Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Department of Economics

Costs and Benefits of Reducing Greenhouse Gas Emissions through Conversion of Wetlands into Forest

Henrik Nordzell

Master's thesis · 30 hec · Advanced level
Agricultural Programme – Economics and Management
Degree thesis No 958 · ISSN 1401-4084
Uppsala 2015

Costs and Benefits of Reducing Greenhouse Gas Emissions through Conversion of Wetlands into Forest

Henrik Nordzell

Supervisor: Katarina Elofsson, Swedish University of Agricultural Sciences, Department of Economics

Examiner: Sebastian Hess, Swedish University of Agricultural Sciences, Department of Economics

Credits: 30 hec
Level: A2E
Course title: Degree Project in Economics E
Course code: EX0537
Programme/Education: Agricultural Programme – Economics and Management
Faculty: Faculty of Natural Resources and Agricultural Sciences

Place of publication: Uppsala
Year of publication: 2015
Cover picture: Leif Thörne, Länsstyrelsen i Jönköpings län
Name of Series: Degree project/SLU, Department of Economics
No: 958
ISSN 1401-4084
Online publication: http://stud.epsilon.slu.se

Key words: Cost Benefit Analysis, Wetlands, Greenhouse gas emissions, Carbon sequestration, Forest, Ecosystem services, Biodiversity, Recreational value

Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Department of Economics

Acknowledgements

I would like to thank everyone who has contributed to this thesis, whether by sharing their knowledge or by supporting me during my struggles. I especially want to thank my supervisor Katarina Elofsson and Björn Hånell, Lars Lundin and Laura Broziat.

Abstract

This thesis calculates the costs and benefits of turning wetlands into forest in order to reduce greenhouse gas emissions. Wetlands emit methane, which has a high global warming potential relative to carbon dioxide, while forests sequester carbon. This benefit in mitigated global warming is compared to the cost of loss in ecosystem services like biodiversity and recreational value. A hypothetical wetland located in the middle of Sweden with average post drainage fertility potential and temperature sum was drained for timber production. The net present value of all benefits and costs up to 2050 was found to be 0.43 million SEK per hectare and the results are mainly driven by wetland emissions and price of carbon dioxide. The sensitivity analysis shows that the result can range from -0.41 to 1.84 million SEK per hectare.

Sammanfattning

Denna uppsats beräknar kostnaderna och fördelarna av att omvända våtmarker till skog för att minska utsläpp av växthusgaser. Våtmarker avger metan, som har en hög Global Warming Potential i förhållande till koldioxid, medan skogar binder kol. Denna fördel i dämpad global uppvärmning jämförs med kostnaden av förlust i ekosystemtjänster som biologisk mångfald och rekreationsvärden. En hypotetisk våtmark belägen i mitten av Sverige med en genomsnittlig efter dränering fertilitet potential och temperatursumma dränerades för virkesproduktion. Det diskonterade nuvärdet av alla förmåner och kostnader upp till 2050 visade sig vara 0.43 miljoner kronor per hektar och resultaten drivs främst av utsläpp från våtmarken och priset på koldioxid. Känslighetsanalysen visar att resultatet kan variera från -0,41 till 1,84 miljoner kronor per hektar.

Table of Contents

1 Introduction

Recent anthropogenic emissions of greenhouse gases are the highest in history. The increased emissions are largely driven by economic growth and an increasing population and predominantly caused by fossil fuel combustion and changes in land use. The atmospheric concentrations of carbon dioxide, methane and nitrous oxide hasn't been this high in hundreds of thousands of years. Scientists are now sure that the effects of the higher concentrations are the dominant cause of the global warming (IPCC, 2014). The combined land and ocean surface annual average temperature has increased with 0.85 °C over little more than hundred years since preindustrial area. Each of the last three decades has been consecutively warmer than any preceding decade since the year 1850 (IPCC, 2014).

With the rising temperature a number of changes to the global climate has occurred. Worldwide glaciers are melting and both Antarctic ice sheets and the Arctic sea ice have been losing mass. As a consequence the sea level has been risen. In the northern hemisphere annual precipitation has increased but there is less snow in springtime. More concerning is the larger extent of extreme conditions. Dry areas are becoming drier while some areas experience more events of heavy precipitation. Changing precipitation or melting snow and ice are altering hydrological systems, affecting water resources in terms of quantity and quality (IPCC, 2014). The global warming also has effects on timing of plant flowering, dates of breeding and migration patterns of insects and animals (IPCC, 2001).

Alongside combustion of fossil fuels land-use change is becoming an increasing threat to global warming, see figure below. Deforestation, mainly to create agricultural land, is the major concern. Forests sequester carbon dioxide and when they are cut down not only does this process cease but the stored carbon is released into the atmosphere. By reforestation or afforestation this important function can be restored and these are potential tools to mitigate climate change.

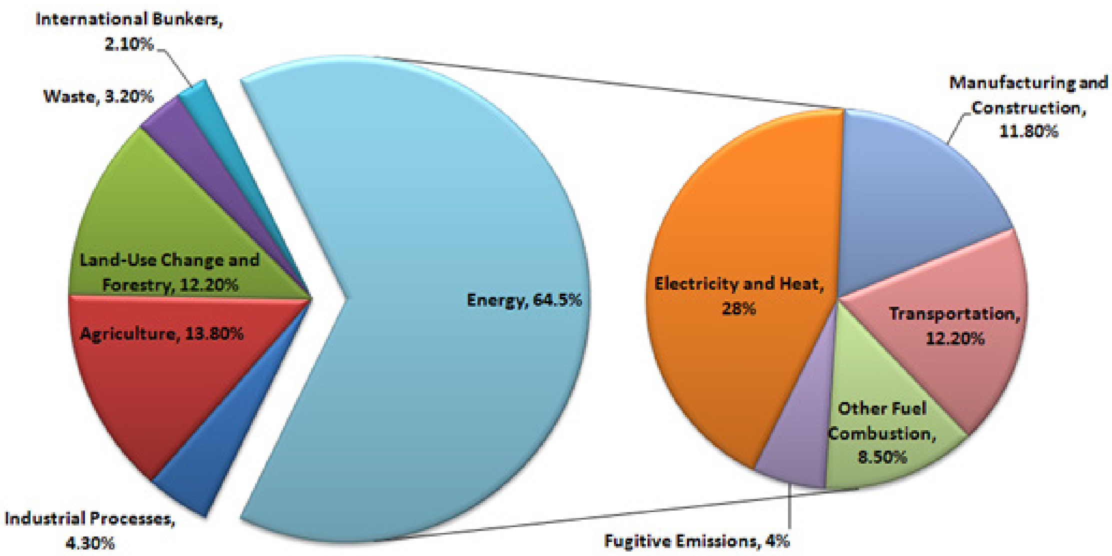

Figure 1.Global anthropogenic GHG emissions by sector (C2ES, 2015)

The United Nations Framework Convention on Climate Change (UNFCCC) works to lower the anthropogenic impact to a level that would achieve stabilization of greenhouse gas concentrations in the atmosphere and prevent dangerous interference with the climate. This must be done within a time-frame sufficient to allow ecosystems to adapt naturally to climate change (UNFCCC, 2014a). The Kyoto protocol, named after the town in Japan where it was adopted in 1997, was the first international agreement which committed the parties of the UNFCCC to set binding emission reduction targets. A second commitment period, from 2013 until 2020, of the Kyoto Protocol was adopted in Doha, Qatar in 2012 (UNFCCC, 2014b). The combined target is set to 18 per cent below 1990 levels. The EU members met their targets in the first commitment period and have now made a unilateral commitment for the second period to reduce emissions by 20 per cent (European Commission, 2014).

Article 3.3 and 3.4 of the Kyoto Protocol defines which land-use practices altering net emissions should be accounted for. Article 3.3 address forestry activities while 3.4 contains additional land-use changes, e.g. cropland management, revegetation and/or grazing land management, that are optional for the member countries to report. For the second commitment period also wetland drainage and rewetting has been added to the optional activities to report under article 3.4 (UNFCCC, 2014c).

Wetlands are natural sources of methane emitting around 30 % of total methane emissions globally. Anthropogenic methane sources from land-use including rice cultivation emits 26 % which makes wetlands the largest source of land related methane emissions, see figure 2.

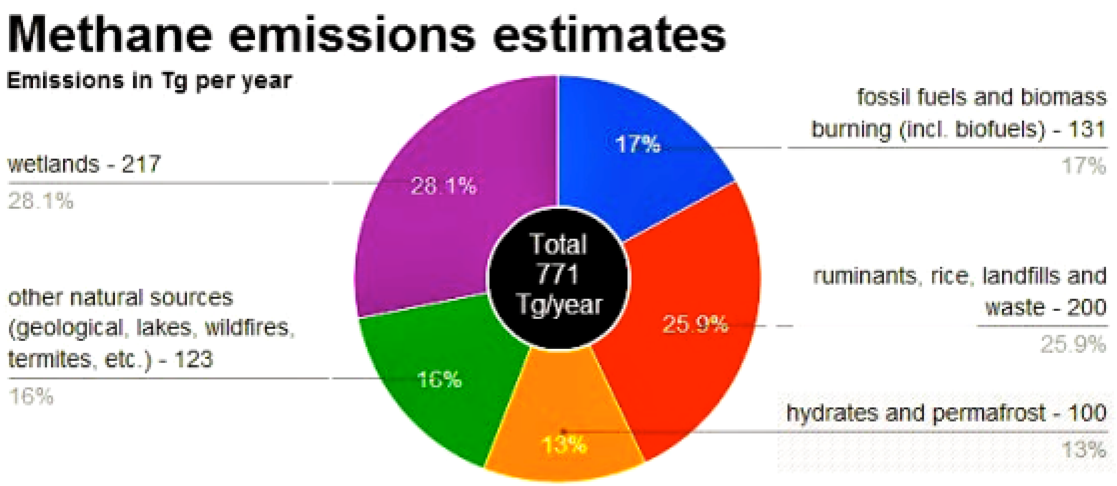

Figure 2.Total global emissions of methane separated by source (Clean Technica, 2015)

Wetlands also sequester CO_2 but the higher global warming potential (GWP) of methane turns most northern freshwater wetlands into net emitters of greenhouse gases (IPCC, 2000). The countries where wetlands constitute a significant landscape type have the opportunity to examine how land-use changes to wetlands can contribute to their total sink or source reserve (Roulet, 2000). The Swedish government announced in the Climate Bill (Government bill 2008/2009:162) long-term national goals up to 2050. It includes a vision of Sweden having a sustainable and resource effective energy supply and zero net emissions of greenhouse gases into the atmosphere (Government, 2014). Reaching such goals requires reductions in fossil fuel emissions and modifications in land-use practices that increase sinks and reduce sources of greenhouse gases, e.g. by draining wetlands and/or creating forest (Roulet, 2000).

There are several good reasons for considering land-use change in climate policy. First of all, the knowledge how to increase the growth ability of the forests, and thereby the sequestration potential, already exists making it an easy alternative. Furthermore it has been found to be a cost-effective way to mitigate climate change. Studies show results between 10 and 25 SEK per tonne carbon dioxide mitigated for Swedish forests with directed fertilization and a global potential of sequestrating up to 7 400 Mtonnes per year over decades. This can be compared to the cost of Carbon Capture and Storage techniques that takes care of the emissions at its source, which has been estimated to 210-630 SEK per tonne carbon dioxide (Konjunkturinstitutet, 2014).

Sweden is one of the most wetland dense countries in the world and roughly 10 per cent of the total land area consist of wetlands (Naturvårdverket, 2009), which make the potential reduction in emissions substantial. However wetlands are normally considered to have high natural value which makes the situation more problematic. Associated impacts from draining wetlands such as loss of biodiversity, increase in flooding and decrease in water quality needs to be weighed against the climate impacts.

1.1 Aim and delimitations

Through land-use change emitting wetlands can be turned into sequestrating forests. This might be an important tool to reach the goal of zero net emissions in Sweden by the year 2050. This study aim to calculate all cost and benefits connected to wetland afforestation, including both climate and ecosystem impacts, as well as the private management costs and incomes. The aim is to determine if the value of the positive climate effects exceed the negative effects from loss in ecosystem values and thereby justify such a policy. The specific objective is; What is the net present value of conversion of wetlands into forest?

The study is limited to Sweden, but could be of value for all countries in the boreal zone that has a lot of wetlands. Only fens will be investigated since they are rich in nutrients and trees grow better on nutrient rich land. The study is also limited to spruce production because it is, among other things, recommended for site types connected to fens and grow fast. The study will be limited to 35 years in order to determine how wetland afforestation projects can contribute to the Swedish national and joint EU targets for emissions by 2050. But also the net present value for a full forest rotation period will be discussed to see what the implications of the policy will be in the long run.

2 Services provided by ecosystems

Ecosystems provide a range of goods and services that humankind can benefit from. Both wetlands and forests are important in the context of climate change but also when it comes to nature and recreational value. Understanding the ecosystem services normally requires a strong foundation in ecology. This part will try to clarify some of the basic ecology of wetlands and forests.

2.1 Wetland ecosystem services

2.1.1 GHG cycle of wetlands

Wetlands sequester carbon dioxide (CO_2) while they emit methane (CH_4) and nitrous oxide (N_2O). Wetlands also to some extent exhibit respiration of CO_2. The carbon dioxide sequestration occurs through plant photosynthesis and by acting as sediment traps for runoff. The magnitude of carbon uptake depends on e.g. wetland type and size, amount and type of vegetation, the depth of the water table, nutrient levels and pH.

Methane is formed in soils by the microbial breakdown of organic compounds in anaerobic conditions, such as below water surface. The methane formed in flooded soils can migrate to the surface and ascend to the atmosphere. The largest difference in wetland methane fluctuation is connected to the water table depth below the surface. Emissions of methane have also been found to vary considerably with the type of vegetation present (Smith et al., 2003).

N_2O is produced during the process of denitrification but only insignificant amounts for undrained to small amounts for drained wetlands has been detected while studying GHG emissions, see e.g. Kasimir-Klemendtsson et al. (1997), Laine et al. (1996) and Hendriks et al. (2007). In other studies like Brix et al. (2001) N_2O has been ignored completely as a consequence of this. A schematic picture of the greenhouse gas cycle can be seen in figure 3 below.

The balance of these greenhouse gases determines if the wetland can be considered a sink or a source. In order to compare the effect of methane with CO_2, methane emissions need to be converted to CO_2 equivalents. One important factor in determining this is the global warming potential (GWP) of the different gases. The lifetime for methane in the atmosphere is 12.4 years and these values of GWP recognize the exponential decay of methane compared to the more prolonged decay of CO_2, which has a lifetime of 120 years (Brix et al. 2001). The GWP of carbon dioxide is always one. Methane has a GWP of 34 on a 100 year timeframe and will thus cause 34 times more damage 100 years from now as an equivalent mass of CO_2 released at the same time. The same number for a 20 year timeframe is 86 (IPCC, 2013b). The difference in lifetime of the gases in the atmosphere is highly significant as this affects the extent to which CH_4 emissions from wetlands contribute to the global warming (Brix et al. 2001).

The 100 year timeframe has so far been the default measurement, established in the IPCC assessment reports (Holdren et al., 2014). This standard is starting to be questioned when it comes to methane since there is no scientific argument for selecting the 100 year timeframe compared to others (IPCC, 2013). Rather, due to methane's relatively short lifetime, scientists argue that the 20 year timeframe should be used when determining short term policies aiming to avoid critical tipping points over the next several decades (Holdren et al., 2014). Since most studies so far use the 100 year timeframe many come to the conclusion that wetlands can be considered as net sinks of GHGs, e.g. Whiting and Chanton (2001) or Hendriks et al. (2007).

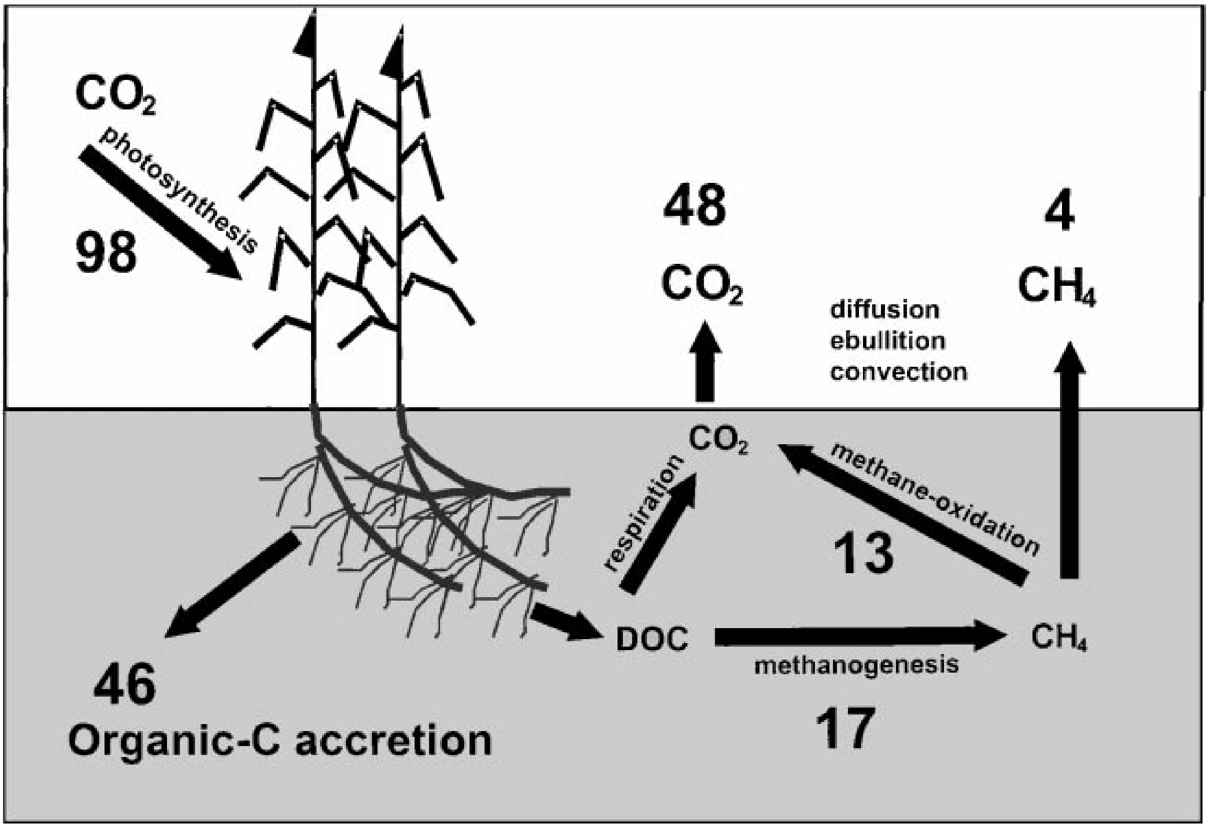

Figure 3. Simplified schematic picture of the GHG cycle of wetlands. Numbers are in mol C per m2 and year and show the result of a study done in Denmark (Brix et al., 2001)

Whiting and Chanton (2001) studied three wetland ecosystems ranging from the boreal zone (Canadian Fen) to the sub-tropic area (Florida Typha). They express both measured annual net-CO_2 uptake and CH_4 emissions as positive numbers and compare them on a molar ratio basis. Higher methane to carbon dioxide ratio, mean that they have a higher effect on global warming. This ratio is highest in fall and winter for all sights, because the CO_2 uptake decreases significantly in lower temperatures. On an annual basis the Canadian boreal fen release 56.15 g/m^2 CH_4 and sequester 1012 g/m^2 carbon dioxide. They have the highest molar ratio (0.13-0.20) and Florida typha the lowest (0.05-0.06). These ratios are then multiplied with the GWP of methane for 20, 100 and 500 year timeframes and compared to a compensation point to determine if the wetland is a sink or source of GHG. The compensation point is calculated as the value of methane GWP that would put CH_4 emitted equal to the net-

CO_2 uptake (GWP_M * $CH_4/CO_2 = 1$). It is concluded that all sites are sources of GHG with a 20 year timeframe, most wetlands are sinks with a 100 year timeframe and all are sinks on a 500 year timeframe.

