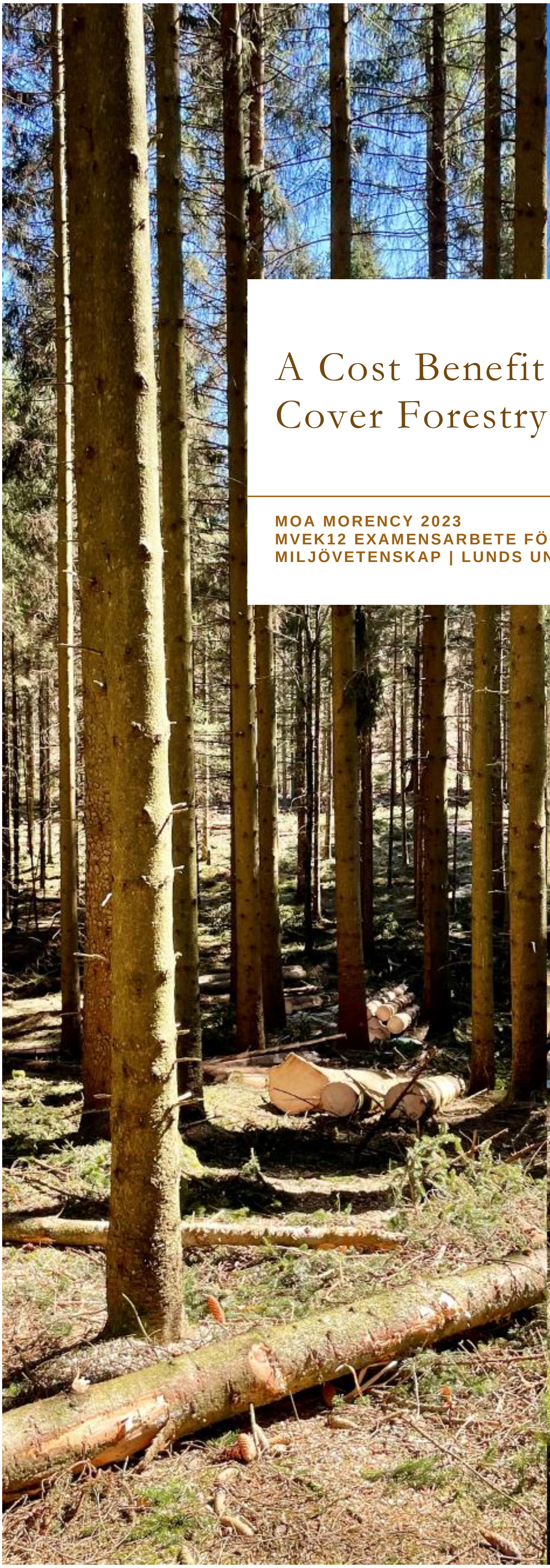


A Cost Benefit Analysis of Continuous Cover Forestry in Djurholmen, Skåne

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A Cost Benefit Analysis of Continuous Cover Forestry in Djurholmen, Skåne

A socio-economic comparison of continuous cover forestry and clear-cut forestry with regards to the wood production and climate mitigation

Moa Morency

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Moa Morency

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Huvudhandledare: Nils Droste, Statsvetenskapliga institutionen, Lunds universitet

Biträdande handledare: Julia Kelly, Centrum för miljö- och klimatvetenskap, Lunds universitet

CEC - Centrum för miljö- och klimatvetenskap
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Abstract

Forests and forest products are important, not just for timber production, the forest ecosystem plays several important roles, such as water purification, carbon sequestration for climate mitigation and recreational values. How the forests are managed varies throughout the globe, in Sweden the most used system is the clearcutting system (CF), however continuous cover forestry (CCF) is gaining popularity and is being tested in several places. The knowledge of the benefits of this kind of system is limited and the aim of this study was to compare the forest management systems, CCF and CF from a societal perspective with regards to wood production and carbon sequestration. This was done through cost-benefit analysis (CBA), comparing the net present value, (NPV) of CCF and CF. The study site at Djurholmen, Skåne consisted of 95 % Norway Spruce (*Picea abies*) and had a final cutting done beginning of May, 2023 where they clear-cut one area and used target diameter-thinning in a second area. The CF got 8 % higher NPV than CCF however it is important to recognize that multiple ecosystem services that have been proven higher for CCF in other studies are excluded in this study such as biodiversity and recreational values. The main conclusion was that the most important factor for forestry to contribute with climate mitigation is to maximize the substitution effect by getting as much of the wood produced as possible to end up in long lived wood products rather than paper or pellets for burning.

Populärvetenskaplig sammanfattning

Har du någonsin funderat på vad något är värt för dig? När du går i affären har du kanske jämfört kilopriser på olika livsmedel, visst är det hjälpsamt att kunna jämföra vilket som är ett bättre val för dig. Detta är vad en miljöekonomisk analys försöker göra med två olika skogsbruksmetoder. I den här kostnadsnyttoanalysen så jämförs hyggesfritt skogsbruk med det vanligare systemet, trakthyggesbruk, utifrån två ekosystemtjänster, träproduktion och klimatnytta. Ekosystemtjänster är tjänster som samhället får från ekosystem och när det kommer till skogsbruket så är det ofta bara träproduktionen som mäts i pengar eftersom de är en vara som köps och säljs, men det finns flera andra grejer med skogen som har värde för oss människor, några exempel är jakt, möjligheten att plocka svamp och bär, luft och vattenrening samt att ta upp koldioxid från atmosfären. Det är sant, vi behöver alltså inte bygga några stora avancerade maskiner som ska suga ut koldioxid ur atmosfären för att lösa klimatkrisen, vi har ju redan sådana maskiner stående över största delen av Sveriges landareal.

