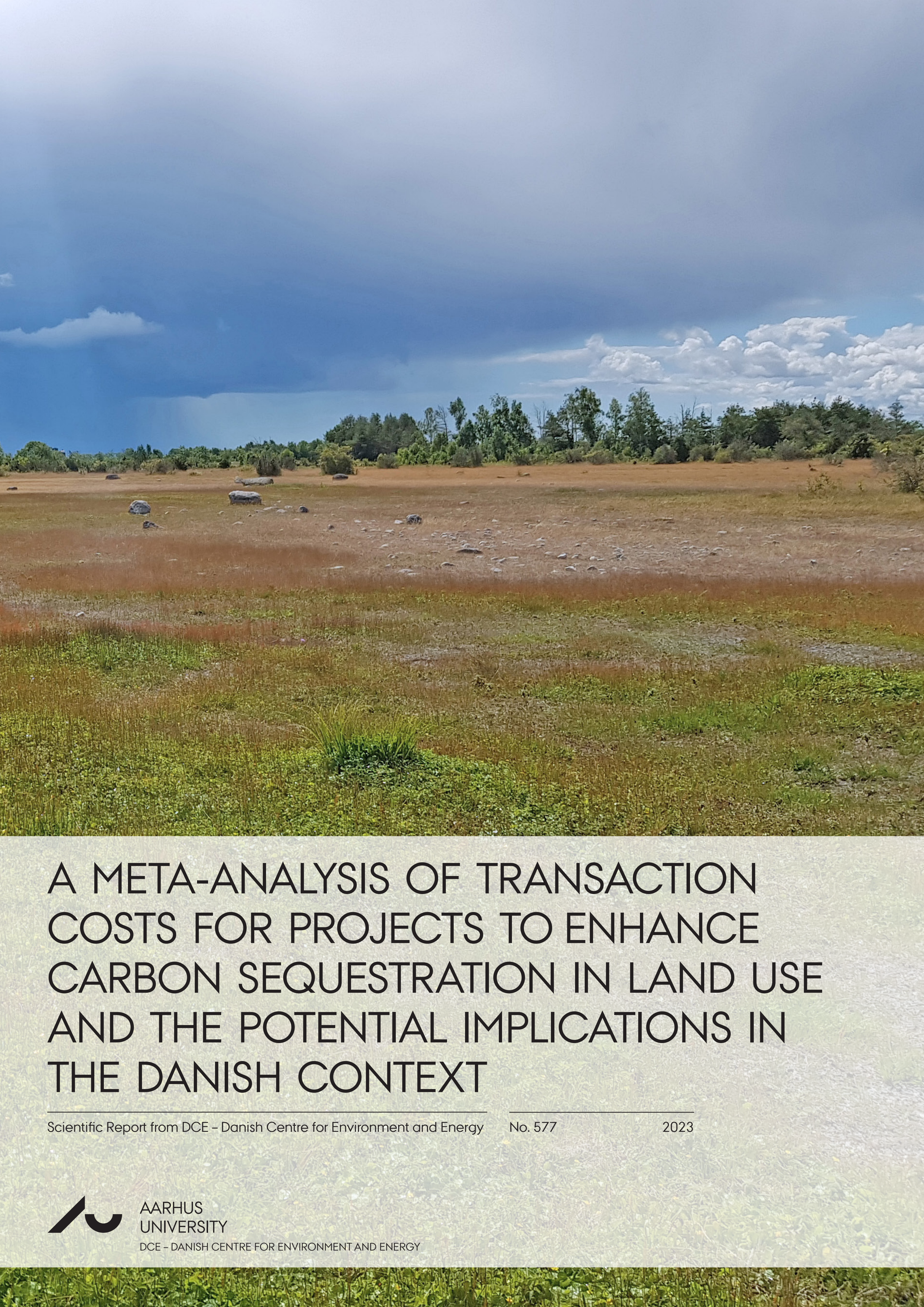

A META-ANALYSIS OF TRANSACTION COSTS FOR PROJECTS TO ENHANCE CARBON SEQUESTRATION IN LAND USE AND THE POTENTIAL IMPLICATIONS IN THE DANISH CONTEXT

Scientific Report from DCE – Danish Centre for Environment and Energy No. 577 2023

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Abstract: This report examines the determinants of transaction costs associated with carbon sequestration projects through a meta-analysis of scientific publications. Further, transactions costs are compared to direct mitigation costs in the Danish context, and the implications for Danish and EU policies to mitigate greenhouse gases from the agricultural sector are discussed.

Keywords: Agriculture, cost-effectiveness, carbon sequestration, forestry, meta-analysis, greenhouse gas taxation, transaction costs

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Contents

Preface

This report was commissioned by the Danish Agricultural Agency. The purpose of the report was to carry out a meta-analysis of transaction costs for projects to enhance carbon sequestration in land use and the potential implications in the Danish context. The implications of interest are those for the cost-effectiveness of carbon sequestration measures compared with other measures, after having considered the transaction costs.

The meta-analysis builds on a review of peer-reviewed scientific articles providing quantitative estimates of transactions costs in carbon sequestration projects or policies in the forestry and agricultural sectors. It investigated how project characteristics, institutional context, and links to specific policy instruments, affect the size of transaction costs. This analysis is carried out while explicitly categorizing transactions costs into four categories: establishment costs, monitoring/verification costs, operation costs and trading costs, to evaluate their role for the total transaction costs. The data is analyzed through systematic comparisons as well as econometric analysis.

Based on the meta-analysis and previous literature, the report discusses the potential magnitude of transaction costs for sequestration measures that could become implemented in the Danish context. These transaction costs are combined with data on the direct implementation costs of such measures. In addition, the transaction costs for land-based carbon sequestration are compared to the corresponding costs in the energy sector. Finally, the report informs us of the cost-effectiveness of carbon sequestration measures in the land use sector, when transaction costs are considered.

Together, the results are discussed in relation to ongoing developments in EU policy for measures in the land use, land use change and forestry sector, and key implications for Danish policy making are derived.

Comments from external review by the Danish Agricultural Agency have been addressed in the below final version of the report.

Sammenfatning

Kulstofbinding hævdes at være en billig foranstaltning til at opfylde klimamålene. For at politikker til kulstofbinding skal være omkostningseffektive, skal jordejernes indsats rettes mod steder og aktiviteter, der giver den største mængde binding pr. euro. For at opnå det, er det nødvendigt at kende den potentielle binding på forskellige steder; og overvågning og håndhævelse er nødvendig for at sikre, at foranstaltningerne implementeres professionelt og fungerer som forventet. Evaluering, overvågning og håndhævelse er alle forbundet med omkostninger, men bidrager ikke i sig selv til kulstofbinding. De kaldes transaktionsomkostninger (TRC). TRC'er omfatter alle omkostninger ved en miljøpolitik, bortset fra reduktionsomkostninger.

Formålet med denne rapport er at undersøge determinanterne for TRC'er i kulstofbindingsprojekter inden for den globale skov- og landbrugssektor og de potentielle implikationer af resultaterne i en dansk kontekst. Dette gøres gennem en metaanalyse af videnskabelige studier offentliggjort mellem 2000 og 2022. Derudover foretager vi en simpel sammenligning af omkostningseffektiviteten af kulstofbindingstiltag, med og uden TRC'er, under den foreslåede danske drivhusgasafgift på landbrugssektoren ved hjælp af resultater fra metaanalysen og litteraturen.

Metaanalysen bygger på peer-reviewed videnskabelige artikler, der indeholder oplysninger om TRC'er forbundet med sekvestreringsprojekter i skovbrugs- og/eller landbrugssektoren, og som indeholder tilstrækkelige oplysninger om projektkarakteristika. En grundig søgning i videnskabelige databaser resulterede i en samling af 31 artikler udgivet over 22 år. Da en enkelt artikel kan give oplysninger om flere projekter og/eller præsentere resultater for flere scenarier vedrørende det samme projekt, består det endelige datasæt af 186 observationer. De fleste af vores observationer er anvendelser i skovbrugssektoren: Kun 6 ud af 31 artikler omhandler projekter, der involverer brug af landbrugsjord. Disse studier omhandler skovrejsning, plantning af buske eller hegn eller skovgræsning (dvs. integration af træer og græsningsarealer) på landbrugsjord.

I vores datasæt er den gennemsnitlige TRC 19,0 EUR/tCO2e. De fleste af de rapporterede TRC-værdier er dog lave, mellem 0 og 1 EUR/tCO2e, mens et lille antal observationer har meget høje TRC-værdier. I denne situation er median TRC, dvs. den midterste observation, et mere repræsentativt mål for datasættet. Median TRC er 1,0 EUR/tCO2e, hvilket er tæt på tidligere estimater af TRC'er i energiintensive sektorer, som typisk ligger mellem 0 og 1,0 EUR/tCO2e. Kun en tredjedel af vores indsamlede data rapporterer både direkte reduktionsomkostninger og TRC'er. For disse udgør TRC mellem <1% og 86,6 % af de samlede projektomkostninger, med en median på 7,8 %.