Friborg et al (2003) studied the net fluxes of CO_2 and CH_4 at a vast wetland area in Siberia. The measurements were carried out during the summer when the growing season reaches its peak and CO_2 uptake is at its highest. The average flux of three different parts of the summer was for CO_2 2.247 g per m^2 and day and for methane 0.136 g per m^2 and day. With a 20 year timeframe GWP the total release from the sight is 6.192 g per m^2 and day. The net emission of GHGs was at its highest in September when CO_2-respiration was higher than -sequestration. They estimated a yearly exchange of GHG by assuming that the measurements done in their study was representative for the part of the year when temperatures are above freezing point, and that results from earlier studies done during parts of the winter represent the rest of the year. With this interpretation the annual emissions of methane is 26 g/m^2 and year and 396 g CO_2 is taken up per m^2 and year. The net exchange is 1216 g CO_2 equivalents per m^2 and year using the 20 year timeframe.

2.1.2 Other ecosystem services generated by wetlands

Wetlands are highly productive and versatile ecosystems. They provide a number of goods and services, including e.g. improved water quality, recreational activities, biological diversity and materials, many of them with public-good characteristics (Woodward and Wui, 2001). Direct use values of a wetland include for example the use of wood, water for irrigation and bird watching. Indirect use values are e.g. water purification or flood protection. Wetlands have a large filtering capacity and take care of e.g. agricultural nutrient run-offs. Non-use values are connected to the existence of the wetland itself or species dependent of the same (Brander et al, 2006).

2.3 Forest ecosystem services

2.3.1 Forest carbon cycle

The primary functions involved in the forest's carbon cycle are photosynthesis and respiration of CO_2. Trees and other plants sequester CO_2 while soil vegetation respires, though everything contributes to both to some extent. Photosynthesis is strongly connected to temperature and decreases with lower temperatures. During winter when the temperature is below zero photosynthesis is close to zero. During summer the availability of water and sunlight determine the level of photosynthesis. Insects, worms, bacteria and fungi release the organic carbon back to the atmosphere when they consume organic matter, as carbon dioxide is a waste product in this decomposition process. Even respiration is dependent on temperature and increases exponentially with higher temperature. In contrast to photosynthesis soil respiration occurs all day every day of the year. The carbon balance can therefore differ a lot between seasons and from one day to another. On a yearly basis the photosynthesis exceeds respiration and carbon is stored in the soil through dead leaves, branches and roots (Bergh et al., 2000).

Carbon dioxide is by far the most important greenhouse gas in the carbon cycle of forests, which is why the others are normally ignored in studies focused on the forest ecosystem balance. However studies done on drained wetlands for forestry are more focused on the soil and include methane and N_2O. Ojanen et al. (2010) who studied forestry-drained peatlands in Finland found that the emissions of N_2O from the forest floor ranged between 0.28-1.16 kg/ha and year for drained sedge (Carex) mires now dominated by spruce. They also measured methane fluxes of -2.8 kg/ha and year on average for forest vegetation dominated sites, i.e. a net uptake. Von Arnold et al. (2005) found annual methane emissions of 0-5 kg/ha and N_2O emissions of 0.4-0.9 kg/ha on drained organic soils in Sweden with 50 and 90 year old Spruce. Turned into CO_2-equivalents (100 year timeframe; 298 for N_2O and 23 for CH_4) these values were together only 2.5-3 % of the net ecosystem uptake of carbon dioxide. The difference in methane emissions is connected to how well drained the sites are. Poorly drained sites tend to emit small amounts while well drained sites sequester methane.

The forest carbon cycle is normally measured as "net ecosystem production" (NEP). It is defined as gross primary production (GPP) less plant respiration and soil respiration, non CO_2-losses such as methane and non-respiratory CO_2-losses through ecosystem disturbances like fires. The GPP is the carbon uptake by plants during photosynthesis. Net primary production (NPP) gives the value of GPP less plant respiration (Randersson et al., 2002).

IPCC (2000) give estimated annual rates of NEP at up to 2.5 tonne C per hectare for managed forests in the boreal zone. However for managed forests the carbon cycle differs a lot with stand age, see figure 4. Young stands emit more carbon then it sequester. The forest floor is at that stage exposed to sunlight which increases respiration through decomposition while the amount of biomass is relatively low. Photosynthesis then increases with time and when the forest reaches canopy closure the ground is shaded and temperature is lower which decreases respiration. The growth rate and the ability to sequester CO_2 decreases in older stands but the forest still increases its carbon pool (Schulze et al., 2000).

How the forest is managed and type of tree species are factors that affect the carbon cycle. Ground preparations that shorten the plant- and young stand phase have a positive impact. However carbon can be released if the humus layer is heavily disturbed by the ground preparations. Tree species with higher growth rate, given certain soil fertility, sequestrate more carbon due to the lager biomass and they reach canopy closer faster (Bergh et al., 2000). Higher leaf area index (LAI) also has a positive effect on the carbon uptake. Coniferous (needle) trees have higher LAI then deciduous (leaf) trees. Spruce, that keeps its needles longer then pine, can reach numbers over 10 m^2 leaf area per m^2 ground area. It takes 10-15 years for spruce species to reach closure. The LAI then does not change until thinning or felling (Nordborg and Bergh, 2014).

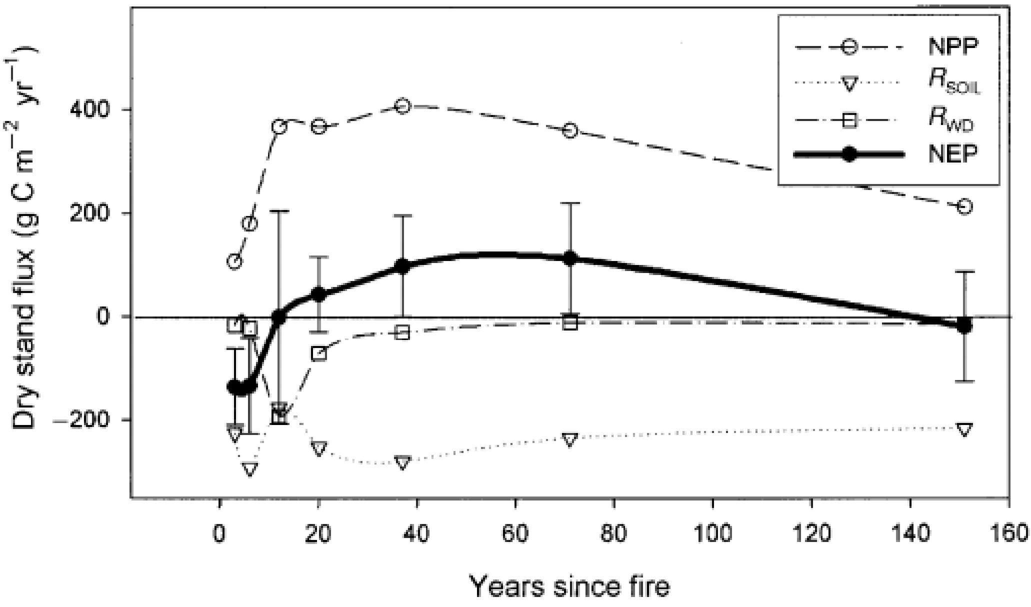

Figure 4. NEP measured from a chronosequence of black spruce in Canada (Bond-Lamberty et al., 2004)

Since it would take decades to measure annual rates of NEP trough all stand phases, chronosequence (age sequence) methods are used to study the time-dependent development of a forest. A chronosequence is a set of forested sites that share similar attributes but are of different stand age (Johnson, 2007). Bond-Lamberty et al. (2004) measured sequestration and plant respiration of a black spruce chronosequence in Canada for a period of three years. The sites burned at different times between 1850 and 1998 which made it possible to obtain fluxes for stand ages of 3-151 years. The measurements were done on both poorly- and well-drained stands. Using data on soil respiration from previous studies of the same chronosequence they calculated values of NEP. It showed that the stand is a moderate source of carbon in young ages, a strong sink in the middle-ages and about neutral with the atmosphere in the oldest stage. The net plant uptake of carbon was the highest (4 058 kg C per ha and year) 37 years after fire while NEP was highest (1 120 kg C) after 71 years for the well-drained stands. The curve follows theory about differences in carbon flux between stand ages. The variability of NEP between years was greater for poorly drained stands and has a peak at 20 years that is high relative to most values in the literature, as discussed by the authors.

Ditches and their role in the forest carbon cycle

The drainage of wetlands, for both agriculture and forestry, requires the creation and maintenance of drainage ditches. Roulet and Moore (1996) reported that drainage of wetlands for forestry did result in a reduction in CH_4 emission from the drained portions of the wetland, but there were large emissions of CH_4 from the ditches. The overall effect of drainage, therefore, was dependent on the spacing of ditches. The thought was that smaller space results in more ditch area which leads to more emissions. Since much of the net reduction in GHG emissions in Laine et al. (1996) resulted from an estimated decrease of CH_4 emissions, the reduction may not be as great as they calculated. It should though be noted that the ditches examined by Roulet and Moore (1996) were not maintained to the same standard as ditches in

Finland, like those examined by Laine et al. (1996). Good maintenance would likely reduce the CH_4 emissions considerably (Roulet, 2000).

Minkkinen and Laine (2006) found that fluxes from ditches are higher in drained fens than in drained bogs and much higher during the summer than in winter. Also ditches with running water have higher emissions than ditches with stagnant water or covered with vegetation. Type of vegetation also has an impact on emissions. Least amount of emissions comes from ditches that are filled with water only after rainfall. They also suggest, in contrast to Roulet and Moore (1996) that higher ditch density would lead to a decrease in net methane emissions from the site since it would deepen the water table and produce drier conditions.

2.3.2 Other ecosystem services generated by forests

In addition to carbon sequestration and the supply of timber, to which most forests in Europe are dedicated, forests provide a multitude of benefits. Direct use values include extraction of timber, recreational activities, game hunting and food supply like berries and mushrooms. Indirect use values are e.g. fresh water supply, erosion control and soil nutrients recycling, while non-use values are mostly connected to biodiversity.

3 Literature review

Even though there is an extensive amount of work done on the topics of whether or not and how to use Cost Benefit Analysis (CBA) in the context of climate change, there seems to be very few CBAs done on actual projects to mitigate climate change. This study treats costs and benefits of reduced greenhouse gas emissions through conversion of wetlands into forest and connected impacts on recreational and non-use values like biodiversity. Therefore literature on CBA in the context of climate change is relevant for this study. Which policies that have been discussed and what role land-use change has played in CBA studies on climate change, especially wetlands and forest and how the altered GHG fluctuations from land-use change are valued is also of interest. Furthermore it is relevant for this study to look at to what extent land-use change has been discussed in the context of other types of climate policy measures than CBA, like cost-effectiveness. In more detail this literature review will examine how earlier studies have dealt with the carbon value, if they are dynamic or static and what gap this study can help to fill.

CBA of climate policies

A couple of studies have evaluated climate policies through CBA, where they compare the benefits of reducing emissions with the possible costs of doing the same. Tol (2012) compares the marginal costs and benefits of greenhouse gas reductions to meet the European Union's targets for 2020. The benefits are expressed in terms of avoided damage, where the marginal damage cost of CO_2 ("social cost of carbon", SCC, see 5.4 for more information) is defined as the net present value of the incremental damage due to a small increase in carbon dioxide emissions. The costs are estimated with the average of a handful of studies that has modelled the economic impact of reaching the abatement targets, which includes a 20% reduction in greenhouse gas emissions and a 20% share of renewables in total energy supply. The SCC is the same for the whole period and thus the CBA is static. Since the intended EU-policy is not cost-effective he also compares the marginal damage costs of climate change to the marginal abatement costs for an ideal policy. The results show that the costs exceed the benefits and a benefit-cost ratio is stated. The study does not specify the abatement cost items that are used to reach the goals, or if land-use change is one of the possibilities.

The Commission of the European Communities, CEC (2005), made a CBA that covered the ultimate target of 2 degrees above pre-industrial level. The benefits are estimated as the difference between the damage costs (also uses SCC) of a business as usual scenario and the damage costs of a 2 degrees increase scenario in the year 2100. They then give the costs (as percentage loss in GDP) of reaching the goal either with a model that only includes the reduction of CO_2 or a model that uses a multi-gas approach as well as carbon sinks. The later has lower marginal costs of stabilizing CO_2 concentrations. Neither this study gives precise examples of how to actually reduce emissions, but includes a discussion on how certain factors influence the cost of different abatement strategies, e.g. that the cost of abatement can be lowered with an EU-wide trading scheme.

CBA with land-use change

Maddison (1995) try to find an optimal policy for climate change using CBA. The study evaluates the trade-off between abatement activity and the costs of climate change related damage. His model is a dynamic non-linear program whose objective is to minimize the present value costs of climate change policy. His results show that with an immediate cut in emissions that increases over time and the establishment of some 37 million hectares of forest the present value costs could be decreased with 700 billion US$. The program includes a carbon tax necessary to push the economy along this path that rises quickly over time. This study includes land-use change through afforestation but is not project specific and does not include any valuation of the benefits of reduced emission.

Neither does Xu (1995) who calculates the costs and benefits of large-scale afforestation to reduce atmospheric carbon. The management costs of producing the forest and the incomes from possible outputs are calculated to give a net present value. The result is then also given in terms of USD per tonne of sequestrated carbon. The study is static and uses average annual net carbon sequestration times the rotation age to calculate total carbon stored. In addition to not including the value of the reduced carbon the opportunity cost of land use is not accounted for.

Land-use change and cost-effectiveness

Much more common is the use of cost-effectiveness in evaluating projects to mitigate climate change. A number of studies have looked at the cost per unit of sequestrated carbon from land-use change, e.g. De Jong et al. (2000), McHale et al. (2007) and Nijnik et al. (2013). They all calculate the costs of imaginative increases in forest biomass in a certain region but use very different models with various inputs and management options, as well as timeframes. Similar to this study Nijnik et al. (2013) consider spruce production over one rotation and calculates carbon uptake for each year after plantation separately. The studied region is the UK and they look at different yield classes, contrary to this study that determines a yield class from a certain type of soil and temperature typical of Sweden. The authors compare the net present value of timber production with the opportunity cost of farming the land and then divide with the amount of carbon sequestrated, to get the cost per tonne. McHale et al. (2007) also compares their cost per tonne sequestrated carbon with the market price of carbon credits to see if the plantation of trees can be cost-effective options for investors. Neither of the studies compares their result with the cost per carbon of other alternative projects.

Missfeldt and Haites (2001) analysed the potential contribution of sink enhancement activities to meeting Kyoto Protocol commitments of industrialised countries. They looked at six scenarios covering different categories of eligible sinks according to the protocol, like afforestation and improved land management. Average costs and potential for each category of sink was evaluated. In each scenario, at least some of the sinks had costs lower than the market price, so the larger the potential sink, the lower the compliance costs for industrialised countries. The results give good reasons for further research that are project specific but tell us little about the actual costs and benefits of climate change mitigation through land-use change.

Value of carbon sequestration

Closest to this study is the work done by Brainard et al (2003, 2006, 2009) who calculates the social value of carbon sequestration in Great Britain's woodlands. The most recent study builds on the previous ones and maps the carbon flux of the total forest ecosystem. The aim of the study is determine the value of potential global warming mitigation by British woodland. The study is dynamic and uses year by year estimates for carbon sequestration and has increasing SCC. They use databases to calculate previous changes in forest which allow them to predict future increases. The increase in spruce production is constant from the year 2002 and the net present value of carbon sequestration is calculated up to the year 3001 with a SCC that increases with one per cent each year for the first 30 years. Using different combinations of discount rate and SCC, suggested by previous studies, they give results for both existing forest and potential future afforestation.

The work done by Brainard et al. is according to themselves unique when it comes to the extent of complete inventory of actual species types, planting dates and management regimes when presenting results from a model that calculates the social value of carbon sequestration in woodlands. The study is also especially thorough in including many aspects of carbon accounting that have often been overlooked in previous studies, including C in thinning products, C displacement in wood products, harvesting and manufacture releases and the lost C sink on disturbed peat soils. In Brainard et al. (2006) they also compare the results of using different soil types, taking the effects on CO_2 releases after draining peat soils into account. The extent of and the details in studying the forest carbon cycle goes beyond this paper. But they choose not to include any other GHGs then CO_2 and only in the discussion mention that forests provide other social benefits like biodiversity, recreation and water quality protection.

Contribution to the literature

This study will like Tol (2012) calculate the benefits of avoided emissions and like Brainard et al. (2009) estimate the value of carbon sequestrated by forests with a price on carbon dioxide. Unlike Tol (2012) the amount of reduced emissions is not based on a target but on data on emissions that will be avoided through land-use change. This study also calculates the costs of producing the forest and the opportunity cost of land, which Brainard et al. (2009) does not. Thus the contribution to the literature is a dynamic cost benefit analysis that includes all impacts over a longer time period of a specific project for mitigating climate change. It will be the first one to value emissions from wetlands. It will include the benefits of less emission from both eliminating a source and creating a sink through land-use change, which is unique.

4 Method

This section mainly contains information on how to do a CBA in general. First however an introduction to why CBA is useful is presented. In the end there is also a discussion on the criticism to and limitations of CBA and alternative approaches.

4.1 Why Cost Benefit Analysis

Cost benefit analysis is a policy assessment method that quantifies in monetary terms the value of all impacts of a policy to all members of society. Simply put it estimates and totals up the equivalent monetary value of the benefits and costs to the society of a project to determine if they are worthwhile. The aggregate value of a policy is measured by its net social benefits (NSB), often shortened net benefits, and equals the social benefits (B) minus the social costs (C): $NSB = B - C$. The broad purpose of CBA is to help policy decision making and to make it more rational. The main advantage is that it is easy to understand, does the benefits outweigh the costs or not. Its simplicity also means that conducting a CBA is possible for various projects, locations and scales (Boardman et al., 2005).

CBA addresses one fundamental economic problem; how to allocate scarce resources when there are multiple demands for the same. Resources are scarce because the sum total of demands on them exceeds their availability and using up resources imposes opportunity costs since the same resources cannot be used for other purposes (Hanley and Barbier, 2009). For example, forest can be planted on drained wetland sites in order to lower greenhouse gas emissions. However, if the land is used to sequestrate carbon dioxide that same land cannot be used to treat polluting nutrient run-offs. If water is removed in order to produce timber, that same water is not available to support recreational activities like bird-watching. Therefore it is useful, in deciding whether to allow for such a policy, to know if the economic benefits of sequestrating carbon dioxide are bigger or smaller than the losses in biodiversity, recreational use and costs of forest plantation. CBA is a decision aiding tool to provide this information to policy makers (Hanley et al., 2009).

Not only does CBA allow a comparison of the benefits and costs of particular actions but it also allows for ordinary people's preferences to be included in government decision making. Economic values in a CBA depend partly on what people like, what they are willing to pay to have more of what they like and what they can afford to pay. CBA is a display of economic democracy and a formal way of setting out the impacts of a project or policy over time, of organizing debate over an issue and of identifying who enjoys the gains and who suffers the losses from the project (Hanley et al., 2009).

4.2 Outline of a Cost-Benefit Analysis

Every CBA should be conducted by following nine basic steps that helps both the analyst to be sure that all possible elements are taken into account and the reader to understand the thought process. In the table below the nine steps are put in order and divided into four separate groups (Boardman et al., 2005).

Table 1. The nine steps of a CBA analysis

Identification

1. Specify alternative projects
2. Decide whose benefits and costs count (standing)
3. Identify all impacts

Quantification

4. Predict all impacts quantitatively over the life of the project

Valuation

5. Monetize all impacts
6. Discount to obtain present values

Assessment

7. Compute the net present value of each alternative
8. Perform sensitivity analysis
9. Make a recommendation

Step one requires the analyst to specify a set of alternative project that would reach the same end result, i.e. can reduction in carbon emissions be made with investments in cleaner technology or by increasing the stock of carbon sinks. The projects should be described in detail concerning space, time and procedure. The net benefits of the alternatives are compared with the net benefits of a project that would be displaced if the evaluated project(s) were to proceed. The displaced project is often called the counterfactual. The counterfactual is usually the status quo, which means there is no policy undertaken.