Om nu bara en av alla skogens ekosystemtjänster mäts i pengar, blir inte det lite missvisande om man ska försöka ta beslut om hur man ska sköta skogen, de är som att bara en bråkdel av varorna i din matbutik skulle ha en prislapp. När du kommer till kassan sen kanske något du vill ha visar sig vara alldeles för dyrt och det hade varit bra att veta när du tog beslut. När vi tar beslut om skogsbruk med bara en prislapp på ekosystemtjänsten trä riskerar vi att i framtiden inse att vi inte har råd att ignorera skogens alla andra ekosystemtjänster.

Det som denna studie har gjort är att kvantifiera klimatnyttan i monetära termer och sedan inkluderat detta i en kostnadsnyttoanalys som jämför hyggesfritt skogsbruk med trakthyggesbruk. Detta gör så att båda ekosystemtjänsterna kan vara med i analysen och gå att jämföra med varandra så att klimatnyttan skogen bidrar med till samhället kan bli inkluderad när beslut om hur vi ska bruka skogen ska tas. Resultat i denna studie visar på en skillnad i samhällsnytta där trakthyggesbruk bara har 8 % högre värde än hyggesfritt skogsbruk och eftersom hyggesfritt skogsbruk visat sig bidra med mer biologisk mångfald och högre rekreationsvärde än hyggesfritt i andra studier kan det vara värt att fundera på varför bara 2-3 % av Sveriges skog brukas på detta sätt.

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1. Introduction

Boreal forests make up about a third of remaining forests globally and provides multiple important ecosystem services (Hansen et al., 2010). These forests provide more than just timber, they deliver ecosystem services such as water purification, carbon sequestration for climate mitigation and recreational values for people (Harrison et al., 2010). The importance of a sustained or increased yield in actively managed forest to increase the climate benefit have been showed in several studies (Canadell and Raupach 2008; Malmsheimer et al. 2008; Poudel et al. 2012; Lundmark et al. 2014; Sievänen et al. 2014). By cultivating our forest, we can maximize some ecosystem services such as getting more wood per hectare, but we can also destabilize the ecosystems by optimizing the rotation of the stand and have an intense management cycle, something that can lead to a decrease in other ecosystem services, for example biodiversity (Peura et al., 2018).

The clear-cut forestry method has been used in most forests in Fennoscandia since the 1950s and have resulted in lower variability on a stand and structural scale as the forest has turned into even-aged monocultures. (Kuuluvainen et al., 2012). To keep the ecosystem intact and utilize forests for as many ecosystem services as possible, there is a big interest and significant body of scientific evidence that suggests that continuous cover forestry (CCF), a form of closer-to-nature management, can provide a higher multifunctionally than the conventional clear-cut forestry (CF) method (Motta & Larsen Jørgen, 2022; Tahvonen 2009; Kuuluvainen et al. 2012; Pukkala et al. 2012). The Swedish forestry association (Skogsstyrelsen) have defined CCF as:

> *"A forestry management strategy that ensures the land is always covered with trees, without any significant clearcut areas"* (Appelqvist et.al., 2021).

A switch from monocultured forests with even aged trees to continuous cover forestry might be beneficial for the movement towards environmental goals in a changing climate. (Tarasewicz & Jönsson, 2021). Environmental science is used to assess and determine what effects are relevant and different between the two types of forestry management systems. These effects will then in their turn determine the resulting final ecosystem services that the forestry management systems provide.

1.1 Aim, research question, case study and limitations

The aim of this study is to compare the forestry management systems, continuous cover forestry (CCF) and clearcut forestry (CF) from a societal perspective with regards to wood production and carbon sequestration. This will be done through cost-benefit analysis (CBA), to compare the net present value, (NPV) of CCF and CF. This resulted in the research question:

- Which of the two forestry methods, CCF or CF, leads to the higher net present value for society with regards to wood production and climate mitigation?

The ecosystem services included in the CBA will be wood production and carbon sequestration. Carbon sequestration will be quantified to monetary terms with the social cost of carbon so that it can be comparable to wood production in the CBA. The study will also take the substitution effect of wood to other material into account since it often is a more carbon cheap option compared to its substitution goods (Sathre and O'Connor 2010; Lundmark et al. 2014). This gives the study a life cycle perspective.

To evaluate the difference between CCF and CF, the study uses a forestry experiment by Stiftelsen Skånska Landskap (SSL). A visit was done to the study site when the first final cutting of the CCF experiment was in action. The personnel responsible for the site were interviewed and harvesting data was obtained from the harvester. These empirical observations have been used to estimate the value of wood production and climate mitigation from both CCF and CF management regimes.

