a-side in the form of unfertilized grass can be used as a measure to reduce GHG emissions. Designating an area as set-a-side implies that the area is taken out of rotation in a period (minimum one year and maximum 4 years); thus, the change is only temporary. On areas used for set aside, neither tillage, fertilization, use of pesticides nor grazing are allowed. The plant cover has to be cut once a year, but the biomass cannot be removed from the area (Olesen et al., 2018).

Olesen et al. (2018) estimates the average total GHG emissions effect of (short-term) set-a-side to be 2,189 kg CO₂-eq/ha/year, where 602 kg CO₂-eq/ha/year can be attributed to reduced N₂O emissions while 1,087 kg CO₂/ha/year comes from reductions in energy use. The remaining 500 kg CO₂-eq/ha/year comes from increased carbon storage in the soil. Here, however, it is important to note the temporary nature of the effect of the measure. Thus, set-a-side, which can also be seen as a grass field, will increase the carbon stock in soil in the years subjected to set-a-side. For all soils, the organic soil carbon stock is an equilibrium between the annual input of organic matter (OM) and the degradation of soil organic matter (SOM). Implementing set-a-side will increase SOC during the set-a-side phase but conversion to annual cropland after the set-a-side period will revert the amount of SOC to its initial equilibrium value. Therefore, to have an effect which is not temporary, set-a-side has to be permanent.

In principle, the measure is relevant on all land in rotation, but in practice the potential of the measure may be more limited. In Denmark, there are demands for having a certain area of agricultural land per livestock head, which is used for manure spreading (harmony area)²². Areas used for set-a-side are not included in the calculation of the harmony area, and this may limit the potential of the measure, particularly on livestock farms where the harmony area requirements represent a constraint (Olesen et al., 2018).

In Denmark set-a-side can be used to fulfill the Environmental Focus Area requirement²³, and can also be used as an alternative to fulfill the requirements for mandatory catch crop requirements related to the use of organic fertilizer²⁴ and livestock production, or in the targeted nitrogen regulation.

Similarly, set-a-side can also be used to fulfill the Environmental Focus Area requirements in Sweden.

22. See: <https://lbst.dk/landbrug/goedning/husdyrgoedning-og-anden-organisk-goedning/harmoniregler>

23. https://lbst.dk/fileadmin/user_upload/NaturErhverv/Filer/Tilskud/Arealtilskud/Direkte_stoette_-_grundbetaling_mm/2019/Vejledning_om_grundbetaling_2019.pdf

24. <https://lbst.dk/landbrug/efteraegroeder-og-jordbearbejdning/efteraegroeder/pligtige-efteraegroeder/#c48967>

3.7. Promoting forest productivity and health

Enhancing production in existing forests, enhanced forest management and strengthening protection against natural disturbances are mentioned as measures to mitigate climate change in existing forests in Finland, but they are also likely to be relevant in the other Nordic countries. It is worth noting however that in Denmark, the management of state-owned forests follows a set of close-to-nature principles, an approach that is quite different from the approaches in the other Nordic countries²⁵. The principles have been implemented since 2005. Some private forest owners are keen to adopt the principles while others hold on to the typical age-class plantation system (Larsen, 2012).

The forest tree improvement²⁶ and efficient silviculture are ways to accelerate the growth of trees in the long run (Hynynen et al., 2017). The growth of stands, which, all else equal, translate into increased carbon sequestration, can also be influenced by the choice of thinning tree species and by regulating the intensity, timing and method of thinnings. The productivity of forest land, in turn, can be increased through soil preparation, fertilization and maintenance ditching in peatlands.

On mineral soils, the forest nitrogen fertilization may increase the growth by 1.5–3 m³ per hectare annually during 6–8 years (Hynynen et al., 2017). On drained peatlands, the fertilization with ash is applied and it has more permanent effect. According to Hynynen et al. (2017), the growth could be increased by 1–3 m³ per hectare annually over the next 20–30 years. In the ILMAVA report (Lehtonen et al., 2021), fertilization is one of the measures for which the potential to increase carbon sequestration has been evaluated. In the scenario for fertilization by ash in peatlands, the area under fertilization is increased annually by 30,000 ha until 2025 and by 100,000 ha annually between 2026–2035. This implies that in 2035 the annual growth of forests would be 1.07 million m³ higher than the growth under current level of fertilization. This corresponds to the increase in the annual carbon sink by 1.2 Mt CO₂ in 2035. For mineral soils, the area under nitrogen fertilization was increased annually by 30,000 hectares until 2025 and 60,000 ha until 2035. The annual increase in forest growth was evaluated to be 0.54 million m³ in 2035 and corresponding additional annual carbon sink was 0.62 Mt CO₂. However, it may be noted that increased use of nitrogen fertilization may have a negative impact on the water environment, manifested through increases in N leaching.

Fertilization has been traditionally subsidized under KEMERA subsidies only if there exists a nutrient imbalance in forest land. Expansion of subsidy for fertilization by ash was recently established in order to increase forest carbon sink. An existing subsidy scheme, that is part of the KEMERA subsidies, was temporarily expanded by removing the requirements for nutrient imbalance. Fertilization by ash is applied mainly in forests in peatlands. It is expected that the area involved annually will increase from 11,000 ha to 30,000 ha and the annual costs would increase from 1.25 million to 4 million years. No estimate on impact on carbon sink or storage has been provided. The act came into force on May 1, 2020.

The Finnish forests are mainly in good health and large damages do not generally exist. Root rot, wind and moose are the main causes of damages in forests. The risks of damages can be reduced with efficient forest management, timing of harvests

25. <https://eng.mst.dk/trade/forestry/https://eng.mst.dk/trade/forestry/>

26. Forest tree improvement refers to a process of improving the genetic quality of a tree species.

and maintaining the mixed tree species in forests (Hynynen et al. 2017). Changing climate will nonetheless increase the risks of damages.

The Act on Forest Damages regulates actions related to forest health. Its aim is to ensure that forest management, harvest and storage practices do not weaken the health of forests, especially by taking care that the number of insects remain low. The root rot control during harvests (excluding winter) became obligatory in 2016.

3.8. Summing up

The review of measures in the previous sections suggests that all but one, namely reduced tillage, represent potentially relevant measures in terms of increasing carbon sequestration and/or reducing GHG emissions from the LULUCF sector. For the measure 'set-aside' it may however be noted that the relative desirability of the measure in terms of climate mitigation to some extent is limited by the fact that the effect ceases by the time the set-aside allocation is terminated i.e. the land is put back into production/cultivation. Thus, using set-aside as a climate measure may not be very relevant, but on the other hand it may be important to include the climate effect of the measure when designing other regulations, e.g. related to N leaching, as including climate side-effect may serve to increase the overall efficiency of N regulation.

All the reviewed measures are seen to be implemented to some extent in one or several of the Nordic countries, although it only is for a minor subset of the measures that the climate effect is the main goal of the implementation. As the climate effect of a given measure in many cases is seen to vary significantly depending on where the measure is implemented, and/or the more specific characteristics of the measure, the fact that climate often is not the prime motive for implementation may imply that the realized climate effect is less than it could have been. For most measures, however, the potential positive effect in terms of climate is acknowledged, and it seems that focus is increasingly being directed at climate as a specific secondary effect of the reviewed measures. Thus, there already seems to be a widespread recognition of the fact that the adoption of a more holistic perspective may increase the cost efficiency of environmental and climate regulation.

The reviewed measures with the largest effect are withdrawal of organic soils from agricultural production and changes in peatland farming practices. Both these measures concern soils with a high soil organic carbon content, and the estimated GHG effect of these measures are up to around 30 tonnes CO₂-eq. per ha per year, although varying significantly depending on local conditions and the type of management change. It should be said that withdrawal of organic soils, including rewetting, will only limit the current CO₂ emission. It will not sequester carbon, which is very important to avoid further global warming. Therefore, in the longer term, withdrawal of cultivated organic soils shall be combined with carbon sequestration measures. While numerous studies have reported how rewetting contributes to emission reduction (e.g. Martens et al., 2021; Günther et al., 2020), studies remain lacking that examine the long-term effects of rewetting for restoration of ecosystem functions and processes such as carbon sequestration and biodiversity (Kløve et al., 2017). It is also important to note the climate mitigation trade-offs of

rewetting, between CO₂ emission reduction on the one side and CH₄ emission increase on the other (e.g. Renou- Günther et al., 2020; Wilson et al, 2019).

Carbon storage in soils as biochar has not been covered in this paper. Biochar is created by pyrolysis of organic matter and the remaining carbon has a very low degradation rate in soil, which leads to an overall increase in the soil carbon stock. The technique is currently under development and it is therefore not possible to give good estimates for the costs and its possible short-term implementation in agriculture. Nonetheless, it seems to be a more promising measure for storing CO₂ even in the longer term compared to afforestation.

The effects of the other reviewed measures are significantly lower, but this does not necessarily imply that they are less cost-efficient. Thus, an important distinction between the reviewed measures is whether they refer to changes in production – implying that either agricultural or forestry production can continue in the future – or to changes that require withdrawal of land from productive use. Just as the effect will vary from case to case the costs are also likely to vary - both across measures and across specific locations, and all else equal, costs will be higher for measures involving withdrawal of land from production than for less invasive measures. Accordingly, less effective measures, which allow production to continue, may be the best option in areas where the land production value is high, while measures requiring withdrawal of land from production may primarily be relevant in areas where the land production value is low.

Overall, there does not seem to be very much variation in terms of policy instruments where the implementation of existing measures is either promoted through subsidization (fixed subsidies or cost coverage) or by command-and-control regulation (e.g. catch crop requirements). As mentioned in Section 3.4 there are ongoing discussions in Finland about implementing a land use change tax, suggesting that focus is starting to be directed at potential new policy instruments that provide economic incentive for landowners to make climate friendly land-use decisions without burdening public finances.

Despite the reviewed measures already being implemented to varying degrees, there seems to be potential for additional future implementation of these measures. Thus, there seems to be ample scope for increasing the contribution of the LULUCF sector to climate mitigation²⁷. Moreover, with reference to the limited variation in the policy instruments applied currently, it seems highly relevant to investigate the potential for expanding the policy instrument portfolio in order to underpin the cost effectiveness of carbon sequestration measures in the LULUCF sector in the Nordic region.

27. In Finland, two comprehensive reports, the climate roadmap for agriculture (Lehtonen et al. 2020) and ILMAVA report (Lehtonen et al. 2021), highlight the important role of land use sector to contribute to Finland's climate target towards carbon neutrality goal by 2035. The realization of the land use sector's participation is expected to require substantial resources for providing sufficient incentives for farmers to implement land use the necessary land use measures.

4. Potential policy instruments for enhancing carbon sequestration in the Nordic countries

At present, as can be seen in the preceding chapter, policy instruments explicitly targeted towards promoting carbon sequestration through land-use activities (LULUCF) in the Nordic region are very limited. However, based on the review of a selection of policy instruments, these instruments can have desirable positive effects on climate mitigation. Moreover, the types of policy instruments that have been used are less diverse, primarily taking the form of subsidies.

In this chapter, drawing from literature and practices elsewhere, a selection of policy instruments that have the potential to be implemented to increase carbon sequestration in agricultural soil, forest, and wetlands/peatlands in the Nordic countries is presented. The pros and cons of the instruments are discussed with respect to the criteria described in chapter 2, i.e. additionality, leakage, permanence, transaction costs, heterogeneity, side-effects and risk.

The chapter is structured in two parts. One presentation of the general instruments on land-based measures, and the other presenting the management of existing forests, as the time dimension and experiences are different between these two subject areas.

4.1. Potential instruments for land-use based carbon sequestration

This section presents policy instruments, focusing on the economic type, which can be potentially deployed to increase carbon sequestration or to reduce emissions through afforestation, wetland management, and climate smart agricultural practices. Insights are drawn from solutions analysed and discussed in the literature as well as those already implemented elsewhere but not yet considered and/or applied in the Nordic countries.

4.1.1. Integration of land-use based carbon sequestration in emission trading schemes

Incorporating land-use-based carbon sequestration, including agricultural soil carbon, into the European Emission Trading Scheme, has been called upon as a potential policy instrument. For example, Verschuuren (2018) argued that existing policy instruments were "inadequate to stimulate large scale adoption of soil carbon projects across Europe". Verschuuren proposed the inclusion of agricultural land use in the EU ETS through sales of carbon credits resulting from climate smart agricultural practices. In this way, farmers/landowners generate income from participating in the trade.