In **step two** the analyst must decide who has standing, whose benefits and costs should be included. The issue of standing is sometimes contentious. Governments usually take only national costs and benefits into account, though the project has impacts on a global scale. Global climate change falls into this category.

Step three requires the analyst to identify the physical impact categories of the proposed alternatives, catalogue them as benefits or costs, and specify the measurement indicator of each impact category. The term impact includes both inputs and outputs. From a CBA perspective, analysts are only interested in impacts that affect the utility of individuals with standing. Impacts that do not have any value to humans are not counted. In order to treat something as an impact, we have to know there is a cause-and-effect relationship between some physical outcome of the project and the utility of human beings with standing. Some impacts may be viewed in opposite ways by groups of people with standing. For example can floods be a cost for residents while duck hunters regard them as a benefit. It is often more useful to then have two separate impact categories. The choice of measurement indicator usually depends on data availability and ease of monetization. Even if the analyst would like to categorize the impact from emissions as the resulting health effects it might be easier to just measure it as the volume of emissions.

The task in **step four** is to quantify all impacts in each time period. Most projects have impacts that extend over time. The analyst must make predictions for each category and in practice this is difficult, but very important for the end result. Prediction is especially difficult where projects are unique, have long timeframes or relationships among variables are complex. When strong supporting evidence is missing the analyst should use policy research, relevant theory and, when all else fails, make informed guesses after learning about the subject. Because of these uncertainties Monte Carlo simulation or other types of sensitivity analysis are essential components of almost any CBA for conveying the degree of certainty in the prediction of net benefits.

In **step five** the analyst has to monetize each of the impacts. Ideally, these estimates should be specific to the place and year the project is conducted. In CBA the value of an output is typically measured in terms of willingness to pay. Where markets exist and work well, willingness to pay can be determined from the appropriate market demand curve. Naturally, problems arise where markets do not exist or do not work well. If no person with standing is willing to pay a positive amount for some impact then that impact has zero value in the CBA. Obtaining values for such impact categories can be a life's work. In practice, most analysts use "plug in" values from previous studies whenever possible. Although catalogues of impact values are not comprehensive, considerable progress has been made in this regard. Sometimes there are plug in values for other places and/or years. The plug in value should then be converted using inflation, exchange rates (taking purchasing power parity into account) and any difference in sociological and geographical variables.

In **step six** future benefits and costs are discounted relative to present benefits and costs in order to obtain their present values (PV). The need to discount arises for two main reasons. First, there is an opportunity cost to the resources used in a project. Second, most people prefer to consume now rather than later. Discounting has nothing to do with inflation per se, although inflation must be taken into account. If predictions of future cost and benefits are put in real terms, inflation is not an issue. The choice of the appropriate social discount rate is contentious and is a good candidate for sensitivity analysis. The discount rate used in this study is more closely discussed in section 5.4 below.

The net present value (NPV) of each alternative is then calculated in **step seven**. When there are more than one alternative to the status quo and all the alternatives are mutually exclusive the rule is to select the project with the largest NPV, where $NPV = PV(NSB) = PV(B) - PV(C)$. Otherwise the simple rule is to proceed with the project if the present value of the benefits exceeds the present value of the costs. Even though the best alternative among the studied projects can be found with this rule, there might be a project that is even better.

It is important to once again point out that these NPVs are estimates and that sensitivity analysis should be conducted before making a final recommendation. This is done in **step eight**. Sensitivity analysis attempts to tackle uncertainties connected to the predicted impacts and the appropriate monetary valuation of each unit of the impact. This is normally done by altering one element of the CBA at a time. Potentially every assumption in a CBA can be varied, but carefully thought-out scenarios are usually more informative than mindlessly varying elements.

In **step nine** the final recommendation whether to proceed with the project or not is given. Finally, it is important to once again note that the analyst make recommendations, not decisions.

4.3 Criticism, limitations and alternative approaches

The biggest advantage of CBA is also its biggest limitation. The simplicity of the yes or no question leaves no room for considerations about how to use scarce resources optimally. If the CBA finds that the benefits of wetland afforestation outweigh the costs and wetlands are drained the remaining wetlands' value will increase on the margin. This means that eventually the net benefits of the forest will equal the net benefits of the wetland and an optimal allocation between forest and wetland has been reached. However CBA does not determine this allocation level but merely tells you if a specific wetland should be drained or not.

Evaluating projects through CBA has met some criticism from many professions including economists, politicians and philosophers. Critics have disputed the fundamental utilitarian assumption of CBA that the sum of individual utilities should be maximized and that it is possible to trade off utility gains for some against losses for others. These critics are not prepared to make trade-offs between one person's benefits and another person's costs. Also, participants in the policy-making process may disagree about such practical issues as what impacts will actually occur over time, how to monetize them and how to make trade-offs between the present and the future (Boardman et al., 2005).

Another issue is that CBA tends to conceal the ethical dilemmas we are facing when evaluating projects that effect human lives, health or the long-term survival of ecosystems. Often in CBA of projects that involves road safety, a monetary value is put on a human life. This is often done with an estimation of future incomes. Even if aggregated for a million lives this value would only amount to a very small part of the global GDP and seem worthless in comparison. This approach would also mean that different people's lives are worth differently, i.e. that people who live in countries where the income level is higher are worth more. In the same way wetlands and other ecosystems in richer countries would be valued more since the people living there can afford to use a part of their income to preserve them. Others would argue that each human life is priceless or that there is no finite monetary value of historical sites or ecosystems and thus CBA is not appropriate to address these kinds of problems.

Thus two types of circumstances make the net benefit criterion an inappropriate decision rule for public policy. First, goals other than efficient allocation of resources might be more relevant to the policy. Second, technical limitations may make it impossible to quantify and then monetize all relevant impacts as costs and benefits. Cost-Benefit Analysis should therefore only be seen as a guide to what projects could be considered. It is then up to the policy-makers to determine how to best relocate benefits between individuals and solve the ethical dilemmas. Boardman et al. (2005) recommend some alternative approaches when CBA comes up short;

Cost-Effectiveness Analysis: Analysts can often quantify impacts but not monetize them all. They often encounter situations in which they or their clients are unable or unwilling to monetize the major benefits, such as human lives saved, injuries avoided or the acres of old-growth forest preserved. Because not all impacts can be monetized, it is not possible to estimate net benefits. The analyst can instead construct a ratio involving the quantitative benefit and the total monetized cost. A comparison then allows the analyst to rank projects in terms of the cost-effectiveness criterion.

Multigoal Analysis: One goal, efficient allocation of resources, underlies CBA. The general public, politicians and even economists, however, often consider goals reflecting other values to be relevant to the evaluation of public policies proposed to solve problems. Other goals such as equality of outcome, expenditure constraints or national security may be as or even more important. When goals in addition to efficiency are relevant, multigoal analysis provides the appropriate framework. Multigoal analysis contains three distinct steps. First, the analyst must move from relevant social values to general goals of specific impact categories. Second, each alternative policy, including the status quo, must be analyzed with respect to each of the impacts. Third, as no policy alternative is likely to dominate the others in terms of improvement in all the goals, the analyst can make a recommendation to adopt one of the alternatives by carefully considering the trade-offs in the achievement of goals it offers relative to the other alternatives.

5 Empirical case study of wetland afforestation

In this part the cost-benefit analysis of wetland afforestation will be done. First a hypothetical scenario based on typical conditions and average numbers for Sweden will be described. In the second part there will be a discussion on possible impacts from the project and then which impacts will actually be attended in the CBA. In the last parts the impacts will be quantified and valued in monetary terms.

5.1 Project description

In this study only one project of wetland afforestation will be evaluated. The magnitude and time consumption of evaluating alternatives would just be too great for this study. Alternatives that also reduce GHG emissions could include technical innovation in the industry or other types of land use change.

The scenario for the CBA project of wetland forestation is based partly on the wetland inventory made by the Swedish organization Naturvårdsverket (2009). The purpose of the inventory was to identify different types of wetlands and describe their biological, hydrological and geological character in order to classify them according to natural value. Wetlands included in the inventory were classified according to their size, level of disturbance and uniqueness. Bigger, more undisturbed and rare wetlands were seen to have a higher total natural value. Values for humans by e.g. recreation were thus not included. They were then divided into a scale with four levels from wetlands with very high natural value (class 1) that should not be allowed to be affected in any way by human activity to low natural value (class 4) wetlands that can be further exploited, see figure 5a. The inventory is supposed to be a help in policy decision making and can be a tool when identifying the most appropriate sites for this project.

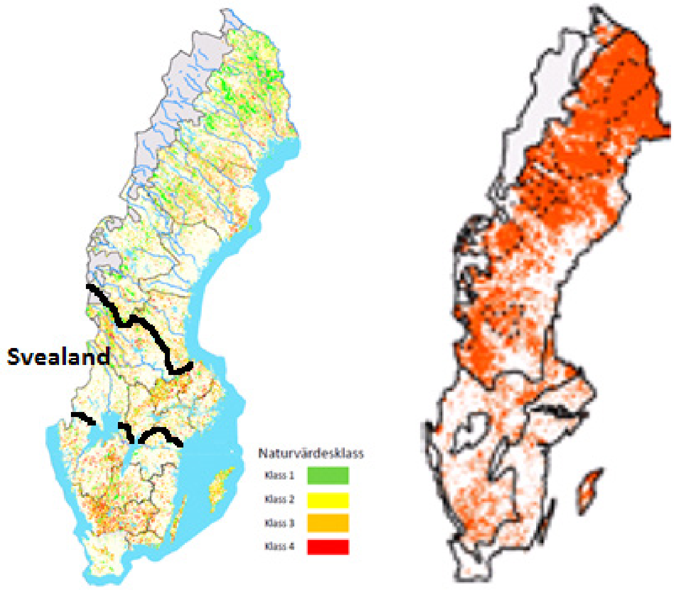

Figure 5. Classification of wetlands by nature value (left) and spread of topogenic fen (right) (Naturvårdsverket, 2009).

Location

By looking at the red and orange dots in figure 5a, wetlands with low natural value according to Naturvårdsverket can be found mainly in the middle of Götaland, eastern parts of Svealand, Dalarna and along the coast of Norrland. These wetlands are close to settlements which imply that they are more disturbed and this is partly why they have a lower natural value, according to Naturvårdsverket. In contrast this should imply that the recreational use is higher. While the wetland for this study is hypothetical, it is the author's opinion that the valuation of Naturvårdsverket and convenience, together with extent of recreational use, should be taken into account when determining which wetland to actually use. In this study the hypothetical wetland will be located in Svealand which has average Swedish climate conditions.

Type of wetland

Since uniqueness is a criterion for high natural value, only common wetland types should be used for this type of project. Mire is a subcategory of wetland and is divided into fens and bogs. Fens are fed with mineral-rich surface- or ground water and are pH neutral in contrast to bogs that are sour and nutrient poor (Godwin et al., 2002). This makes drained fens more suitable for forest production. Fens and bogs can also be separated by the plants that grow on them, where fens (figure 6) are normally filled with grass and bogs (figure 7) with moss. In Sweden topogenic fens are common throughout the country (Naturvårdsverket, 2009), see figure 5b.

Figure 6. Fen with its caractheristic plant Carex Rostata (Naturvårdverket, 2009)

Size

During the inventory 35 000 objects were identified with a total area of 3.4 million hectare and thus a Swedish wetland has an approximate average size of just below 100 hectare. All the smallest wetlands in each province were omitted in the inventory and the correct number is probably lower. Since larger wetlands have a higher total natural value according to Naturvårdsverket only small wetlands should be targeted for the project. In the scenario of this thesis a wetland of 50 hectare will be used.

Conditions for timber production

There are two main factors that determine timber productivity; site type and climate. The most common mire site types in Sweden are called Low sedge and Tall sedge (Carex rostrata) type. Carex is a type of grass which normally grows in fens, see figure 6. The site type Tall sedge has medium post drainage forest productivity and is therefore suitable for this project. The second most important factor for forest productivity is the climate, and especially the temperature sum (Hånell and Päivänen, 2012). The average temperature sum for the area that is interesting for this project is 1300 degree days per year.

The recommended tree species for Tall sedge type is spruce, if the site is moist and healthy (Bergquist et al., 2005). Together with the fact that spruce has a higher growth potential than pine given a certain fertility potential (Bergquist et al., 2005), has a higher LAI and is less exposed to moose grazing (Hånell and Päivänen, 2012) it will be a suitable specie for the project.

Ditches

The ditches are assumed to be made in a way that the end result can be considered as well drained, i.e. a water table at >50 cm below ground. Well drained sites have higher post drainage fertility potential and more biomass sequester more carbon. Ditch spacing and how they are managed has been found to have an impact on how much greenhouse gases that are emitted from the drained wetland. In this project the ditches will be presumed to be as well maintained as possible. Therefore the ditches will have the recommended spacing of 40 m (Lundin, 2014) and the calculations will include the cost of decluttering.

Project lifetime

The valuation of the project stops in 2050, which is when the latest emission targets are set. All costs and incomes of the timber production from e.g. ditching, planting and ash-fertilization until first logging will be calculated. Only the costs and benefits from the first 35 years will however be included in the reference case. In the sensitivity analysis, a longer time frame up to 75 years will be considered.

Counterfactual

The counterfactual of this project is letting the wetland be as it is during the project lifetime. It will be presumed that the wetland stay unchanged during this time. This is a simplification because if global warming continues during this time the water table might sink which will change the emissions of methane. Also biodiversity might change due to global warming and as an effect of this the recreational values.

Standings

Standing has all people that values the wetland, either by e.g. recreational activities or by appreciating the thought of its existence (consumers), the companies who are interested in expanding their timber production (producers), and the ones who are affected by global warming (third party). These are not necessary limited to Sweden since climate change is a global issue.

5.2 Impacts

Altering the wetland ecosystem through forest drainage will have a big impact on the ecological services. As pointed out by Brander et al. (2006), wetlands provide a number of goods and services that will fully or partly disappear through drainage. Especially the hydrological functions of the wetland will be deprived. Biodiversity which is normally high in wetlands might decrease. The existence value of the wetland and species dependent on it will decrease to zero. Recreational values connected to bird watching and hunting will be lower while recreational values of the forest connected to game hunting and mushroom or berry picking might be added. The planted forest will increase the timber production in Sweden and the climate will be improved.

Biodiversity and other non-use values

Wetlands are high in biodiversity, many of the endangered bird species in Sweden can be found there. They are attracted by the many bugs and insects. There is also a large variety of plants in or close by wetlands that are uncommon on dry land. As mentioned before only common and damaged wetlands with low natural value should be used for this type of project. Then the impact on biodiversity will be low and the overall biodiversity in Sweden will not be altered.

Biodiversity and other non-use values are also high in forests. Increasing the forest area might help some ecological functions that require a minimum threshold of forest habitat area (Brander et al., 2006), e.g. more nesting options could help a bird population to increase and survive.

Figure 7. A hunter and his target put down on a bog in Värmland

Recreational values

Both wetlands and forests are used for hunting. Moose sometimes use wetlands to move between forest areas which make them good hunting grounds, see figure 7. As a consequence of draining the wetland recreational activities like hunting and birdwatching on wetlands will be loosed. These two activities might seem conflicting but is normally divided by seasons. Open treeless wetlands provide suitable grounds for the Black grouse's courtship ritual during mating seasons when these birds are not hunted. This ritual is popular to witness (Hånell and Päivänen, 2012). Other birds that are popular for hunting such as ducks are only found in or close to water.

Big animals like moose utilize wetlands for cooling but it is not a natural habitat for big animals. The new forest plantation can attract animals that like to graze on plants and small trees and the open space scenery can work as good hunting grounds. The presence of berries and mushrooms might increase with the added forest area.

Climate

The emissions from the wetland will disappear after drainage. However the water cleaning function of the wetland will no longer be available. Neither will the flooding control. The biomass of the planted forest after drainage will add to the carbon sink, while there will be some respiration from the forest soil. Only CO_2 fluxes will be considered for the forest since both Von Arnold et al. (2005) and Ojanen et al. (2010) found that methane and N_2O have a very small effect on the GHG balance.

Possibly there will be methane emissions coming from the ditches. With a ditch spacing of 40 m there will be a total of 250 m ditches. Each ditch will be 1.5 m wide (Henriksson and Mattson, 2012) and the total area of ditches is 375 m^2 per ha forest, less than four per cent. The methane that is emitted from ditches will thus likely not affect the results but given all the contradicting evidence on how much is emitted this will be treated in the sensitivity analysis.

Summary

The impacts on the forest included in the study will be the timber production and net carbon uptake ability as well as recreation and biodiversity. The impacts on the counterfactual (wetland in the table below) will be its nature values and greenhouse gas net emissions. The table below shows the cost and/or benefit items for all impacts that will be calculated in this study. They are divided into four parts where the natural values of wetlands is one, the second and third parts are the climate impact of wetlands and forest respectively and the last part is the natural values of forests. Impacts within brackets are not included in the reference case, but in the sensitivity analysis for the full 75-years version until first logging.

Table 2. Cost and benefit items connected to the forest and the counterfactual (wetland)

Wetland		**Forest**	
Benefit	Cost	Benefit	Cost
Carbon sequestration	Methane emissions	Carbon sequestration	Carbon emissions
Recreational activities		Recreational activities	Permission
Biodiversity		Biodiversity	Planning
Water Supply		Thinning -30	Ditching
Water Quality		[Thinning -45]	Ground preparation
Flood control		[Logging -75]	Ash fertilization
Hunting			Planting
			Clearance -10
			Ash fertilization -30
			Thinning -30
			[Ditch cleaning -45]
			[Thinning -45]
			[Ash fertilization -60]
			[Logging -75]

The value of the project and the counterfactual will later be compared and the difference of these two, i.e. the total value of the project, will be given as the result.

5.3 Quantification

In this section the cost and benefit items will be quantified using numbers found in the literature. When more than one study is usable the average of those will be used in this project. The four parts described in the table above will be dealt with separately.

5.3.1 Nature values of wetlands

The wetland's services and goods will not be quantified separately. The main reason for this is that most studies valuating wetlands do not quantify e.g. biodiversity and then multiply that quantity with a value of each unit. Instead they go straight to estimating the total value of the wetland with stated or revealed willingness to pay methods. The wetland will be totally eliminated and therefore all goods and services will be zero after drainage. Thus the quantity is the ecosystem services provided by one wetland with a size of 50 hectare. This will be more clearly explained in section 5.6.1.

5.3.2 Wetland emissions

The net emissions from wetlands will be calculated using average annual GHG exchange measured in previous studies. Estimated emissions of methane and CO_2 sequestration from three studies conducted on boreal fens are compiled in the table below. The numbers are adjusted so that all have the same unit, kg ha^{-1} $year^{-1}$. How this was done can be seen in Appendix A.

Table 3. Estimated CH4 emissions, CO_2 uptake and net emissions from boreal fens

Study	**CH_4** (kg ha^{-1} year^{-1})	**CO_2** (kg ha^{-1} year^{-1})	**Net (GWP=34)**
Whiting and Chanton (2001)	562	10 120	8988
Kasimir-Klemedtsson et al. (1997)	200	600	6200
Friborg et al. (2003)	260	3960	4880
Average	**341**	**4893**	**6701**

In order to compare these greenhouse gases, methane emissions are converted into CO_2-eqvivalents using a GWP for methane. As discussed in section 2.1.1 above a timeframe of 100 years is normally used in policy-making decisions. Lately it has been recommended that for the short lived methane a 20 year timeframe should be used (Holdren et al., 2014). But since the timeframe for this study is until 2050 and new GHGs will be emitted each year until then neither of these is suitable.

Dessus et al. (2008) say that applying a GWP in order to estimate the impact at a given timeframe without caution to events which continue over time may lead to serious errors. As the atmospheric lifetime of CH_4 is short compared to that of CO_2, the GWP of methane varies considerably depending on the timeframe. With the rule of the GWP being 34 (100 year timeframe) it is therefore impossible to estimate the true impact when the real timeframe differs from 100 years, as is the case for this study. To make this estimate it is necessary to take into account the difference between the year of emission and the year of interest for a certain policy (Dessus et al., 2008). In this study the methane emissions from each year will therefore be assigned the GWP that corresponds to the number of years until 2050. That is, methane emissions year 2020 will be multiplied with the GWP for a 30 year timeframe and so on. The GWP of methane over time is showed in the graph below.