The main delimitations of this study are:
There are multiple ecosystem services other than wood production and climate change mitigation/greenhouse gas sequestration that forests provide but due to the time limitation and extent of this paper only these two core values have been chosen (Harrison et al., 2010). The selection of what core values to prioritize and include was based on the importance of the ecosystem service for society but also on what kind of data was possible to get from the study site. The discussion will further explore what inclusion of more ecosystem services might imply for the results.

2. Methodology

2.1 Case study description

The study site is part of Djurholmen recreation area located on the southern part of the ridge Hallandsåsen in northwest Skåne, Sweden (Stiftelsen Skånska Landskap, n.d.). The study site is an even aged stand consisting of over 95 % Norway Spruce (*Picea abies*) (E. Sandell Festin, personal communication, May 20, 2023). The site had a final cutting scheduled first week of May for both CF and CCF. The forest stand is a very good representation of how most forest in Sweden look today with regards to tree species and age distribution (E. Sandell Festin, personal communication, May 9, 2023). 0,3 hectare was clear-cut, and 4,1 hectare was cut with target diameter cutting. Target diameter cutting is a form of CCF where a target diameter is set, in this case 45cm, and all the trees are then measured and marked for harvest by the forest manager (Goude et.al., 2022).

SSL has a forestry-strategy where they state their aims and how to work towards them with their forestry management. One of the aims is to achieve climate net benefit and one goal they have set to do so is to have as much wood as possible of what they harvest to go to sawtimber (Bernö, 2022). This is because sawtimber is a more long-lived wood product than for example paper or pellets for bioenergy and therefore the better option for climate mitigation purposes (Lundmark et al. 2014). SSL have also implemented fossil fuel free management and therefore uses the biodiesel HVO100 for the harvester and the forwarder (S.Olsson, personal communication, May 2, 2023).

2.2 Interviews

Two expert-based qualitive interview were held. The recruitment was done based on the chosen study site. The organization who owned the area chosen as this study's study site was contacted over the phone and thereafter two interviewees were chosen based on their knowledge and involvement in the study site, Djuholmen, and the organization's project to try CCF. The first interview was with the forest manager at Djurholmen, Stefan Olsson. The purpose of this interview was to get comprehensive information about the site, both historical and current events. A visit was also done in connection to the interview when the final cutting was happening which gave good insight to Stefan's plan and how it worked out practically. The interview was done in person and documented through note taking.

The second interview was with the forestry research coordinator at SSL, Emma Sandell Festin. She has a Ph.D. in Forestry and purpose of the interview was to get insight on suitable limitations and assumptions as well as what core values to focus on in the study. This was a way to confirm and add to the information found in the literature search. The interview was done over videocall and documented through an audio recording and processed with selective transcription of especially valuable quotes. After the processing, categorization of key themes in the interview was identified to make an analysis possible, comparing statements from the interview with statements in literature on the same theme and subject.

2.3 Cost Benefit Analysis

The method used was a cost benefit analysis (CBA) and all the calculations were done in excel. This method subtracts all the costs from all the benefits for every year of operation and then discount al the net benefits to a given year to get the net present value (NPV) (Ekvall & Bostedt, 2009; OECD, 2018). The study site did a final cutting in the end of April 2023, it was therefore possible to get fresh data on the cost of harvesting, price of wood and how much wood they got. Everything was calculated per hectare. Because this is an economic analysis and not a financial analysis taxes counts as a money transfers and is therefore excluded in the calculations.

Some of the data for the CBA was collected from the study site but some had to be collected through benefit transfer. This data was selected through studying and searching literature for studies that had data on any of this study's core values and had a study site of similar nature as the study site. The data that was collected through benefit transfer was the social cost of carbon (SCC) per ton CO_2, the substitution effect in CO_2 per volume of harvested wood and the heterotrophic respiration (RH) of carbon from the forest ground. In the CBA different values that forestry contributes to society is quantified and transformed into monetary terms to make them comparable.

The discount rate used was i = 2,5 % and is a commonly used discount rate approved by many scientists in the field of economic analyses (Drupp et.al., 2018; Ekvall & Bostedt, 2009). The present value net benefits were then summarized to a net present value for each forestry management system and resulted in two net present values (NPV). A net present value (NPV) is the net difference between the sum of discounted benefits (B) and sum of discounted costs (C), see equation 1.

$$NPV\ (i,T) = \sum_{t=0}^{T} \frac{B}{(1+i)^t} - \sum_{t=0}^{T} \frac{C}{(1+i)^t}\ (eq. 1)$$

To get an accurate representation of the NPV for the CF a mean was calculated of two scenarios. In the first scenario the final cutting was done year 0 and in the second scenario the final cutting was done the last year, year 59. This was done to counterbalance the discount effect.

Lastly, a sensitivity analysis was done by conducting 4 scenarios beyond the baseline scenario. The factors changed were the discount rate from 2,5 % to 0 %, the price of fuel from biodiesel to diesel, the substitution effect from a max value to a min value from the study (Lundmark et.al., 2016) and in the last scenario both the fuel price and the substitution effect were varied, with the max substitution effect and high fuel price for CCF and the min substitution effect and low fuel price for CF.

2.3.1 Wood production

The study site had, as mentioned, a final cutting done in the beginning of May, 2023 for both CCF and CF. The harvester was able to collect data on the size of area, the hard volume of wood under bark (m^3fub) of the harvested logs and their distribution according to quality classifications (see table 1).