While the potential has been acknowledged, realising a carbon market for the land-based sector will necessitate 1) secure carbon price in the long run, and 2) robust and reliable mechanisms for monitoring, reporting and verifying (MRV) the carbon effects generated from the implementation of the chosen land-based measures (Verschuuren, 2018; van Kooten et al., 2009, Walcott et al., 2009). In order to facilitate individual landowners to participate in the carbon market, the MRV requires reliable methods and analysis as well as accurate data that can accommodate small units and scales and the variation in soil types and land uses. Equally important is how to ensure that the carbon sequestration takes place as a result of the implementation of certain management practices (i.e. due to human interventions) not something that would otherwise occur naturally; hence requiring an assessment of how the soil carbon contents change under different management options (Walcott et al., 2009).

A number of challenges/issues have been highlighted, affecting the legitimacy of carbon offset credits from biological/terrestrial carbon sequestration, hence their incorporation into carbon trading scheme. These include high transaction costs for MRV, leakage, additionality, impermanence, uncertainty, heterogeneity of land and landowners, distributional impacts on land managers/farmers (van Kooten et al., 2009, Walcott et al., 2009; Gren and Aklilu, 2016; Grosjean et al., 2017). In addition, a selection of land-based measures for climate mitigation particularly those on agricultural land may not be attractive as carbon offset. Therefore, CAP is expected to play an important role to fill the gap but needs to be geared more explicitly towards climate mitigation and adaptation objectives and to remove or reduce barriers for participation by land managers/farmers (Grosjean et al., 2017, Verschuuren, 2018). Reallocation of CAP funds, for example for buying carbon offset from land managers/farmers, is worth considering. However, it is important to not only assess the carbon effect but also to account for the full greenhouse gas emission effect of implementing agricultural practices for carbon sequestration, for example using a life cycle analysis (Walcott et al., 2009). In the same vein, any potential trade-offs with other environmental objectives have to be evaluated (Grosjean et al., 2017).

Some solutions to a selection of the aforementioned challenges/issues have been suggested, for example a review by Gren and Aklilu (2016). To address uncertainty in land-based carbon sequestration risk, discounting can be applied whereby the value of carbon sequestered from land-based measures is discounted to a fraction of that from permanent sequestration. For example, in a carbon offset system, carbon sequestered through land-based measures is set to be worth half the carbon credits derived from permanent sequestration or from technology-based emission abatements. Meanwhile, solutions to manage risks of non-permanence in land-based carbon sequestration projects have also been identified. One of the solutions is to apply buffer credits by deducting and setting aside a certain percentage of the eligible carbon credits (e.g. 10%), which can be claimed back at the end of a project if it successfully demonstrates the absence of carbon reversals. Another solution is a combination of setting a minimum timescale for carbon sequestration projects, assigning liability for carbon reversal events and applying a penalty for project withdrawal. To manage additionality of land-based carbon projects, designing optimal contract and emissions baselines has been suggested. It can also be addressed by additionality tests following approved standards on a project-by-project basis. Furthermore, to account for permanence, leakage and additionality, Murray et al. (2007) highlighted three methods to account for carbon reversal in

order to adjust carbon credits from agricultural soil carbon sequestration: 1) Comprehensive method – assigning carbon credits based on either “carbon stock change” or average carbon storage, which are informed by regular measurements of carbon stock; 2) Ex ante discounting – to discount the carbon credits of a project by X% based on the amount of expected future carbon loss. As such, carbon credits are assigned based on expected (ex-ante) rather than measured carbon storage over time; 3) Temporary crediting – assigning carbon credits to be valid only for a finite period of time. In this case, one of the key tasks is to determine the appropriate credit period hence the expiry date of the temporary credits.

While many studies have reported on the marginal costs of land-use-based carbon sequestration and on how these are comparable to the marginal cost of technology-based abatement, reports on the transaction costs remain lacking. For example, a meta regression by Kooten and Sohngen (2007) on studies of carbon offset credit from forestry activities show that none of the studies reported transaction costs. Van Kooten's analysis (2009) indicates that most carbon sink projects in the analysis would not be economically viable due to the large transaction costs. Furthermore, van Kooten also argued that in general the opportunity cost of land is high which poses an important barrier to the development of terrestrial carbon sinks.

Van Kooten (2009) highlights the need to clearly assign debits and credits as they occur at a certain point in time. A debit occurs whenever an anthropogenic activity releases CO₂ into the atmosphere, regardless of the source. A credit is earned by removing CO₂ from the atmosphere and storing it in a terrestrial sink. Example from forest, credit accrues from carbon stored in products (e.g. harvested timber) and in soils but by the time the wood products decay and/or carbon released from soils then these become debit. Credits can be earned from avoided deforestation only when countries agree to have targets on deforestation. Otherwise, it would only result in avoided debits.

The prospect for creating carbon markets for land-based sequestration in the Nordic countries is likely to be determined by the future direction of EU ETS. Until now, carbon sinks from land-based measures are not covered by EU ETS. Views on the matter among relevant actors are still divided whereby those opposing the proposal of including land-based activities into EU ETS are concerned by a number of factors including the high uncertainty and reversibility/non-permanence of land-based carbon credits (Hirsbrunner et al., 2011), which consequently require paramount resources for verification, monitoring and control and lead to large transaction costs. Selecting relevant measures for inclusion in carbon markets therefore need to ensure that uncertainty in the magnitude of and reversibility of the carbon credits resulting from the measures are minimized. Still, the realization of carbon markets for land-based sequestration in the Nordic countries depend on the future development of EU ETS and necessitate joint forces between the countries included in the EU ETS.

Considering the various challenges previously discussed, which reduce the likelihood of incorporating LULUCF into EU ETS, alternatively, a separate trading scheme for land-based carbon sequestration maybe explored in the future. This highlights the need for future studies on how to design such a scheme cost effectively. In the meantime, the idea of creating a market for carbon from land-based activities (agricultural land, forested land, and wetlands) could well be linked to more recent EU directives. Within the European Union (EU), Member States are required to compensate carbon emissions from land use, land-use change, and forestry (LULUCF) by an equivalent removal of CO₂-equivalents from the atmosphere until

2030 (EU, 2018a). Limited crediting of increases in carbon pools against national targets for fossil fuels but not against the EU Emission Trading Scheme is permitted (EU, 2018b), implying a risk that the cost saving potential is underutilized (Gren et al., 2012). However, flexibility rules permit Member States to buy and sell net LULUCF carbon removals between each other, encouraging countries with low removal costs to reduce the sectors' emission below the point of carbon neutrality (EU, 2018b). Even so, policy instruments targeting carbon sequestration are lacking at the EU level, and are scarce and nontransparent at national level (Vrebos et al., 2017; Gren and Aklilu, 2016).

4.1.2. Result-Based Schemes for Land-Based Climate Mitigation

Existing economic instruments to incentivize landowners in Europe are predominantly action based; also known as input based or practice based or measure based (cf. Derissen and Quaas, 2013; Burton and Schwarz, 2013). This observation also applies to the Nordic countries. With action-based schemes, landowners receive payment for undertaking a set of land-use and/or management practices irrespective of the magnitude of the environmental effects that the actions deliver. An alternative instrument, which is gaining growing interest in the academic literature, is the so-called result-based scheme (RBS) whereby landowners are compensated based on the actual or expected outcome/performance such as the amount of carbon sequestered. In a way, RBS takes into account the fact that the environmental outcomes that landowners deliver depend not only on the choice of technical measures but also on the spatial/environmental heterogeneity of the lands e.g. soil properties and topography. Under RBS, landowners have the flexibility and the incentive to be innovative; to identify cost effective strategies by focusing on a portfolio of measures that deliver large effects on the biophysical characteristics of their lands while ensuring that the costs are minimized (cf. Burton and Schwarz, 2013).

While the appeal of RBS has gained attention, some cautions are worth mentioning. The operationalization of RBS will need to be supported by new/hybrid legislative framework and institutional settings (Colombo and Rocamora-Montiel, 2018). An appropriate advisory system will also be required to support innovation and flexibility (Moxey and White, 2014). Moreover, it has been argued that RBS does not necessarily address all the downsides of the design of the current, action-based incentive mechanism. It has been further argued that attention could be given towards better spatial targeting, payment differentiation and monitoring (Moxey and White, 2014). Others have called for an optimal approach that combines action-based and performance-based incentives. While purely action-based schemes are optimal only in the absence of information asymmetry between landowners and the regulator, exclusively performance-based payments are optimal only if the performance is not risky (i.e. no environmental uncertainty present) or if landowner and the regulator are risk-neutral (Derissen and Quaas, 2013). As information asymmetry increases, the welfare gain of a purely action-based scheme over a combined scheme reduces. In the same vein, as environmental uncertainty increases, the welfare gain of an exclusively result-based scheme over a combined scheme reduces (Derissen and Quaas, 2013).

A growing body of research on RBS thus far largely pertains to biodiversity conservation while examples with respect to land-based climate schemes remain scant (e.g. Colombo and Rocamora-Montiel, 2018). It is worth noting nonetheless

that practical applications of RBS in Europe, although mostly still at their early phase, are gaining importance as exemplified by the four initiatives below.

Woodland Carbon Code

The overall purpose of the Woodland Carbon Code (WCC) is to generate verified carbon credits from woodland creation projects in the UK²⁸. These carbon credits are then made available for sale to companies as carbon offsets. WCC therefore provides a platform that makes landowners have the incentive to voluntarily plant woodland and gives companies in need of carbon offsets the confidence that they purchase verified carbon units. Woodland creation is only approved for mineral and organomineral soils. Organic soils are not eligible. Project applicants are required to provide proof that the proposed land has not been wooded in the last 25 years and to commit to permanent land use change. Replanting is required for any loss due to natural and anthropogenic causes. Immediate notification of any loss and report should be submitted within 6 months.

Each eligible project is required to identify any potential risks to permanence and to develop strategies to mitigate these risks. A risk buffer system is in place whereby 20% of the carbon credits are reserved as buffer in case of any losses and these buffer credits cannot be traded. Regular verification is in place in order to verify the net carbon sequestration for a given period. Regardless of the management regimes chosen by the landowners, the maximum carbon credits that can be claimed is the long-term average carbon stock of the woodland type and management on the site. There are two types of projects. For small projects (<5ha), the baseline assessment is not required and the baseline is 'no change in carbon stocks over time'. For standard project (>5ha), baseline assessment is necessary if significant sequestration is to be expected under the baseline scenario. Nevertheless, the baseline of 'no change in carbon stocks over time' applies to most projects on previously grazed pasture or arable land. Projects are not allowed to claim emission reductions resulting from land use change.

Peatland Code

The Peatland Code in the UK aims to mimic the Woodland Carbon Code albeit the target is on peatland restoration projects²⁹. It is designed so that landowners have an incentive to undertake voluntary peatland restoration projects. Under this initiative, peatland restorations cover revegetation and/or rewetting of peatland although removal of plantation forest is not eligible. These restorations must result in a condition category with a lower emission factor compared with baseline scenario. Management activities are also eligible provided these maintain or enhance the emission reduction factor compared to business as usual. Net emission reductions are used which refer to the difference between the emission level during the project period and the baseline and further corrected by a 10% precision buffer and any anticipated leakage.

The minimum project length is 30 years. If project length is greater than 55 years, it must demonstrate that the field has a minimum of peat depth equal to 1 cm for one project year. To illustrate, a project with a duration of 70 years must provide

28. <https://woodlandcarboncode.org.uk/>

29. <https://www.iucn-uk-peatlandprogramme.org/funding-finance/peatland-code>

evidence that the peat depth across the proposed project field is 70 cm at the minimum. The requirement is put in place to avoid a situation where the project ends up with a complete loss of peat resource before the end of the project. This follows an assumption of expected maximum loss in peat depth by one centimeter per year.

Project verifications initially take place after one year and five years of the start date, thereafter every 10 years. Projects are subject to two additionality tests namely legal compliance and financial feasibility. Projects are also subject to another additionality test where applicants can choose between the following: economic alternative or barrier. In principle, all these tests ensure that the project would not otherwise be economically viable in the absence of carbon finance and that the GHG emission reductions are exclusively tied to the initiative. Several stipulations are in place to ensure permanence. Firstly, the project is obliged to undertake remedial action if it fails to deliver the expected result five years after the start date. Secondly, the project is required to identify potential risks and corresponding mitigation strategies and implement these strategies as necessary and to the extent possible. Thirdly, only 85% of net GHG emission reduction units can be claimed by the project as the remaining 15% of the units are reserved as a risk buffer. Project applicants must assess potential GHG leakage. Leakage ^{35%} would be deemed significant and must be accounted for in the project.

MoorFutures

The overall aim of the MoorFutures is to incentivize emission avoidance projects through the rewetting of peatlands extending across three regions of Germany³⁰. Land use after rewetting must not compromise the goal of reducing GHG emissions. Beside GHG emission reduction, it also targets other ecosystem services for example biodiversity. Quantification of other ecosystem services follows the methodology described in Joosten et al. (2013).