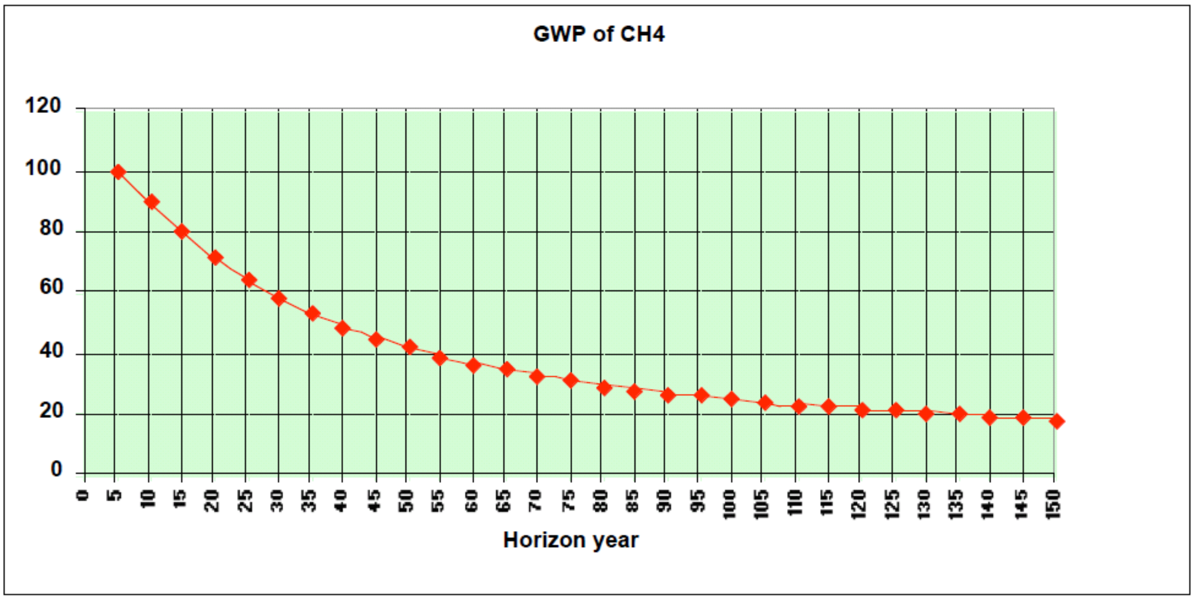

Figure 8. GWP of methane over time (Dessus et al., 2008)

The values of GWP in the graph are based on numbers given in the fourth IPCC assessment report from 2007. Since updated numbers came with the latest assessment report in 2013 the graph needs to be updated for this study. This update and the complete calculations of net emissions from each year, which are done in excel, can be found in Appendix A. Total net emissions from the period 2015-2050 are 964 327 kg CO_2-eq per hectare.

5.3.3 Forest sequestration

The NEP measures the net carbon uptake of the forest. In this study it will be estimated by following the curve of the well-drained forest in the chronosequence studied by Bond-Lamberty et al. (2004), see figure 4. The quantities are recalibrated to match the data given by IPCC, i.e 160 kg C per ha emitted on average per year (IPCC, 2006) during the transition period and 2 500 kg C per ha taken up on average each year (IPCC, 2000) by boreal forests. The default transition period given in IPCC (2006) is 20 years. As seen in figure 4 the value of NEP is zero at year 12 with means that the ecosystem has reached carbon balance. In this study the transition period will therefore be estimated to 12 years. Over the whole rotation (75 years) the annual average is then 1 900 kg C per ha, or 7 000 kg CO_2, see figure 9.

Von Arnold et al. (2005) found that the net GHG ecosystem exchange of CO_2, CH_4 and N_2O (i.e. not NEP) on drained organic soils in Sweden with 50 and 90 year old spruce stands was 6 600 kg CO_2-eq per ha and year and 7 800 kg CO_2-eq per ha and year respectively. The sites studied by von Arnold had less trees than this study (1350 and 750 compared to 2300 trees) and was poorly drained with a water table at 27 and 22 cm below ground. Both these factors indicate that the carbon sequestration should be higher in this study. Even though these two measurements are not equivalent it tells us that average data for boreal forests in general are not far from Swedish estimates and that the quantities used in this hypothetical study is in the range of real site data.

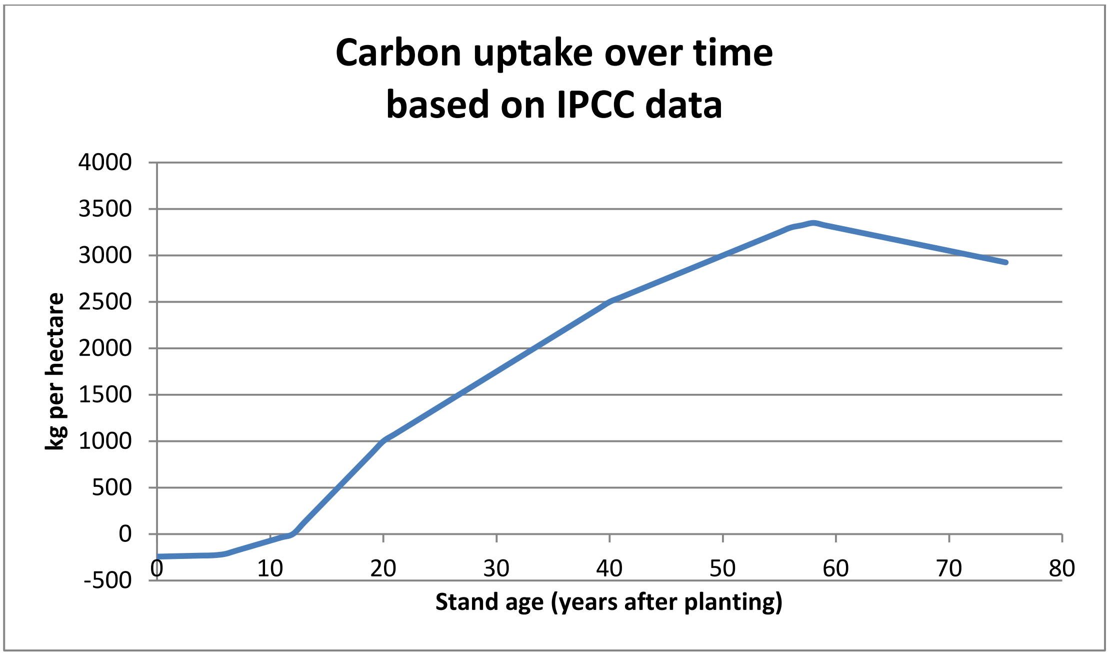

Figure 9. Carbon fluxes by forest stand age based on IPCC data

The chronosequence method gives a better picture of how the carbon fluxes (and thus benefits) are distributed over time than using average per rotation or per project measurements. Using the NEP measurement also has the advantage that it includes the total forest ecosystem carbon fluxes compared to those studies that derive carbon uptake solely from tree growth rates and does not include all soil and plant respiration. The disadvantage however for this study is that there is no connection between the calculated timber production and the estimated carbon uptake, since these are dealt with separately.

The net carbon uptake from the updated curve is then expressed in terms of CO_2 using the difference in molar weight of C and CO_2, i.e. how much CO_2 you get from a certain weight of carbon. The total net uptake of 26 336 kg C per hectare over 35 years corresponds to 96 564 kg CO_2 per hectare. All the calculations are done in excel and are found in Appendix A.

5.3.4 Nature values of forests

The quantity of produced timber and wood will be gathered from Henriksson and Mattsson (2012). They do an investment analysis of draining wetlands for spruce production where all future costs and incomes are discounted into a net present value. It is carried out on five different site types within four parts of Sweden with different climate. The hypothetical wetland in the study was 50 ha and the ditch spacing 25 m. All the cost items in this study will be the same as they used but adjusted so that it matches the ditch spacing of 40 m instead of 25 m. With a spacing of 40 m there is a total of 250 m of ditches per hectare. Most costs are connected to how many meters each machine can process per hour. The cost items include the ditching and the ground preparation that enables planting trees on a former wetland. The produced spruce timber and wood per hectare calculated in Henriksson and Mattsson (2012) on Tall sedge type with a temperature sum of 1300 degree days and post drainage fertility potential of 8 m^3 ha^{-1} $year^{-1}$ is compiled in the table below.

Table 4. Volume of timber and wood from thinning and logging of a Spruce production on Tall sedge with 1300 degree days

	Timber (m^3 ha^{-1})	**Wood** (m^3 ha^{-1})
1st thinning (30 years)	13.5	16
2nd thinning (45 years)	32.4	25
Logging (75 years)	220.8	86.4

For the non-market values of the forest the same issue arises as with the nature values of the wetland. There is no quantity per hectare of these services found in the literature. The quantity of recreational and non-use values is thus the size of the forest and its value will be estimated with average per hectare data from previous studies.

5.4 Discount rate

Before valuating the impacts it is important to decide on a discount rate so that cost and benefit items that appear in the future can be correctly calculated. The choice of social discount rate is often critical in determining whether projects pass social cost benefit analysis.

The social discount rate (SDR) depends on the pure rate of time preference δ and the marginal elasticity of utility with respect to consumption η (the percentage change in welfare derived from a percentage change in consumption) and is given by the relation;

$$SDR = \delta + \eta g$$

where g is the growth rate of per capita consumption over time. The pure rate of time preference is the rate at which future utility is discounted simply because it is in the future. Inherent in the determination of the pure rate of time preference is the assumption that people prefer to consume now rather than later. A higher pure rate of time preference means that the costs of climate change incurred in the future have a lower present value

Based on the social opportunity cost of capital method it is recommended by Burgess and Zerbe (2011) to use a real SDR of 6-8 % in CBA of public projects. Following some criticism Boardman et al. (2013) suggest, using the same method, a lower rate of 5 per cent. They also think that future impacts would be better discounted using the rate of social time preference method and after employing recent United States data estimated a SDR of 3.5 per cent.

For issues like climate change, biodiversity losses and nuclear waste the debate is more about controversy in intergenerational equity rather than the correct foundation for the SDR. Conventional exponential discounting can yield results that appear to be contrary to intergenerational equity and sustainable development. Discount rates at even moderate levels imply that costs and benefits in the future are almost irrelevant. E.g. carbon storage provides benefits to generations living far in the future and thus exponential discounting is probably not a satisfactory basis for public policy (Hepburn and Koundouri, 2007).

Also in forestry economics discounting plays a huge role because harvesting cycles are often very long, much longer than project cycles for other investments. It has been suggested that CBA of such long-term investments should use a social discount rate that declines over time. The basis for this is that the future state of the economy is uncertain. Incorporating the uncertainty into economic models show that the discount rate should decline over time (Hepburn and Koundouri, 2007). The concept of a time declining SDR has been accepted by many scholars and practitioners, including the HM Treasury in 2003 and the European Commission in 2008 (Boardman et al., 2013)

Based upon the ethical position that the weight placed upon a person's utility shouldn't be reduced simply because they live in the future a zero utility discount rate could be tempting. However the social discount rate isn't dependent only on utility but also the consumption growth rate which has been positive and is expected to grow in the future, making a zero SDR unrealistic (Hepburn and Koundouri, 2007).

This project will use a SDR starting at 3.5 % declining to 3.0 % after 30 years, same as HM treasury (Hepburn and Koundouri, 2007), where η is 1 %, g is 2 % and δ is 1.5 % for the first 30 years. The results will also be tested for a high discount rate of 6 %, implying that future generations are less important, and a low rate of 1 per cent reflecting only low growth in consumption.

5.5 Value of carbon dioxide

To find the true unit value of CO_2 one would ideally be able to predict all future impacts and costs arising from climate change. Climate change has a wide range of impacts like sea level rise, heavy precipitation and drought that lead to more extreme conditions. Estimating the cost of climate change is complex mainly because it is so uncertain, and not only about the impacts themselves. The economic consequences of each impact are also difficult to predict. The extreme conditions will affect the demand for winter heating, the demand for summer cooling, the supply of wind and water power, the demand for water, crop yields, farm animal welfare and productivity, and tourism flows. It also affects human health, nature and biodiversity, things that themselves are not easy to value. The future number of people, their wealth, their energy consumption and their emissions are as well uncertain (Tol, 2009). Nevertheless there are two main methods for estimating the unit value of carbon dioxide that deal with these uncertainties slightly different. The methods are (Konjunkturinstitutet, 2012);

1) Social Cost of Carbon (SCC): the marginal cost of the damage from further carbon dioxide emissions to the atmosphere
2) Shadow Price of Carbon (SPC): the marginal cost of reducing emissions associated with a certain reduction goal.

The most used and discussed method is the social cost of carbon. It is defined as: "The social cost of carbon (SCC) measures the full global cost today of an incremental unit of carbon [dioxide] (or equivalent amount of other greenhouse gases) emitted now, summing the full global cost of the damage it imposes over the whole of its time in the atmosphere" (DEFRA, 2007). Researchers that study SCC do their best to estimate the total economic damage by using models and a set of assumptions about future emissions and impacts of climate change (Tol, 2012). The value of SCC is estimated by looking at loss in social welfare connected to the damage of the impacts. According to a compilation of previous studies done by Tol (2008) the mean of estimations of SCC is 0.49 SEK/kg CO_2 (2015-value). The spread is however very large. The value of the 99th percentile is 4.4 while the median is 0.32 SEK/kg CO_2, implying that the mean is driven by a few very large estimates. This theory has been the basis for social economic consequence analysis in the US, United Kingdom (until 2008) as well as in the transport project HEATCO within EU (Konjunkturinstitutet, 2012).

While the SCC gives the cost of the damage that climate change can generate, the SPC is based on a given climate policy. The shadow price is the marginal cost of the reduction measurements needed to reach the goal of the policy. Also the SPC is estimated with different models where the necessary reduction is found from a comparison between the emission target and a business as usual scenario. The price then depends on the target and available measurements to reduce emissions. Since the marginal abatement cost curve increases with more reduction the price increases with more stringent targets (DECC, 2011).

An alternative approach of the shadow price method is to look at existing prices on carbon dioxide. These are e.g. the market price of carbon in trading schemes like the EU Emission Trading Scheme (EU ETS) and the CO_2-tax (Konjunkturinstitutet, 2012). The price of carbon under the EU ETS was initially around 5 EURO/tonne but quickly increased to a range of 25-30 EURO. Since then it has gradually gone down and has been as low as 2.81 EURO in January 2013. Accept from dealing out to many credits the reasons for this can be the economic recession, renewable policies and the use of international credits (Koch et al., 2014). Recent years the price has been stable between 5 and 10 EURO per tonne. Most forecasts however tell us that the price will increase again (Ferdinand, 2014; Trotignon, 2012). While the low price level might be a disadvantage the biggest advantage with the market price approach is that it is very real, it is the figure financiers and business people use and the one affecting business decisions.

The different methods have strength and weaknesses. Most commonly discussed is the uncertainty in the model of SCC. Since e.g. damage from catastrophic events and ecosystem losses are difficult to estimate they are often assigned a zero value, which means that SCC values tend to be underestimates. Another problem with SCC is that the price decrease with lower concentration levels because the damage is smaller. But the general idea is that to reach lower concentration the price of carbon needs to increase and give incitement to reduce emissions. The SCC method thus has no way of ensuring goal fulfilment. Also the models used in the SPC method are troubled with uncertainty, especially in estimating abatement cost curves. However whereas the SCC is by definition static and determined solely through the best estimate of the damage caused and the way it is valued, the SPC can adjust to reflect the policy and technological environment in a dynamic way. This makes it a better tool to ensure that the carbon price is compatible with the climate change goals and commitments.

No matter the method, the price of carbon might change over time for several reasons. First and foremost, as the concentration of carbon in the atmosphere is rising the expected damage from an extra unit of emission will increase. This indicate that the price should increase over time, until the concentration level has been stabilised, since carbon emission will do more damage the later it is emitted. The price of carbon should also be increased in the future if it is showed that the current price is not adequate to reach the goal of stabilisation level. However increased technological change will lower the abatement cost curve and thus the price of carbon. Other factors that will affect the price of carbon are income and price level, where higher levels indicate higher price of carbon since the monetary value of damage is likely to grow (DEFRA, 2007).

Today there are unfortunately no common national guidelines in Sweden for how CO_2 should be valued. Different sectors and regions work with different rules and towards different climate goals. The sectors that are a part of the EU ETS (mainly industry) follow the goals set by EU while the non-trading sectors (transport, agriculture, housing etc.) follow a Swedish goal of reduction in emissions. Several Swedish authorities use the ASEK- (Arbetsgruppen för samhällsekonomiska analyser) value of 1.5 SEK/kg to value carbon dioxide in projects, even though it was initially constructed to be used in the transport section. Meanwhile Luftfartsverket follow the EU ETS price In addition there is a general CO_2-tax in Sweden, which at the moment is 1.1 SEK/kg (Konjunkturinstitutet, 2012).

This study will focus on SPC in the reference case since the project wetland afforestation is proposed as a way to reach the climate goals of Sweden and the joint targets for EU. In the UK they use SPC to value carbon dioxide in cost benefit analysis and often use EU targets. The UK governmental Department of Energy and Climate Change (DECC, 2011) used a set of models (among GLOCAF) to estimate needed prices of carbon dioxide on a fully working global market in the years 2030-2100 to meet the EU long term target of a maximum increase of 2 degrees Celsius over preindustrial level. In this study the EU ETS price today will be connected with their estimate for 2030.

This means that the value will increase from 0.10 SEK/kg (10 EURO/tonne) in 2015 to 0.87 SEK/kg (70 GBP/tonne) in 2030, SEK given in 2015-value, and then follow the curve until 2090, see figure 7. In the year 2050 the value is 2.5 SEK/kg (200 GBP/tonne), which implies an average increase of 8.5 % per year. The results can be seen in the graph below.

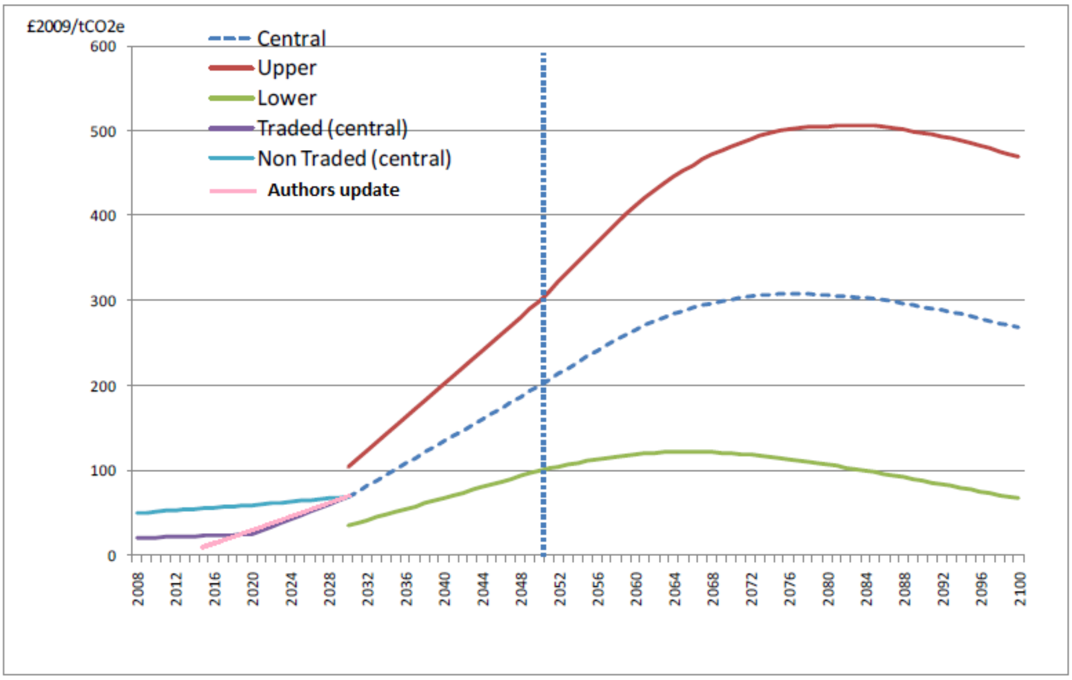

Figure 10. Estimated prices of carbon dioxide 2008-2100 in order to meet the 2 degrees Celsius target (DECC, 2011)

5.6 Valuation

In this part the quantified impacts will be put into monetary terms using values found in the literature and then discounted to the base year 2015.