SSL provided a pricelist for the wood, the hourly rate of the harvester and the forwarder and the additional management costs for CCF. Lastly Stefan Olsson provided the costs and revenues from CF management between the clearcuttings (personal communication, May 10, 2023). For the CCF the costs and benefits come on the years when the selective logging is done so there were no costs or benefits between the years of the cuttings.

The costs of CF are site preparations and planting in year 1, then in years 9 and 15 there are small thinning's. In the years 24 and 32 two bigger thinning's were estimated and the trees were expected to be big enough to yield significant revenue. The costs and revenues amounts are presented in table 2 (S.Olsson, personal communication, May 10, 2023).

2.3.2 Climate mitigation

The climate mitigation of the forestry methods was measured by the net ecosystem production (NEP) of carbon and the substitution effect of the wood produced. The annual NEP is calculated by subtracting the sum of carbon flux from the soil each year with the flux of carbon stored in aboveground biomass each year (see equation 2).

$$NEP = biomass - heterotrophic\ respiration\ (eq. 2)$$

The calculation to get ton CO_2 from the volume of hard spruce wood under bark (m^3fub) started out with calculating the dry volume of wood (V_{dry}) with a change factor of 0,88 because hardwood shrinks with about 12 % when dried,

$$V_{dry} = V * 0{,}88. (eq. 3)$$

To get the whole above ground dry biomass of the tree (V_{dry}^{tot}), not just the trunk, the V_{dry} was multiplied by a factor of 1,61, taken from the study done by Johansson (1999),

$$V_{dry}^{tot} = V_{dry} * 1{,}61. (eq. 4)$$

The V_{dry}^{tot} where then multiplied by the dry-density of spruce wood, 380 kg/m^3 to get the mass of wood (m_{wood}) (Svenskt trä, n.d.),

$$m_{wood} = V_{dry}^{tot} * 380. (eq. 5)$$

The m_{wood} where then multiplied by the ratio of carbon in dry wood biomass (0,5) to get the mass of carbon (m_C),

$$m_C = m_{wood} * 0{,}5. (eq. 6)$$

The change factor to go from m_C to carbon dioxide mass (m_{CO2}) was calculated by dividing the atomic mass of carbon dioxide, (12 + 16 * 2) g/mol = 44 g/mol, by the atomic mass of carbon, 12 g/mol, which gave a change factor of, 44 / 12 = 3,67. To get the m_{CO2} this change factor (3,67) was multiplied by the m_C,

$$m_{CO2} = m_C * 3{,}67. (eq. 7)$$

Equations 3-7 can be summarized as a factor of change (F_c)= 0,88 * 1,61 * 0,5 * 3,67 * 380 * 0,001 = 0,9879 and will be referred to as F_c in further calculations.

To measure the NEP biomass growth was estimated as a linear relationship from the point in time of the final cutting to the estimated next final cutting. The point in time for the next final cutting was estimated by Stefan Olsson based on the stand age of this year's final cutting, many years of experience as a forestry manager and the average stand age of spruce felling's in this area in Sweden (Nilsson et.al., 2022).

Firstly, the CF was plotted with a rotational period of 60 years and assumed that the biomass would go back to the level that was harvested this year's final cutting which was a total volume of wood of 743 m^3fub (see total volume of wood in table 1). This gave the relationship seen in appendix 1 and equation 8.

$$Volume \text{ of } stemwood = 12{,}599 * Stand\ age\ (eq. 8)$$

Secondly the CCF was assumed to have the same harvest percentage in ten years as this year which was 15 % of what was harvested in the CF final cutting, so 743 * 0,85 = 632 m^3fub. The CCF volume of stemwood went down to 632 m^3fub after every final cutting and then in ten years went back to 743 m^3fub. One rotational period was plotted (see appendix 2) and gave the following relationship:

$$Volume \text{ of } stemwood\ = 12{,}389 * Stand\ age + 631{,}83\ (eq. 9)$$

Since the growth of biomass is assumed to be a linear relationship the flux of carbon into biomass will be equal to the slope of the growth function, (see equations 8 and 9), multiplied by the factor of change, $F_c = 0{,}9879$, to get the value in ton CO_2 instead of volume of hard spruce wood under bark (m^3fub) (see equations 3-7 for deduction of F_c).

To then get the value for the ecosystem as a whole, the flux of carbon dioxide from soil respiration was subtracted from the flux of carbon from biomass growth. The values of soil respiration were taken from two studies, for the first three years after the clear cut the study done by Vestin et.al. (2020), (blue dots in figure 2). For the constant RH a mean value was calculated from the study Peichl et.al. (2022) (orange dotted line in figure 2). For the CCF the constant value of heterotrophic respiration (RH) was used for every year but for the CF the first three years was plotted as a linear relationship. The point of intersection with the constant RH was between stand age 5 and 6, therefore the assumption was made that the flux RH in years 4 and 5 would follow the function from Vestin et.al. (2020), see dotted blue line in figure 2.

The soil CO_2 could then be subtracted from the biomass CO_2 and this gave the NEP per hectare per year. The NEP was then multiplied with the SCC. The SCC is a global index from the study (Ricke et.al., 2018). The study Rickie et.al. from 2018 estimated the SCC based on future scenarios of climate change and the costs that will lead to for society.