Eligible projects are rewarded carbon credits for reduction in GHG fluxes resulting from the rewetting of peatlands. The GHG emission reduction units are calculated as the difference between the GHG fluxes as result of the rewetting and the baseline i.e. GHG fluxes under the land use in the absence of rewetting. In both project and baseline scenarios, conservative estimates (highest likely emissions) are used. This is done through underestimation of emissions in the reference scenario and/or overestimation of emissions in the project scenario. These GHG emission reduction units are then certified and sold to companies or households as voluntary offsets.

Project durations range between 30 to 50 years. A minimum of 30-year contract is required in order to account for possible transition effects (increased methane emissions, settlement of new species). Project must demonstrate that the proposed duration corresponds with the availability of the peatland resources; that the peat does not completely deplete before the end of the project. For Germany, 1 cm per year depletion rate is assumed. This means a 30-year project must demonstrate that the proposed field/site has a minimum of 30 cm peat depth across the site. Should the project argue otherwise, it has to be substantiated (e.g. using literature for reference).

Any land use changes or intensification likely to occur outside the project area due to the implementation of the project – leakage – must be assessed to determine the potential GHG emission effects. This must be outlined in the application. The same

30. <https://www.moorfutures.de/>

principle applies in relation to other ecosystem services and guidance can be found in Joosten et al. (2013).

In order to qualify, projects must pass an additionality assessment to demonstrate that the project would not be financially feasible without the sale of carbon certificates from MoorFutures. Projects must demonstrate that the implementation of the project will not cause negative effects on other ecosystem services. It must also not cause undesirable effects on the socioeconomic condition of the region. For this, all stakeholders must be identified and actions to avoid negative effects must be implemented.

Permanence is secured through long term contracts with clear specification of ownership/user structure and terms of contracts including requirement for permanent land use change, usage conditions, designation as a protected area, etc. Parts of the proposed area that are in risk of peat depletion due to continuous oxidation in 100 years are not eligible for inclusion. Residual risks are covered by a 30% buffer. This means that only 70% of the certified GHG emission reduction units/credits can be claimed and the other 30% are reserved to buffer any deviations from the initial plan. Transparency of the awarding of the carbon certificates as well as the sale and purchase must be ensured through a registration system of that is publicly available.

The first monitoring takes place between 3 to 5 years after rewetting which is then followed by regular monitoring every 10 years. GHG emission reduction estimates must be corrected following the monitoring outcomes.

French Label Bas Carbone

French Label Bas Carbone is a low carbon labeling/certification launched in 2018 by the French Ministry of Ecological and Inclusive Transition (Ministère de la Transition écologique et solidaire)³¹. The overall aim is to encourage the development of local projects for GHG emission reductions through changes in sectoral practices (e.g. improvement of farming practices) or enhancement of carbon sequestration in natural sinks (e.g. afforestation projects). The platform is expected to contribute to the country's goal for carbon neutrality by 2050. The labeling guarantees the quality and integrity of the projects thus providing assurance to potential funders or buyers of the certified carbon credits. The project operators (e.g. farmers) get rewarded through the sale of labeled and traceable carbon credits. Prospective projects are submitted to the Ministry but the certification is carried out by an independent body. Thirteen forestry projects have been certified/labelled. Meanwhile, 24 other forestry projects and 391 agricultural projects are currently under development.

Any persons or legal entities are eligible to propose a project for certification. Several actors may wish to form a collective project. Individuals, companies, communities, and associations are welcome to finance low-carbon projects as either a single player or by several players forming a collective project.

For low carbon label in forestry, three measures are eligible, namely afforestation, reforestation and balivage (conversion of coppice into high forest on stumps). For agriculture, three methods are accepted. The first method, "Carbon Agri", is developed for emission reductions in cattle and field crops. The second method "Hedges" is directed towards sustainable management of hedges. The third method

31. <https://www.ecologie.gouv.fr/label-bas-carbone>

is called "Plantation of orchards".

Risk of non-permanence is managed by demanding projects to verify controllable risks and undertake actions to mitigate such risks and by applying a discount to the estimated carbon credits for risks that are not controllable. The larger the risk involved, the higher the discount. For illustration, with respect to fire risk in the case of afforestation, 5% discount is applied to projects with low risk, 10% to medium risk and 15% to high or very high risk. For general risks (e.g. pests and diseases) 10% discount is applied.

Projects are subject to verification by independent auditors, paid by the project applicants/owners. In the case of afforestation, field verification of the emission/sequestration must be done 5 years after the end of afforestation. The field verification is done by an independent auditor, paid by the project owner.

The amount of carbon credits to be awarded label/certificate is determined by calculating the difference in the emission/sequestration under the proposed project and the baseline scenario (i.e. without project) for example between afforestation (with project) and fallow land (without project). The quantification must follow a method that has been approved by the Ministry of Ecological and Inclusive Transition.

A project must demonstrate through additionality checks that it exceeds current regulation and practices and that the expected emission reductions/sequestration would not have otherwise taken place without the labeling. The additionality checks are specified according to the methods used by the proposed projects. The project must account for both direct, and to the extent relevant, indirect climate effects of the project. The project must not cause negative effects on other environmental objectives nor on socioeconomic aspects. Projects that demonstrate environmental and socioeconomic co-benefits are given favorable assessment.

France Carbon Agri Association (FCAA)³² facilitates farmers with project set up, pooling of several farms, development of partnerships with potential institutions/organizations, administrative follow up with the authorities, as well as communication (on farm demonstration about the initiative). Consultancy and certification costs can be minimized by pooling several farms into joint regional and national projects. FCAA also facilitates companies or individuals wishing to support/finance projects and/or purchase the certified carbon credits from low-carbon agricultural projects.

As can be seen above, result-based instruments for land-based climate mitigation do exist in Europe. The principles of these instruments have the potential to be transferred to the Nordic countries. Relevant measures that can be potentially tailored into result-based schemes in the Nordic countries including but not limited to afforestation and wetland restoration/rewetting. It is nonetheless important to highlight that in order to operationalize this type of instrument several factors have to be put in place first. To illustrate this, reliable and approved methods are needed for quantifying, verifying and monitoring the "result" i.e. the magnitude of carbon sequestration/GHG emission reduction of proposed projects. Moreover, the existence of mechanisms to finance eligible projects is also crucial. The examples reviewed above show that one mechanism for financing projects is by setting up a platform for selling the certified carbon credits from qualified projects as voluntary offsets to businesses or private households in the countries where the instrument is

32. <https://www.france-carbon-agri.fr/>

implemented. Such financing mechanism could potentially be set up not only specific to individual countries but also for Nordic wide coverage. It can benefit from the long standing close cooperation between the Nordic countries. All in all, it is important to highlight the importance of securing financial/economic viability of result-based schemes by reconciling both the supply and demand sides of carbon/GHG benefits from land-based measures.

4.1.3. Land-use contracts for carbon sequestration using reverse auctions

Transaction costs, as has been discussed in the preceding sections, are among the key factors determining the efficiency of policy instruments to foster carbon sequestration using land-use measures. Van Kooten et al. (1995) maintained that land-use contracts offer a solution as the use of this policy instrument can minimize transaction costs in land-use-based carbon sequestration. The use of land-use contracts for land-based carbon sequestration has received growing interest in practice in a number of countries with reverse auction mechanisms used to administer the instrument. A conventional auction setting is characterised by one seller with multiple potential buyers placing their respective bids for a good/service on sale which concludes with the highest bidder as the ultimate buyer. A reverse auction, on the contrary, involves one buyer with multiple sellers who express their respective prices (bids) at which they are willing to sell a good/service to the buyer. Land-use contracts using reverse auctions can be set up for either action/input based or output based mechanisms.

Examples of the application of reverse auction for carbon sequestration projects exist. In Australia, since 2014, reverse auction has served as the principle mechanism underpinning the country's Emission Reduction Fund (ERF) whereby governments purchase the lowest cost projects for emission reductions and/or carbon sequestration³³. ERF is administered by the Clean Energy Regulator which is the Australian government body dedicated to accelerating the country's carbon abatement. Eligible projects span various sectors including transport, waste management, and land sector. ERF sets a list of approved "methods", or technical measures, for delivering emission reductions and/or carbon sequestration. In the land sector, these include soil carbon enhancement, reduction of livestock emissions, carbon plantings, and reforestation. There are three key criteria for project eligibility, which address the issue of additionality potentially arising from a project. The first criterion ensures the "newness" of the project whereby the project must satisfactorily demonstrate that the project is not already on-going. The second criterion refers to "the regulatory additionality requirement" which means that a project is not eligible if it belongs to those projects that are actually mandatory under a Commonwealth, State or Territory law. To satisfy the third criterion, a project must demonstrate that government programs other than ERF are not available from which financial/funding mechanism can be secured for implementing the project.

Auctions are open twice a year, each involving multiple rounds. ERF considers two types of contracts: fixed delivery contract and optional delivery contract. Under both contracts, eligible projects have the rights to sell their carbon credit units to the government (i.e. the Clean Energy Regulator) at secured prices as stipulated in the contracts. The difference is that projects under optional delivery contract have the

33. <http://www.cleanenergyregulator.gov.au/About/Pages/Accountability%20and%20reporting/Annual%20Reports/Annual%20Report%202017-18/Emissions-Reduction-Fund.aspx>

flexibility of not having to sell their carbon credits to the government in case of, for example, a higher carbon price on the market such as from a business wanting to purchase carbon offset during project timeframe.

Eligible projects can choose one of the three types of contract lengths under ERF: a) standard contract (7 – 10 years), short term (less than 7 years), and immediate delivery (10 days). The average price per tonne of abatement (CO₂-eq) was close to \$14 at the first batch of auction in 2015, went down to about \$10 in 2016, and has consistently increased since, reaching \$16 in 2020.

To assure accurate calculation of carbon credit units to be delivered by eligible projects, ERF adopts a risk-based audit system. Audits must be arranged and paid for by project owners. All projects are typically subject to two types of audits: one initial audit (covering a minimum period of 6 months) and a number of subsequent audits (each covering a minimum period of 12 months). The frequency of the latter varies depending on the size of the project in terms of the average annual abatement capacity: two subsequent audits for a small project (≤50,000 t CO₂-eq per year), three for a medium project (50,000 t CO₂-eq 2-eq), and five for a large project (>150,000 t CO₂-eq). However, in certain cases, the Clean Energy Regulator may demand an additional, third type of audit known as unscheduled, or triggered audits. Only a registered greenhouse and energy auditor (within the meaning of the National Greenhouse and Energy Reporting Act 2007) who is registered as a Category 2 auditor (under the National Greenhouse and Energy Reporting Amendment Regulation 2015) is qualified to carry out the audits.

All area-based sequestration projects are subject to permanence obligations and they can choose to apply for a permanence period of either 20 or 100 years. This means that projects are obliged to maintain carbon storage for the entirety of the chosen permanence period. All projects are subject to 5% risk of reversal buffer – deducted from the calculated carbon units to be generated by the projects. Moreover, projects with 20-year permanence are subject to a further 20% deduction of the carbon units. This deduction is reserved by the Government for covering the likely cost of replacing carbon storage after the completion of the project. Projects are obliged to self-safeguard against carbon loss risks. In the events of carbon loss, for example due natural disturbance, projects have two options: 1) to undertake management activities to restore the carbon storage to the expected level, or 2) to return carbon units to the Clean Energy Regulator. Projects must inform the Clean Energy Regulator in writing within 60 days in situations where more than 50 hectares or five per cent of total project area has been affected by fire.

Reverse auction mechanism in support of carbon sequestration efforts has also recently been adopted in the UK. In November 2019, the UK government, through its ministerial Department for Environment, Food & Rural Affairs (Defra) introduced a £50m scheme called “the woodland carbon guarantee”³⁴. The scheme has twofold purposes, namely providing stimulus for landowners to create new woodlands/forest and for the development of domestic market for carbon generated from woodland based sequestration. Through a reverse auction set up, landowners have the possibility to bid for prices (£/tCO₂) at which they are willing to sell their Woodland Carbon Units (WCUs) to the government under the so called “option contracts” for establishing woodlands. This type of contract secures a guaranteed price at which successful bidders can sell their Woodland Carbon Units (WCU) to the government every five or ten years up until 2055/56 while having the flexibility to opt for selling

34. <https://www.gov.uk/guidance/woodland-carbon-guarantee>

the WCUs to an open market instead in the event of more attractive prices.

The contracts run between 30 and 35 years. In general, projects of any size are welcome (i.e. there is no requirement for minimum project size) except for landowners who are already participating in other woodland creation grant schemes whereby to be eligible, a project must meet a minimum contract size of three hectares.