Den økonometriske analyse viser, at en stigning på 1 % i projektområdet fører til en stigning på 1,2 % i de samlede TRC'er. På samme måde er en stigning på 1 % i mængden af bundet kulstof forbundet med en stigning på 1,0 % i projektets samlede TRC'er. Det tyder på, at man ikke sparer TRC'er ved at have større projekter. Projekter, der genererer offset-kreditter, har betydeligt højere TRC'er end andre projekter, hvilket potentielt kan forklares ved, at offset-købere står over for strengere lovgivningsmæssige forpligtelser, der også gælder for de købte carbon offsets. Vi finder nogle tegn på, at projekter i det globale nord har højere TRC'er end dem, der gennemføres i det globale syd, hvilket kan forklares med højere lønninger og strengere regler for f.eks. overvågning og håndhævelse. Resultaterne tyder på, at projekter, der implementeres på landbrugsjord, har lavere TRC'er sammenlignet med dem, der kun implementeres på skovjord, men dette skal fortolkes med forsigtighed på grund af det begrænsede antal landbrugsrelaterede studier.

En tilsvarende økonometrisk analyse blev foretaget for TRC'er specifikt relateret til overvågning, rapportering og verifikation, som var tilgængelige i omkring to tredjedele af observationerne. Resultaterne var i overensstemmelse med dem, der brugte alle TRC'er, men vi fandt ikke signifikante effekter af valget af overvågningssystem eller overvågningspræcisionen.

I betragtning af det globale datasæt og dominansen af skovrelaterede projekter, er gennemsnittet og medianen af TRC'er i vores data ikke direkte anvendelige i en dansk kontekst. Et mere relevant estimat er givet af Mettepenningen et al, som beregner den gennemsnitlige TRC pr. hektar for støtteordninger til miljøvenligt landbrug i EU-lande ved hjælp af data fra landmænd i otte lande. Deres estimat af TRC, 52,5 euro pr. hektar, kunne være relevant for de projekter, der implementeres i Danmark. Hvis denne omkostning lægges til de direkte omkostninger ved at reducere kulstofudledningen fra den danske landbrugssektor, vil flere foranstaltninger måske ikke længere være omkostningseffektive, hvis den foreslåede drivhusgasafgift på landbrugssektoren, svarende til 100 euro pr. tCO2e, implementeres.

EU-forordningen om jord, ændringer i arealanvendelse og skovbrug (LULUCF) er for nylig blevet revideret, og de politiske instrumenter, der skal anvendes, vil sandsynligvis blive bestemt af medlemsstaterne. Politiske beslutningstagere står så over for en afvejning mellem øgede TRC'er til forbedret overvågning, rapportering og verificering og politikkernes evne til at målrette foranstaltninger med lave direkte omkostninger til kulstofreduktion. På samme måde er der en afvejning mellem at reducere TRC ved at forenkle reglerne for kulstofregnskab og reducere nøjagtigheden af målingen af kulstofpåvirkningen. Hvis flere politiske instrumenter anvendes samtidigt, f.eks. programmerne for udvikling af landdistrikter, EU's LIFE-program og frivillige CO_2-kompensationsordninger, kan TRC'erne stige, hvis ordningerne har forskellige regler for måling af kulstoflagre, ikke-permanens, additionalitet og miljømæssige sideeffekter. Alligevel kan et bredere sæt af finansieringsmuligheder øge den samlede finansiering, der er til rådighed for kulstofbinding, hvilket kan være en fordel, hvis bindingen kun stimuleres gennem subsidier.

Denne rapport viser, at TRC'er for kulstofbindingsprojekter i landbrugssektoren er underundersøgte. En vigtig vej til fremtidig forskning kunne derfor være at undersøge TRC'er for projekter og politikker, der implementeres på landbrugsjord i Danmark gennem f.eks. dækafgrøder, pløjefri dyrkning, skovlandbrug og genfugtning af organiske jorde. Det ville være særligt interessant at undersøge, hvordan en fokuseret politik på jordbaseret kulstofbinding kunne udformes for at opnå en optimal balance mellem transaktionsomkostninger og evnen til at målrette steder og foranstaltninger med et højt kulstofbindingspotentiale pr. brugt euro. Ved at udvide anvendelsesområdet til at omfatte landbrugsspecifikke kulstofbindingstiltag, kan fremtidig forskning give en mere nuanceret forståelse af de involverede transaktionsomkostninger og give beslutningstagere et bredere sæt værktøjer til afbødning af klimaforandringer.

Summary

Carbon sequestration is argued to be a low-cost measure for meeting climate targets. For policies towards carbon sequestration to be cost-effective, landowners' efforts must become directed to locations and activities that provide the largest amount of sequestration per EUR. To achieve that, it is necessary to know the potential sequestration at different locations, and monitoring and enforcement is necessary to assure that measures are professionally implemented and perform as expected. Evaluation, monitoring, and enforcement are all associated with costs but do not in themselves contribute to carbon sequestration. They are called transaction costs (TRCs). TRCs include all the costs of an environmental policy excluding abatement costs.

The purpose of this report is to investigate the determinants of TRCs in carbon sequestration projects within the global forestry and agricultural sectors, and the potential implications of the results in the Danish context. This is done through a meta-analysis on scientific studies published between 2000 and 2022. In addition, we make a simple comparison of the cost-effectiveness of carbon sequestration measures, with and without TRCs, under the proposed Danish greenhouse gas tax on the agricultural sector using results from the meta-analysis and the literature.

The meta-analysis builds on peer-reviewed scientific articles that contain information on the TRCs associated with sequestration projects in the forestry and/or the agricultural sectors and include sufficient information on project characteristics. A thorough search in scientific databases resulted in a collection of 31 articles published over 22 years. As a single paper could provide information on multiple projects and/or present results for several scenarios relating to the same project, the final dataset consists of 186 observations. Most of our observations are applications to the forestry sector: only 6 out of 31 papers consider projects that involve the use of agricultural land. These studies consider afforestation, plantation of shrubs or hedges, or silvopasture (i.e., integration of trees and grazing land) on agricultural land.

In our dataset, the average TRC is 19.0 EUR/tCO2e. However, most of the reported TRC values are low, between 0 and 1 EUR/tCO2e, while a small number of observations have very high TRCs. In this situation, the median TRC, i.e. the midpoint observation, is a more representative measure for the dataset. The median TRC is 1.0 EUR/tCO2e, which is close to previous estimates of TRCs in energy intensive sectors that typically fall between 0 and 1.0 EUR/tCO2e. Only one third of our collected report both direct abatement costs and TRCs. For those, TRCs represent between <1% and 86.6 % of the total project costs, with a median of 7.8 %.

The econometric analysis shows that a 1 % increase in the project area leads to a 1.2 % increase in total TRCs. Similarly, a 1 % increase in the amount of sequestered carbon is associated with a 1.0 % increase in the project's total TRCs. This suggests that having larger projects will not save on TRCs. Projects that generate offset credits have significantly higher TRCs than other projects, which is potentially explained by offset buyers facing stricter regulatory obligations also applying to the purchased carbon offsets. We find some evidence that projects located in the global north have higher TRCs than those implemented in the global south, which might be explained by higher salaries and

more stringent regulations for, e.g., monitoring and enforcement. Results suggest that projects implemented on agricultural land have lower TRCs compared to those implemented only on forest land, but this should be interpreted with care given the limited number of agriculturally related studies.

A corresponding econometric analysis was made for TRCs specifically related to monitoring, reporting, and verification, which were available in about two thirds of the observations. Results were consistent with those using all TRCs, but we did not find significant effects of the monitoring system choice, or the monitoring precision.

Given the global dataset and the dominance of forest-related projects, the mean and median TRCs in our data are not directly applicable to the Danish context. A more relevant estimate is provided by Mettepenningen et al., who calculate the average TRC per hectare for agri-environmental support schemes in EU countries using data from farmers in eight countries. Their estimate of TRCs, EUR 52.5 per hectare, could be relevant for sequestration projects implemented in Denmark. If this cost is added to the direct costs for mitigating carbon emissions from the Danish agricultural sector, several measures might no longer be cost-effective if the suggested greenhouse gas tax on the agricultural sector, equal to EUR 100 per tCO2e, is implemented.

The EU Regulation on land, land use change and forestry (LULUCF) is recently revised, and the policy instruments to be applied are likely to be determined by the Member States. Policy makers then face a trade-off between increased TRCs for enhanced monitoring, reporting, and verification, and the ability of policies to target measures with low direct carbon mitigation costs. Similarly, there is a trade-off between reducing TRCs by simplifying the rules for carbon accounting and reducing the accuracy of the measurement of carbon impact. If multiple policy instruments are applied simultaneously, e.g., the Rural Development Programs, the EU LIFE program, and voluntary carbon offsetting schemes, TRCs could increase if the schemes have different rules for measuring carbon stocks, non-permanence, additionality, and environmental side-effects. Still, a broader set of funding options could increase the total funding available for carbon sequestration, which can be an advantage if sequestration is only incentivized through subsidies.

This report shows that TRCs for carbon sequestration projects in the agricultural sector are understudied. An important avenue for future research could therefore be the exploration of TRCs for projects and policies implemented on farmed land in Denmark through, e.g., cover cropping, no-till farming, agroforestry, and rewetting of organic soils. It would be particularly interesting to examine how a focused policy on soil-based carbon sequestration could be designed to achieve an optimal balance between transaction costs and the ability to target locations and measures with a high carbon sequestration potential per euro spent. By extending the scope to include agriculturally specific carbon sequestration measures, future research could offer a more nuanced understanding of the transaction costs involved and provide policymakers with a broader set of tools for climate change mitigation.

1 Introduction

Carbon sequestration is argued to be a cost-effective tool to meet climate targets (Bosetti et al., 2011; De Jong et al., 2000; Lubowski et al., 2006). However, transaction costs associated with the establishment, administration, monitoring, and enforcement of policies could potentially challenge this. For example, the transaction costs could be large if policies for carbon sequestration should consider variability in carbon sequestration across space and time.