The value of a maximized substitution effect was taken from the study (Lundmark et.al., 2016) and was 0,90 ton CO_2-eqv for each cubic meter of harvested biomass in the baseline scenario. The study (Lundmark et.al., 2016) also provided a min-substitution effect of 0,47 ton CO_2-eqv for each cubic meter of harvested biomass. Only the biomass harvested has a substitution effect and therefore there is only a substitution effect the year of the final cutting in the CF and every ten years for CCF.

3. Results

The aim of this study was to compare the forestry management systems, continuous cover forestry (CCF) and clearcut forestry (CF) from a societal perspective with regards to wood production and carbon sequestration. To answer the research question, which of the two forestry methods, CCF or CF, leads to the higher net present value for society with regards to wood production and climate mitigation, two CBAs were done and resulted in a 8 % higher NPV for CF than CCF.

3.1 Net benefits from wood production

The net benefits calculations from the final cutting can be found in table 1 and the net benefit and cost of site preparations, planting and thinnings between the final cuttings for CF can be found in table 2. There was no cost of benefits for CCF between the years of the final cuttings.

Table 1

Table 1 shows the net benefit calculations for one final cutting. The area managed with CF was 0,3 hectare and the area manged with CCF was 4,1 hectare. The revenue was calculated with timber classifications and their volume per hectar for the different forestry managemnt systems, CF and CCF, multipied by the price of wood. The cost was calculated buy multiplying the hurly rate of the harvester, forwarder and and the forest manager by the time put in per hectar.

Revenue of one final cutting	Volume of wood (m3fub/ha)		Price (SEK/m3fub)	Revenue	
Timber classification	CF	CCF		CF	CCF
Sawtimber (grantimmer)	563	91	1 083 SEK/m3fub	610 090 SEK	98 865 SEK
Light timber (klentimmer)	53	3	720 SEK/m3fub	38 400 SEK	2 490 SEK
Pallet wood (pallkubb)	70	6	610 SEK/m3fub	42 700 SEK	3 879 SEK
Pulpwood (barrmassaved)	57	8	550 SEK/m3fub	31 167 SEK	4 303 SEK
Total volume of wood:	743	109	**Total revenue:**	722 357 SEK	109 537 SEK
Cost of one final cutting	Time (h/ha)		Price (SEK/h)	Cost	
Type of cost	CF	CCF		CF	CCF
Harvester	13,3	4,6	2 084 SEK/h	27 787 SEK	9 530 SEK
Forwarder	30,0	4,0	1 225 SEK/h	36 750 SEK	4 930 SEK
Additional management costs		1,5	400 SEK/h		600 SEK
Total cost:				64 537 SEK	15 060 SEK
Net benefit				**657 820 SEK**	**94 477 SEK**

Table 2
The net costs and revenues of CF management in SEK/hectare except the year of the final cutting.

Costs	Year	Price (SEK/ha)
Site preparations and planting	1	24 000 SEK/ha
Thinning 1	9	4 500 SEK/ha
Thinning 2	15	4 500 SEK/ha
Revenues	**Year**	**Price (SEK/ha)**
Thinning 3	24	13 008 SEK/ha
Thinning 4	32	37 167 SEK/ha

3.2 Net benefits from climate mitigation

When the relationship between volume of stemwood and stand age for CCF was plotted over the rotational period for the CF, 60 years, it resulted in the blue line seen in figure 1. The relationship between volume of stemwood and stand age for CF resulted in orange dotted line seen in figure 1. The two growth functions, for CCF and CF together, can be seen in figure 1.

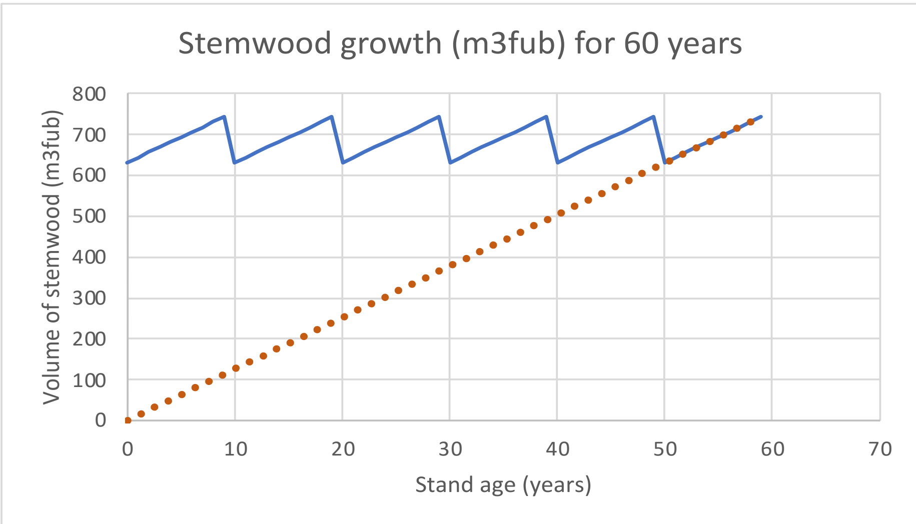

Figure 1
Figure 1 shows the stemwood growth for CF (orange dotted line) and CCF (blue line) over time for 60 years, from year 0 to year 59. 60 years is one rotational period for the CF and 6 rotational periods for the CCF.