All projects must be registered with the Woodland Carbon Code (WCC)³⁵, which is now managed by Scottish Forestry, the Scottish Government Agency responsible for forestry policy, support and regulation, on behalf of the Forestry Commission in England, the Welsh Government and the Northern Ireland Forest Service. WCC serves as a focal point for validation of the projects, taking place at the beginning of the projects, and also for the verification of the projects' WCUs, taking place every five or ten years. To be eligible, landowners/managers must demonstrate that they have full control of all management activities on the lands where woodland plantings will take place. The UK government plans to run two auction windows per year up to five years.

Two studies from Canada evaluated the potential of using the reverse auction mechanism for the wetland restoration programme. Hill et al. (2011) carried out the study for the Assiniboine River Watershed (ARW) of east-central Saskatchewan. The auctions were based on discriminatory price principle, took place in two rounds and participants had two contract length options to choose from: 12 year-terms and perpetual easement. In the first round, 20 bidders participated to restore a total area of 670 acres at a price of \$837,000 giving an average restoration price of approximately \$1250/acre. Following a ground verification, participants were then asked to revise their bids and to submit to the second round. In the end, 7 bidders were approved to restore a total area of 211 acres at a price of \$182,000 giving an average restoration price of approximately \$863/acre. The price of successful bids ranged between \$20.83 and \$391.22 per acre per year (average \$118.52).

One important finding from the study was that none of the participants opted for perpetual contracts. In fact, many land managers express a greater preference for annual contracts which suggests their preference for a flexibility on their land management. While the participation in the scheme was considered to be low, Hill et al. (2011) found that land managers who have had previous cooperation conservation agency projects were more likely to participate in the auction. In the same vein, media campaign was found to have a positive influence on land managers participations in the auction.

Novak (2017) reported the application of reverse auction for wetland restoration in the Wintering Hills area of Wheatland County, Alberta, Canada. They implemented a single round auction under a uniform pricing mechanism hence contrary to the approach of Hill et al. (2011). Moreover, the length of the contract for wetland restoration in the case of Wheatland County Reverse was 10 years, slightly shorter compared with that of Hill et al. (2011). In the end, 26 bids were approved covering a total area of 275.22 for wetland restoration, resulting in an average area of 10.56 acres per bid and average price of restoration of \$3,000/acre. Comparing the findings from the two studies, in 2015 prices, Novak (2017) found that wetland restoration scheme in Wheatland County Reverse (WCR) was in absolute terms more expensive than in the Assiniboine River Watershed (ARW). The average

35. <https://woodlandcarboncode.org.uk/>

securement costs were \$3000 per acre and \$970 per acre in WCR and ARW respectively. However, further analysis showed that while the average securement cost in WCR is equivalent to 2.9 times land rental rates in the area, the figure is higher in ARW (4.6 times). Another important insight from the study in WCR was that the bidders' price motivation was not solely driven by opportunity cost of land but also by rent-seeking behaviour. Nevertheless, similar to the case of ARW, participation rate in WCR reverse auction was also low (9.19% of landowners).

Land-use contracts using reverse auction mechanism can potentially offer an alternative, more cost-effective policy instrument to the existing subsidy schemes that have implications for land-based climate mitigation in the Nordic countries. Existing economic instruments related to land-based measures, albeit mostly not directly targeted for climate mitigation, are in principle based on a uniform incentive provision. Even though specific requirements/details may be attached in the existing economic incentive instruments, it does not lead to the implementation of the most effective/efficient land-based projects per se. This is partly because the instruments do not differentiate payments according to variation in costs and effects across the target landscape. On the contrary, a reverse auction-based contract provides incentives that accommodate the heterogeneity of the farmers and their lands. This type of instrument can be expected to encourage wider and more efficient implementation of various land-based measures. Under this instrument, the society is expected to get the most value of the incentives provided to the landowners as the cheapest projects can be picked up from the reverse-auction bids. As examples from other countries have shown, the reverse-auction based contract can be used to target various land-based mitigation measures including tree planting and wetland restoration. For the Nordic countries, this instrument can be directed towards a selection of measures such as afforestation, wetland creation and cessation of agricultural production on peatlands/organic soils. The scope for implementing this instrument is expected to differ between the Nordic countries depending on the remaining potential of the relevant measures to be realized in the respective countries.

4.1.4. Tailoring insurance schemes to boost carbon sinks in agricultural land

Jørgensen et al. (2020) report the results of a survey assessing Danish farmers' preferences for a climate risk insurance scheme coupling climate friendly natural insurance practices with market insurance. The approach is novel and although the focus of the article is on climate adaptation rather than mitigation, the framework could nevertheless be relevant in relation to regulatory initiatives aimed at promoting carbon sequestration within the land-use sector. The investigated scheme is designed so that adoption of climate friendly agricultural practices – here reduced tillage and/or mulching – is a prerequisite for entering the market insurance scheme; this way, the two types of insurance become complements rather than substitutes. Unlike pure market insurance schemes, which may potentially lead to unsustainable land management, the analyzed scheme discourages moral hazard while jointly providing incentives for adopting sustainable land management practices by reducing the risk associated with doing so.

The results of the study show that farmers are interested in the scheme, although there are differences across farm types. Arable farmers are found to be more interested in the insurance scheme than pig farmers; probably a result of the fact that arable farmers' income is more vulnerable to climate induced crop losses than

pig farmers who produce a wider range of products. Similarly, farmers with poorer soils, on which crop production may be less robust to withstand e.g. droughts or heavy rains, are more interested than farmers with good soils.

In relation to instruments to increase carbon sequestration in the land-use sector, insurance schemes – similar to the one analyzed in Jørgensen et al. (2020) – could potentially be relevant for the Nordic region. The benefit in the form of reduced climate related risk may provide incentive for some land owners to engage in climate mitigation activities that they would otherwise not dare engage in due the potential risks associated with implementing new practices or land use changes. To illustrate, in a case where measures are subsidized, but the subsidy scheme fails to induce the desired amount of land use changes, the additional incentive provided by an insurance scheme may provide the necessary stimulus for landowners to change their practices. Furthermore, in this set up, insurance may be developed to cater both climate change adaptation and mitigation whereby farms are insured against the risk of financial loss due to adverse climate impacts (e.g. crop failure) conditional upon implementation of measures that contribute positively towards enhancing carbon sinks on agricultural soils (e.g. mulching, application of catch crops).

Despite the potentials, the fact that landowners often get ad hoc compensation from governments in the case of a crisis of some kind may create barriers to such insurance schemes to work well. This highlights the need for some changes in the governance mechanisms to remove or reduce the aforementioned barriers so that farmers appreciate the value of the insurance schemes more. Nonetheless, the frequency and magnitude of extreme events are expected to increase in the future climate (IPCC, 2012). The role of insurance is therefore expected to become more prominent as an adaptation strategy for hedging the farms against the risks of climate change in general and of extreme events in particular (Falco et al., 2014). A tailored insurance scheme, whereby it is compulsory for farmers to undertake a set of pre-approved land management practices that enhance soil carbon, offer a solution that jointly tackles mitigation and adaptation to climate change. Technical measures that potentially can be integrated into this instrument include, but are not limited to, catch crops, set aside allocation, soil conservation measures and other climate smart agricultural practices.

4.1.5. Supply chain approach to reward carbon sequestration in agricultural soils

An emerging instrument to incentivize enhancement of carbon sinks in agricultural soils entails a supply chain mechanism that links farmers, retailers and consumers. An example is drawn from the Healthy Soil for Healthy Food project in Austria. It won the Land and Soil Management Award in 2017³⁶. It involves a cooperation between 69 farmers, a retailer company – SPAR, and WWF Austria. WWF provides knowledge and advisory support for farmers while SPAR covers the costs of the project including WWF support and the financial incentive for farmers. When the project was launched in 2015, it covered a total area of 800 hectares. Within four years, it had increased to 1,050 hectares.

The partnership provides incentives for farmers to integrate soil conservation practices into their agricultural production to build up soil organic matter which in turn contributes to soil health and carbon sequestration. Farmers are advised to implement any combination of these four soil-conserving practices: fertilisation

36. https://www.europeanlandowners.org/awards/soil-land-award?mc_cid=c92ed4112a&mc_eid=aebccd827b

using compost, minimum tillage and direct sowing, permanent green cover, crop rotation and mixed crops.

The incentive for farmers consists of two components. Farmers secure contracts for the sale of their agricultural produce (mainly vegetables) and receive financial rewards for increase in humus content following a verification by an independent certified engineer. The verification is undertaken by analyzing spatially referenced soil samples in two stages – first at the start of participation in the project and at year 2 or 3 (or after 5 years at the latest). While in the beginning the incentive was intended to be result/performance based, where farmers were to receive rewards for increased humus content, in reality it turned out to be an action-based scheme.

The vegetables from the project are sold in 1,600 shops across Austria and have the stickers of the project and WWF to make it easily recognizable by customers. To increase public awareness, SPAR and WWF include articles communicating the projects through their periodical magazines. In addition, WWF makes soil theme highly visible on its website and publishes reports covering contents about the project.

Among the important points to highlight about the project pertains to permanence. The project contracts run until 2021. It would therefore be important to see what happens when the project terminates. Securing continuity in the long term is key to maintaining what has been achieved in terms of soil organic matter accumulated through the project and to enhance this further.

This supply chain approach as an instrument to incentivize farmers to enhance carbon sequestration in agricultural soils can be potentially transferred to the Nordic countries. The realization of this instrument is expected to open up opportunities for collaboration between supermarkets, farmers, farmer advisors and research sector.

4.2. Potential policy instruments to enhance carbon sequestration in existing forests

The section begins with an overview of alternative economic instruments to incentivize forest owners to gear their forest management activities towards increasing carbon sequestration. Subsequently, discussions on the likely effects of policy instruments on forest carbon sink enhancement as well as the costs and budgetary implications of enacting such policies are presented. Then the likely impacts of forest carbon policies are further discussed in relation to the dynamics of forest management, timber market and wood-based fuel for energy production. Other aspects highly relevant when considering the development and choice of policy options for forest carbon including risks are also discussed. Insights are drawn from available studies in the Nordic region which in general employ two distinct approaches namely 1) market models and 2) stand level models.

4.2.1. Overview of policy options for enhancing forest carbon sequestration

In the scientific literature, incentives for forest owners to enhance carbon sequestration has been suggested since 1990's based on two different schemes:

1. A flow-based forest carbon policy subsidizes carbon capture by growing biomass and taxes the release of this carbon during the harvests (van Kooten et al., 1995).
2. An alternative way to design a forest carbon policy is to pay forest owners a 'carbon rent', which is based on the anticipated carbon stock measured or calculated for a forest stand (Sohngen and Mendelsohn, 2003; Uusivuori and Laturi, 2007).

Lintunen et al. (2016) show that these two schemes provide identical incentives for forest owners under assumptions commonly applied in forest economics, namely access to perfect capital markets and non-additive preferences on consumption and timber amenities. These assumptions prevail also in the analysis of either of the instruments separately. The equivalence result holds also for non-constant carbon prices over time if both forest owner and regulator have rational expectations over changing carbon prices. In addition, the regulator has to buy the carbon stock from the forest owner when implementing the tax/subsidy scheme.

Policy instruments that are directly set to promote carbon sequestration are cost-effective, because the forest owner is able to choose how to achieve the sequestration. For example, the forest owner can adjust the rotation length as well as timing and intensity of thinnings. In addition, he or she can invest in fertilization or, in the longer term, change the composition of tree species in the forests. Thus, the forest owner can choose the cost-effective combination of measures to increase carbon sequestration on his or her site which would not be the case when the regulator rolls out a specific instrument for example a subsidy on fertilization that would only regulate and promote the use of fertilizers.

The impacts of tax/subsidy and carbon rent schemes have been studied both with stand-level and market models for Finland, Norway and Sweden. Early studies utilize stand level models which focus on impacts on the amount of carbon sequestered, forest management and incomes of the forest owner. The results present the changes in the long run with constant timber prices. More recently, market models that add the time path towards a new equilibrium have also been applied. In market models, the payments for carbon sequestration are paid in a stand level. However, the changes in timber prices due to the market adjustment affect also the decision to cut timber or sequester the carbon that is not taken into account in the stand level models. On the other hand, detailed impacts on rotation length and thinnings are not typically reported when applying the market models. Both model types can report the costs of sequestration and impacts on the use of bioenergy.

Most of the current analysis of the economics of carbon storage is based on the studies with single-species even-aged stands (Assmuth, 2020). In the market models, optimization is also typically based on the even-aged stands. Some stand-level studies exist for continuous cover forests. The preferable approach applied in Assmuth (2020) is to determine the applied regime through optimization and examine the effects of carbon storage on this choice (Assmuth, 2020).