The greenhouse gas mitigation potential of carbon sequestration is considerable: an expansion of global forest areas by 1 billion hectares could reduce net emissions by between 0.5 and 10.1 Gt of carbon dioxide equivalents (CO2e) per year (Popp et al., 2017). Therefore, policymakers are increasingly considering the land use sector as a potential avenue for implementing projects aiming at carbon dioxide (CO2) sequestration from the atmosphere, thus complementing reductions in fossil fuel consumption in the mitigation of climate change (Bosetti et al., 2011; Murray et al., 2009; Van Kooten and Sohngen, 2007; Vass and Elofsson, 2016).

Few policy instruments that directly target carbon sequestration are currently in place in the EU. Existing policy instruments that contribute to carbon sequestration typically target other, or multiple, environmental outcomes, such as the Danish support to catch crop cultivation which primarily targets nutrient leaching, and afforestation, which simultaneously aims at sequestration and biodiversity enhancement. Moreover, the compensation to landowners for such agri-environmental measures is typically based on input and management costs rather than the environmental outcome, e.g., in terms of carbon sequestration (Hasler et al. 2022). This reduces the cost-effectiveness of the policy, as it fails to direct the efforts to locations and activities that provide the largest amount of sequestration per EUR. To achieve cost-effectiveness, it is necessary to carry out a thorough evaluation of the potential environmental performance of measures in different locations. Also, a considerable amount of monitoring and enforcement is necessary to verify that landowners have implemented the agreed management measures, and/or verify the actual environmental performance. Increased evaluation, monitoring and enforcement are all associated with additional costs. These costs are so-called transaction costs (TRCs). Carbon sequestration policies could be associated with comparatively high TRCs, explained by the difficulties of measuring the carbon sequestration, which can vary over time and across space.

The purpose of this report is to investigate the determinants of TRCs in carbon sequestration projects within the global forestry and agricultural sectors, and the potential implications in the Danish context. This is done through a meta-analysis on scientific studies published between 2000 and 2022. In addition, we make a simple comparison of the cost-effectiveness of carbon sequestration measures under the proposed greenhouse gas tax on the agricultural sector, with and without TRCs, using results from the meta-analysis and the literature.

Most economic studies on carbon sequestration in the forestry and agriculture sectors focus only on the direct abatement costs. For those that study TRCs, few analyze TRC composition or the relationship between TRCs and the choice of policy instrument (Antinori and Sathaye, 2007; Bakam et al., 2012;

Joas and Flachsland, 2016; Phan et al., 2017). Studies that quantify TRCs are relatively heterogeneous, explained by the different nature of projects and contexts studied, and differences in research focus and method. It is therefore difficult for policymakers that consider introducing a new policy for carbon sequestration to find one or a few studies that they could rely on when trying to understand the likely magnitude of the TRCs. A meta-analysis on a larger set of studies, such as done in this report, could therefore help to better understand what factors determine the size of TRCs for carbon sequestration projects and policies.

Earlier meta-analyses have investigated the determinants of total costs (i.e., abatement costs plus TRCs) of sequestering carbon in forests, including for example Van Kooten and Sohngen (2007) and Phan et al. (2014), but do not examine TRCs in depth. In contrast, Phan et al. (2017) explicitly distinguish between abatement costs and TRCs. They study the key drivers of TRCs in carbon credit-generating forest projects implemented in the global south, based on interviews with project developers on 17 different projects implemented between 1992 and 2011. A limitation of their study is that it only considers TRCs for project establishment, i.e., search, design, and negotiation costs that arise before project implementation. This is a concern because for example monitoring and verification costs are argued to be large for sequestration projects (Cacho et al., 2004), suggesting it is important to take also other types of TRCs than those for project establishment into account.

To the best of our knowledge, there is no previous meta-analysis that considers multiple types of TRCs in projects for carbon sequestration in land use. We fill this gap by considering not only establishment costs but also costs for monitoring and verification, operation, and emission trading. Also, we add to the literature by including studies applied in both developing and developed countries.

The remainder of the report is organized as follows: in section 2, we define and describe transaction costs. Section 3 describes the method for the meta-analysis including the selection of studies, the classification of transaction cost types, land types, and policy instrument types, and the econometric method used to analyze the resulting data. Section 4 provides the results, including an overview of the data, and the outcome of the econometric estimations. Section 5 compares the direct abatement costs and transaction costs for carbon sequestration in the Danish context and relates the results to the suggested greenhouse gas tax on the agricultural sector. Section 6 discusses the potential links between ongoing developments in EU policy for carbon sequestration in land use and the magnitude of TRCs.

2 Transaction costs: definitions and determinants

TRCs were first defined by Coase (1960) as the general costs of carrying out market transactions. With a specific focus on TRCs related to environmental policy, Sathaye et al. (2006) and McCann et al. (2005) argue that these TRCs can be defined as all costs associated with establishing, administering, monitoring, and enforcing policy. These costs may occur before, during, and after environmental policy implementation (Krutilla and Krause 2011). Thus, TRCs of environmental policies include not only the private agent's costs for setting up contracts or trading emission permits, but also other costs borne by policymakers and relevant stakeholders for policy design, stakeholder participation, monitoring, verification, enforcement, and compliance. Hence, TRCs are all the costs of an environmental policy excluding abatement costs (Joas and Flachsland 2016).

Project attributes, including physical and institutional factors, can affect both TRCs and abatement costs (McCann, 2013). The size of TRCs is suggested to depend on the magnitude of abatement, the type of policy instrument used, agents' characteristics, the governance structure, and the institutional environment in which the transaction takes place (Michaelowa et al., 2003; Reeling et al., 2020; Rørstad et al., 2007; Stavins, 1995). Therefore, TRCs can be expected to vary significantly across countries, sectors, and firms.

TRCs are of importance for the total costs of a policy (Stavins, 1995), and can affect the ranking of abatement measures with respect to cost-effectiveness (Nainggolan et al., 2021; Ofei-Mensah and Bennett, 2013). Often, landowners also face considerable fixed transaction costs for policy adoption. For example, the time spent on applying for support or negotiating contracts on carbon offsetting could be independent of the project size. This can discourage small landholders from adopting voluntary schemes (Heindl 2017). Moreover, the amount of transaction costs spent on monitoring and enforcement could be related to the accuracy of carbon sequestration measurement, and such accuracy could be important for policy makers.

3 Method

We carry out a meta-analysis on peer-reviewed studies containing information on TRCs in the land use sector. A meta-analysis is the systematic review and quantitative synthesis of empirical economic evidence on a given effect (Havránek et al., 2020). It has two main objectives: to summarize available information on a given topic and to explain the variation among reported results. We follow the MAER-NET reporting guidelines (Havránek et al., 2020) to direct our methodology.

3.1 Identification process

We searched for peer-reviewed scientific articles written in English that contained information on the TRCs expressed in monetary terms, associated with sequestration projects in the forestry and/or the agricultural sectors, and including sufficient information on project attributes, i.e., project characteristics. To this end, we used a keyword database search in Scopus and Google Scholar, carried out in February 2022. We used combinations of three search strings: a carbon sequestration string ("carbon sequestration" or "carbon sink"), a cost string ("transaction cost", "monitoring cost", "administration cost", "verification cost", "cost of transaction", "cost of monitoring", "cost of administration" or "cost of verification") and a sector string ("forestry", "forest", "agri-forestry" "farm" or "agriculture").

Potentially relevant documents were then screened for eligibility, i.e., relevance and completeness. We eliminated duplicates, and a few documents were excluded because it was not possible to retrieve the full text. Subsequently, we checked whether the remaining papers: (i) studied an existing or potential project targeting biological carbon sequestration in agriculture or forestry, and (ii) were original empirical studies that modelled, estimated, identified, or made expert judgements of, TRCs in monetary terms. Only studies where the answer was "yes" in both cases were included in the review. This resulted in a sample of 48 papers containing values of TRCs in sequestration projects.

We further excluded 17 studies that did not report values for the project's sequestration output, despite containing quantitative information on TRCs. Thus, out of 1,700 studies identified during our search, 31 were considered eligible and within scope, and were selected for the meta-analysis. The identification process is summarized in Figure 1, using a PRISMA flow diagram (Page et al., 2021).