The flux of carbon into biomass per year was 12,599 * 0,9879 = 12,447 ton CO_2/hectare/year for CF and 12,389 * 0,9879 = 12,239 ton CO_2/hectare/year for CCF (see equations 3-9 in methodology). The NEP was then calculated by subtracting the annual sum of soil carbon respiration flux, RH, from the annual flux of carbon into biomass. The annual sum of soil carbon respiration flux, RH, is calculated as constant for every year in the CCF management. This constant of 8,05 ton CO_2 per hectare per year was calculated as mean of the values from the study Peichl et.al. (2022). For the CF and all years except the first five years had the same constant. The first five years after a clear-cut emits more carbon from the soil than if the forest is continually covered by forest (Vestin et.al., 2020). The values for the first five years after the clear cut was calculated based om values taken from the study Vestin et.al. (2020) (see figure 2 and table 3).

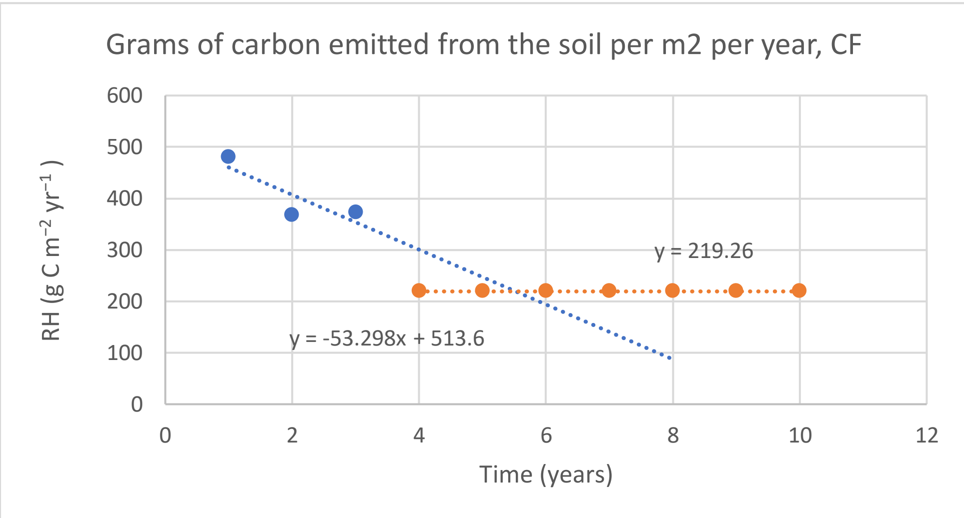

Figure 2
Plotting of RH for CF with values from Vestin et.al. (2020) (blue dotted line) and Peichl et.al. (2022) (orange dotted line).

Table 3

Table 3 shows the first 5 years of carbon emitted from soil respiration calculated from values taken from Vestin et.al. (2020). These values are only used for the management system CF because it considers the additional carbon emissions from the soil after a clear-cutting and in CCF no clear-cuts are done.

Additional carbon emissions from the soil after a clear-cutting for the CF management system			
Year	RH flux (ton CO2/ha/year)	Biomass flux (ton CO2/ha/year)	NEP (ton CO2/ha/year)
0	17,61	12,45	-5,16
1	13,50	12,45	-1,05
2	13,70	12,45	-1,25
3	11,02	12,45	1,42
4	9,07	12,45	3,38

The SCC was taken from the study (Ricke et.al., 2018) and they calculated a global index of 150-200 US$ and the mean, 175 US$ of these values was used in this study. A currency exchange from US$ to SEK was done and it resulted in the SCC's shown in table 4.

Table 4

Table 4 shows the NEP and what price that reults in per year per hectar when multiplied with the SCC US$175/ton CO_2 taken from Ricke et.al., (2018). From year 5 to year 59 the values for NEP and SCC for both management systems are going to be constant and the table 3 therefore does not include all the years, this is the meaning of the sign (– II –).

	NEP		SCC	
Year	CF	CCF	CF	CCF
0	-5,165	4,192	- 9 328 kr	7 572 kr
1	-1,053	4,192	- 1 901 kr	7 572 kr
2	-1,252	4,192	- 2 262 kr	7 572 kr
3	1,422	4,192	2 568 kr	7 572 kr
4	3,378	4,192	6 101 kr	7 572 kr
5	4,400	4,192	7 947 kr	7 572 kr
6	4,400	4,192	7 947 kr	7 572 kr
7	– II –	– II –	– II –	– II –

The substitution effect for was 669 ton CO_2 for CF and 98 ton CO_2 per hectare per final cutting and multiplied by the SCC it gave a benefit in monetary terms of 742 315 SEK for CCF and 5 065 668 SEK for CF.

3.3 The net present values

The NPV was 3 442 994 SEK for CCF. For the CF the NPV was 5 925 336 SEK when the final cutting was done year 0 and 1 547 658 SEK wen the final cutting was done year 59, the mean of these two values was 3 736 497 SEK. This mean calculation is done in all the scenarios to account for how sensitive the timepoint of the clear-cut was to the discounting.