5.6.1 Nature values of wetlands

Predicting or estimating the value of an ecosystem can be done through value transfer given that there is knowledge of its physical and socio-economic characteristics. There are two general approaches to value transfer, direct value transfer and function value transfer. Direct value transfer consists of transferring the value estimated in one or more primary studies to the site in question. The previous studied sites need to be as similar in its characteristics as possible or adjustments should be made to the transferred value (Brouwer, 2000). Function value transfer involves transferring values based on characteristics of the site of interest using a suitable function, e.g. estimated through meta-regression. It is generally accepted that function transfer perform better than direct value transfer (Brander et al., 2006). There are a number of reasons for this. While producing the function a larger number of studies is used to get information, differences in methods between primary studies can be controlled for and explanatory variables can be adjusted to represent the current site. Also meta-analysis value transfer performs better than other function value transfers (Brander et al., 2006).

Valuation of single wetlands
While most studies focus on one or two ecosystem services of wetlands a small number of studies have tried to estimate the total economic value of all important goods and services, e.g. Whitehead (1990), Leitch and Hovde (1996), Dillman et al (1993) and Folke (1991). Whitehead (1990) does a CVM study with a dichotomous choice survey through household mailing with the purpose to estimate WTP for preservation of the Clear Creek wetland in Kentucky, US. The respondents are informed about the wetland's functions and include; flood and erosion control, water quality enhancement, ground water recharge, habitat for animals and recreation such as hunting and nature observation. The values of WTP are given per person per year. Woodward and Wui (2001) estimated a value for this study of 870 US$ per acre and year (24 500 SEK/ha and year in 2015-value) with information about the population of Kentucky and the size of the wetland.

Folke (1991) studied a Swedish wetland system on Gotland that has lost a lot of life-support functions, such as cleansing nutrients, maintaining the level and quality of drinking water, processing sewage, sustaining genetic diversity and preserving species, through exploitation. He estimates the value of these losses through the replacement cost method by looking at the cost of creating these environmental functions with technical processes such as irrigation dams, water purification, sewage treatment plants and efforts to save endangered species. The estimated value of wetland is in the range of 2.5-7 million SEK annually most of which is connected to biogeochemical processes. Only ten percent are related to biological factors. The reduced amount of wetland was 3105 hectares and the average value of this is about 1500 SEK per hectare per year (2100 SEK in 2015-value).

Meta-analysis
Today a large number of wetland valuation studies exist. As a result, attempts to summarize these in order to predict the value of any wetland have been made, for example through meta-analysis. Brander et al. (2006) made a meta-analysis where they included all suitable earlier studies (80 in total) and included socio-economic variables such as GDP per capita and population density as well as geographical attributes like latitude. They hoped that this together with variables reflecting wetland and study characteristics would improve the possibility of value transfer.

From the 80 studies they found 215 separate observations of values. For the whole dataset the average annual wetland value is about 2800 US$ per hectare in 1995 $-value, with a median of only 150 US$ (about 24 400 and 1300 SEK/ha and year in 2015-value respectively). The mean and median value with respect to continent, wetland type, service and valuation method are given in graphs. Some of the results from the meta-analysis go against what can be concluded from these graphs. For example is the value of biodiversity tenfold higher than most of the other services in the studies but only slightly above average according to the regression.

Lastly they discuss value transfer and even evaluate their own meta-regression to be used for such transfer. Transfer errors may be a big problem if the characteristic of the site that is going to be evaluated is not well represented in the data underlying the estimated value function. The authors have tried to overcome this by including non-sample information like GDP per capita and population density. Their transfer error is according to the authors in level with other value transfers from the literature and considering the high costs and time consumption of performing site specific valuation studies, transfer values could be acceptable in wetland policy decisions.
For this reason and the fact that the number of studies valuing wetland services in Sweden is few the meta-analysis function produced by Brander et al. (2006) will be used to value the hypothetical wetland in this project. Below is their semi-logged regression function. The notations in the function are explained in table 5.

$$\ln Y = -6.98 + 1.16 \ln GDP + 0.47 \ln POP - 0.11 \ln Size + 0.03\, Lat - 0.0007\, Lat^2 + 0.84\, EUR + 1.49\, CVM - 1.46\, Fresh + 0.06\, Rec + 0.06\, Biod - 0.49\, Supply + 0.63\, Qual + 0.14\, Flood - 1.10\, Hunt$$

Some ecosystem services that are not of interest for this study, e.g. recreational fishing, are omitted from the function above, as well as the dummy variables for other continents, other wetland types and different valuation methods.

The total value of the wetland will be estimated with the GDP per capita of Sweden for 2013 (in 1995 US$ value), latitude for Svealand and a projected population density which is the average of Borlänge, Borås, Linköping, Umeå, Uppsala and Örebro municipalities (“kommun”). These relatively big cities are located close to where most low valued wetlands can be found (see figure 5) and their population densities give an estimate of how many people use the wetlands for recreation. The value method will be CVM, since it is the only one capturing non-use values. The ecosystem services are dummies. They will be valued as the average of the studies in the meta-analysis. These are obtained by dividing the number of observations for each service with the total number of observations, 215, and then multiply with the respective coefficient. The value of each post in the regression function used in this study is showed in the table below.

Table 5, Value of each post in the regression function used to obtain the total value of the wetland

Denotation	**Socio-economic**	**Value**		**Source**
GDP	GDP per capita (1995 US dollars)	33 167.8		CIA, 2014
POP	Population density (people/km^2)	100		SCB, 2014
	Geographical			
Lat	Latitude (degrees North)	60		Maps of world, 2014
Size	Size (ha)	50		Author
	Dummies (study characteristics)			
EUR	Europa	1		Author
CVM	Valuation method CVM	1		Author
Fresh	Freshwater	1		Author
	Dummies (ecosystem services)	**Number of observations**	**Value**	
Rec	Recreational activities	60	0.279	Brander et al., 2006
Biod	Biodiversity	19	0.088	Brander et al., 2006
Supply	Water Supply	23	0.107	Brander et al., 2006
Qual	Water Quality	31	0.144	Brander et al., 2006
Flood	Flood control	34	0.158	Brander et al., 2006
Hunt	Hunting	50	0.233	Brander et al., 2006

The result of the regression is 902 US dollars in 1995 value. Using Swedish consumer price indexes and an exchange rate adjusted for purchasing power parity this value is converted to 9624 SEK per hectare and year in 2015. This value is higher than in Folke (1991) and Whitehead (1990) and higher than the median but way below the average of the studies used in Brander et al. (2006). The net present value of one hectare of wetland until the year 2050 is 0.20 million SEK in 2015-value and of the total 50 ha it is 10 million SEK. See Appendix A for the full calculations.

5.6.2 Wetland emissions

The net emissions of CO_2-eq for each year is multiplied with the unit value of CO_2 and then discounted to the base year 2015. The total cost is 0.56 million SEK per hectare and 28 million SEK for the full 50 hectare. The calculations are found in Appendix A.

5.6.3 Forest sequestration

The net carbon dioxide taken up by the forest will be valued in the same way as above with an increasing price. The value over 35 years of the carbon taken up is 190 238 SEK/ha. Using the NPV method for each year give a total value of 71 824 SEK/ha, which shows that much of the value is obtained when the forest is older. The spread of net present value over time can be seen in the figure below. Total value of 50 hectare is 3.6 Million SEK. Again the calculations can be found in Appendix A.

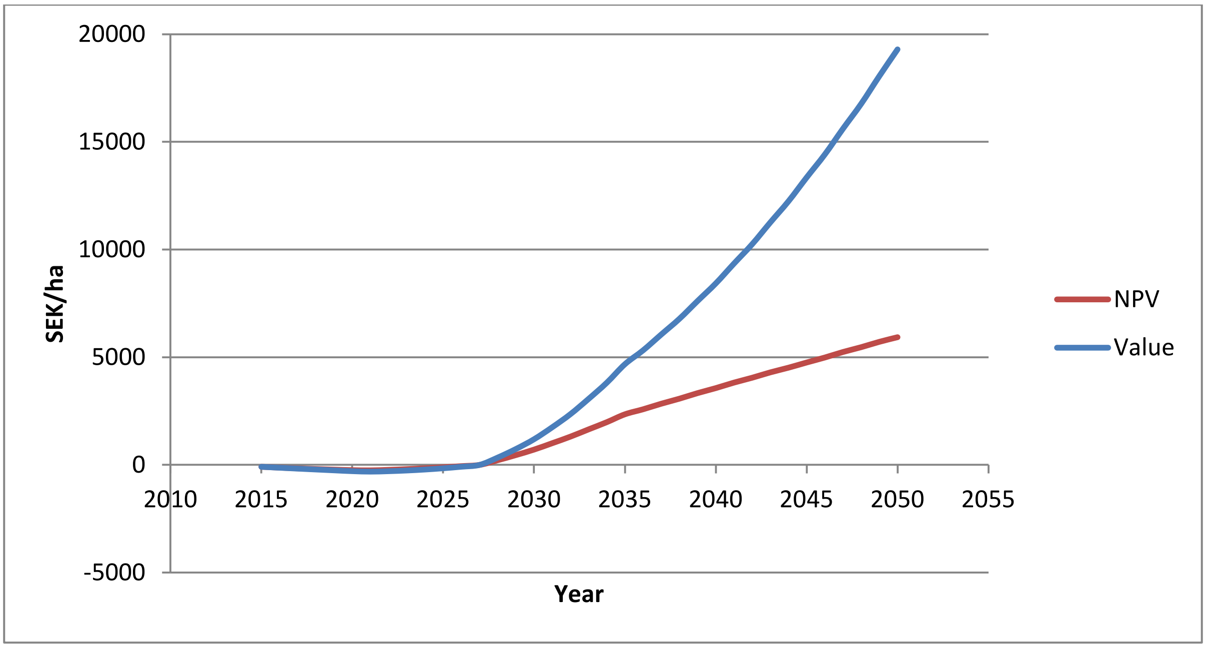

Figure 11. Net present value compared to value of forest carbon sequestration over time, in 2015-SEK

5.6.4 Nature values of forests

Eliasson (1994) estimated the net national income from natural resources in the Swedish forests, based on previous work done by Hultkrantz (1992). The calculations included timber, game hunting, berries and mushrooms, reindeer fodder, biodiversity, soil nutrients and carbon sequestration. The values are based on demand, i.e. individuals' willingness to pay, when possible. The timber is valued with market prices of sawn timber, pulpwood, fire wood, Christmas trees and other round timber. These are then used to estimate the value of non-market firewood and stock increase. The total value of the timber was 21.3 billion SEK (in 1991-value).

The value of berries and mushrooms were estimated with survey data, from the National Forest Inventory, on utilization combined with market prices. The value of hunting was studied in a national survey done by Mattson and Li (1993) where Swedish hunters gave their perceived total value with respect to recreation and meat. The value of the game meat was included in the calculations and estimated to 750 million SEK. Biodiversity was valued through replacement cost. Ecologists in Sweden have proposed that at least 15 % of the forest needs to be unexploited in order to protect endangered species. As of year 1991 only five percent of the forest area was exempted from exploitation and thus the cost of not protecting the remaining 10 % is at least equivalent to 10 % of the total revenues from timber production. The cost of "missing" biodiversity in 1991 was then estimated to 1.46 billion SEK.

The total value of the forest is calculated to 23.2 billion and is a highly uncertain lowest value estimation done with the precautionary principle. Adding the recreational value of hunting of 1.6 billion the total value of the forest would be 24.8 billion SEK. The total forest area of

Sweden in 1991 was 23.4 million hectare (Skogsstatistisk årsbok, 1991). Dividing the total forest value with the total area gives a per hectare value of 1060 SEK.

Henriksson and Mattsson (2012) calculated profitability of draining wetlands for wood production. The calculations were based on temperature sums, drainage fertility potential, timber prices and relevant expenses and done with a growth model for spruce. They investigated two scenarios, only drained or drained and fertilized with ash, and used different levels of interest rate. The setting for the study was a 50 hectare big mire in one of four different parts of Sweden drained with ditches separated by 25 m. The four parts of Sweden had different temperature sum and in each part they looked at five site types, all with different post drainage fertility potential. The profit was then given in SEK per hectare for all future incomes and costs. With a low interest rate (2 %) both scenarios was profitable in the warmer southern to middle parts of Sweden but not profitable with a high interest rate (3 %). In the northern parts it was never profitable. Higher post drainage fertility potential and fertilizing always had a positive effect on profitability due to the increased growth of timber. The net present value of timber production on drained mires of Tall sedge site type is according to this study just over 10 500 SEK in 2011-value.

This approach to value timber production is preferred to the one made by Eliasson (1994) since it suits the purposes of this study better. It includes a lot more cost items, is site specific and calculated for spruce only. The prices of timber and wood in Henriksson and Mattson (2012) are taken from *Skogsstatistisk årsbok* (2011). The real price of timber is assumed to be constant over time, as are the machine per hour costs connected to thinning and logging. The machine cost per volume however decrease with stand age because of the relationship between the bark volume and total volume of the tree. The incomes from spruce production on Tall sedge with post drainage fertility potential of 8 m^3 ha^{-1} $year^{-1}$ (thanks to ash fertilization) are showed in the table below. Benefits within brackets are not included in the reference study.

Table 6. Income in (SEK ha^{-1}) from the spruce production. Prices and costs in (SEK m^{-3}) and volumes in (m^3 ha^{-1})

Benefit	Timber	Price	Wood	Price	Quantity	Machine cost	Income
1st thinning (year 30)	13.5	438	16	315	29.5	178	5702
[2nd thinning (year 45)]	32.4	438	25	315	57.4	176	16 874
[Logging (year 75)]	220.8	438	86.4	315	307.2	83	121 478

Since the ditch spacing has been updated for this study the costs depending on the spread between ditches need to be recalculated. The total costs of the production are compiled in the table below. These costs also involve converting the wetland into a forest through drainage. All incomes and costs are then discounted into a net present value of -11 518 SEK/ha. The total value of 50 ha is thus -0.58 million SEK. The complete calculations can be found in Appendix A.

Table 7. Costs connected with the spruce production. Total cost in (SEK ha^{-1})

Cost item	Total cost
Permission	340
Machines for ditching	3086
Planning for ditching	750
Ground preparations	1142
Planting	5708
Help planting (year 5)	876
Thinning (year 10)	2500
[Ditch cleaning (year 45)]	2000
[Planning for cleaning (year 45)]	750

Eliasson's (1994) estimated values of recreational hunting and biological diversity results on average in 93.8 and 85.6 SEK/ha and year respectively after converting to 2015-SEK using consumer price indexes. In a study by Chiabai (2009) they found WTP results for boreal recreational and non-use values using meta-analysis. For European boreal forest the marginal value of recreation was 1.33 EURO/ha and year and for non-use values (biological diversity included) 99 EURO/ha and year in 2007-value. Corresponding values in 2015-SEK are 13.2 and 983 SEK/ha and year.

Eliasson (1994) states that his estimates are minimum values and since the recreational value only includes hunting it is possible to believe that the total recreational value for Swedish forests should be at least 93.8 SEK/ha and year. The non-use values in Chiabai (2009) are solely for forest areas designated to biodiversity conservation, which make this estimate a bit high for the managed forest in this study. The true non-use value for Swedish forests thus probably lies somewhere in between Chiabai's estimate and the minimum value of Eliasson, and the average of the two is 534.2 SEK/ha and year. The total net present value of recreation and non-use values over the period until 2050 is 13 205 SEK/ha.

6 Results

The results of the quantified and valued impacts on the forest and wetland show that draining wetlands to plant forest gives a positive result. For the forest the loss from the timber production is balanced by the increased nature values from biodiversity and recreation. The sequestrated carbon gives the project a net profit of 3.7 million SEK. The wetland has high nature values but the release of methane results in a loss of 17.8 million SEK. The results of the project (P), the counterfactual (C) and the total difference are compiled in the table below.

Table 8. The results of the impacts on the forest, the wetland and total value of wetland afforestation until year 2050. All values are in 2015-SEK

	Impact	1 ha	50 ha
Forest	*Carbon*	71 824	3 591 189
	Timber	-11 518	-575 915
	Nature value	13 205	660 232
	Project	**= 73 510**	**= 3 675 506**
Wetland	*GHGs*	-558 899	-27 944 952
	Nature value	202 325	10 116 230
	Counterfactual	**= -356 574**	**= -17 828 722**
Total	**P - C**	**= 430 085**	**= 21 504 228**

For a full rotation of 75 years the timber production is profitable since it includes the income from the logging and has a NPV of 0.16 million SEK. The value of forest carbon sequestration increases a lot with a longer timeframe since the uptake is peaking at 50-70 years after planting and the carbon dioxide unit value continues to increase until the year 2080. The nature values increase linearly with time because of the annuity NPV formula, see Appendix A.

Table 9. The results of the impacts on the forest, the wetland and total value of wetland afforestation for a full rotation of 75 years. All values are in 2015-SEK

	Impact	1 ha	50 ha
Forest	*Carbon*	329 720	16 486 005
	Timber	3 175	158 769
	Nature value	17 666	883 322
	Project	**= 350 562**	**= 17 528 097**
Wetland	*GHGs*	-824 889	-41 244 474
	Nature value	261 066	13 053 300
	Counterfactual	**= -563 823**	**= -28 191 174**
Total	**P - C**	**= 914 385**	**= 45 719 271**

The results are still mainly driven by the value of the wetland's emission and sequestration of GHGs, however it does not increase as much as the value of forest carbon uptake due to the declining methane GWP over time.

7 Analysis and discussion

This part contains the sensitivity analysis of the project where alternative scenarios are compared with the reference scenario in the study. After that the cost-effectiveness of wetland afforestation will be examined and then there is a discussion on the whole thesis.

7.1 Sensitivity analysis

The sensitivity analysis is important because there are a number of uncertainties in the quantities and values used in the reference scenario. The parts that drives the results in this study, e.g. the price of carbon and discount rate, will be investigated in more detail. Also a minimum and maximum result with different quantities and values from the literature will be given. Lastly the topic where the researchers seem to be the most divided, the amount of methane emissions from draining ditches, will be discussed. In the sensitivity analysis the discount rate will be 3.5 % for the first 35 years instead of 30 years as in the study, except in the part where the discount rate is discussed in detail.

Discount rate

Since various levels of social discount rate have recently been discussed in the literature the declining SDR used in the reference scenario will be compared with two extreme situations; one with a very high SDR of 6 % and one with zero pure rate of time preference and 1 % consumption growth rate. The calculations are done in the same way as before, see Appendix A, and the results are shown in the table below.

Table 10. Results of project, counterfactual and total value of wetland afforestation with different discount rates. All values are in 2015-SEK

	1 %		**Declining**		**6 %**	
	1 ha	*50 ha*	*1 ha*	*50 ha*	*1 ha*	*50 ha*
Project	152 157	7 607 844	73 510	3 675 506	34 245	1 712 273
Counterfactual	-708 044	-35 402 204	-356 574	-17 828 722	-179 374	-8 968 690
Total (P-C)	860 201	43 010 048	430 085	21 504 228	213 619	10 680 963

The project improves the situation and the counterfactual is still negative for all different discount rates. The graph below show the net present value of all impact with the different discount rates. The biggest difference between the discount rates, in percentage, is for the forest carbon sequestration where the impact value with one per cent is four times higher than the value with six per cent. For the impact wetland GHGs the value with declining discount rate is three times as high as with six per cent. All impacts except timber production follow the same pattern, i.e. the numbers decrease with higher discount rate. The timber production is instead more negative with higher discount rate, which has to do with the incomes from the first thinning after 30 years. The difference until the year 2050 is however very small and it is more interesting to analyse the changes over the full rotation.