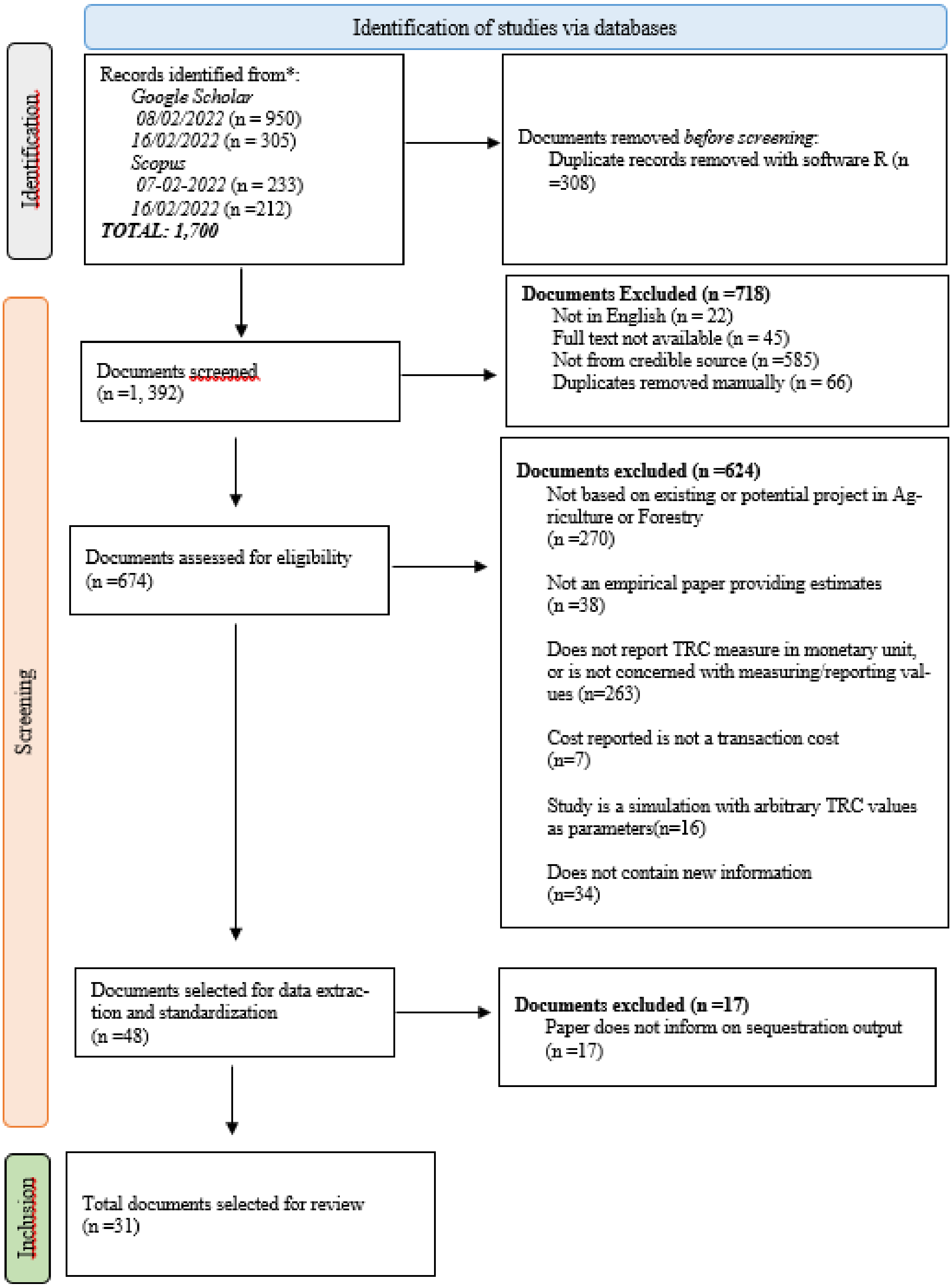

Figure 1 PRISMA flow diagram, adapted from Page et al. (2021).

3.2 Extraction of data

The 31 selected papers were published in 20 different journals over 22 years. A single paper could often provide information on multiple projects, either in the same country or in different countries, or present results for several distinct scenarios, i.e., results for different versions of the same project. In the following, we treat these different projects and scenarios as separate observations in the dataset. The final dataset therefore consisted of 186 observations.

The TRC values in this report are expressed in EUR in 2022 year value.[1] The amount of sequestered carbon (measured in tCO2e) was mostly provided directly in the studies. In some cases, we calculated the amount of sequestered carbon from a reported change in forest biomass volume, using a conversion factor for biomass to carbon of 1.8 tCO2e per ton of biomass in line with suggestions by Penman et al. (2003).

3.3 Classifying transaction cost types, land type, and policy instrument type

Most studies present a breakdown of TRCs into several components. We classify these components into four different categories based on the timing and the nature of the activities. "Establishment costs" are costs appearing *ex ante* before the project starts. Those are the costs necessary to research, design and first establish a sequestration project or policy. The remaining types of TRCs arise during projects' lifetime. "Operation costs" are directly related to the administration of the sequestration activities implemented. "Monitoring costs", are the costs of monitoring and verification of carbon fluxes. Other TRCs are directly related to the type of policy instrument, such as the costs for emitting, certifying, validating, and trading, carbon credits. For those, we use the term "costs of trading". Table A.1 in the Appendix provides an overview on the terminology used in the papers for the different types of TRCs, and how we attribute each of those terms to the four mentioned cost categories.

Most of our observations are applications to the forestry sector: only 6 out of 31 papers consider projects that involve the use of agricultural land. Almost all of those consider afforestation, plantation of shrubs or hedges, or silvopasture (i.e., integration of trees and grazing land), on agricultural land. We have classified these 6 papers as involving both forestry and agricultural land. It should thus be borne in mind that they do not study measures that are specific to the agricultural sector[2]. It is still relevant to control for the cases where projects are implemented on agricultural land, because in many countries conversion between different land uses can require approval from authorities, which involves administrative efforts. Obviously, there are substantial direct costs for converting forest land into agricultural land, due to the need for removal of stubbles, extensive plowing, and basic fertilization. This could entail additional transaction costs for planning, and for contracting entrepreneurs. However, projects in our data consider the opposite, namely conversion of agricultural land into land with more trees or shrubs, where the direct cost, and therefore also the associated transaction costs are likely to be smaller. In addition to that, different requirements might be applied for environmental projects established on forest and agricultural land. Therefore, projects on agricultural land might be associated with smaller or larger TRCs than projects implemented only on forest land, but the direction of the effect cannot be judged beforehand.

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[1] The econometric estimations were made using TRCs expressed in USD in 2022 year value. For studies published at earlier dates, the TRCs were inflated to 2022 using the US Consumer Price Index (OECD 2022a,b). The use of USD in the regressions does not affect the interpretation of results provided in this report. USD values are converted in EUR using the average exchange rate for 2022 from the ECB Data portal, where 1 EUR = 1.0683 USD.

[2] For example, the literature suggests measures such as cover crops and no-till for increasing carbon pools in agricultural soils. However, we have not found studies that examine the transaction costs of such measures and the related policies.

In general, different rules and practices apply for Payments for Ecosystem Services (PES) programs[3] and carbon offset trading schemes, which could lead to differences in TRCs. PES involves financial support to landowners or resource users to implement practices that enhance carbon sequestration and other environmental outcomes. Carbon offset programs typically allow firms that consume fossil fuels to undertake smaller reductions in fossil fuel use by compensating through the purchase of carbon offsets. It is not initially evident which of those one should expect to generate higher TRCs, partly because there are many different schemes in place for each type of scheme. In our analysis, we check for whether a project is related to a PES program, and/or a carbon offset market. Three studies are classified as being both PES and offset projects.

3.4 Econometric empirical strategy

We apply our dataset in meta-regressions with the aim to explore the impact of project attributes on total TRCs. The attributes considered include projects' physical characteristics (in terms of size in hectares, size of sequestration per hectare, duration, and year of implementation), sector (in terms of being applied on pre-existing forest land or on agricultural land), policy instrument applied (PES, carbon offsets, or undefined), and project location (global north or global south).

First, one can expect that a larger project area and/or higher sequestration output per hectare, might demand more administration, leading to higher total TRCs. However, there can be fixed costs per project for establishment, operation, and monitoring. This implies that the average TRC per unit of area and per unit of CO2e sequestered could be lower for larger projects, i.e., there could be economies of scale. A longer project duration may also be associated with higher total TRCs, due to the adding up of annual management, administrative, and monitoring costs[4].

We control for whether the project was implemented on agricultural land, for reasons mentioned above. We also control for whether the project is located in the global south or global north. This is motivated by the fact that global north countries tend to have both more stringent regulations (Nachmany et al., 2014) and generally higher salary levels. Based thereon, one could expect that TRCs are on average higher in the global north than in the global south. Finally, we control for whether the study considers a PES and/or a carbon offset project, or none of those.

We then estimate the following regression:

$$ln(TRC_i) = \beta_0 + \beta_1 ln(area_i) + \beta_2 ln(seq_i) + \beta_3 duration_i + \beta_4 y_i + \beta_5 DPES_i + \beta_6 Doffset_i + \beta_7 Dgn_i + \beta_8 Dexist_i + \beta_9 Dagr_i + \epsilon_i. \qquad (1)$$

In equation (1) which is our base model, the dependent variable is $ln(TRC_i)$, the natural log of the TRCs for project i. The explanatory variables are: the natural logs of the project's area in hectares, $ln(area_i)$ and the project's se-

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[3] PES involves financial support to landowners or resource users to implement practices that enhance carbon sequestration and other environmental outcomes.

[4] TRCs can be related both to the management of land, i.e., the planning of operations, and to administration, e.g., setting up contracts with funders and reporting back to those and managing tax and legal issues.

questration output, $ln(seq_i)$, in tCO2e per hectare per year, the project's duration in years, $duration_i$, and the year of project implementation, y_i. We use dummy variables to control for whether the project is associated with a PES scheme ($DPES_i$, equal to 1 if yes and 0 otherwise) and whether the project generates offset credits ($Doffset_i$, equal to 1 if yes and 0 otherwise). Finally, we include a dummy Dgn_i , equal to 1 if the project is located in a global north country and 0 otherwise, a dummy variable capturing whether the project is an existing or potential project $Dexist_i$, equal to 1 if an existing, implemented project and 0 otherwise, and a dummy $Dagr_i$, equal to 1 if the project is implemented on agricultural land and 0 otherwise. In additional models, we also include dummy variables specifying what particular cost categories were accounted for, and dummy variables indicating the number of cost categories considered in the study. All regressions include an intercept (β_0) and an error term (ϵ_i). All regressions are made using the tobit model. The tobit model is suitable for our purpose because non-normality is an issue in our data: the distribution of the residuals from the OLS regression are right-skewed due to the left censoring in our dependent variable, as reported TRCs are always above zero. This is additionally confirmed by a low p-value in Shapiro and Wilk's (1965) W test for normal data.