4.2.2. The potential to increase carbon sinks with price mechanisms

The impact of carbon policy instrument on the amount of carbon sequestered, presented in Table 4.1, varies a lot between models applied for the Nordic countries. The outcomes of the studies are difficult to compare as the increase in carbon sequestration is reported by using different metrics (annual sink in national level, annual sink per hectare, average increase in carbon storage over rotation). In addition, the range of carbon price used in defining the size of subsidy/tax or carbon rent differs between studies. In all these studies, carbon price is assumed to be constant over time. Moreover, the range of measures included in the analysis also differs between models. Some include only forest management as a measure for increasing carbon sequestration while some others include also fertilization and change in species. Importantly, there seem to be differences between the models in modeling the behavior of forest owners and how sensitive the timber supply is to the changes in timber and carbon prices.

From market models, the impact is clearly largest according to Pohjola et al. (2018) with additional annual sink of 40–45 million ton of CO₂ in the first 20 years in Finland. By converting their results from national level to carbon sequestered per hectare, we obtain the maximum increase of 2.5 t CO₂/ha/yr that is clearly larger than maximum impact of 1.2 t CO₂/ha/yr obtained in Sjolie et al (2013) whereby a notably higher carbon price is used. The lowest impact is provided by Guo and Gong (2017) with impact on annual sink in Sweden varying between 2 and 7 million t CO₂. Their study is based on the carbon prices of 170–1428 SEK/t CO₂ that is quite similar price range compared with Sjolie et al. (2013) while notable higher than in Pohjola et al. (2018).

Table 4.1 The increase in carbon sink under carbon rent scheme (Pohjola et al. 2018) or tax/subsidy scheme (other studies) at different carbon prices, analyzed in different Nordic studies. The examined time period in all market models is 100 years.

Studies included	Measures included	Carbon prices used	Increase in carbon sink
Market models			
Sjolie et al. (2013) Norway	Rotation length, thinnings, fertilization, tree species	0–100 €/t CO ₂ with intervals of 12.5 mill.t CO ₂	0.3–0.6 t CO ₂ ha ⁻¹ yr ⁻¹ in 2020, 0.2–1.0 t CO ₂ ha ⁻¹ yr ⁻¹ in 2050 and 0.2–1.2 t CO ₂ ha ⁻¹ yr ⁻¹ in 2100
Pohjola et al. (2018) Finland	Rotation length, thinnings	0, 5,15 and 30 €/t CO ₂ (carbon rent)	Annual sink: 5–45 million t CO ₂ up to 40 years, 10–20 mill.t CO ₂ at 100 years
Guo and Gong (2017) Sweden	Rotation length, thinnings	0–1428 SEK /t CO ₂	Annual sink: 2–7 million t CO ₂ in the short/medium run, declining
Stand level models			
Backeus et al. (2005) Sweden	Rotation length, thinnings	36 €/t CO ₂	0.66 t CO ₂ ha ⁻¹ yr ⁻¹ , average over a 100-year period
Pohjola & Valsta (2007) Finland	Rotation length, thinnings	10 and 20 €/t CO ₂	40 / 80 t CO ₂ /ha for Scots Pine and 90 / 235 t CO ₂ /ha for Norway spruce, increase in average carbon storage during the rotation period

In addition, the time path of the impact differs between studies. The impact on the annual carbon sink is largest in the short run according to Guo and Gong (2017) and Pohjola et al. (2018) while in Sjolie et al. (2013) the largest impact is obtained in the long run with the modest short run response. In Pohjola et al (2018), the carbon price of 30 €/t CO₂ leads to a lower carbon sink in the long-run than the carbon price of 15 €/t CO₂. This is because in the scenario with higher price, forests grow old faster, and thus end up having a lesser annual growth rate than in the scenario with a lower carbon price.

The differences in dynamics of the increase in carbon sink between Sjolie et al. (2013) and other studies might be due to the fact that in Sjolie et al., the possibility to change forest management is more limited than in other studies. In addition, fertilization and especially changing tree species and regeneration methods, which affect the C sequestration in the longer term, are included only in Sjolie et al. (2013).

4.2.3. Costs of carbon sequestration

The measurements of costs related to carbon sequestration are important to distinguish for the evaluation and understanding of how instruments work and how they take private versus welfare economic costs into consideration.

Based on market models, both Guo and Gong (2017) and Sjolie et al. (2013) use producer and consumer surpluses to measure the social cost (welfare impact) of carbon sequestration. While the producer surplus is the difference between the price a firm receives and the price it would be willing to sell at, the consumer surplus is a measure of the welfare gained in the population from consuming goods and services. The measurement of this is the difference between what consumers are willing to pay and the market price. In Guo and Gong (2017) producer surplus refers to forest owners' profits from timber production (the NPV of timber revenues minus the NPV of management costs).

In Guo and Gong (2017), the social cost of carbon sequestration varies from 142–180 SEK/t CO₂ for increase of carbon sequestration by 14–100 million ton of CO₂ for time period 2010–2030 and 80–105 SEK/t CO₂ for increase of carbon sequestration by 30–220 million ton of CO₂ for time period 2010–2050. The costs are explained by the fact that the loss for the timber consumers exceeds the benefits for forest owners. Timber consumers suffer both from increase in timber price and lower harvests while for forest owners the benefit from increase in timber prices exceeds the loss from decrease in harvests. In addition, non-timber benefits for forest owners slightly increase due to the larger amount of older forests. On the other hand, in Sjolie et al. (2013) the welfare impact is unexpectedly reported to be positive as the benefits for forest owners notably exceed the losses for timber consumers. The possible explanation for this might be that in Sjolie et al. (2013) the income from subsidy/tax scheme for forest owners is included in producer surplus but not subtracted from consumer surplus. In Guo and Gong (2017), the income from carbon tax/subsidy scheme is excluded.

Costs of carbon sequestration have been evaluated also using stand level models. Assmuth et al. (2018) find that marginal abatement costs range from 3 to 46 €/ t CO₂ for 10 to 70 tonnes of carbon abatement per hectare with a 2% interest rate, and are somewhat higher with a 4% interest rate. Thus, the results suggest that increasing carbon storage through changes in forest management practices is relatively inexpensive.

4.2.4. Budgetary impacts of carbon rents and tax/subsidy scheme and additionality

Lintunen et al. (2016) compares the budgetary impacts of carbon rent and tax/subsidy schemes. Although the two policies imply the equivalent harvest decisions of forest owners and the net present values of the subsidy streams are equal under the assumed conditions, the policies differ in their budgetary effects. This holds naturally both for the forest owner and the policy regulator, such as the government. The introduction of a *tax/subsidy scheme* would initially be expensive for the regulator because of the initial payments to the forest owners based on the carbon stock. A problematic situation exists when selling the land, especially in the case of mature forests in which the seller of the land has received the subsidies from sequestered carbon while the buyer has to pay the taxes in final cutting. As a consequence, the land price should be reduced according to the subsidies obtained. In comparison, *the carbon rent policy* does not have any extra costs in the period of introduction. Under the carbon rent scheme, the money transfers are always from the government or other administrator to the forest owner. On the contrary, in a tax/subsidy scheme the forest owner also pays a carbon tax at the moment of harvest implying two-way monetary flows. These budgetary differences suggest that the carbon rent model could perhaps be more easily implemented in a real-world context. However, when the carbon payments are based on the additional sequestration over baseline without carbon policy, these results change: the baseline reduces and possibly eliminates the initial payments making the implementation of tax/subsidy policy easier. In addition, the baseline may introduce money transfers from forest owners to administrator. Consequently, with a baseline, the two policies tend to generate effects that are less different from each other.

Tax/subsidy schemes and carbon rents may be expensive if the payments are based on the all net sequestration or storage, including what would otherwise be obtained for free. Correspondingly, these policy instruments would imply large income transfer to forest owners. Considerable share of this income would be provided to forest owners even if they do not increase the carbon sink by changing their forest management both in the case of tax/subsidy scheme (Pohjola and Valsta, 2007) and carbon rents (Pohjola et al. 2018). According to Pohjola et al. (2018), with a carbon rent policy, the amount of this “wind-fall” payment would be 920 million euros and 1.55 billion euros in 5 years and 50 years respectively after implementing the policy. To limit the use of public funds, the regulator may apply an additionality principle and solely subsidize carbon storage that exceeds a baseline level (Tahvonon and Rautiainen, 2017).

Setting the policy instruments to handle the additionality is analyzed in Tahvonon and Rautiainen (2017). From a theoretical point of view, the additionality problem should be solved by adding a general land taxation to compensate the income that would be received without any increase in carbon sequestration. However, a more practical approach could be to pay only for the delay in the final cut in mature forest (Uusivuori and Melkas 2006). Another practical approach would be to pay for the carbon sequestration additional to one obtained following the guidelines for forest management for forest owners to maximize timber profits by Tapio³⁷ (Pohjola et al., 2018). With this approach, setting the baseline and measuring the deviations from it could be relatively straightforward. Additionality, however, cannot be fully

37. Tapio is the advisory and consulting service provider in the field of forest management, owned by the Government of Finland.

guaranteed as the aforementioned guidelines are not mandatory and the preferences of forest owners are not known. Therefore, forest owner might apply longer rotations than those in the guidelines even without carbon sequestration payments.

4.2.5. Impact of carbon policy instruments on forest management

The forest management impacts are typically reported in analyses with stand level models. Carbon payments increase the rotation length and typically delay the thinnings. Seminal articles focus on the effects of carbon pricing on optimal rotation length (e.g. Hoen and Solberg, 1997). A smaller body of research analyses carbon storage using an even-aged model that incorporates thinnings. The Nordic studies include e.g. Pohjola and Valsta (2007) for Scots pine and Norway spruce, Niinimäki et al. (2013) for Norway spruce, and Pihlainen et al. (2014) for Scots pine, the latter two applying highly detailed process-based growth models. According to these studies, adapting thinnings may be as, or even more, important for increasing carbon storage than lengthening the rotation period (Assmuth, 2020).

According to Pohjola and Valsta (2007), applying the carbon subsidy/tax programme with a carbon price of 10 €/ton of CO₂ increases the rotation length by 4–13 years in the Scots pine stands examined. Doubling the price of carbon increases the rotation length almost linearly, with an average increase of 21 years. In addition, thinnings are postponed by approximately the same amount of years as clearcutting. Thinnings tend to be lighter except the first thinning. For Norway spruce, clearcuttings are postponed by 13–19 years compared to the base case with carbon price of 10 €/ton of CO₂. Doubling the carbon price to 20€/ton of CO₂ increases the rotation length more than linearly with average increase of 46 years relative to the base case. The stand level models do not however take into account the increase in timber prices. According to market models, thinnings might be increased during the first years after the implementation of the policy as found in Pohjola et al. (2018).

Assmuth et al. (2020) investigate the economics of carbon sequestration in mixed-species size-structured stands with possibility for continuous cover forestry, thus extending the previous analysis for single-species even-aged stands. According to their study, a continuous cover forestry is economically superior to rotation forestry on the studied stand types given a 3% interest rate and a carbon price range of 0–50 €/ tCO₂. Applying thinnings, performed from above, without clearcutting, is therefore optimal. The results show that carbon pricing postpones thinnings and increases the mean total stand volume regardless of the stand's species composition. Their results also suggest that tree species diversity may play a role in cost-effective carbon abatement in forestry.

Fertilization leads to mixed results according to Sjolie et al. (2013), which is the only study reviewed in this report that includes fertilization. In the *Base* scenario, approximately 0.7 million € is spent on fertilization annually. In the *Full market* scenario, the cost of fertilization increases to 1.8 million €/year for carbon prices up to 50 €/t CO₂, but decreases close to the *Base* level with the highest carbon price of 100 €/t CO₂. In the *Limited market* scenario, fertilization investments increase as the carbon price rises, until they reach 2.4 million €/year. In *Limited market* scenario, the harvest, imports, and exports are constrained at *Base* scenario levels in each period and thus increasing fertilization and changing tree species and regeneration methods are the main options to enhance carbon sequestration.

The comparison of the size of carbon sequestration in 'Limited market' and 'Full market' scenarios in Sjolie et al. (2013) indicates that fertilization is likely to have only a limited role in increasing carbon sequestration. Under the 'Limited market' scenario, the carbon sequestration increases by 0.1 t CO₂/ha/yr in 2050 and 0.3 t CO₂/ha/yr in 2100 with carbon prices over 40 e/t CO₂, while the corresponding impacts are 0.8–1.0 and 1.0–1.2 t CO₂/ha/yr in the 'Full market' scenario. Sjolie et al. (2013) might however underestimate the impact of fertilization as fertilization was allowed only after thinnings according to current forest management practices.

4.2.6. Impacts of carbon policy instruments on timber markets

Market models provide both the new equilibrium and the path towards it with adjusted timber prices, while stand level models provide impact on timber supply only in the new steady state with exogenous prices. In stand level models, forest carbon policy typically increases the long-run timber supply due to the higher timber stock. In market models, the similar result has been obtained for Faustmannian forest owners maximizing profits from selling the timber (Pohjola et al 2018). However, the total impact, which includes also harvests performed by forest owners that have amenity values, remains negative even in the long run. In addition, the adjustment period takes decades, e.g. according to Pohjola et al. (2018) about 70 years.