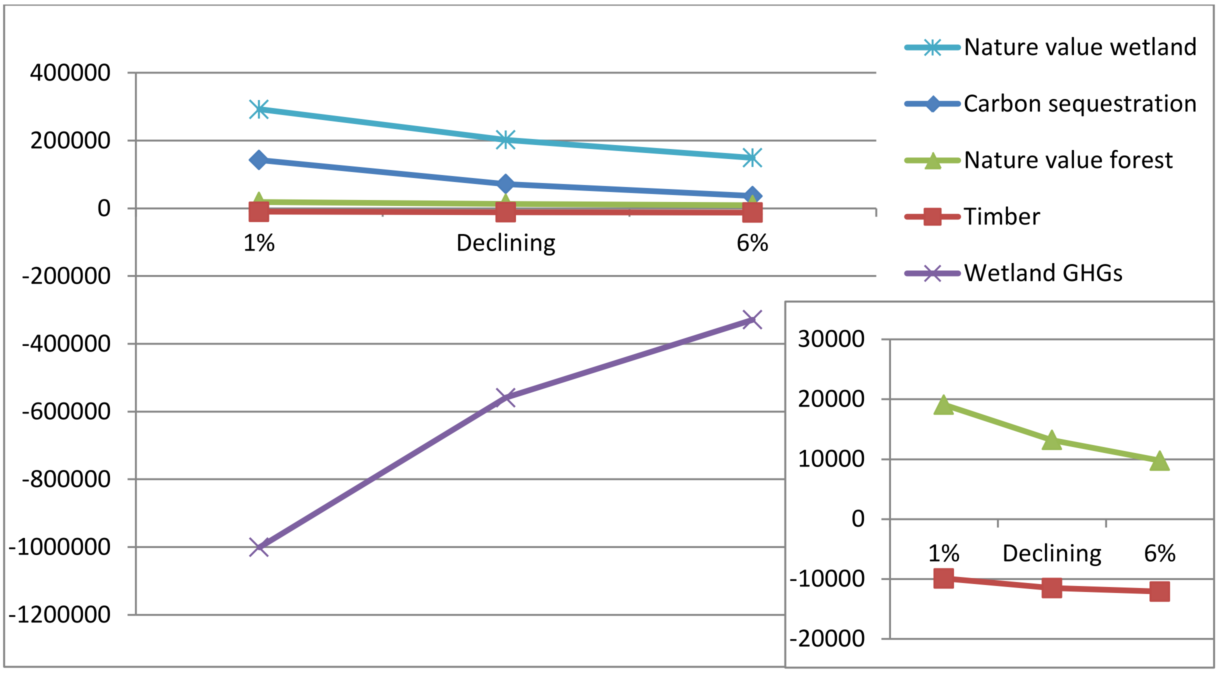

Figure 12. Net present value, in 2015-SEK, of the different impacts with different discount rates. The box in the corner is a magnification of the bigger graph.

In the reference scenario with declining discount rate the timber production is profitable over the full rotation, giving revenues of 3 200 SEK per ha. This gives an incitement for forest companies to invest in this kind of project, and even more so if the SDR is one per cent. Then the profit is 56 800 SEK per ha. With a 6 % SDR the income from the logging is not worth much in present value and the timber production gives a relatively large negative revenue.

Table 11. Net present value, in 2015-SEK, for timber production with different discount rates

Timber	**1 %**		**Declining**		**6 %**	
	1 ha	*50 ha*	*1 ha*	*50 ha*	*1 ha*	*50 ha*
35 years	-9 904	-495 204	-11 518	-575 915	-12 099	-604 927
75 years	56 804	2 840 195	3 175	158 769	-9 533	-476 626

In the table above are the net present values of the timber production with different discount rates for the reference scenario and a full rotation. The table shows evidently how important the discount rate and the income from the logging are for the profit, giving results between -0.48 and 2.84 million SEK over 75 years compared to the rather equal results for 35 years where all are around -0.5 million SEK.

Price of carbon dioxide

This topic is a tricky one. To reach the goal of a maximum increase of 2 degrees over preindustrial level researchers agree that the peak of carbon emissions should be reached as soon as possible and that the only way to make that happen is to have a rapid increase in the price of carbon emissions. They also agree that the most cost-effective way of reaching the goal is to have a global permit market for all emissions. Yet the reality looks completely different, emissions are still rising, the EU ETS is failing to live up to its potential and most countries have additional policies to reach national goals outside international agreements.

This makes it difficult to predict how the price of carbon will develop over time. The DECC price model (see section 5.5) used in this study is just one of many such models who all have the 2 degree target as their goal. The models of course differ in their assumptions, objective function, e.g. cost minimisation or welfare maximisation, and when or if there will be a global market for permits. In the graph below the price development needed to reach the 2 degree target for a few different models can be seen. It is not known what level of carbon dioxide

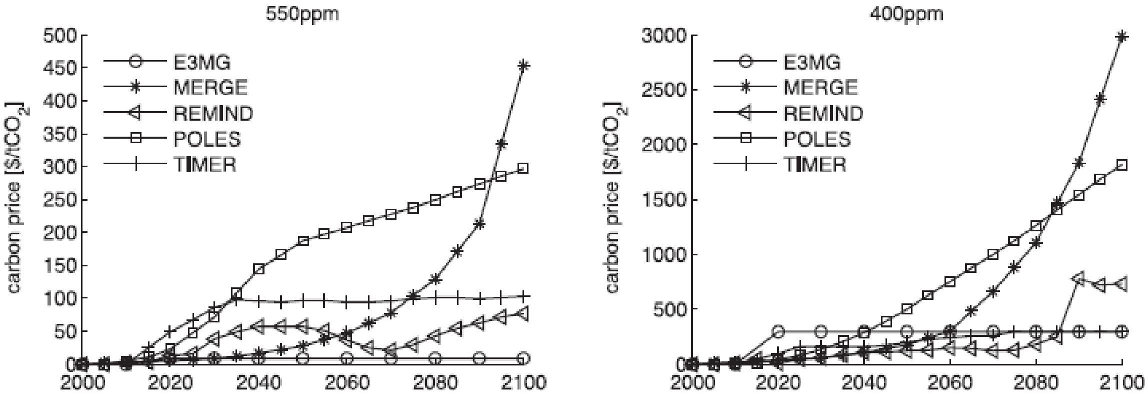

Figure 13. Estimated prices of carbon dioxide 2000-2100 in order to meet the 2 degrees Celsius target, with CO_2 concentrations of 550 resp 400 ppm.100 \$/tCO_2 is 0.70 SEK/kg(Edenhofer et al., 2010)

concentration will be sufficient to reach the target, but theories range from 400-550 ppm. This affects the price enormously and the more stringent policy gives prices five times as high. This study will not try to argue why one model would be better than any other but simply recognise the fact that the different models would yield very different results for this project, even though the approach is the same. The reason for using the DECC model was because it was developed for EU climate policy and to be used in cost-benefit analysis.

More interesting is to study the difference between the two main theories, the social cost of carbon and the shadow price. The SCC is deeply researched and used in many cost-benefit analyses and needs to be given the same importance as the shadow price, which was used in this study. Tol (2008) put together all former predictions of the social cost of carbon and found that the median of the studies using a 1 % pure rate of time preference, which is closest to what is used in this study, was 0.20 SEK. Tol concludes that a few very high predictions raise the mean way over the median and the mode, which is why the median might be a better indication of the true SCC. The 99 percentile of all the studies, regardless of SDR, was 4.36 SEK and the mean 0.49 SEK. The SCC predictions studied by Tol (2008) do not change over time and the price will thus be the same in 2050 as in 2015.

Also the shadow price might develop differently from the model used in the reference scenario. There might not be any global permit market in the near future or a sudden raise in the permit price in the EU ETS. Therefore one scenario where the price of the EU ETS only increases very little from today's level will be investigated, starting at 0.10 SEK in 2015 and increasing by 1 % of the initial price for the first 30 years to 0.40 SEK in 2045. The price is

then the same until 2050. This is more or less the same level of SCC Brainard et al. (2009) connected to the HM Treasury discount rate of 3.5 %.
There is also a possibility that reduced emissions from land-use change will not be a part of any permit trading system and that wetland afforestation in Sweden only can help to reach the national goals for the non-trading sector. The price of carbon dioxide is then the Swedish tax, which Konjunkturinstitutet (2014b) predicts will increase to 4.1 SEK in 2030 from today's 1.1 SEK. This is if the non-trading sector will reduce its emissions to 30 % below 2005 level by 2030 in a cost-effective way. This price will then continue to increase slowly until 2050 when the price reaches 5.1 SEK, to stimulate further reductions. The result from the scenario with the tax is in level with what would be the result if the true SCC is among the higher predictions.

Brainard et al. (2009) also investigated the level of SCC that for a brief period, before switching to SPC in 2008, was the HM Treasury's preferred one, equal to 1.32 SEK in 2015-value increasing to 1.71 in 2045 and ending at the same level in 2050. In the table below the results with the five alternative carbon prices discussed above are compared to the reference scenario. Since the timber production and the nature values are not affected by the carbon price the value of those impacts is the same for all scenarios.

Table 12. The results of the impacts on the forest, the wetland and total value of wetland afforestation until year 2050 with different carbon prices. All values are in 2015-SEK

	Impact	Low ETS	Tol 1%	Tol mean	Reference	Old HMT	SWE Tax
Forest	*Carbon*	4 489	6 961	17 056	71 419	59 669	181 727
	Timber	-11 518	-11 518	-11 518	-11 518	-11 518	-11 518
	Nature value	13 205	13 205	13 205	13 205	13 205	13 205
	Project	**6 176**	**8 648**	**18 743**	**73 106**	**61 356**	**183 414**
Wetland	*GHGs*	-59 408	-102 769	-251 784	-556 845	-789 724	-1 854 457
	Nature value	202 325	202 325	202 325	202 325	202 325	202 325
	Counterfactual	**142 917**	**99 556**	**-49 459**	**-354 520**	**-587 399**	**-1 652 132**
Total	**P - C**	**-136 741**	**-90 908**	**68 202**	**427 626**	**648 755**	**1 835 546**

With the different carbon prices the result of the project ranges from 6 180 SEK to 183 000 SEK/ha and the result of the counterfactual is between 0.143 and -1.65 million SEK/ha. This means that the total value of wetland afforestation can be anything between -0.137 and 1.84 million SEK per hectare. In two of the six scenarios, slow increase in EU ETS and median of SCC with 1% PRTP, the total value is negative since the counterfactual is more positive than the project. The average of the six scenarios is 0.459 million SEK. This means that there is a small risk that this type of project will make the situation worse for the society. The value of forest sequestration is always positive and the value of wetland emissions is negative no matter which carbon price is used.

Minimum and maximum
In section 5.3 and 5.6 of this study the quantity of GHG exchange and value of ecosystem services have been discussed. The literature gives examples of a wide range in the levels of

these quantities and values and in the reference scenario the average of these numbers has been used in most cases. Since the scenario is hypothetical there is some uncertainty in what will be the true level and therefore a minimum and maximum result of the project and counterfactual with different numbers from the literature will be investigated. The price of carbon and the method of calculating the results are the same in all three scenarios, except from the value of wetland GHGs in the minimum scenario. There the methane GWP for a 100 year timeframe (34) has been used for every year, which is in fact still the standard approach.

The references used in the minimum scenario is e.g. for the forest the NEP data from Bond-Lamberty et al. (2004) and the average wetland value from the studies used in the meta-analysis by Brander et al. (2006). In the maximum scenario the exchange of GHGs found by Whiting and Chanton (2001) and the forest non-use values in Chiabai (2009) was used. The value of carbon uptake is the same in the maximum scenario, since the conditions for the forest are made ideal already in the reference scenario. There is also no reason to doubt the results for the timber production from Henriksson and Mattson (2012) since their study was hypothetical and based on theory, which is why the value is the same in all three scenarios. The results might change for a full rotation when the logging is included if there is some uncertainty about how fast the trees will grow. All the references used for each impact can be found in Appendix B.

Table 13. The results of the impacts on the forest, the wetland and total value of wetland afforestation until year 2050 with minimum and maximum data. All values are in 2015-SEK

	Impact	Minimum	Reference	Maximum
Forest	*Carbon*	15 129	71 419	71 419
	Timber	-11 518	-11 518	-11 518
	Nature value	2 076	13 205	22 612
	Project	**5 686**	**73 106**	**82 513**
Wetland	*GHGs*	-93 854	-556 845	-878 194
	Nature value	512 416	202 325	43 231
	Counterfactual	**418 562**	**-354 520**	**-834 963**
Total	**P - C**	**-412 877**	**427 626**	**917 476**

In the table above the minimum and maximum results are compared with the reference scenario. The total value of wetland afforestation ranges from -0.413 to 0.917 million SEK per hectare with the different data mentioned in this study. The results for each impact can off course be mixed in any way and together with different carbon prices create a variety of total wetland afforestation values that might point policymakers in any direction. One observation is however that the value of GHG exchange from the wetland is always negative, even in the minimum scenario where the GWP for a 100 year timeframe was used.

Methane emissions from ditches

The NEP measure for the forest carbon cycle includes non-CO_2 emissions like methane from the ground. For drained wetlands however there are possibly methane emissions from the drainage ditches. This question seems to be debated until this day and within IPCC (2000) there is contradicting evidence. Methane emissions were e.g. assumed to be negligible as late as in the 2006 IPCC guidelines. Recent studies show results ranging from drained wetlands for forestry being net sinks of CH_4 (Ojanen et al. 2010) to as large methane emissions as 783 kg CH_4/year and hectare ditch from a drained treed fen (Minkkinen and Laine, 2006). The same authors have also presented studies where drained wetlands for forestry are net sinks of CH_4, Laine et al. (1996) and Minkkinen et al (2011), so it is not a question of bias or researchers intentionally giving result to suit their purposes. But since the ditches only take up 3.75 % land of each hectare forest this might not be an issue.

The amount of methane per hectare ditch that can be tolerated for the forest to be neutral with the atmosphere will be calculated below. The average annual carbon dioxide that is sequestered by the forest in the reference scenario during the years 2015-2050 is about 2 700 CO_2/ha. This is the annual amount of methane emitted, in CO_2-eq, which would make the forest GHG neutral over this period. The amount of methane that can be emitted per hectare of ditch is found by using the equation; $2682 = GWP * CH_4 * 0.0375$.

In the table below the amount of methane is calculated using three different levels of GWP; the one for a 100 year timeframe (34) and the ones used for the years 2015 and 2050 in the reference scenario, 66 and 128 respectively. The NPV of carbon sequestration during this period is 71 000 SEK/ha. The cost of the added methane emissions would be 51 000 SEK/ha if the emissions were divided equally every year, and thus the result is then 20 000 SEK/ha.

Table 14. Amount of annual methane emissions from the ditches that make the forest neutral with the atmosphere, calculated for different levels of methane GWP.

	Impact	Ref[c]	CO2[a]	CH4[a] CO2-eq	CH4[b] GWP=34	CH4[b] GWP=66	CH4[b] GWP=128	Result[c]
Forest	*Carbon*	71 419	2682	2682	2254	1161	599	19 831
	Timber	-11 518						-11 518
	Nature value	13 205						13 205
	Project	**73 106**						**21 518**
Wetland	*GHGs*	-556 845						-556 845
	Nature value	202 325						202 325
	Counterfactual	**-354 520**						**-354 520**
Total	**P - C**	**427 626**						**376 038**

Notes a) kg per year and hectare forest b) kg per year and hectare ditch c) 2015-SEK

With the different levels of GWP the annual amount of methane that can be released in order for the forest to be neutral ranges between 600 and 2 300 kg per hectare ditch. As mentioned above the question about whether methane is emitted or not and how the fluxes will change with time is very uncertain. But these levels of methane emission can be compared with the IPCC (2013) supplement for GHG inventories. It gives emission factors of 217 kg CH_4 per ha ditch and year for drained wetlands in boreal areas in general and 139 kg CH_4 per ha ditch and year for drained afforested fens, based on a study in Russia.

Von Arnold et al. (2005) found methane fluxes from ditches in Sweden of about 96 kg/ha ditch and year on average, however they were given as hourly rates (0.4 mg m^{-2} h^{-1}) and only measured during two days in June. Furthermore even with these high emissions the consequence for the total value of wetland afforestation is relatively small. With the update of methane emissions from the ditches the total value is 0.38 million SEK compared to 0.43 million SEK in the reference scenario.

7.2 Cost-effectiveness

Even if the project has a positive result it might not be as good as alternative ways of reducing emissions. A good way to compare alternatives is to look at their respective cost-effectiveness, where the cost per abated tonne of carbon dioxide is measured. This approach also eliminates the difficulty of having to put a value on carbon dioxide. McKinsey (2013) put together all plausible alternatives to reduce emissions in Sweden and compared them concerning abatement cost and potential. The study found that with measures costing up to 500 SEK/tonne CO_2-eq (which is their estimated carbon price) Sweden can reduce its emissions with 5.5 million tonnes below the baseline scenario in 2020, see figure below. In the baseline scenario the emissions fall by three per cent until 2020. Together this is equivalent to a 10 % reduction in emissions from all sectors compared to 2005-level. For the trading sector it is an 8 % reduction and the non-trading sector an 11 % reduction.

It is determined that the emissions in the trading sector of the EU ETS should be reduced by 21 %, compared to 2005-level. The goal for the non-trading sectors in Sweden is 17 %. This means that the abatement alternatives in the McKinsey abatement cost curve are not enough. Measures that have higher marginal reduction cost than the market price of carbon dioxide are unlikely to be implemented as it is more cost-effective to get emission permits and to reach the goals these need to be purchased (McKinsey, 2013). The non-trading sector has to rely on investments in other countries or clean development mechanism to reach its goal.

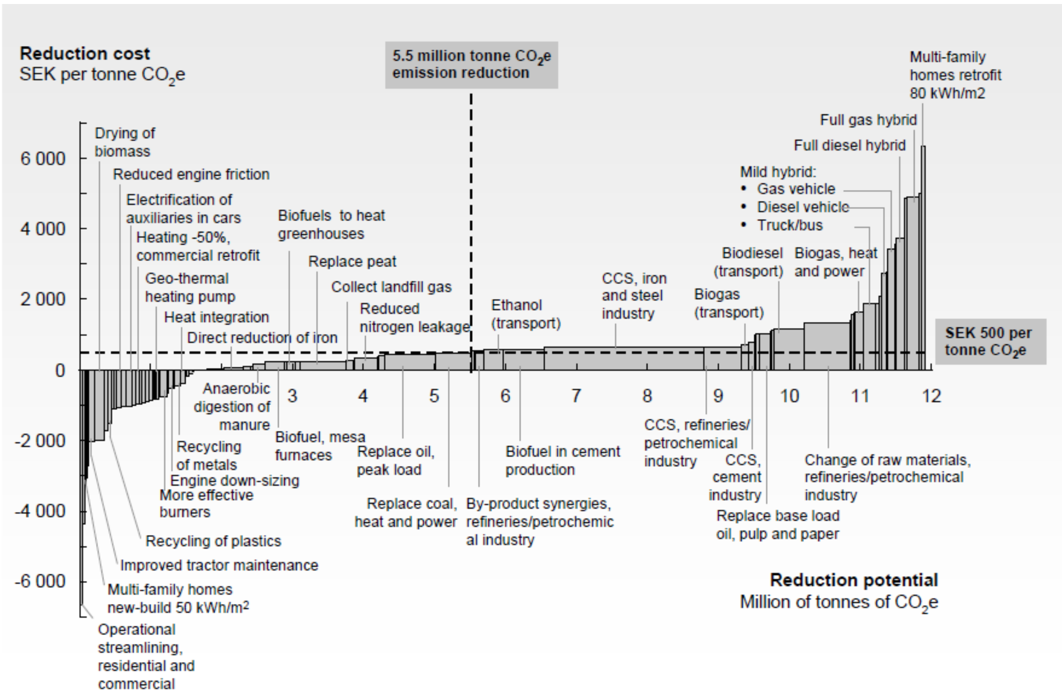

Figure 14. The McKinsey cost curve of Sweden's alternatives to reduce emissions in 2020

The potential for reducing GHG emissions through wetland afforestation is relatively large. Sweden has 3.44 million hectares of wetlands, out of which 14 % is valued in class 4 according to Naturvårdverket, see section 5.1 and figure 5. In this study the cost per tonne reduced CO_2-eq emission during 2015-2050 is 189 SEK. The annual average in reduced emissions is 29.5 tonnes/ha, see table below. With a GWP for methane equal to 34 for all years (100-year timeframe) this cost would increase to 594 SEK/tonne CO_2-eq and the reduced emissions annual average decreases to 9.4 tonnes/ha. If all of the wetlands in class 4, i.e. 0.48 million hectares would be drained and turned into forests this would reduce total emissions with 14.2 or 4.5 million tonnes CO_2 per year respectively for the reference scenario and GWP with 100 year timeframe.