3.4.1 Monitoring and verification costs

Only one of our four cost categories, monitoring and verification costs, is reported in a sufficient number of studies for a separate analysis to be feasible. In an extension of the above analysis, we therefore use "monitoring and verification costs" as the dependent variable. For this analysis we take into account that there are two different possible systems for monitoring carbon fluxes: field assessments (i.e., measurements conducted on site to estimate the carbon stored above and/or below ground) and remote sensing (see, e.g., Hamburg, 2000; Cacho et al., 2004). Moreover, when conducting field assessments, the precision of the monitoring results will depend on the number of plots sampled. Both an increase in the number of plots, and monitoring more carbon pools, are expected to increase the monitoring costs.

As before, we assume that the monitoring and verification costs of a project are a function of above-described project attributes. We additionally include variables to control for the monitoring system used: $Dbelow_i$ is a dummy equal to 1 if below-ground biomass was also monitored and 0 otherwise, and $Dremote_i$ is a dummy equal to 1 when remote sensing technology was used and 0 otherwise. It is not evident how the use of remote sensing would affect monitoring costs. Although the use of remote sensing technologies could decrease the running costs of monitoring and verification, the fixed costs for the purchase of such technologies can be high. Finally, in some regressions we additionally control for the logged number of monitored plots per project hectare, $ln(plots\_per\_ha_i)$, which indicates monitoring precision. Due to the risk of a high correlation between the sequestration in a project and the other explanatory variables[5], sequestration is excluded from these regressions.

We estimate the monitoring and verification cost equation (2) as:

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[5] In particular, a high correlation can be expected between reported sequestration and the choice of carbon pools to monitor.

$$ln(MV_i) = \beta_0 + \beta_1 ln(area_i) + \beta_2 DPES_i + \beta_3 Doffset_i + \beta_4 agr_i + \beta_5 duration_i + \beta_6 y_i + \beta_7 Dremote_i + \beta_8 Dbelow_i + \beta_9 ln(plots\_per\_ha_i) + \epsilon_i. \quad (2)$$

The dependent variable, $ln(MV_i)$, is the log of the monitoring and verification costs (MV) in project i. As before, all regressions include a constant, β_0.

4 Results

This section presents the results: first, the descriptive statistics and then outcome of the meta-regressions. In Table 1, we present the frequency of the different cost categories in our dataset, i.e., how many observations include a given cost category. As can be seen, most of the observations include monitoring costs (148), and 98 observations include solely this cost category. The second most common category is establishment costs, followed by operation and then trading costs. Nine observations in the dataset include TRCs from all cost categories.

Table 1 Frequency of TRC cost categories.

	Number of cost categories in observation				
	One	**Two**	**Three**	**Four**	***Sum***
Establishment costs	9	42	14	9	*74*
Monitoring costs	98	33	8	9	*148*
Operation costs	7	10	14	9	*40*
Trading costs	0	3	6	9	*18*

Table 2 presents an overview of summary statistics. The average TRC is 19.0 EUR/tCO2e, which is a relatively high number. However, more than 48 % of the reported TRC values in the studies are low, between 0 and 1 EUR/tCO2e. About 5 % of the observations report high TRCs, between 100 and 1,016 EUR/tCO2e. These studies tend to increase the average TRC but are not really representative for the dataset as a whole. In this situation, the median TRC, i.e. the midpoint observation, is a more representative measure for the dataset as a whole (Peck et al., 2015). The median TRC is 1.0 EUR/tCO2e. This estimate is relatively close to previous estimates of TRCs in energy intensive sectors, that typically fall between 0 and 1.0 EUR/tCO2e (Coria and Jaraite, 2019; Heindl, 2012; Joas and Flachsland, 2016; Krey, 2005; Michaelowa et al., 2003).

Table 2 Descriptive statistics of selected variables.

Variable	# obs.	# of studies	Mean	St. dev.	Median	Min	Max
Total TRC per project (EUR)	126	29	3.50E+09	1.50E+10	4.16E+05	5.5	1.04E+11
TRC per unit of tCO2e (EUR/tCO2e)	186	31	19.0	88.6	1.0	<0.1	1015.3
Transaction costs/ total project cost (%)	36	10	16.9	20.0	7.8	0.0	86.6
Area (ha)	124	28	3.98E+06	1.37E+07	1.02E+04	20.2	1.06E+08
Total sequestration per project (tCO2e)	126	29	6.65E+08	2.68E+09	1.49E+06	30.3	2.36E+10
Sequestration per hectare and year (tCO$_2$e/ha *yr)	118	28	10.9	17.0	3.5	0.1	77.2
Project duration (years)	184	30	45.3	30.0	34.5	3.0	100.0
PES project (1=yes)	186	31	0.2	0.4	0	0	1
Offset project (1=yes)	186	31	0.4	0.5	0	0	1
Global north (1=yes)	184	30	0.4	0.5	0	0	1
Existing project (1=yes)	186	31	0.3	0.4	0	0	1
Agricultural land (1=yes)	186	31	0.1	0.2	0	0	1
TRC establishment costs (1=yes)	186	31	0.4	0.5	0	0	1
TRC monitoring costs (1=yes)	186	31	0.8	0.4	1	0	1
TRC operation costs (1=yes)	186	31	0.2	0.4	0	0	1
TRC trading costs (1=yes)	186	31	0.1	0.3	0	0	1
TRC one cost category (1=yes)	186	31	0.6	0.5	1	0	1
TRC two cost categories (1=yes)	186	31	0.2	0.4	0	0	1
TRC three cost categories (1=yes)	186	31	0.1	0.3	0	0	1
TRC four cost categories (1=yes)	186	31	0.0	0.2	0	0	1
Year of implementation	186	31		-	-	1997	2020
Discount rate (%)	97	7	9.4	3.3	10.0	2.0	15.0

Note: 0 is exactly equal to zero. 0.0 is a rounded number.

As can be seen in Table 2, the projects in our dataset have a median area of 10,234 hectares, an estimated median sequestration of 1.49 million tonnes of CO2e (or 3.5 tonnes of CO2e/ha*yr), and a median duration of 34.5 years. Only 10 out of the 31 studies report both abatement costs and TRCs. For those, TRCs represent between <1% and 86.6 % of the total project costs, with a median of 7.8 %. Moreover, only seven studies explicitly inform on discounting TRCs, at rates varying between 2 % and 15 %, with a median of 10 %. This median is high compared to discount factors suggested in the environmental economics literature (cf., e.g., Newell and Pizer, 2003; Nordhaus, 2007). However, this might reflect the heterogeneity of policy guidelines for discounting across countries, as found in a review by Groom et al. (2022). Due to the few observations including discount rates, we cannot include the discount rate as a control in the regressions.

The average and median TRCs for different project types can be found in Table 3. The results in this table suggest that TRCs are lower for PES and offsets projects, as well as for projects based in the global south. The use of remote sensing appears to be more common in projects with lower average monitoring costs. Also, adding the measurement of below-ground biomass in field assessments is associated with higher monitoring costs, in line with what could be expected given that monitoring more carbon pools is more expensive. Finally, the table suggests that potential and non-agricultural projects are associated with higher TRCs. For all project types, the standard deviation is high, implying that there is a large variation in TRCs across different individual projects.

It should be noted that Table 2 and 3 only provide an overview of the raw data and do not control for other variables. To get a more accurate picture of the determinants of TRCs, it is necessary to take into account the simultaneous impact of multiple different project characteristics. To do that, econometric analysis is needed.

Table 3 Mean and median total TRCs and TRCs, and mean and median monitoring and verification TRCs for different project types, in EUR/tCO2e.

	Observations (#)	**Mean**	**Std.dev.**	**Median**
Total TRCs across all cost categories:				
PES projects	39	1.3	2.2	0.7
Non-PES project	147	23.8	99.1	1.3
Offsets project	70	9.4	28.1	0.5
Non-offsets project	116	24.9	109.8	1.9
Global north	76	37.1	134.3	3.8
Global south	108	6.7	22.8	0.5
Existing project	49	1.5	3.3	0.1
Potential project	137	25.4	102.5	1.3
Agricultural project	12	1.1	3.2	0.2
Non-agricultural project	174	20.3	91.5	1.3
Monitoring and verification costs:				
Projects with remote sensing	10	0	0.1	0
Projects without remote sensing	98	28.2	119.3	0.9
Field assessment above ground biomass only	46	14.3	79.3	0.5
Field assessment above and below ground biomass	62	33.9	133.9	1.3
Agricultural project	11	0	0	0
Non-agricultural project	43	21.9	1.3	0

4.1 Results from econometric regressions: determinants of total TRCs

Table 4 presents the results for the econometric estimation of equation (1). Model (1) is exactly the estimation of the equation. Model (2) adds dummy variables for the number of cost categories considered in the study: more cost categories are expected to be associated with higher total TRCs[6]. The results then compare the level of total TRCs in studies that include, for example, two cost categories to the level of total TRCs in studies that only include a single cost category. Model (3) adds dummy variables that specify what type of cost categories are accounted for in the observation: establishment, monitoring, operation, and trade. The results compare the level of monitoring, operation, and trade costs reported in the studies to the level of the reported establishment costs. Model (4) controls for both sets of dummies. Because it includes all relevant project characteristics and has the best statistical fit[7], our preferred specification is model (4). We will therefore focus on this model in the following.