A sensitivity analysis was done for a couple of the factors. Firstly, a scenario 2 was conducted where the discount rate was changed from 2,5 % to 0 % and the difference in NPV of CCF and CF were than smaller than the baseline scenario, only 2 %. CF had a NPV of 6 172 921 SEK and CCF had a NPV of 6 311 859 SEK so the NPV for CCF was higher than the NPV for CF.

In scenario 3, the price of regular diesel was used in the place of the more expensive biodiesel. The difference in NPV of using diesel instead of biodiesel was higher for CCF than CF. The NPV's were then 3 450 786 SEK for CCF and 3 742 116 SEK for CF.

In scenario 4 the substitution effect was changed from 0,9 to 0,47 ton CO_2-eqv for each cubic meter of harvested biomass (Lundmark et.al., 2016). CCF got a NPV of 955 470 SEK and the CF got a NPV of 1 002 593 SEK. The difference between CF and CCF was lower than the baseline scenario with only 5 % difference.

There was one last scenario done, scenario 5, comparing a baseline scenario of how most forests Sweden are managed were there the lower substitution effect was used as well as the lower price of fuel, the price of diesel instead of biodiesel, to get a picture of how the management strategy that SSL are implementing compares to a conventional management strategy in Sweden. This resulted in a NPV of 3 442 994 SEK for CCF in alignment with the SSL's forestry management strategy and a NPV of 1 008 211 SEK for the conventional CF management strategy.

Table 3

Table 3 shows the NPVs for scenarios 1-4, where scenario 1 is the baseline scenario with a discount rate of 2,5 % with biodiesel as the fuel and the max-substitution effect. In scenario 2 the discount rate was changed to 0 %. In scenario 3 the fuel used was diesel instead of biodiesel and in scenario 4 the substitution effect was changed to the minimal value of 0,47 instead of 0,9. It is worth noting that scenario 4 is the only scenario where CCF had the higher NPV and by as much as 154 %.

		NPV			
Scenario	**Changing factor**	**CF**	**CCF**	**Difference**	**% Difference**
1	Baseline scenario	3 736 497 SEK	3 442 994 SEK	293 503 SEK	7,9%
2	0% discoundt rate	6 172 921 SEK	6 311 859 SEK	138 937 SEK	2,3%
3	Diesel	3 742 116 SEK	3 450 786 SEK	291 329 SEK	7,8%
4	Min-substitution effect	1 002 593 SEK	955 470 SEK	47 123 SEK	4,7%
5	Coventional vs SSL	1 008 211 SEK	3 442 994 SEK	2 434 783 SEK	241,5%

The key finding of this study are the that the substitution factor is very sensitive and has a big impact on the NPV, that SSL's forestry management strategy gives a much higher NPV than a more conventional forestry management strategy. If the discount rate is changed to 0 % the CCF scenario has a higher NPV than CF by 2 %. Most importantly, the answer to our research question, that CF in the baseline scenario has an 8 % higher NPV than CCF.

4. Discussion

The result showed that from a social economic perspective, with regards to wood production and climate mitigation, CF is the option with a higher NPV. This is in alignment with other studies such as (Lundmark et.al., 2016), but there are also studies that have gotten the result that CCF is the preferable management system or that the management system have a similar production levels (Pukkala et.al., 2009). The studies showing a higher value of CCF have taken more ecosystem services into account than what was possible for the scope of this study (Pukkala et.al., 2009).

4.1 Wood production

There are multiple factor changes that could affect the outcome of this CBA. Firstly, SSL uses a fossil free fuel, HVO100, for the harvester and the forwarder. Beyond being an already more expensive fuel, about 3 SEK per liter, there is an item tax refund for forestry managers and farmers on diesel, that do not include biofuel. This makes the price difference even bigger, up to 5 SEK per liter (Gustavsson Binder, 2022). In the scenarios where diesel was used instead of biodiesel there was less difference between the NPVs because the harvesting time per hectare was higher for CCF. If diesel had been used instead of the biodiesel it would have resulted in higher emissions, and it would ideally have been accounted for in the economic analysis but because of limited time and scope of the study these additional emissions were overlooked.

In Sweden, the sawmills have optimized their production for logs that are 37,5 cm or less in diameter and if the logs harvester surpasses the limit there is an added fee from the sawmill on those logs. Since CCF often leads to bigger timber this extra fee acts as an incentive against a protentional transition from CF to CCF (E. Sandell Festin, personal communication, May 9, 2023). There is also a possibility for slower growing, more dense trees with CCF than CF. This could result in a nicer quality of wood. If the quality and valuation of wood accounted for density this could lead to higher wood-prices for CCF. (E. Sandell Festin, personal communication, May 9, 2023).

In this study it was assumed that CCF does not have any site preparations or plantation and is therefore solely relying on natural regeneration for new tree growth. This removes a big cost for CCF compared to CF however some studies have shown that by site preparing and planting the yield and growth of the forest is higher because of the genetic constellation of the new trees can be optimized for the aim of the forestry management (Nilsson et al., 2011).