Table 15. Abatement cost and potential for the study and a scenario with methane GWP=34

	Impact	Reference	Unit	GWP=34	Unit
Forest	*Carbon*	*97*	*ton/ha*	*97*	*ton/ha*
	Timber	-11 518	SEK	-11 518	SEK
	Nature value	13 205	SEK	13 205	SEK
	Project	**1 687**	**SEK**	**1 687**	**SEK**
Wetland	*GHGs*	*964*	*ton/ha*	*241*	*ton/ha*
	Nature value	202 325	SEK	202 325	SEK
	Counterfactual	**202 325**	**SEK**	**202 325**	**SEK**
Total	**P - C**	**-200 638**	**SEK**	**-200 638**	**SEK**
	Carbon+GHGs	*1 061*	*ton/ha*	*338*	*ton/ha*
	Abatement cost	**189**	**SEK/ton**	**594**	**SEK/ton**
	Average reduction	*29.5*	*ton/ha*	*9.4*	*ton/ha*
	Wetland area class 4	0.48	Mha	0.48	Mha
	Potential	**14.2**	**Mton**	**4.5**	**Mton**

Thus wetland afforestation projects can strongly contribute to reach the Swedish targets. Assuming that 15 per cent of the class 4 wetlands would be drained in 2015 they would in 2020 reduce emissions with 2.5 million tonnes (GWP is then 116, corresponding to a 5 year timeframe). This together with the already suggested measures would put the non-trading sector 17 % below 2005-level. The cost savings from implementing this policy compared to alternative measures costing more than 500 SEK per tonne CO_2 is then minimum 755 MSEK.

To reach the 2 degree target at the end of the century emissions in the EU need to be reduced by 80-95 % below 1990-level in 2050 according to The Low Carbon Roadmap presented by the European Commission (2011). In Sweden the total emissions in 1990 was 72 million tonnes CO_2-eq. An 80 % reduction would mean that only 14 million tonnes can be emitted and the reduced emissions need to be 58 million tonnes. As emissions are lowered it will become increasingly difficult to get additional reduction potential from measures based on current technology (McKinsey, 2013). If the reference scenario in this study is true wetland afforestation can alone reduce 509 million tonnes over the years 2015-2050 and 14.2 out of the needed 58 million tonnes in 2050, almost a quarter. This to a relatively low cost compared to the alternatives that McKinsey (2013) found fitting for Sweden.

7.3 Summary

The result of project wetland afforestation was found to be 0.43 MSEK/ha. The results are mainly driven by the price of carbon and emissions from the wetland (and indirect how the global warming potential of methane is treated). There is also a big difference in nature value of wetlands. Using different prices of carbon the total value of wetland afforestation range between -0.14 and 1.8 MSEK/ha. With the same price as in the reference scenario but with different levels of emissions and nature values the total value is between -0.41 and 0.92 MSEK/ha. If these two factors would be analysed simultaneously the results would be even more extreme and further from the results of the reference scenario. Also the discount rate is important for the end result. The emissions from drainage ditches however were found to have very little impact on the results.

The cost-effectiveness of this project is estimated to 189 SEK/tonne CO_2 with a potential to mitigate 14 Mtonne carbon dioxide equivalents annually. Compared to 10-25 SEK/tonne CO_2 found by Lundmark and Johansson (2013) for Swedish forests it is high but they didn't include negative environmental effects in their study. Nijnik et al. (2013) did a study similar to this one where they converted livestock land to forest and found a cost of 85-210 SEK/tonne carbon dioxide sequestrated.

7.4 Discussion

Using a hypothetical scenario creates a number of issues that makes it difficult to actually make conclusions on the potential of wetland afforestation. Since Sweden is such a long spread country from north to south the temperature difference with the reference scenario can be very big, which has impacts both on greenhouse gas emissions from wetlands and potential forest growth. According to the wetland inventory many of Sweden's fens are located in the north where both emissions and forest growth potential are smaller than in the reference scenario. Also a big part of the wetlands in Sweden are bogs. Bogs have not been studied in this thesis but have a lower methane carbon dioxide ratio than fens and a lower post drainage potential, since they are nutrient poor. If many of the wetlands in class four of the inventory are bogs and/or located in the north the value and potential of wetland afforestation is lower than suggested in the study. However the opposite is of course true if the conditions are better than in the reference scenario. The average numbers used in this hypothetical study give a good picture of how the situation most likely looks but it is of course the best suitable wetlands that should be drained. The wetland inventory determines which wetlands not to use but among the rest each specific site needs to be evaluated economically and emissions measured to determine if the benefits are higher than the costs.

The methodology of this study is a good tool in that determination. One shortcoming of this study is however that there is no connection between the timber production and estimated forest carbon sequestration. In the calculations of the timber production an annual average growth has been determined. This growth rate could after some conversion be used to calculate the sequestrated carbon by the trees, and this is a common approach in other studies.

With this approach the emissions from the soil has to be dealt with separately to get the forest ecosystem total. If this approach had been used the reference, minimum and maximum scenarios would have been easily distinguished using different post drainage potentials. It was the author's decision that the NEP measure was a better alternative for a newly planted forest since it gives year by year sequestration rates that shows the difference between stand ages. This is important when discounting values over a longer period since the highest sequestration rates occurs when the forest is older.

The result of the study is mainly driven by the value of avoided wetland emissions. This in turn depends heavily on the used methane GWP. In the cost-effectiveness part, section 7.2, the difference in the results between the approach in the reference scenario and using a 100 year timeframe shows just how important this is. Though there is convenience in using the same GWP for all projects no matter the timeframe, the 100 year digit fails to show the real impact methane has on global warming in short term. With this in mind it is up to the policy makers to determine which approach is the correct one, and the results of the study can easily be recalculated if needed. The sensitivity analysis' minimum value of wetland GHGs give a good indication of what the results would be if the GWP=34 is used.

Another uncertainty that has a big impact on the results is the price of carbon. There is no guarantee that there will be a global market for carbon permits or that reduced emissions from land-use change will be allowed to be used on that market. And even if that happen the price might stay on today's low level. Then it is very unlikely that the benefits of wetland afforestation are higher than the costs. If on the other hand reduced emissions from land-use change will be a part of the trading sector in the future (which is currently discussed) it can mean that Sweden does not have to buy permits from other countries to meet the targets. This is a potential source of income that can be used to found other projects to further reduce emissions or buy permits to sectors that can't meet their targets. It can also be used to protect and restore wetlands with higher value, or even create new ones that are highly beneficial for the society, like Hemmesta sjöäng in Värmdö municipality. It was landscaped in 2014 and estimated to generate 20 million SEK in its first six months, mainly through recreation.

Even if the numbers show that wetland afforestation is a good way to reduce global warming it is a sensitive subject. Some might argue that it is impossible to put monetary value on ecosystems, that biodiversity is too important. But with further global warming wetlands in Sweden may dry out, even the ones with the highest recreational and biodiversity value. If the project isn't carried out we then risk losing the values of them without gaining the benefits of reducing emissions now.

The concluding remarks of the discussion is that doing site specific evaluations is very important and will avoid a project ending up at the minimum end of the results in the sensitivity analysis.

8 Recommendation

If the main goal of a policy is to reduce greenhouse emissions wetland afforestation is highly recommended. This study has showed that greenhouse gas emissions from wetlands are a cost for the Swedish society, no matter what methane GWP and price of carbon is used, and that that this cost in most scenarios is higher than the nature value of the wetland. Sweden has a large area of wetland and with the new additions to article 3.4 in the Kyoto protocol draining wetlands can contribute significantly to reach both short and long term targets for emission levels in Sweden. Planting forest on the drained land is also recommended. It will generate extra reductions in emissions through plant sequestration and partly compensate for the loss in biodiversity and recreation since it creates new possibilities for both. Furthermore timber production can be a good long-term investment for forest companies in both private and public sector.

However since this study only is hypothetical the implications on recreational value, biodiversity and other non-use values should be studied for each specific site before drainage. To limit the number of potential sites to drain the wetland inventory made by Naturvårdsverket can be used, and the class one and two wetlands should remain untouched. The wetlands in class three and four that seems interesting ought to be valued economically and the GHG exchange with the atmosphere should be measured over at least a summer and a winter to determine an annual average. The sensitivity analysis showed that what happens after the drainage is less important than the conditions before. The ideal scenario is a wetland that emits a lot of methane and has low recreational and biodiversity value. Then whether the conditions for forest production after drainage are perfect or not has little significance.

Bibliography

Literature and publications

Bergh, J., Linder, S., Morén, A.-S., Grelle, A., Lindroth, A. & Roberntz, P., 2000. 'Skogens kolbalans – många faktorer inverkar', *Fakta Skog*, vol. 15.

Bergquist, J., Ekö, P.-M., Elving, B., Johansson U. & Thuresson T., 2005. *Jämförelse av produktionspotential mellan tall, gran och björk på samma ståndort*. Skogsstyrelsens förlag, Jönköping.

Boardman, A., Greenberg, D., Vining, A. & Weimer, D., 2005. *Cost-Benefit Analysis: Concepts and Practice 3rd ed.* Pearson Education Inc., New Jersey.

Boardman, A., Moore, M.A. & Vining, A.R., 2013. 'More appropriate discounting: the rate of social time preference and the value of the social discount rate', *Journal of Benefit-Cost Analysis*, vol. 4, no. 1, pp. 1-16.

BOND-LAMBERTY, B., WANG, C. & GOWER, S., 2004. 'Net primary production and net ecosystem production of a boreal black spruce wildfire chronosequence', *Global Change Biology*, vol. 10, pp. 473–487.

Brainard, J., Lovett, A. & Bateman, I., 2003. 'Carbon sequestration benefits of woodland', *Social & environmental benefits of forestry phase*, vol. 2

Brainard, J., Lovett, A. & Bateman, I., 2006. 'Sensitivity analysis in calculating the social value of carbon sequestered in British grown Sitka spruce'. *Journal of Forest Economics*, vol. 12, pp. 201-228

Brainard, J., Bateman, I. & Lovett, A., 2009. 'The social value of carbon sequestered in Great Britain's woodlands', *Ecological Economics*, vol. 68, pp. 1257-1267

Brander, L., Florax, R. & Vermaat, J., 2006. 'The empirics of wetland valuation: a comprehensive summary and a meta-analysis of the literature', *Environmental and Resource Economics,* vol. 33, no. 2, pp. 223-250

Brix, H., Sorrell, B.K. & Lorenzen, B., 2001. 'Are Phragmites-dominated wetlands a net source or net sink of greenhouse gases?', *Aquatic Botany*, vol. 69, pp. 313-324

Brouwer, R., 2000. 'Environmental Value Transfer: State of the Art and Future Prospects', *Ecological Economics*, vol. 32, pp. 137–152.

Burgess, D. F., & Zerbe, R. O., 2011. 'Appropriate discounting for benefit-cost analysis', *Journal of Benefit-Cost Analysis*, vol. 2, no. 2, pp. 169-189.

CEC, 2005. 'Winning the battle against global climate change'. Available at: <http://ec.europa.eu/smartregulation/impact/ia_carried_out/docs/ia_2005/sec_2005_0180_en.pdf> (2015-06-01)

Chiabai, A., Travisi, C., Ding, H., Markandya, A., & Nunes, P. A., 2009. 'Economic valuation of forest ecosystem services: methodology and monetary estimates'. Available at: <http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1396661> (2015-06-01)

De Jong, B. H., Tipper, R., & Montoya-Gómez, G., 2000. 'An economic analysis of the potential for carbon sequestration by forests: evidence from southern Mexico', *Ecological Economics*, vol. 33, pp. 313-327

DEFRA, 2007. 'The social cost of carbon and the shadow price of carbon: what they are, and how to use them in economic appraisal in the UK', *Department for Environment Food and Rural Affairs, UK*

Department of Energy and Climate Change, 2011. 'Guidance on Estimating Carbon Values Beyond 2050: An Interim Approach'. Available at: < https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/48108/1_20100120165619_e____carbonvaluesbeyond2050.pdf> (2015-03-10)

Dessus, B., LaPonche, B. & Le Treut, H., 2008. "Global Warming: The Significance of Metanhe". Available at: < http://www.global-chance.org/IMG/pdf/CH4march2008.pdf> (2015-02-27)

Dillman, Buddy L., Lawrence J. Beran, & Donald D. Hook, 1993. 'Non-market valuation of Freshwater Wetlands: The Francis Biedler Forest'. Report 135, South Carolina Water Resources Research Institute, Clemson Univ. 47p

Edenhofer, O., Knopf, B., Barker, T., Baumstark, L., Bellevrat, E., Chateau, B., ... & Van Vuuren, D. P., 2010. 'The economics of low stabilization: model comparison of mitigation strategies and costs', *The Energy Journal*, vol. 31, pp. 11-48

Eliasson, P., 1994. *Miljöjusterade nationalräkenskaper för den svenska skogen åren 1987 och 1991*. Sveriges Lantbruksuniversitet, Institutionen for Skogsekonomi.

Ferdinand, M., 2014. 'The MSR: Impact on balance and prices'. Available at: <http://www.ceps.eu/system/files/u153872/Ferdinand.pdf> (2015-03-05)

Folke, C., 1991. 'The Societal Value of Wetland life-support' in Folke, C. and Kaberger, T. (eds.) Linking the Natural Environment and the economy: Essays from the Eco-Eco Group, Kluwer Academic Publishers, pp. 141-171

Friborg, T., Soegaard, H., Christensen, T.R, Lloyd, C.R. & Panikov, N.S., 2003. 'Siberian wetlands: Where a sink is a source', *Geophysical Research Letters*, vol. 30, no. 21, 2129

Godwin, K.S., Shallenberger, J.P., Leopold, D.J. & Bedford, B.L., 2002. 'Linking landscape properties to local hydrogeologic gradients and plant species occurrence in New York fens: a hydrogeologic setting (HGS) framework', *Wetlands*, vol. 22, no.4, pp. 722–737

Hanley, N., Barbier, E. B., & Barbier, E., 2009. *Pricing nature: cost-benefit analysis and environmental policy*. Edward Elgar Publishing.

Hendriks, D. M. D., van Huissteden, J., Dolman, A. J. & van der Molen, M. K., 2007. 'The full greenhouse gas balance of an abandoned peat meadow', *Biogeosciences Discuss*, vol. 4, pp. 277–316

Henriksson, A. & Mattsson, E., 2012. *Lönsamhetskalkyl för produktion av gran på markavvattnad och askgödslad myrmark.* Umeå: SLU, Institutionen för skogens ekologi och skötsel

Hepburn, C. J. & Koundouri, P., 2007. 'Recent advances in discounting: implications for forest economics', *Journal of Forest Economics*, vol. 13, no. 2–3, pp. 169–189

Holdren, J., Boots, M., Moniz, E., McCarthy, G. & Utech, G., 2014. 'Recommendation to accurately account for warming effects of methane'. Available at: <http://www.biologicaldiversity.org/programs/climate_law_institute/global_warming_what_how_why/methane/pdfs/Scientist_letter_re_methane_GWP_7-29-14.pdf> (2015-03-30)

Hultkrantz, L., 1992. 'National Account of Timber and Forest Environment Resources in Sweden', *Environmental and Resource Economics*, vol. 2, pp. 283–305.

Hånell, B. & Päivänen, J., 2012. Peatland *Ecology and Forestry – a Sound Approach*. University of Helsinki Department of Forest Sciences, Helsinki.

IPCC, 2000. *Land use, land-use change and forestry: a special report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, New York.

IPCC, 2001. *Climate Change 2001: Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, New York.

IPCC, 2006. 'Guidelines for National Greenhouse Gas Inventories - Volume 4 Agriculture, Forestry and Other Land Use'. Available at: <http://www.ipccnggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_04_Ch4_Forest_Land.pdf> (2012-06-01)

IPCC, 2013. 'ADOPTION AND ACCEPTANCE OF THE "2013 SUPPLEMENT TO THE 2006 GUIDELINES: WETLANDS"'. Available at: <http://www.ipcc.ch/meetings/session37/Doc_8b_Rev_2_Accepted_Report_Wetlands.pdf > (2014-11-05)

IPCC, 2013b. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, New York.

IPCC, 2014. *Climate Change 2014: Synthesis Report. Approved Summery for Policymakers.* Cambridge University Press, New York.

Johnson, E. A., 2007. *Plant disturbance ecology: the process and the response*. Academic Press, Waltham.

Kasimir-Klemedtsson, Å., Klemedtsson, L., Berglund, K., Martikainen, P., Silvola, J. & Oenema, O., 1997. 'Greenhouse gas emissions from farmed organic soils: a review', *Soil Use and Management*, vol.13, pp. 245-250

Koch, N., Fuss, S., Grosjean, G., & Edenhofer, O., 2014. Causes of the EU ETS price drop: Recession, CDM, renewable policies or a bit of everything?—New evidence. *Energy Policy*, vol. 73, pp. 676-685.

Konjunkturinstitutet, 2012. 'Miljö, ekonomi och politik'. Available at: < http://www.konj.se/download/18.768d17ac139d0d0248f2fd2/Milj%C3%B6+ekonomi+och+politik+2012-webb.pdf> (2015-03-04)

Konjunkturinstitutet, 2014. 'Utsläpp och upptag från skogsbruk och annan markanvändning (LULUCF) i 2030-ramverket'. Available at: <http://www.konj.se/download/18.430b4a041455d3e6ba31905/PM28-Utslapp-och-upptag-fran-skogsbruk-och-annan-markanvandning-%28LULUCF%29-i-2030-ramverket.pdf> (2015-06-01)

Konjunkturinstitutet, 2014b. 'Samhällsekonomiska konsekvenser av olika bördefördelning av ett europeiskt klimatmål'. Available at: <http://www.konj.se/download/18.430b4a041455d3e6ba311fb/PM-26-Samhallsekonomiska-konsekvenser-av-klimatmal.pdf> (2015-06-01)

Laine, J., Jouko Silvola, Kimmo Tolonen, Jukka Alm, Hannu Nykänen, Harri Vasander, Tapani Sallantaus, Ilkka Savolainen, Jukka Sinisalo & Pertti J. Martikainen, 1996. 'Effect of Water-Level Drawdown on Global Climatic Warming: Northern Peatlands', *Ambio*, vol. 25, no. 3, pp. 179-184

Leitch, J. A. & Hovde, B., 1996. ‘Empirical Valuation of Prairie Potholes: Five Case Studies’, *Great Plains Research*, vol. 6, pp. 25–39

Maddison, D., 1995. ’A cost-benefit analysis of slowing climate change’, *Energy Policy*, vol. 23, pp. 337-346

Mattsson, L. & Li, C., 1993. ’The non-timber value of northern Swedish forests: An economic analysis’, *Scandinavian Journal of Forest Research*, vol. 8, pp. 426–434.

McHale, M. R., McPherson, E. G., & Burke, I. C., 2007. ’The potential of urban tree plantings to be cost effective in carbon credit markets’, *Urban Forestry & Urban Greening*, vol. 6, pp. 49-60

McKinsey, 2013. ‘Möjligheter och kostnader för att reducera växthusgasutsläpp i Sverige’. Available at: <http://www.gamenetwork.se/gamearrangerar/referat/091216/M_jligheter_och_kost_12841a.pdf> (2015-06-01)

Minkkinen, K. & Laine, J., 2006. ’Vegetation heterogeneity and ditches create spatial variability in methane fluxes from peatlands drained for forestry’, *Plant and Soil*, pp. 289–304.