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[6] Thus, the reference level is when the TRC value only includes one cost category.

[7] Based on having the lowest AIC value.

Results show that project area and sequestration both have a positive and significant effect on total TRCs, as observed in models (2)-(4) in Table 4. Based on model (4), we find that a 1 % increase in the area of a project leads to a 1.2 % increase in total TRCs. Similarly, a 1 % increase in the amount of sequestered carbon is associated with an increase by 1.0 % in the project's total TRCs. Thus, we find no evidence of economies of scale, i.e., having larger projects does not save on TRCs.

All models in Table 4 additionally show that projects that generate carbon offsets have relatively higher TRCs. Using the coefficient from model (4), the generation of offset credits increases TRCs in a project by a factor of approximately 21. A potential explanation could be that projects that are labelled as offset projects in our dataset involve buyers that face regulatory obligations regarding their CO2e emissions. They could then purchase compensatory activities, i.e., carbon offsets, but there are more stringent requirements for monitoring and verification. Buyers in PES programs could be public or private entities (such as conservation groups) that do not directly use the ecosystem service to prove their environmental performance, implying that requirements for follow-ups could be less demanding (Salzman et al. 2018).

Table 4 Meta-regressions on transaction costs and their determinants. The dependent variable is *ln(TRC)*.

	Model			
Variables	**(1)**	**(2)**	**(3)**	**(4)**
Log area (ha)	1.121***	1.157***	1.163***	1.175***
	(0.168)	(0.115)	(0.0957)	(0.0830)
Log sequestration per hectare (tCO2e/ha)	1.403***	0.835***	1.115***	0.970***
	(0.364)	(0.221)	(0.347)	(0.207)
Duration (years)	0.0251*	0.0122	0.0172	0.0217**
	(0.0131)	(0.0127)	(0.0117)	(0.0100)
PES project (1=yes)	-0.0905	1.010	0.877	1.132
	(0.984)	(0.809)	(0.762)	(0.755)
Offset project (1=yes)	2.005*	2.208***	2.766***	3.047***
	(1.173)	(0.747)	(0.840)	(0.954)
Global north (1=yes)	2.330*	2.009	1.624**	0.767
	(1.293)	(1.352)	(0.798)	(0.872)
Existing project (1=yes)	-1.909	-1.552*	-1.620**	-1.648**
	(1.207)	(0.864)	(0.792)	(0.758)
Agricultural land (1=yes)	-1.260	-1.241**	-2.361**	-2.333***
	(0.860)	(0.522)	(1.049)	(0.685)
Year of implementation	-0.0445	-0.0318	-0.0393	-0.0372
	(0.120)	(0.0676)	(0.0753)	(0.0630)
TRC two cost categories (1=yes)		2.998***		2.579***
		(0.743)		(0.743)
TRC three cost categories (1=yes)		5.154***		2.380*
		(1.199)		(1.221)
TRC four cost categories (1=yes)		1.658		-
		(1.548)		-
TRC establishment costs (1=yes)				
TRC monitoring costs (1=yes)			2.895***	1.615*
			(0.747)	(0.867)
TRC operation costs (1=yes)			-1.648*	-1.937***
			(0.931)	(0.674)
TRC trading costs (1=yes)			1.001	1.146
			(0.637)	(0.815)
Constant			-0.662	-0.954
			(1.052)	(1.043)
Observations	118	118	118	118
Cluster (n of papers)	27	27	27	27
Sigma (for ML estimator)	2.169***	1.651***	1.611***	1.345***
	(0.292)	(0.194)	(0.233)	(0.188)
AIC	539.488	481.189	477.403	438.796

Note. The dependent variable is measured in USD. Robust standard errors in parentheses, clustered at paper level. ‘
*** $p<0.01$, ** $p<0.05$, * $p<0.1$.

We find some evidence that projects located in the global north have higher TRCs,[8] but the variable is not significant in the preferred model (4). The results further suggest that projects implemented on agricultural land have lower TRCs compared to those implemented strictly on forest land. From our preferred model (4), the TRCs for projects on agricultural land are only 10 % of those on forest land. However, this result should be interpreted with caution, given that we have few observations where the projects are implemented

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[8] See models (1) and (3), Table 4.

on agricultural land. Finally, our model suggests that TRCs increase with project duration, though the estimated coefficient is not significant in all models.

4.2 Results from econometric regressions: determinants of TRCs for monitoring and erification

We now turn to the determinants of monitoring and verification costs. Table 5 presents the results when we use monitoring and verification costs as the dependent variable, see equation (2) above. In model (5), we control only for the same project attributes as in Table 4. In model (6) we additionally include controls for the monitoring system, with the reference category being field assessments of above ground biomass. Model (7) adds to model (5) the variable $ln(plots\_per\_ha_i)$, as a proxy for the monitoring precision. Model (8) is the combination of models (6) and (7) and is exactly the estimation of equation (2).

We do not find any significant impact of the monitoring system choice, or the monitoring precision, on the monitoring and verification costs. However, we find consistent evidence that larger projects have higher monitoring costs. Taking the results from model (8), which has the best statistical performance, we find that a 1 % increase in project area increases monitoring costs by 1.1 %. This is very similar to the results in Table 4. Also consistent with results in Table 4, projects on agricultural land tend to have lower monitoring and verification costs compared to projects on forested land, albeit the effect is not significant in all models, including model (8). The findings further show that offset projects in our dataset have about 14 times higher monitoring and verification costs compared to projects that do not generate carbon credits.

Table 5 Meta-regressions on monitoring and verification costs and their determinants. Dependent variable: *ln(MV)*.

	Model			
Variables	**(5)**	**(6)**	**(7)**	**(8)**
Log area (ha)	1.029***	0.839***	1.004***	1.064***
	(0.0987)	(0.0547)	(0.0576)	(0.0600)
Duration (years)	0.0158	0.0126	0.0367**	0.0432*
	(1.196)	(0.430)	(1.211)	(1.764)
Year of implementation	-0.110	-0.0291	0.204***	0.0998*
	(1.048)	(1.367)	(0.266)	(1.696)
Agricultural land (1=yes)	-1.623	-1.118***	-2.079*	-1.904
	(1.551)	(1.106)	(1.063)	(0.725)
PES project (1=yes)	1.401	0.205	1.918***	1.204
	(1.048)	(1.367)	(0.266)	(1.696)
Offset project (1=yes)	-0.868	1.066	3.020***	2.641***
	(1.551)	(1.106)	(1.063)	(0.725)
Remote sensing (1=yes)		-0.123		-0.234
		(1.497)		(1.930)
Field assessment below ground biomass		-2.191		-2.073
		(1.503)		(1.596)
Log number of plots per project hectare			-0.340	-0.251
			(0.224)	(0.230)
Constant	221.1	60.56	-410.6***	-201.5*
	(198.1)	(111.6)	(116.6)	(119.8)
Observations	83	54	48	48
Cluster (n of papers)	14	9	8	8
Sigma (for ML estimator)	1.853***	0.695***	0.650***	0.604***
	(0.310)	(0.159)	(0.160)	(0.145)
AIC	353.242	129.9045	108.8513	101.8815

Note. The dependent variable is expressed in USD. Robust standard errors in parentheses, clustered at paper level.

*** p<0.01, ** p<0.05, * p<0.1.

5 Direct and transaction costs for carbon sequestration in the Danish context

This section discusses the relevance of results from the above meta-analysis for the Danish context. We further compare the direct costs and the transaction costs for mitigating greenhouse gas emissions through carbon sequestration in Denmark and relate this comparison to carbon prices recommended by the Danish Climate Council (2023).

5.1 Relevance of results from the above meta-analysis for the Danish context

The above meta-analysis made use of data from the scientific literature. A considerable share of the observations, 40 %, are related to projects implemented in the global north. Countries in the global north can be expected to generally have higher transaction costs due to both higher salaries and more stringent requirements on monitoring and enforcement. On the other hand, countries in the global north tend to have more well-functioning governmental institutions, which could tend to lower the transaction costs of environmental policies for involved stakeholders. Our results suggest that the former two factors are more important, implying that transaction costs are higher in the global north.

One could then ask whether the transaction costs in Denmark specifically could be higher or lower compared to global north countries in general. We can then first note that Denmark is highly ranked for GDP per capita, implying high labor costs. Moreover, the OECD environmental policy stringency index for Denmark in 2020 equaled 3.72, which was higher than the average of 3.37 for the OECD countries (OECD 2023). In addition, the World Bank Governance Indicators for Government Effectiveness and Regulatory Quality are comparatively higher in Denmark than in many countries in mid and south Europe, suggesting institutions are perhaps more well-functioning than in other global north countries (World Bank, 2023). Related to this, there is a high availability of yearly updated data on land use activity in the Danish context. The already existing robust data infrastructure, with frequent updates, could potentially reduce the added cost of monitoring and verification for carbon sequestration related projects, which is an advantage. Taken together and considering the seemingly high importance of the labor cost level, it seems plausible to believe that transaction costs for environmental policies are at least as large as in other global north countries.