The harvest reaction to the carbon policy may be strong according to both Pohjola et al. (2018) and Sjolie et al. (2013). In Pohjola et al. (2018), with a carbon price of 5 €/t CO₂, the carbon rent causes a relatively steady and moderate (5%) reduction in the annual fellings. With carbon prices of 15 and 30 €/t CO₂, harvest decrease is largest during the first 20 years with maximum reactions of 25% and 50% below the baseline (i.e. without carbon rent). Harvests recover over time and the long run impacts after 70 years are 10 and 15%, correspondingly. The immediate impact is that many forest owners delay the final cuttings while thinnings are increased in order to partly compensate the loss from postponing the final cuttings. In the medium and long term, both final cuts and thinnings are below the baseline levels.

In Sjolie et al (2013), the maximum harvest reaction is 40% but takes place in the long run and with a considerably higher price of carbon than in the case of Pohjola et al. (2018). In their analysis, the maximum harvest reduction at a carbon price of 12.5 €/t CO₂-eq. is 1.1 million m³ (10%), meanwhile, at 100 €/t CO₂-eq., harvest decreases by a maximum of 4.7 million m³. The stronger impact on timber supply in Pohjola et al. (2018) compared to Sjolie et al. (2013) may be partly explained by the fact that in Pohjola et al. (2018), the forest owners are able to increase the amount of carbon sequestration only by delaying and lightening the cuttings while in Sjolie et al. (2013) carbon sequestration can also be increased by enhancing the growth of forest through fertilization.

The dynamics of impacts of carbon policy instruments on timber prices also differs between studies, as expected based on the results presented above. According to Guo and Gong (2017) and Pohjola et al. (2018), the reaction is strongest in the short run, while in Sjolie et al. (2013) the price impact increases over time. In Pohjola et al. (2018) with high carbon prices (15 and 30 euro/tCO₂), the short-run timber price increase is 35–100% but the impact deteriorates rapidly and after 30 years the price increase is only 20–35% in the case of logs. Both the demand and supply sides contribute to the smaller price impact over time. First, the impact on demand is

reduced as the lower profits cause a gradual reduction of production capacity. Second, the supply recovers as forest stands age towards their new equilibrium rotations and, as a result, the annual per hectare yield increases.

In Sjolie et al (2013), the timber prices even double due to the carbon policy, but in the long run. The carbon policies have large impacts on the timber prices in the long run, but small impacts in the short run. Spruce sawlog price increases from 33 €/m³ without carbon policy to 42 €/m³ with a carbon price of 100 €/t CO₂-eq. in 2020; for 2050 the corresponding increase is from 41 to 85 €/m³.

The differences in the dynamics of the impacts of carbon policy on harvests and timber prices between Sjolie et al. (2013) and other studies might be due to the fact that in Sjolie et al., the possibilities to change forest management are more limited than in other studies. Moreover, fertilization and especially changing tree species and regeneration methods, which are included only in Sjolie et al. (2013), affect carbon sequestration in the long run.

4.2.7. Impacts of carbon policy instruments on the use of wood-based fuels in energy production

If forest owners react to carbon payments by delaying and lightening thinnings and delaying the final cut, the carbon policy reduces the supply of wood-based fuels. This affects the fuel-mix and the total use of fuels in the energy sector. The supply of forest residues and pulpwood decreases because of the lower level of harvests, while the supply of by-products reduces due to the lower level of production in sawmills. The higher prices make wood-based fuels less competitive against fossil fuels. The impacts on the supply side are largest in the short run (Pohjola et al. 2018, Guo and Gong 2017), while the demand side impacts strengthen in the long term. The demand side adjustments include a gradual depreciation of old capital stock and an accumulation of new capital through investments, both of which take time. In Pohjola et al. (2018) the total impact of carbon policy, measured in terms of deviation from the BAU scenario (i.e. scenario without carbon policy), is the largest 15–25 years after the carbon rent policy is established. According to Pohjola et al. (2018), the share of wood-based fuels in combustion plants would reduce from 64% in the BAU scenario to 52% with carbon price of 15 €/tCO₂ and from 69% to 44% with carbon price of 30 €/tCO₂. Carbon rents would reduce investments in CHP (combined heat and power) plants using wood, especially in the first decades of the policy. The joint share of fossil fuels and peat would increase correspondingly. The use of natural gas would increase most according to model calculations.

On the other hand, if carbon sequestration is mainly increased by boosting forest growth e.g. with fertilization, the impacts on wood-based fuels remain small.

4.2.8. Extensions: Full forest carbon policy, albedo and non-constant carbon prices

In the studies reported in the preceding sections, the policy instrument on existing forest is set only to enhance carbon sequestration. An optimal full carbon policy is analyzed in Lintunen and Uusivuori (2016). As a general optimality principle, the release of carbon is penalized by a tax while the capture of carbon is subsidized. Lintunen and Uusivuori (2016) show that the tax/subsidy scheme for forest carbon sequestration should be complemented with carbon payments for forest residues based on their decay rates, and subsidies for production of wood products according

to carbon sequestration. In practice, this could be a rather complicated task as there is a big variation in product life time even within the same product category. Pohjola et al. (2020) has evaluated, with a detailed numerical forest-energy sector model FinFEP, the impacts of a full carbon policy. Their results suggest that the impacts on carbon sequestration, harvests and use of wood-based fuels are rather close to the ones obtained with carbon rent policy alone. This indicates that, in order to reduce administrative burdens, harvest residues and wood-based products could be excluded from the carbon policy.

Rautiainen et al. (2018) focus on the two mechanisms affecting climate, namely albedo³⁸ and carbon storage. There is a trade-off between these mechanisms as increasing carbon storage means expanding forest area or density, both of which reduce Earth's albedo (i.e. making the Earth's surface darker). The inclusion of albedo regulation softens the overall impact of policy compared to regulating carbon alone. Consequently, the increases in carbon storage per hectare and rotation length remain slightly smaller when a policy is pricing both albedo and carbon compared to pricing carbon alone. Rautiainen et al. (2018) suggest that an effort should be made to measure and regulate all climate externalities. Most notably, the impact of aerosols emitted by forests is so far not considered in the economic analysis and the inclusion of aerosols in the analysis may lead to further refinements in the policy recommendations.

Ekholm (2016) and Rautiainen et al. (2018) have extended the forest carbon policy analysis to cover the case of increasing price of carbon over time. The numerical illustrations of these studies are based on the stylized models with a long-time horizon. According to Ekholm (2016), increasing carbon price leads to longer optimal rotations, especially if the carbon is released to the atmosphere after harvesting. The impact on the rotation is larger the higher the initial carbon price is. Due to discounting and forest growth dynamics, the effect of increasing carbon price on the optimal rotation is not however trivial. For stands that are close to the optimal rotation age, an increasing carbon price can also lead to shorter rotations than the one with a constant carbon price. In line with Ekholm (2016), Rautiainen et al. (2018) illustrate that the harvests are considerably reduced and the carbon stock is notably higher in the case of increasing carbon price compared to a situation under a constant price.

4.2.9. Risks related to forest carbon policy

In most of the above studies, a longer rotation period is suggested as an important tool to increase forest carbon sequestration. The longer rotations imply a higher average age of forests. These old and volume rich forests may lead to increased risks, e.g. related to fires, pests and diseases. These risks could increase under climate change. It is likely that the above models do not fully capture the risks and thus the amount of carbon sequestration is overestimated in the medium and long run. To illustrate, according to Pohjola et al. (2018), the average age is about 100 years at the end of the simulation in the case of carbon price of 30 €/t CO₂. The change in age-structure is substantial, when compared to the current average age of 55 years and the average age of 70 years at the end of simulation without carbon

38. Albedo is the ratio of the intensity of light reflected from an object, such as planet, to that of the light it receives from the sun

rents. At the same time, the average density triples from its current level of $100\text{m}^3/\text{ha}$ to about $300\text{m}^3/\text{ha}$. This corresponds to the current typical densities of $200\text{--}330\text{m}^3/\text{ha}$ in central European countries (Metla, 2014). According to the results of Pohjola et al. (2018), the implementation of a carbon policy could lead to a situation where even quarter of the total standing stock is over 150 years. In the current situation only 3% of the total standing stock is in forests of that age.

5. Conclusions and Perspectives

A number of land-based measures related to agricultural lands, forestry, and wetlands with significant impacts on carbon sequestration and/or emission reduction have been implemented in one or more of the three Nordic countries, which are the focus of the present report. However, the implementation of many, if not most, of these measures have not necessarily been primarily driven by climate change mitigation objectives but more targeted on other environmental goals e.g. water management and biodiversity. In the same vein, the choice of technical measures for enhancing carbon sequestration should take into account the full unintended consequences, both desirable and undesirable, on other objectives e.g. food provisioning, water management, biodiversity conservation.

We have reviewed a selection of relevant land-based measures, the likely effects on climate mitigation and some insights into their implementation in the three Nordic countries. These measures can be broadly divided into two: land use changes (e.g. withdrawal of organic soils from cultivation, afforestation) and land management (e.g. reduced tillage). The effects on carbon sequestration or emission reduction of the reviewed measures differ. To illustrate this, measures to withdraw organic soils from agricultural production and measures to reduce GHG emissions from cultivated peatland seem to have large effects while other measures are associated with lower effects. Nonetheless, less effective measures may prove to be the best option for land areas with high production value. Moreover, the climate mitigation effects also vary according to the site conditions. This further implies regional differences in the potential of increasing carbon sequestration across the Nordic countries. Despite the reviewed measures already being implemented, albeit in most cases not directly deployed for climate objective, there seems to be potential for additional implementation of these land-based measures in the Nordic region.

To date, policy instruments to support the implementation of land-based measures that deliver carbon sequestration or emission reduction effects do exist albeit rather scarcely especially instruments that are primarily targeted towards climate objective. Of the existing policy instruments, the majority takes the form of subsidy scheme for example in the case of catch crops, energy crops, afforestation, and wetland creation/restoration.

We have reviewed a selection of policy instruments that can potentially be considered as part of the portfolio of policy instruments to further enhance carbon sequestration and/or emission reduction in agricultural lands, forest, and wetlands in the Nordic countries. We focused on potential instruments that have grounded scientific investigations and have practical prospects for implementation. It is important to note that the goal of this report is to give an overview of possibilities in terms of policy instruments that could be introduced in the Nordic countries. However, the final choice of instrument remains a political decision which needs to be informed by further primary, empirical research for example with respect to how designs of the different instruments could/should be custom tailored to the Nordic conditions.

Among the ***promising instruments*** that have been called upon in the literature is to establish a ***market for carbon offset credits from land-based measures*** implemented, for example, in agricultural lands and forested areas. This could be institutionalized, for example, through inclusion of carbon credits from LULUCF sector in the EU Emission Trading Scheme. Despite the claimed potentials, some challenges and possible solutions have been discussed in the literature. For example, standardized additionality tests and differentiating between temporary and permanent buffer credits can be respectively used to manage additionality and permanence issues. Nevertheless, high transaction costs (e.g. for monitoring and verification including data availability) remain an important barrier. Despite the growing number of studies demonstrating the competitiveness of land-based sequestration compared to technology-based approaches from marginal cost point of view, there are still not many available studies on the associated transaction costs. While this type of instrument is relevant for the Nordic countries, the realization will largely depend on the future direction of EU ETS and demands close collaborations with other countries participating in EU ETS.

Result-based schemes for land-based climate mitigation are currently being implemented in a few European countries. At the heart of this type of instrument is to establish a platform for certifying carbon/GHG benefits from land-based measures which can then be made available for purchase by companies or private households towards their voluntary offsets. Key features of the schemes can be transferred to the development of similar instruments in the Nordic countries. The existing examples have been set up to target land-based measures that are also relevant in the Nordic region for example wetland restoration and afforestation. As is the case with other potential instruments, it is prerequisite to have a standard and reliable methodology in place for quantifying, verifying and monitoring the GHG benefits from projects to be included in the schemes. It is also crucial to have viable financing mechanisms in place, for example, through sale of the certified carbon/GHG benefits as voluntary offsets to companies or households.

Land-use contracts using reverse auctions has the potential for adoption in an effort to further enhance carbon sequestration through land-based measures in the Nordic countries. The model has been implemented for some time in Australia and more recently in the UK with the latter specifically targeted towards tree/forest planting. Among the attractive features of this instrument is that it can minimize transaction costs. Under this scheme, landowners have the incentive to invest in activities for land-based carbon sequestration with guaranteed price of carbon credits in accordance with the outcome of the auctions while at the same time they have the flexibility to sell their carbon credits to the open market (instead of the government) if a better price exists. Based on the examples from Australia and the UK, the reverse auction-based land-use contracts can be potentially deployed in the Nordic countries especially in relation to afforestation measures. The implementation of this policy instrument necessitates a number of infrastructures including for example appropriate/accepted methods for the assessment, verification and monitoring of the carbon sequestration. The scale of the implementation reflects how many resources the government is willing to allocate and how much landowners are willing to partake in the scheme.