Minkkinen, K., Lohila, A., Aurela, M., Tuovinen, J.-P., Penttilä, T., Ojanen, P. & Laurila, T., 2011. ’Greenhouse gas flux measurements in a forestry-drained peatland indicate a large carbon sink’, *Biogeosciences*, vol. 8, pp. 3203-3218.

Missfeldt, F., & Haites, E., 2001. ‘The potential contribution of sinks to meeting Kyoto Protocol commitments’, *Environmental Science & Policy*, vol. 4, no. 6, pp. 269-292

Naturvårdsverket, 2009. *Våtmarksinventeringen – resultat från 25 års inventeringar*. CM Gruppen AB, Bromma

Nijnik, M., Pajot, G., Moffat, A. J., & Slee, B., 2013. ’An economic analysis of the establishment of forest plantations in the United Kingdom to mitigate climatic change’, *Forest Policy and Economics*, vol. 26, pp. 34-42

Nordborg, F. & Bergh, J., 2014. ’Granens naturliga produktionsförmåga – uthållig produktionsförmåga’. Available at: <http://www-gran.slu.se/Webbok/PDFdokument/Uth%C3%A5llig%20produktion.pdf> (2014-11-04)

Ojanen, P., Minkkinen, K. Alm, J. and Penttilä, T., 2010. ’Soil-atmosphere CO2, CH4 and N2O fluxes in boreal forestry-drained peatlands’, *Forest Ecology and Management*, vol. 260, pp. 411-421

RANDERSON, J. T., CHAPIN III, F. S., HARDEN, J. W., NEFF, J. C. & HARMON, M. E., 2002. ’NET ECOSYSTEM PRODUCTION: A COMPREHENSIVE MEASURE OF NET CARBON ACCUMULATION BY ECOSYSTEMS’, *Ecological Applications*, vol. 12, no. 4, pp. 937–947

Roulet, N. T., & Moore, T. R., 1995. ’The effect of forestry drainage practices on the emission of methane from northern peatlands’, *Canadian Journal of Forest Research*, vol. 25, pp. 491-499

Roulet, N.T., 2000. ’Peatlands, carbon storage, greenhouse gases, and the Kyoto protocol: prospects and significance for Canada’, *Wetlands,* vol. 20, no. 4, pp. 605-615.

Smith, K. A., Ball, T., Conen, F., Dobbie, K. E., Massheder, J., & Rey, A., 2003. ‘Exchange of greenhouse gases between soil and atmosphere: interactions of soil physical factors and biological processes’, *European Journal of Soil Science*, vol. *54 no.*4, pp. 779-791

Schulze, E.-D., Wirth, C. & Heimann, M., 2000. 'CLIMATE CHANGE: Managing Forests After Kyoto', *Science*, vol. 289, no. 5487, pp. 2058-2059.

Tol, R. S., 2008. 'The social cost of carbon: trends, outliers and catastrophes', *Economics: The Open-Access, Open-Assessment E-Journal*, vol 2

Tol, R. S., 2009. 'Why worry about climate change', *Research Bulletin*, vol. 9, pp. 2-7

Tol, R. S., 2012. 'A cost–benefit analysis of the EU 20/20/2020 package', *Energy Policy,* vol. 49, pp. 288-295.

Trotignon, R., 2012. 'In search of the carbon price: The european CO2 emission trading scheme: from ex ante and ex post analysis to the protection in 2020', *Economics Thesis from University Paris Dauphine*.

Von Arnold, K., Weslien, P., Nilsson, M., Svensson, B. H., & Klemedtsson, L., 2005. 'Fluxes of CO 2, CH 4 and N 2 O from drained coniferous forests on organic soils', *Forest Ecology and Management*, vol 210, pp. 239-254

Whitehead, J.C., 1990. 'Measuring WTP for Wetlands Preservation with the Contingent valuation Method', *Wetlands,* vol. 10, no. 2, pp. 187-201

Whiting, G. & Chanton, J., 2001. 'Greenhouse carbon balance of wetlands: methane emission versus carbon sequestration', *Tellus*, vol. 53B, pp. 521-528.

Woodward, R. T. & Wui, Y.-S., 2001. 'The Economic Value of Wetland Services: A Meta-Analysis', *Ecological Economics,* vol. 37, pp. 257–270

Xu, D., 1995.' The potential for reducing atmospheric carbon by large-scale afforestation in China and related cost/benefit analysis', *Biomass and Bioenergy*, vol.8, pp. 337-344

Internet

Center for Climate and Energy Solutions (www.c2es.org)

a) Global anthropogenic GHG emissions by sector (2015-06-01) http://www.c2es.org/facts-figures/international-emissions/sector

Central Intellegence Agency (www.cia.gov)

a) Library – The World Factbook (2014-11-03) https://www.cia.gov/library/publications/the-world-factbook/fields/2004.html

Clean Technica (cleantechninca.com)

a) Catalyzing Action at the September 2014 UN Climate Summit (2015-06-01) http://cleantechnica.com/2014/09/29/catalyzing-action-september-2014-un-climate-summit/

European Comission (ec.europa.eu)

a) EU Greenhouse gas emissions and targets (2014-11-11) http://ec.europa.eu/clima/policies/g-gas/index_en.htm

Maps of World (www.mapsofworld.com)

a) Sweden Latitude and Longitude (2014-11-03) http://www.mapsofworld.com/lat_long/sweden-lat-long.html

OECD Stat Extracts (stats.oecd.org)

a) PPPs and exchange rates (2014-11-03)
   http://stats.oecd.org/Index.aspx?datasetcode=SNA_TABLE4

Regeringskansliet (www.government.se)

a) Sweden – an emission-nutreal country by 2050 (2014-12-09)
   http://www.government.se/sb/d/5745/a/181428

Statistiska Centralbyrån (www.statistiksdatabasen.scb.se)

a) Befolkningstäthet (2014-11-03)
   http://www.statistikdatabasen.scb.se/pxweb/sv/ssd/START__BE__BE0101__BE0101C/BefArealTathetKon/?rxid=ef23ccff-9cfe-4c50-862d-0d764947ae8e

b) Konsumentprisindex (2015-03-23)
   http://www.scb.se/sv_/Hitta-statistik/Statistik-efter-amne/Priser-och-konsumtion/Konsumentprisindex/Konsumentprisindex-CPI/33772/33779/Konsumentprisindex-CPI/272151/

Svensk Energi (www.svenskeneregi.se)

a) Mål och Styrmedel (2014-11-03)
   http://www.svenskenergi.se/Elfakta/Miljo-och-klimat/Mal-och-styrmedel/

United Nations Framework Convention on Climate Change (unfcc.int)

a) Essential Background; The convention (2014-11-11)
   http://unfccc.int/essential_background/convention/items/6036.php
b) Essential Background; Kyoto Protocol (2014-11-11)
   http://unfccc.int/essential_background/kyoto_protocol/items/6034.php
c) Methods; Land Use, Land Use-change and Forestry (2014-11-11)
   http://unfccc.int/methods/lulucf/items/4129.php

Personal messages

Lars Lundin
Professor, Vatten och miljö, Geokemi och hydrologi
E-mail, 2014-10-22

Appendix A: Calculations

Wetland emissions from part 5.3.2

Whiting and Chanton (2001): 3.5 mol CH_4/m^2 and year, 23 mol $CO_{2/}m^2$ and year
3.5 mol/m^2 * 16.0425 g/mol = 56.15 g/m^2 = 561.5 kg/ha
23 mol/m^2 * 44 g/mol = 1012 g/m^2 = 10120 kg/ha and year
Kasimir-Klemedtsson et al. (1997): 200 kg CH_4 per ha and year, 600 kg CO_2 per ha and year
Friborg et al. (2003): 26 g CH_4/m^2 and year = 260 kg/ha and year,
396 g CO_2/m^2 and year = 3960 kg/m^2 and year

GWP of methane from part 5.3.2

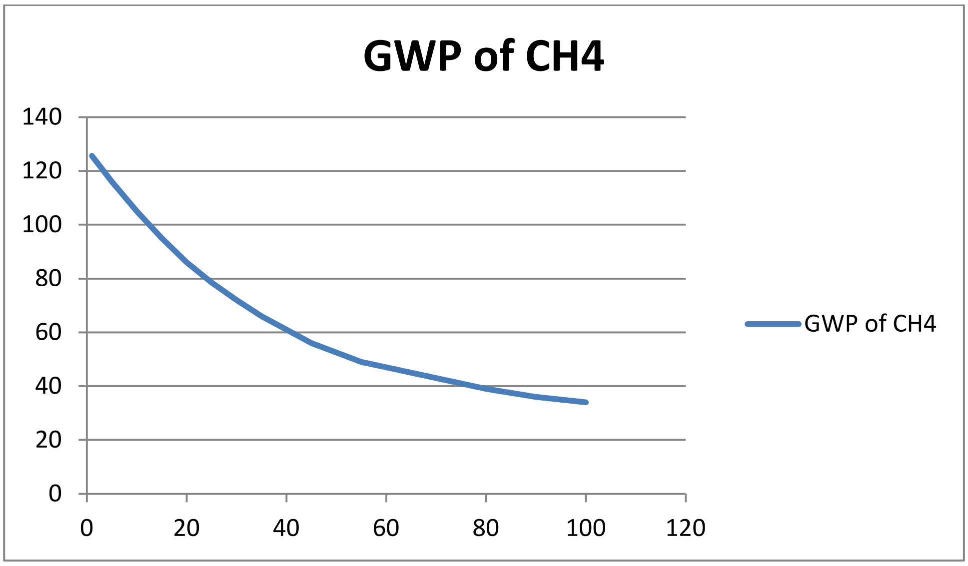

Figure A1. Updated values of methane GWP from Dessus et al (2008) based on the latest numbers from IPCC

Wetlands net emissions and present value for each year from part 5.3.2 and 5.6.2

Table A1. Net wetland emissions and net present value 2015-2050

Year	Methane kg/ha	GWP	Emissions kg/ha	Sequestration kg/ha	Net kg/ha	Price SEK/kg	Cost SEK/ha	Present value SEK/ha
2015	341	66	22506	4893	17613	0,099	1744	1744
2016	341	67,2	22915	4893	18022	0,149	2677	2587
2017	341	68,4	23324	4893	18431	0,198	3651	3408
2018	341	69,6	23734	4893	18841	0,248	4665	4208
2019	341	70,8	24143	4893	19250	0,297	5720	4984
2020	341	72	24552	4893	19659	0,347	6815	5738
2021	341	73,3	24995	4893	20102	0,396	7964	6479
2022	341	74,6	25439	4893	20546	0,446	9157	7197
2023	341	75,9	25882	4893	20989	0,495	10394	7893
2024	341	77,2	26325	4893	21432	0,545	11675	8566
2025	341	78,5	26769	4893	21876	0,594	13000	9216
2026	341	80	27280	4893	22387	0,644	14412	9872
2027	341	81,5	27792	4893	22899	0,693	15876	10506
2028	341	83	28303	4893	23410	0,743	17390	11119
2029	341	84,5	28815	4893	23922	0,805	19250	11893
2030	341	86	29326	4893	24433	0,867	21174	12639
2031	341	87,8	29940	4893	25047	0,953	23877	13770
2032	341	89,6	30554	4893	25661	1,028	26368	14692
2033	341	91,4	31167	4893	26274	1,114	29276	15761
2034	341	93,2	31781	4893	26888	1,189	31957	16623
2035	341	95	32395	4893	27502	1,275	35070	17625
2036	341	97	33077	4893	28184	1,349	38033	18468
2037	341	99	33759	4893	28866	1,436	41455	19449
2038	341	101	34441	4893	29548	1,510	44630	20230
2039	341	103	35123	4893	30230	1,597	48280	21144
2040	341	105	35805	4893	30912	1,671	51665	21862
2041	341	107,2	36555	4893	31662	1,758	55663	22757
2042	341	109,4	37305	4893	32412	1,832	59389	23460
2043	341	111,6	38056	4893	33163	1,919	63638	24288
2044	341	113,8	38806	4893	33913	1,993	67597	24926
2045	341	116	39556	4893	34663	2,080	72096	25686
2046	341	118,4	40374	4893	35481	2,154	76434	26439
2047	341	120,8	41193	4893	36300	2,241	81343	27317
2048	341	123,2	42011	4893	37118	2,315	85934	28018
2049	341	125,6	42830	4893	37937	2,402	91116	28843
2050	341	128	43648	4893	38755	2,476	95961	29492
SUM:					**964 327**		**1 285 348**	**558 899**
AVE:					26 787		35 704	15 525
50 ha					**48 216 325**		**64 267 395**	**27 944 952**

Forest carbon uptake and net present value for each year from 5.3.3 and 5.6.3

Table A2. Forest carbon sequestration and net present value 2015-2050

Year	Carbon kg/ha	CO2 kg/ha	Price SEK/kg	Value SEK/ha	Present value SEK/ha
2015	-243	-890	0,099	-88	-88
2016	-240	-880	0,149	-131	-126
2017	-237	-870	0,198	-172	-161
2018	-234	-859	0,248	-213	-192
2019	-231	-849	0,297	-252	-220
2020	-229	-838	0,347	-291	-245
2021	-214	-786	0,396	-311	-253
2022	-179	-655	0,446	-292	-229
2023	-143	-524	0,495	-259	-197
2024	-107	-393	0,545	-214	-157
2025	-71	-262	0,594	-156	-110
2026	-36	-131	0,644	-84	-58
2027	0	0	0,693	0	0
2028	125	458	0,743	340	218
2029	250	917	0,805	738	456
2030	375	1375	0,867	1192	711
2031	500	1833	0,953	1748	1008
2032	625	2292	1,028	2355	1312
2033	750	2750	1,114	3064	1650
2034	875	3208	1,189	3813	1983
2035	1000	3667	1,275	4676	2350
2036	1075	3942	1,349	5319	2583
2037	1150	4217	1,436	6056	2841
2038	1225	4492	1,510	6784	3075
2039	1300	4767	1,597	7613	3334
2040	1375	5042	1,671	8426	3566
2041	1450	5317	1,758	9347	3821
2042	1525	5592	1,832	10246	4047
2043	1600	5867	1,919	11258	4297
2044	1675	6142	1,993	12242	4514
2045	1750	6417	2,080	13346	4755
2046	1825	6692	2,154	14415	4986
2047	1900	6967	2,241	15611	5243
2048	1975	7242	2,315	16765	5466
2049	2050	7517	2,402	18054	5715
2050	2125	7792	2,476	19293	5929
SUM:	**26 336**	**96 564**		**190 238**	**71 824**
AVE:	732	2682		5 284	1 995
50 ha	**1 316 800**	**4 828 214**		**9 511 876**	**3 591 189**

The weight of C is 12 g/mol and weight of O is 16 g/mol. Total weight for CO_2 is thus 44 g/mol. 26 336 * 44/12 = 96 564

Wetland nature values from 5.6.1

GDP per capita 2013 (adjusted for PPP): 40 900 $ (CIA, 2014)
CPI 2015: 311.8
CPI 2013: 314.2
CPI 1995: 254.8 (SCB, 2015b)
Value in 1995: 40 900 $ * (254.8/314.2) = 33 167.8 $
Exchange rate (average for 2013): 6.51 SEK per US$, PPP 0.747 (OECD, 2014)

Annuity net present value: $NPV = A\ \frac{(1-(1+r)^{-n})}{r}$

A = 9623.6 SEK
r = 3.0 % year 2050-2046 and 3.5 % year 2045-2015

Table A3. Wetland nature value from meta-analysis and net present value 2015-2050

Item	**Formula**	**Value** SEK/ha	**Value 50 ha** SEK
Ln Y	(-6,98+1,16*LN(33167,8)+0,47*LN(100)-0,11*LN(50)+0,03*60-0,0007*60^2+0,84+1,49-1,46+0,06*0,279+0,06*0,088-0,49*0,107+0,63*0,144+0,14*0,158-1,1*0,233)	6,8	
Y	EXP(6,8)	902	
2013-US$	902,4*314,2/254,8	1 113	
2013-SEK	1112,8*6,51/0,747	9 698	
2015-SEK	9697,7*(311,8/314,2)	9 624	
NPV ‘50-‘46	(9623,6*(1-1,03^-5))/0,03	44 074	
NPV ’50-‘15	44073,5/1,035^30+(9623,6*(1-1,035^30))/0,035+9623,6	202 325	10 116 230

Timber production and other forest nature values from part 5.6.4

Incomes from spruce in Svealand on Bilberry-horsetail with 1300 day degrees;
1st thinning (30 years): 13.5 * 438 + 16 * 315 – 178 (13.5 + 16) SEK/ha = 5702
2nd thinning (45 years): 32.4 * 438 + 25 * 315 – 176 (13.5 + 16) SEK/ha = 16 874.2
Logging (75 years): 220.8 * 438 + 86.4 * 315 – 83 (13.5 + 16) SEK/ha = 121 477.9

Costs depending on the spread between ditches needs to be recalculated;
Machines for ditching: 11.43 SEK/m * 250 m/ha + 228 SEK/ha = 3085.5 SEK/ha
Planning for ditching and cleaning: 3 SEK/m * 250 m/ha = 750 SEK/ha
Ditch cleaning (year 45): 8 SEK/m * 250 m/ha = 2000 SEK/ha
Total cost at start up = Permission 340 + Ditching (3085.5+750) + Ground preparations 1142 + Planting 5708 = 11 025.5 SEK/ha
Other costs; help planting (year 5): 875.6 SEK/ha, thinning (year 10): 2500 SEK/ha

CPI 2015: 311.8
CPI 2011: 311.4
CPI 2007: 290.5
CPI 1991: 227.2 (SCB, 2015)

Timber value 2015: -11 504 * 311.8/311.4 = 11 518

Table A4. Net present value of timber production and other forest nature values 2015-2050

Item	**Formula**	**2011** SEK/ha	**2015** SEK/ha	**50 ha** SEK
Timber	(-11025,5-875,6/1,035^5-2500/1,035^10+5702/1,035^30)	-11 504	-11 518	-575 915
Recreation	(1600/23,4)*(311,8/227,2)		93,8	
Biodiversity	(1460/23,4)*(311,8/227,2)		85,6	
	(99*9,25*311,8/290,5)		982,9	
	(85,6+982,9)/2		534,2	
Nature value	93,8+534,2		628,1	
NPV ’50-’46	(628,1*(1-1,03^-5))/0,03		2 876,4	
NPV ’50-’15	3058,9/1,035^30+(628,1*(1-1,035^-30))/0,035+628,1		13 204,6	660 232
Timber full rotation		**’90-’46**		
	(16874,2/1,03^15-(2000+750)/1,03^15+121477,9/1,03^45)	41189,2		
		’90-’15	**2015**	**50 ha**
	(-11025,5-875,6/1,035^5-2500/1,035^10+5702/1,035^30+41189,2/1,035^30)	3171,3	3175,4	158769,0

Appendix B: References Min and Max scenarios

Table B1. References used to calculate the minimum and maximum value of the project

	Impact	Minimum	Reference	Maximum
Forest	*Carbon*	Bond-Lamberty et al.(2006)	IPCC (2000; 2006)	IPCC (2000; 2006)
	Timber	Henriksson & Mattson (2012)	Henriksson & Mattson (2012)	Henriksson & Mattson (2012)
	Recreation	Chiabai (2009)	Elisasson (1994)	Elisasson (1994)
	Biodiversity	Elisasson (1994)	Average	Chiabai (2009)
	Project	**5 686**	**73 106**	**82 513**
Wetland	*GHGs*	Friborg et al. (2003)	Average	Whiting & Chanton (2001)
	Nature value	Brander et al. (2006)	Function value transfer	Folke (1991)
	Counterfactual	**418 562**	**-354 520**	**-834 963**
Total	**P - C**	**-412 877**	**427 626**	**917 476**