The data gathering for the meta-analysis showed that most studies were applied to projects on forest land, while a smaller number studied projects where trees were planted on agricultural land. Given the few studies considering measures on agricultural land, we think that the results cannot be used to compare transaction costs between measures implemented on forest and agricultural land, respectively. Also, the absence of studies that consider measures on agricultural land other than planting trees or shrubs implies that the meta-analysis cannot be used to better understand differences in transaction costs between forest related projects and agriculturally specific measures. Instead, the results are mainly applicable to forest related sequestration projects.

Given the above, it is not evident that the results from the meta-analysis are applicable to agriculturally specific carbon sequestration measures in the Danish, and wider European, context. We therefore compare the results from the meta-analysis with the study by Mettepenningen et al. (2009), which specifically examines farmers' transaction costs of participation in European agri-environmental schemes. Different to our meta-analysis their study does not consider the specific purpose of the schemes. They quantify transaction costs by asking farmers to register labor hours, and operational and administrative costs, for searching, negotiations, monitoring, and enforcement. This data is registered for both parcels of land under an agri-environmental scheme, and comparable parcels of land not under such a comparable scheme. The difference in costs between the parcels is then argued to be a relevant measure of the transaction costs for the agri-environmental scheme. Results reported are based on data from 139 farmers, and 278 pairs of land parcels, across eight EU countries. These results show that the total TRCs per hectare amounted to an average of EUR 52.5, whereof labor time costs made up EUR 22.0, in 2022-year value.

We can then compare the results from Mettepenningen et al. (2009) with our dataset with our raw data in Table 2. If we divide the median total TRCs in Table 2 by the median project area, we obtain TRCs equal to EUR 43.6 per ha. If, instead, we carry out the same exercise using the mean values, we obtain TRCs equal to EUR 879.4 per ha. Thus, the median TRCs per hectare in our dataset are of a similar order of magnitude as the estimate provided by Mettepenningen et al. (2009), while the mean TRCs from our data is an order of magnitude larger.

A plausible explanation for the lower per hectare cost in our raw median data described in Table 2 is that more than half of the observations apply to the global south. The high per hectare cost obtained when using the mean data rather than the median data in our dataset is partly due to the particularly high TRCs for the top 5 % of the observations. We judge that such high TRCs are unlikely to be found on average for policies that are applied on a larger scale. The estimate by Mettepenningen et al. (2009) applies for agri-environmental schemes in the EU that are typically targeting management measures or input use. We think that their estimate is plausible for a sequestration scheme that is designed similarly as the agri-environmental support schemes under the rural development programs, where monitoring mostly focusses on farmers' inputs and efforts, rather than the environmental output. However, this level could be in the lower end for a sequestration policy that explicitly considers spatial heterogeneity and non-permanence, and allows for trading in carbon offsets. Based on this, we judge that TRCs per hectare for carbon sequestration projects in the Danish context could be above 52.5 EUR per hectare.

An alternative to using the per hectare TRCs is to calculate the TRCs per tCO2e. To do this, we divide the TRCs per hectare from Mettepenningen et al., by the median per hectare sequestration in table 2, equal to 3.5 tCO2e.[9]

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[9] In practice, there is a large variation in the per hectare CO2e mitigation effect, i.e., afforestation could entail that 5 to 12 tCO2e are sequestered per year on sand and clay soils, respectively, whereas catch crop cultivation could entail about 0.9 tCO2e per hectare and year (Climate Council, 2023). Given this spread in per hectare sequestration among potential measures, we think that our median sequestration from Table 2 seems a more plausible estimate than the corresponding mean.

This gives us EUR 15.0 per tCO2e, which is in the following used as a plausible indication of the costs in the Danish context.

Bearing in mind the considerable uncertainties associated with the above TRC estimates, we can now proceed to comparing TRCs and the direct costs for greenhouse gas mitigation in Danish forestry and agriculture in the next section.

5.2 Direct costs and transaction costs for sequestration in Danish forestry and agriculture

First, we will examine the role of the TRCs in carbon mitigation measures' total cost, i.e., the sum of direct CO2e mitigation costs and TRCs. This is motivated by the fact that many scientific studies express TRCs as a percentage of total costs. As could be seen in Table 2 above, the median share of TRCs in total mitigation costs is 7.8 % in our raw data. Also, Mettepenningen et al (2009) found TRCs in the previous literature ranging from a few percent up to above 9 %.

In Figure 2, we show the percentage share of TRCs in total costs for a measure. The TRCs are in all cases assumed to be equal to EUR 15.0 per tCO2e (see section 5.1), while the direct CO2e mitigation cost varies across measures. The direct mitigation costs for different measures in Table 2 have been obtained from Dubgaard and Ståhl (2018) and the Climate Council (2023). These sources provide low-end and high-end estimates of the direct mitigation cost for a range of measures. As can be seen from the figure, the cost share becomes large for measures with low direct CO2e mitigation costs and small for expensive measures.[10] It could be argued that it is an oversimplification to assume that all measures incur the same absolute TRCs per rCO2e. However, it should be borne in mind that our econometric regressions show that sequestration is a major determinant of TRCs, motivating this choice. Thus, figure 2 is included here to warn against assuming that TRCs are proportional to the direct carbon mitigation costs for different measures[11], because it is not at all evident why the TRCs should be lower for measures with a low direct CO2e mitigation cost, and *vice versa*.

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[10] One measure in Klimarådet's inventory, the low-end estimate for catch crops without crop rotation, has a negative value for the direct mitigation cost. In this case, our estimated TRC exceeds the negative direct cost for that measure, suggesting there is a small positive net cost for the farmer.

[11] I.e., we warn against assuming that TRCs would always be x percent of the direct mitigation costs (where the direct mitigation costs are the costs for implementing the physical measures.

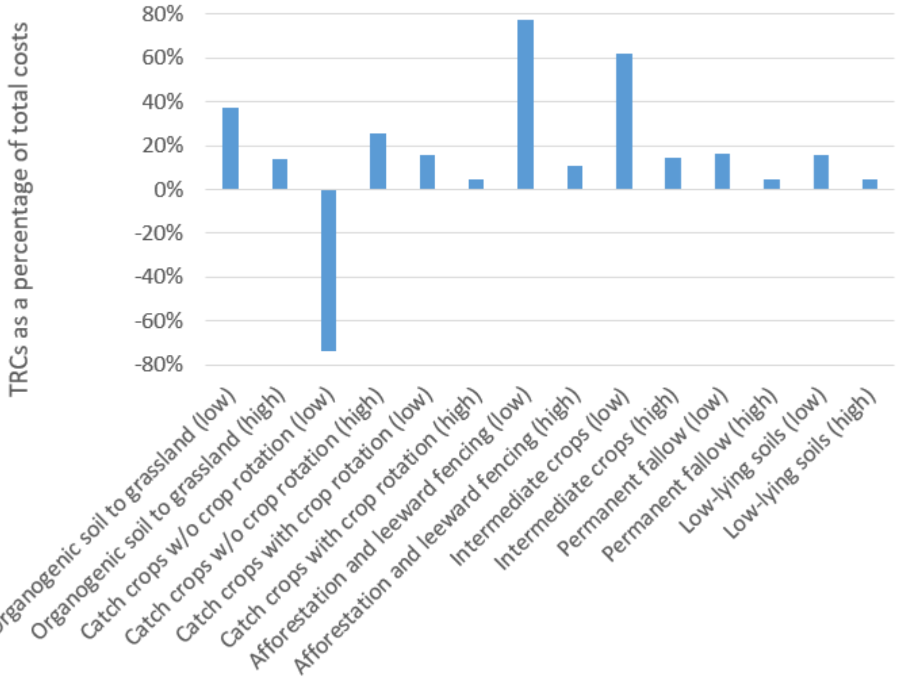

Figure 2 The percentage of TRC in comparison with direct CO2e mitigation costs.
Note. For the data on conversion of organogenic soils to permanent grassland, from Dubgaard and Ståhl (2018), we use the social cost for soil carbon sequestration, excluding ancillary benefits in terms of impacts on other environmental services. This is motivated by the need for consistency with the Climate Council's (2023) data. The data from Dubgaard and Ståhl (2018) are inflated to 2022-year value using the Danish CPI. All other data are from the Climate Council (2023) that provides a cost range, which reflects the variations in costs of implementing the measure on different soil types, in different catchments and on conventional and organic farms, respectively. It should be noted that the Climate Council takes existing agri-environmental support as given, including e.g., the climate motivated support to low-lying land, "klimalavbundsordningen".

Policy makers are typically more interested in implementing measures with low direct CO2e mitigation costs. We will therefore take a closer look at how TRCs affect the cost-effectiveness of sequestration measures in relation to the suggested Danish tax on greenhouse gas emissions from the agricultural sector. It can be of interest to understand if a measure's total costs, including abatement and transaction costs, can exceed the planned tax when the transaction costs are included. This could imply that the tax would not be sufficiently high to incentivize their implementation.