Conditional insurance scheme to stimulate climate smart agricultural production.

Under this set up, in order to be eligible for insurance coverage against the risk of adverse impact of the climate, farmers are obliged to undertake certain land/soil management measures which contribute towards carbon sequestration and/or emission reduction. The magnitude of the effect of implementing this scheme could be limited considering the fact that to date the uptake/penetration of private crop/weather insurance among farmers in the Nordic countries remain limited. However, as the risk of extreme events under a changing climate is becoming more pronounced, enacting this type of insurance will become an important strategy for climate change adaptation. In the short run it may require substantial public/governmental support during the establishment and consolidation of the insurance scheme. However, this may prove to be a better alternative in the long run as it shifts the burden on public budget from providing ad hoc supports into a more systematic private-public strategy. The strategy is important for hedging against future risk of natural catastrophes especially in view of extreme climates, which in the future are expected to increase in frequency as well as magnitude.

As policy instruments for forest owners to enhance carbon sequestration in existing forests, **tax/subsidy scheme and carbon rents** have been proposed in the scientific literature. The Nordic studies suggest that notable increases in carbon sequestered could be achieved even with carbon payments based on the low carbon prices. The size of the impact however differs between studies.

Some studies suggest that carbon sequestration in forests could provide a low-cost option to mitigate climate change compared to reducing emissions from fossil fuels. Timber market effects are however notable with lower harvests and a higher price of timber, implying higher costs for the forest industries. In addition, the supply of forest-based biomass for energy production is reduced and this could lead to higher CO₂ emissions in energy sector. These impacts are smaller if fertilization is used as a measure to increase the amount of carbon in forests. One study tested fertilization but concluded that this measure is not cost-effective.

Some studies suggest that the impacts of forest carbon payments on carbon sequestration and timber markets are largest in the short run while others emphasize the long run impact. The difference in the size and timing of sequestration and timber market impacts are likely to follow from the differences in the models used in the analysis instead of differences in country conditions. All the studies presumed an exogenous carbon price and thus they could not consider whether it could be worthwhile to save carbon sequestration opportunities later when the carbon price is likely to be higher.

In all studies reviewed, the carbon sequestration policy was implemented unilaterally as they are based on single-country models. The imports of timber were increased in all studies. This means that harvest and release of carbon are increased in countries without forest carbon policy. The assumption of unilateral implementation strengthens the impact of carbon rents on the carbon sink compared to multilateral implementation of a policy (Pohjola et al 2018). In order to prevent carbon leakage, it would be important to implement the incentive system internationally.

All in all, the Nordic studies suggest that a notable increase in carbon sequestered in existing forests could be achieved even with carbon payments based on the low carbon prices. If the increase in carbon sequestration is mainly driven by lengthening rotation and delaying thinning, the impacts on timber market could be notable. It

might be feasible to implement these policies gradually by starting with low carbon rent and by increasing it over time. Under such policies, it is important to define the baseline in order to pay forest owners only for additional carbon sequestration. Moreover, the policies should be made permanent.

6. References

- Assmuth, A., 2020. Economics of carbon storage in heterogeneous forests. *Dissertationes Forestales* 304. <https://dissertationesforestales.fi/pdf/article10464.pdf>
- Assmuth, A., Rämö, J. and Tahvonen, O., 2018. Economics of size-structured forestry with carbon storage. *Canadian Journal of Forest Research* 48(1): 11–22. <https://doi.org/10.1139/cjfr-2017-0261>.
- Backéus, S., Wikström, P. and Lämås, T., 2005. A model for regional analysis of carbon sequestration and timber production. *Forest ecology and management*, 216(1-3), pp.28-40.
- Burton, R.J. and Schwarz, G., 2013. Result-oriented agri-environmental schemes in Europe and their potential for promoting behavioural change. *Land Use Policy*, 30(1), pp.628-641.
- Derissen, S. and Quaas, M.F., 2013. Combining performance-based and action-based payments to provide environmental goods under uncertainty. *Ecological Economics*, 85, pp.77-84.
- Colombo, S. and Rocamora-Montiel, B., 2018. Result-oriented Agri-Environmental Climate Schemes as a means of promoting climate change mitigation in olive growing. *Outlook on Agriculture*, 47(2), pp.141-149.
- Ekholm, T., 2016. Optimal forest rotation age under efficient climate change mitigation. *Forest Policy and Economics* 62, 62-68.
- Eriksen, Jørgen; Thomsen, Ingrid Kaag; Hoffmann, Carl Christian; Hasler, Berit; Jacobsen, Brian H.; Baattrup-Pedersen, Annette; Strandberg, Beate; Christensen, Bent Tolstrup; Boelt, Birte; Iversen, Bo Vangsø; Kronvang, Brian; Børgesen, Christen Duus; Abalos Rodriguez, Diego ; Zak, Dominik Henrik; Hansen, Elly Møller; Blicher-Mathiesen, Gitte; Rubæk, Gitte Holton; Ørum, Jens Erik; Rasmussen, Jim; Audet, Joachim; Olesen, Jørgen E; Elsgaard, Lars; Munkholm, Lars Juhl; Jørgensen, Lise Nistrup; Martinsen, Louise; Bruus, Marianne; Carstensen, Mette Vodder; Pedersen, Michael Friis; Nørremark, Michael; Hutchings, Nick; Gundersen, Per; Kudsk, Per; Sørensen, Peter; Lærke, Poul Erik; Gislum, René; van't Veen, Sofie Gyritia Madsen; Larsen, Søren Erik; Petersen, Søren O; Riis, Tenna; Jørgensen, Uffe. 2020. Virkemidler til reduktion af kvælstofbelastningen af vandmiljøet. Aarhus : Aarhus Universitet - DCA - Nationalt Center for Fødevarer og Jordbrug, 2020. 454 p. (DCA rapport; No. 174).
- EU, 2018a. Regulation (EU) 2018/841 - 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.
- EU, 2018b. Regulation (EU) 2018/842 of the European Parliament and of the Council of 30 May 2018 on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement and amending Regulation (EU) No 525/2013 (Text with EEA relevance).
- Falco, S.D., Adinolfi, F., Bozzola, M. and Capitanio, F., 2014. Crop insurance as a

- strategy for adapting to climate change. *Journal of Agricultural Economics*, 65(2), pp.485-504.
- Felby, C., Nord-Larsen, T., Bentsen, N.S., Thybring, E.E., Johansen, V.K., Larsen, J.B. (2018): Forskere: Skoven bruges bedst til biomasse – ikke som CO₂-lager. Kronik, Altinget: Energi og Klima. <https://www.altinget.dk/energi/artikel/forskere-skoven-bruges-bedst-til-biomasse-ikke-som-co2-lager>
- Georgiadis, P., Vesterdal, L., Stupak, I. and Raulund-Rasmussen, K., 2017. Accumulation of soil organic carbon after cropland conversion to short-rotation willow and poplar. *Gcb Bioenergy*, 9(8), pp.1390-1401.
- Gren, M., Carlsson, M., Elofsson, K., & Munnich, M. (2012). Stochastic carbon sinks for combating carbon dioxide emissions in the EU. *Energy economics*, 34(5), 1523-1531.
- Gren, I.M. and Säll, S., 2015. Cost-effective nutrient and green-house gas management in the Baltic Sea region. *Environmental economics*, (6, Iss. 1), pp.80-90.
- Gren, M. and Aklilu, A.Z., 2016. Policy design for forest carbon sequestration: A review of the literature. *Forest Policy and Economics*, 70, pp.128-136.
- Grosjean, G., Fuss, S., Koch, N., Bodirsky, B.L., De Cara, S. and Acworth, W., 2018. Options to overcome the barriers to pricing European agricultural emissions. *Climate Policy*, 18(2), pp.151-169.
- Günther, A., Barthelmes, A., Huth, V., Joosten, H., Jurasinski, G., Koebisch, F. and Couwenberg, J., 2020. Prompt rewetting of drained peatlands reduces climate warming despite methane emissions. *Nature communications*, 11(1), pp.1-5.
- Guo, J. and Gong, P., 2017. The potential and cost of increasing forest carbon sequestration in Sweden. *Journal of Forest Economics*, 29, pp.78-86.
- Guo, J. and Gong, P., 2017. The potential and cost of increasing forest carbon sequestration in Sweden. *Journal of Forest Economics*, 29, pp.78-86.
- Hirsbrunner, S., Taenzler, D. and Reuster, L., 2011. Important aspects of sinks for linking emission trading systems. Link: <https://www.osti.gov/etdeweb/servlets/purl/21461463>.
- Hill, M.R., McMaster, D.G., Harrison, T., Hershmillier, A. and Plews, T., 2011. A reverse auction for wetland restoration in the Assiniboine River Watershed, Saskatchewan. *Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie*, 59(2), pp.245-258.
- Hoen, H.F. and Solberg, B., 1997. CO₂-taxing, timber rotations, and market implications, *Critical Reviews in Environmental Science and Technology*, 27:sup001, 151-162, DOI: 10.1080/10643389709388516.
- Hutchings, Nick; Lærke, Poul Erik; Munkholm, Lars Juhl; Elsgaard, Lars; Kristensen, Troels; Rasmussen, Jim; Lund, Peter; Børsting, Christian Friis; Løvendahl, Peter; Mikkelsen, Mette Hjorth; Albrechtsen, Rikke; Gyldenkerne, Steen; Møller, Henrik Bjarne; Hansen, Michael Jørgen; Feilberg, Anders; Adamsen, Anders Peter S. 2020. Opdatering af effekter og potentialer af klimavirkemidler til anvendelse i landbrug. Nr. 2019-0035910, 2020. 23 s., mar. 02, 2020.
- Hynynen, Huuskonen and Kojola (eds.), 2017. METSÄ 150 – Metsänkasvatuksen keinot lisätä puuntuotantoa kestävästi ja kannattavasti (Forest 150 – The measures in silviculture to increase timber production sustainably and profitably. Luonnonvara- ja biotalouden tutkimus 16/201.

IPCC, 2012: Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation. A Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change [Field, C.B., V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor, and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK, and New York, NY, USA, 582 pp

Johansen, V.K., Nord-Larsen, T., Vesterdal, L., Bentsen, N.S. (2019): Danish National Forest Accounting Plan 2021-2030 - resubmission 2019. IGN Report. Department of Geosciences and Resource Management, University of Copenhagen, Frederiksberg. https://static-curis.ku.dk/portal/files/232139225/DNFAP_revised_2019_web20191220.pdf

Joosten H, Brust K, Couwenberg J, Gerner A, Holsten B, Permien T, Schäfer A, Tanneberger F, Trepel, M, Wahren A (2013): MoorFutures. Integration von weiteren Ökosystemdienstleistungen einschließlich Biodiversität in Kohlenstoffzertifikate - Standard, Methodologie und Übertragbarkeit in andere Regionen, BfN-Skripten 350.

Jordbruksverket. 2012. Ett klimatvänligt jordbruk 2050. Report 2012:35.

Jørgensen, S.L., Termansen, M. and Pascual, U., 2020. Natural insurance as condition for market insurance: Climate change adaptation in agriculture. Ecological Economics, 169, p.106489.

KAISU, 2017. Valtioneuvoston selonteko keskipitkän aikavälin ilmastopolitiikan suunnitelmasta vuoteen 2030 – Kohti ilmastoviisasta arkea Government (Report on Medium-term Climate Change Plan for 2030 – Towards Climate-Smart Day-to-Day Living), Ympäristöministeriön raportteja 21/2017.

Kärkkäinen, L., Haakana, M., Heikkinen, J., Helin, J., Hirvelä, H., Jauhiainen, L., Laturi, J., Lehtonen, H., Lintunen, J., Niskanen, O., Ollila, P., Peltonen-Sainio, P., Regina, K., Salminen, O., Tuomainen, T., Uusivuori, J., Wall, A. and Packalen, T., 2019. Maankäyttösektorin toimien mahdollisuudet ilmastotavoitteiden saavuttamiseksi (Potential of land use measures in climate change mitigation). Valtioneuvoston selvitys- ja tutkimustoiminnan julkaisusarja 67/2018. Publications of the Government's analysis, assessment and research activities 67/2018. <http://urn.fi/URN:ISBN:978-952-287-618-8>

Klimarådet. 2020. Kendte Veje og Nye Spor til 70 Procents Reduktion: Retning og tiltag for de næste ti års klimaindsats i Danmark. Link: [Kendte veje og nye spor til 70 procents reduktion Klimarådet \(klimaraadet.dk\)](https://www.klimaraadet.dk/kendte-veje-og-nye-spor-til-70-procents-reduktion)

Kløve, B., Berglund, K., Berglund, Ö., Weldon, S. and Maljanen, M., 2017. Future options for cultivated Nordic peat soils: Can land management and rewetting control greenhouse gas emissions?. Environmental Science & Policy, 69, pp.85-93.