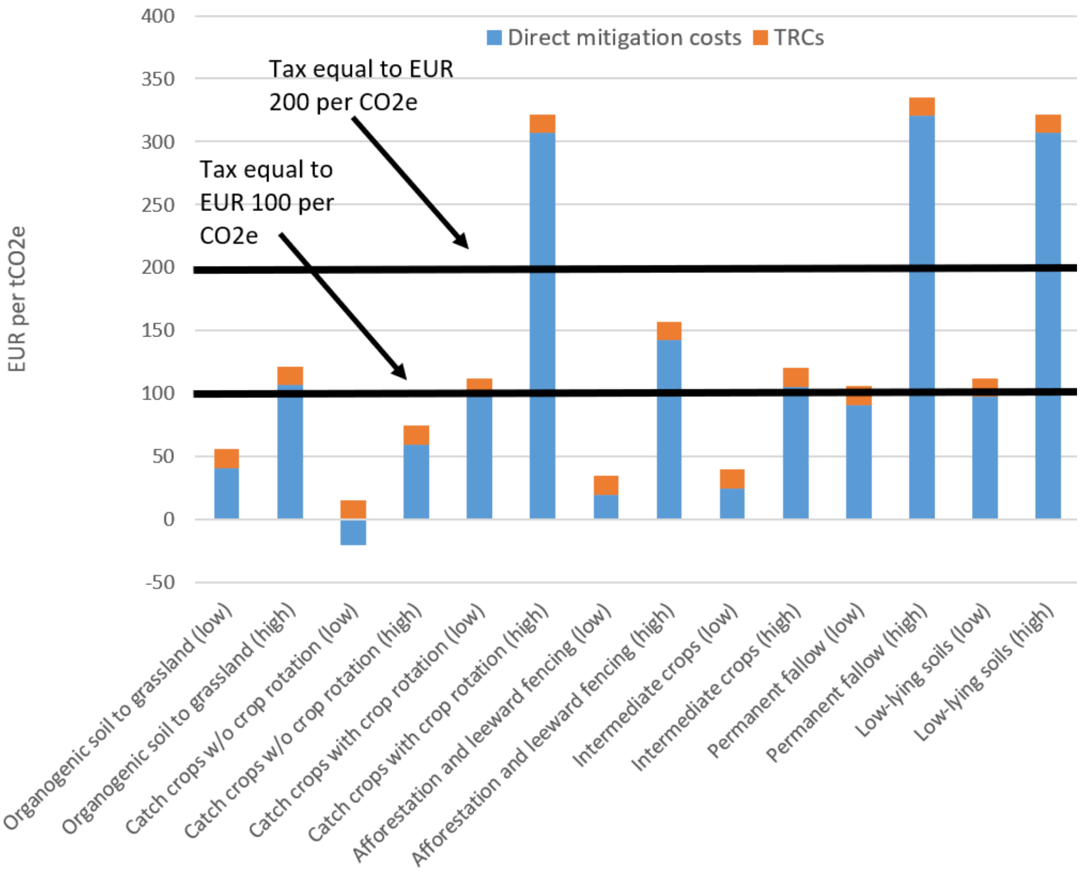

Figure 3 Total costs for measures in EUR/tCO2e and the suggested Danish agricultural tax on greenhouse gas emissions, and cross sectoral tax on greenhouse gas emissions.

In Figure 3, we compare the total costs (direct costs plus TRCs) for different measures to the Climate Council's suggested Danish agricultural tax on greenhouse gas emissions of EUR 100 per tCO2e, and the previously suggested cross sectoral tax on greenhouse gas emissions of EUR 200 per tCO2e. The greenhouse gas tax of EUR 100 per tCO2e (DKK 750 per tCO2e) was set to match the political agreement on a fee of DKK 750 per tCO2e emitted in 2030 for a large part of the companies that are not covered by the EU's quota trading system. The council previously suggested a uniform tax with a total incentive of around EUR 200 per tCO2e (DKK 1,500 per tCO2e) across all sectors. The difference between these two levels might not be so large as it could seem at first glance, given the existing environmental subsidies for agriculture, where some of those are climate motivated. Here both levels are included for illustrative purposes.

As can be seen from Figure 3, a considerable number of measures change from being cost-effective under the agricultural greenhouse gas tax of EUR 100 per tCO2e, to not being cost-effective when transaction costs are added. The situation is different when a greenhouse gas tax of EUR 200 per tCO2e is considered. In that case the tax does not affect the choice of cost-effective measures to apply. This illustrates the fact that if TRCs are relatively similar across measures, they play a larger role for the cost-effective choice of measure at low carbon prices, compared to the situation at high carbon prices. This also indicates that the supply of greenhouse gas mitigation from the Danish agricultural sector could be highly sensitive to the choice of tax level if the tax is to be set about EUR 100 per tCO2e.

6 Transaction costs and ongoing developments in EU policy for the land use sector

The EU Regulation on land, land use change and forestry (LULUCF) was recently revised and now includes separate targets for land-based net carbon removals at EU and national level by 2030. Simultaneously, the quality of monitoring, reporting and verification should be enhanced, and the rules for carbon accounting should be simplified. The former could tend to increase TRCs, while the latter could decrease them.

The specific policy instruments to be applied are likely to be determined by the Member States. One option for the Member States is to make use of the Rural Development Program. The agri-environmental support schemes provided within that program focuses on management measures and input choices, rather than the environmental output of these actions, as mentioned in the introduction. Consistent with this, Mettepenningen et al. (2009) reports lower per hectare costs for agri-environmental support in the EU than those that were obtained from our meta-analysis of carbon sequestration projects. For the carbon sequestration projects, monitoring and verification of the environmental output, i.e., carbon pool changes, are an important part of the TRCs. Thus, policy makers in the Member States face a trade-off between increased TRCs for enhanced monitoring, reporting, and verification, and the ability of policies to target measures with low direct CO2e mitigation costs. They also face a trade-off between reduced TRCs from simplifying the rules for carbon accounting and reduced accuracy of the measurement of the effect of measures undertaken to enhance carbon sequestration.

There are also other sources of funding at the EU level, such as for example the EU LIFE program. Moreover, the EU has developed a voluntary carbon removal certification framework which aims to strengthen business initiatives to scale up carbon removal activities and fight greenwashing, helping to increase the amount of funding available for the purpose (EC 2022). The certification scheme can become useful for voluntary buyers and sellers of carbon offsets, e.g., food companies, construction industry, and public authorities. The presence of multiple policy instruments, e.g., both the Rural Development Programs, LIFE, and voluntary carbon offsetting schemes, with potentially different rules and procedures for managing issues such as carbon stock measurement, nonpermance, additionality, and potential other environmental impacts, implies that TRCs could increase both before and during project implementation. Before project implementation the landowners need to spend more time on evaluating the different available options for funding carbon sequestration in order to find the most suitable alternative. During implementation, landowners could end up with contracts in different schemes, which creates additional costs for time spent on evaluating whether there are illegitimate overlaps, and time spent on managing multiple procedures for reporting and monitoring. On the other hand, a broader set of funding options could increase the total funding available for carbon sequestration which can be an advantage if the policy instrument toolbox is limited to subsidization[12]. It might be an advantage to have a consistent procedure for carbon accounting

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[12] An alternative is to tax greenhouse gas emissions from the land use sectors, similarly as suggested for the agricultural sector in Denmark.

across schemes, with rules for the management of carbon stock measurement, nonpermance, additionality, and other environmental impacts, across agri-environmental support schemes and voluntary carbon offset, because this uniform framework could reduce TRCs. However, such a uniform framework is only a net improvement if the scheme is also a well-designed one, suitable for the purpose of incentivizing measures and actions that deliver the largest amount of sequestered carbon per EUR spent. Again, one must conclude that there is a trade-off between saving on TRCs and maintaining sufficiently accurate procedures for evaluating the environmental output from measures undertaken.

7 Future research needs

This report provides a comprehensive analysis of TRCs in carbon sequestration projects and policies, showing that such costs have hitherto mainly been studied in forest-related projects and policies. An important avenue for future research could therefore be the exploration of TRCs for projects and policies implemented on farmed land. Given the significant role of agriculture in Denmark and many other countries, understanding the transaction costs associated with soil-based carbon sequestration measures could be both scientifically enriching and policy-relevant. Such research could delve into the specifics of incentivizing and implementing soil-based carbon sequestration measures, such as cover cropping, no-till farming, agroforestry, and rewetting of organic soils. It would be particularly interesting to examine how a focused policy on soil-based carbon sequestration could be designed to achieve a relevant balance between transaction costs on one hand and the ability to target locations and measures with a high carbon sequestration potential per euro spent on the other. This could include leveraging Denmark's robust data infrastructure, which is updated yearly, to potentially reduce monitoring and verification costs and enhance the environmental effectiveness of policies. By extending the scope to include agriculturally specific carbon sequestration measures, future research could offer a more nuanced understanding of the transaction costs involved and provide policymakers with a broader set of tools for climate change mitigation.

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Appendix

Table A.1 Classification of TRC terms reported in the papers into four cost categories.

***Ex-ante* TRCs**	**TRCs applying during a project’s lifetime**		
Establishment costs	**Monitoring costs**	**Operation costs**	**Trading costs**
Plantation or land establishment costs	Cost of organizational set-up of monitoring	Tending/treatment costs of projects	Brokerage fees paid by permit buyers
Cost of establishing baseline sequestration	Plot establishment and measurement costs	Management costs of projects	Validation cost
Initial costs	Laboratory costs	Overhead costs	Registration fees
Project development costs	Field data collection costs	Insurance costs	Costs of trading
Stakeholder or “people involvement” cost	Annual verification/due diligence fees	Administrative costs	Certification costs
Costs of feasibility studies	Fixed and annual monitoring costs		
Fixed and annual monitoring costs	Data analysis and reporting costs		
Negotiation costs	Cost of monitoring personnel or training people to do monitoring		
Costs for village consultation on REDD+ research	Costs for data analysis reporting		
	Costs of inventory equipment		

A META-ANALYSIS OF TRANSACTION COSTS FOR PROJECTS TO ENHANCE CARBON SEQUESTRATION IN LAND USE AND THE POTENTIAL IMPLICATIONS IN THE DANISH CONTEXT

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