Koljonen, T., Soimakallio, S., Asikainen, A., Lanki, T., Anttila, P., Hilden, M., Honkatukia, J., Karvosenoja, N., Lehtilä, A., Lehtonen, H., Lindroos, T.J., Regina, K., Salminen, O., Savolahti, M., Siljander, R. and Tiittanen, P. 2017. Energia- ja ilmastostrategian vaikutusarviot: Yhteenvetoraportti (Impact assessments of the Energy and Climate strategy: The summary report). Valtion selvitys- ja tutkimustoiminnan julkaisusarja 21/2017. (Publications of the Government's analysis, assessment and research activities 21/2017)

Konrad, M.T., Andersen, H.E., Gyldenkerne, S. and Termansen, M., 2017. Synergies and trade-offs in spatially targeted water quality and climate change mitigation

policies. *Land Economics*, 93(2), pp.309-327.

Larsen, J.B., 2012: Close-to-Nature Forest management: The Danish approach to Sustainable Forestry. In: Garcia, J.M.; Casero, J.J.D. (Eds.) *Sustainable Forest management – Current research*, InTech open science, 2012, 119-218. Retrieved online via <https://cdn.intechopen.com/pdfs-wm/36975.pdf>

Lehtonen, H., Saarnio, S., Rantala, J., Luostarinen, S., Maanavilja, L., Heikkinen, J., Soini, K., Aakkula, J., Jallinoja, M., Rasi, S., Niemi, J. 2020. Maatalouden ilmastotiekartta – Tiekartta kasvihuonekaasupäästöjen vähentämiseen Suomen maataloudessa (Climate road map for agriculture – the Road map for reducing greenhouse gas emissions in Finnish agriculture). Maa- ja metsätaloustuottajain Keskusliitto MTK ry. Helsinki. Available in Finnish with English summary: <https://www.mtk.fi/ilmastotiekartta>

Lehtonen, A., Aro, L., Haakana, M., Haikarainen, S., Heikkinen, J., Huuskonen, S., Härkönen, K., Hökkä, H., Kekkonen, H., Koskela, T., Lehtonen, H., Luoranen, J., Mutanen, A., Nieminen, M., Ollila, P., Palosuo, T., Pohjanmies, T., Repo, A., Rikkinen, P., Rätty, M., Saarnio, S., Smolander, A., Soinne, H., Tolvanen, A., Tuomainen, T., Uotila, K., Viitala, E.-J., Virkajärvi, P., Wall, A. & Mä[1]kipää, R. 2021. Maankäyttösektorin ilmastotoimenpiteet : Arvio päästövähennysmahdollisuuk[1]sista. Luonnonvara- ja biotalouden tutkimus 65/2021. Luonnonvarakeskus. Helsinki. 122 s. (Measures to mitigate climate change in land use sector: Evaluation on emission reduction potential). <http://urn.fi/URN:ISBN:978-952-380-275-9>

Lintunen, J., Uusivuori, J., Laturi, J., Pohjola, J., & Rautiainen, A. 2016. Metsät ja hiilivirtoja ohjaava ilmastopolitiikka. *Metsätieteen aikakauskirja* 3–4/2016: 157–164.

Lintunen, J. and Uusivuori, J., 2016. On the economics of forests and climate change: Deriving optimal policies. *Journal of Forest Economics*, 24, pp.130-156.

Lintunen, J., Laturi, J. and Uusivuori, J., 2016. How should a forest carbon rent policy be implemented?. *Forest Policy and Economics*, 69, pp.31-39.

Maljanen, M., Sigurdsson, B.D., Guðmundsson, J., Óskarsson, H., Huttunen, J.T. and Martikainen P.J., 2010. Greenhouse gas balances of managed peatlands in the Nordic countries – present knowledge and gaps. *Biogeosciences* 7: 2711–2738.

Martens, M., Karlsson, N.P., Ehde, P.M., Mattsson, M. and Weisner, S.E., 2021. The greenhouse gas emission effects of rewetting drained peatlands and growing wetland plants for biogas fuel production. *Journal of Environmental Management*, 277, p.111391.

Metla 2014. Finnish Statistical Yearbook of Forestry. Finnish Forest Research Institute, Vantaa.

Meurer, K.H., Haddaway, N.R., Bolinder, M.A. and Kätterer, T., 2018. Tillage intensity affects total SOC stocks in boreo-temperate regions only in the topsoil—A systematic review using an ESM approach. *Earth-Science Reviews*, 177, pp.613-622.

Ministry of the Environment. 2020. Vägen till en klimatpositiv framtid. SOU 2020:4. As available 202100518 at <https://www.regeringen.se/rattsliga-dokument/statens-offentliga-utredningar/2020/01/sou-20204/>.

Moxey, A. and White, B., 2014. Result-oriented agri-environmental schemes in Europe: A comment. *Land Use Policy*, 39, pp.397-399.

Murray, B.C., Sohnsen, B. and Ross, M.T., 2007. Economic consequences of

consideration of permanence, leakage and additionality for soil carbon sequestration projects. *Climatic change*, 80(1), pp.127-143.

Munkholm, L. J., Hansen, E. M., Melander, B., Kudsk, P., Jørgensen, L. N., Heckrath, G. J., Ravnskov, S. og Axelsen, J. 2020 Vidensyntese om Conservation Agriculture. Aarhus Universitet, DCA - Nationalt Center for Fødevarer og Jordbrug. 134 s. – DCA rapport nr. 177 <https://dcapub.au.dk/djfpdf/DCArapport177.pdf>

Nainggolan, D., Hasler, B., Andersen, H.E., Gyldenkerne, S. and Termansen, M., 2018. Water quality management and climate change mitigation: Cost-effectiveness of joint implementation in the Baltic Sea region. *Ecological Economics*, 144, pp.12-26.

Niinimäki, S., Tahvonen, O., Mäkelä, A. and Linkosalo, T., 2013. On the economics of Norway spruce stands and carbon storage. *Canadian Journal of Forest Research*, 43(7), 637-648.

Novak, L.L., 2017. A Reverse Auction for Wetland Restoration in Southern Alberta. MSc Thesis. Department of Resource Economics and Environmental Sociology University of Alberta. Retrieved online: https://era.library.ualberta.ca/items/3e53c5d0-fc75-4ef3-9b02-32fca3b268a0/view/37537f4f-187c-422d-998a-3dce63b338f5/Novak_Lucas_L_201707_MSc.pdf

Ogle, S.M., Alsaker, C., Baldock, J., Bernoux, M., Breidt, F.J., McConkey, B., Regina, K. and Vazquez-Amabile, G.G., 2019. Climate and soil characteristics determine where no-till management can store carbon in soils and mitigate greenhouse gas emissions. *Scientific reports*, 9(1), pp.1-8.

Olesen, J E, Petersen SO, Lund PE, Jørgensen UF, Kristensen TR, Elsgaard LA, Sørensen P, Lassen J. 2018. Virkemidler til reduktion af klimagasser i landbruget. DCA-Nationalt Center for Fødevarer og Jordbrug; 2018. 119s – DCA rapport nr 130.

Pihlainen, S., Tahvonen, O. and Niinimäki, S., 2014. The economics of timber and bioenergy production and carbon storage in Scots pine stands. *Canadian journal of forest research*, 44(9), pp.1091-1102.

Pohjola, J. and Valsta, L., 2007. Carbon credits and management of Scots pine and Norway spruce stands in Finland. *Forest Policy and Economics*, 9(7), pp.789-798.

Pohjola, J., Laturi, J., Lintunen, J. and Uusivuori, J., 2018. Immediate and long-run impacts of a forest carbon policy—A market-level assessment with heterogeneous forest owners. *Journal of Forest Economics*, 32, pp.94-105.

Pohjola, J. , Lintunen, J., Laturi, J. & Uusivuori, J. 2020. Setting the emission payments on wood based bioenergy: Impacts of partial and optimal climate policies on the energy and forest sectors. Manuscript.

Rabinowicz, E., and Jörgensen, C., 2021. Möjliga klimatåtgärder och styrmedel i ett framtida landsbygdsprogram. Evaluation report 2021:1. Board of Agriculture, Jönköping.

Rautiainen, A., Lintunen, J. and Uusivuori, J., 2018. Market-Level Implications of Regulating Forest Carbon Storage and Albedo for Climate Change Mitigation. *Agricultural and Resource Economics Review* (2018) 1–33

Richards, K.R., 2004. A brief overview of carbon sequestration economics and policy. *Environmental Management*, 33(4), pp.545-558.

Romppanen, S., 2020. The LULUCF Regulation: the new role of land and forests in the EU climate and policy framework. *Journal of Energy & Natural Resources Law*,

38(3), pp.261-287.

SCB. Use of agricultural land 2019. JO 10 SM 1902.

SEGES (2019): Conservation agriculture i praksis. Danske landmænd fortæller om deres erfaringer med conservation agriculture. Landbrug og Fødevarer, SEGES.
https://www.landbrugsinfo.dk/afrapportering/innovation/2019/sider/PL_19_4580_Conservation_Agriculture_i_praksis.pdf

Sjølie, H.K., Latta, G.S. and Solberg, B., 2013. Potentials and costs of climate change mitigation in the Norwegian forest sector—Does choice of policy matter?. *Canadian Journal of Forest Research*, 43(6), pp.589-598.

Sohngen, B. and Mendelsohn, R., 2003. An optimal control model of forest carbon sequestration. *American Journal of Agricultural Economics*, 85(2), pp.448-457.

Tahvonen, O. and Rautiainen, A., 2017. Economics of forest carbon storage and the additionality principle. *Resource and Energy Economics*, 50, pp.124-134.

Timonen, R., 2020. Selvitys rakentamisen maankäyttömuutosmaksusta. (Report on payment on land use change due to the construction). Ympäristöministeriön julkaisuja 2020: 11. <http://urn.fi/URN:ISBN:978-952-361-204-4>

Uusivuori, J.; Hilden, M., Lehtonen, H., Rikonen, P., Makkonen, M. (eds.) 2015. Poliitiikka ja luonnonvarat. Luonnonvara- ja biotalouden tutkimus 20/2015: p. 4-7.

Uusivuori, J., Hilden, M., Lehtonen, H. and Makkonen, M. eds., 2015. Poliitiikka ja luonnonvarat. (Policy and natural resources). Luonnonvara- ja biotalouden tutkimus 20/2015.

Van Kooten, G.C., Binkley, C.S. and Delcourt, G., 1995. Effect of carbon taxes and subsidies on optimal forest rotation age and supply of carbon services. *American journal of agricultural economics*, 77(2), pp.365-374.

Van Kooten, G.C. and Sohngen, B., 2007. Economics of forest ecosystem carbon sinks: a review.

Van Kooten, G.C., 2009. Biological carbon sequestration and carbon trading re-visited. *Climatic Change*, 95(3), pp.449-463.

Van Kooten, G.C., Laaksonen-Craig, S. and Wang, Y., 2009. A meta-regression analysis of forest carbon offset costs. *Canadian Journal of Forest Research*, 39(11), pp.2153-2167.

Verschuuren, J., 2018. Towards an EU regulatory framework for climate-smart agriculture: the example of soil carbon sequestration. *Transnational Environmental Law*, 7(2), pp.301-322.

Vrebo, D., Bampa, F., Creamer, R., Gardi, C., Ghaley, B., Jones, A., Rutgers, M., Sanden, T., Staes, J. and Meire, P. 2017. The Impact of Policy Instruments on Soil Multifunctionality in the European Union, *Sustainability* 9(3), 407.

Walcott, J.J., Bruce, S. and Sims, J., 2009. *Soil carbon for carbon sequestration and trading: a review of issues for agriculture and forestry*. Canberra: Bureau of Rural Sciences, Department of Agriculture, Fisheries & Forestry.

Wejberg, H. 2020. Metsitystuen mahdollisuudet ilmastopoliitikassa (The prospects of afforestation subsidy in climate policy). Master's thesis for University of Helsinki

Renou-Wilson, F., Moser, G., Fallon, D., Farrell, C.A., Müller, C. and Wilson, D., 2019. Rewetting degraded peatlands for climate and biodiversity benefits: Results from

two raised bogs. *Ecological Engineering*, 127, pp.547-560.

World Bank, 2016. Carbon Credits and Additionality: Past, Present, and Future. PMR Technical Note 13. Partnership for Market Readiness, World Bank, Washington, DC.
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