The discount rate used in CBA's have a big impact on the outcome of the analysis. The study gave a higher NPV for CF than CCF in the baseline scenario but with a 0 % discount rate CCF had a higher NPV than CF. What discount rate to use in this kind of environmental assessment is a debated topic and can be used to tweak results in the direction in line with a researcher's interests (Fregonara & Giuseppe Ferrando, 2023; Bureau et.al., 2021). If an investor has no interest in future generations, it is possible to put a high discount rate and claim that long-term environmental interventions won't pay of and are not worth pursuing.

4.2 Climate mitigation

The substitution effect is clearly the biggest factor in the analysis based on the 5th scenario where the CF management system got the lower substitution effect and the CCF got the higher substitution effect to simulate a conventional forestry management strategy compered to SSL's strategy that aims to have a climate benefit. The result that the substitution effect has the largest impact on the NPV of the forestry management system aligns with results shown in the study (Lundmark et.al., 2016).

It is important to know this and have this perspective when debating over what forestry management to use, that wood as a material is one of the best materials from a sustainability perspective (Sathre and O'Connor 2010; Lundmark et al. 2014). Therefore, the forestry industry is hugely important, and it is maybe more important to have a supporting environment and cooperation in the industry rather than polarization of a "wood producing" side and a "environmentally friendly" because both approaches do work towards sustainability in their ways and are necessary for a sustainable world.

For the carbon sequestration, the sum of carbon stock changes in tree-biomass and the substitution effect was calculated. The flux of carbon from the soil decomposition subtracted from the sum of carbon flux into biomass. This was an important factor because of the additional release of carbon from the soil after a clear-cut felling that is avoided with CCF (Vestin et.al., 2020). The calculations did not include how much branches, stumps, and other forms of residue from the final cutting is left behind because that information was not available but would have been ideal for the study's biomass calculations.

The area that was managed with CF was assumed to have the same soil properties as the area of the CCF for the to get a fair comparison of the different management systems but in reality, the area that was clear-cut is a drained peatland. Because of this the ground was too soft to do a target-diameter cutting and so the only option for harvest here was to clear cut which also is also the worst area to clear-cut because it will leak more greenhouse gas than the ground in the rest of the stand (Korkiakoski et.al., 2023).

The problems that come with forestry on drained wetlands are a common issue in the whole of Sweden and the best option from especially a climate mitigation perspective is by many argued to rewet the wetlands (Minkkinen et.al., 2020). In Djurholmen this is not an option because the area so closely borders to a neighbor property (E. Sandell Festin, personal communication, May 9, 2023).

When a target-diameter cutting is done in an even aged stand like the one on Djurholmen there is an overhanging risk of the forest to blow down during a storm (S.Olsson, personal communication, May 4, 2023; Shorohova et.al., 2008; Pukkala et.al., 2016). This was also one reason for why the drained peatland with a softer ground was clear-cut as Norway spruce is known to have shallow root system and growing on wetter and softer soils, the risk of storm felling is higher (E. Sandell Festin personal communication, May 9, 2023).

4.3 Future studies

A drawback of the study is that the forest at Djurholmen is going through a transition into CCF from CF. If the study site had been managed with CCF for longer it would have been possible to look back on data from earlier final cuttings/thinning's. Because the forest is in a transition the forest is now made for the CF management and it could possibly lead to less profitable results for the new method, partly because the people working in the forest, for example the harvester and the forest manager have not done this before and might need more time to design the thinnings and partly because of the structure of the forest.

To get a better understanding of what management strategies should be used in societies best interest more long-term trials needs to be conducted. However, some of the issues that forestry affects like biodiversity and climate change cannot wait for very long so conducting research on future scenarios are necessary (Beyer et.al., 2020; Brandt, & Rouillard, 2020).

The study would have benefited greatly from a more comprehensive sensitivity analysis with more scenarios and preferable a max and min for all the changing factors. For future studies to improve results, the estimated function on biomass growth used would preferable be a nonlinear function that is based on a forestry scenario, to better represent reality and could be adjusted to the environmental factors of the forest stand in question. The scale of the experiment is small and done on only one location in Sweden. For future studies is would be beneficial to do experiment of a larger scale and in multiple part of Sweden.

One big delimitation of this study was the number of ecosystem services included in the analysis. If other ecosystem services had been included this could have given a different result were CCF have been shown to provide a higher multifunctionality and lager rage of ecosystem services than the conventional forestry management system, CF (Eyvindson et.al., 2021; Motta & Larsen Jørgen, 2022; Tahvonen 2009; Kuuluvainen et al. 2012; Pukkala et al. 2012).

4.4 Ethical reflection

Do we have the right to put monetary value on a life? Many people say that it is impossible and inhumane but in the society we live in we have to do it and have for a long time. For example insurance companies do it so that they can evaluate damage cost for losing a loved one or having the quality of your life be affected in other ways. When it comes to evaluating ecosystem services it sometimes takes the human health into account like with air quality but it can also be about a dying species or ecosystem. To some degree it is dangerous to put a monetary value on those kinds of things because they can arguable be invaluable for us and our species existence but to make a change in our capitalist society, money is the main comparative variable for decision making. This study will only put the monetary value on the ecosystem services for the purpose of comparing it to other as a way of making better decisions. There is also the risk of misleading results that are not objective. This could lead to decision-making that do not benefit the society and does not follow its intentions. It is important to be clear about how the study was conducted and expose its flaws.

5. Conclusion

From the results in this study, we can conclude that the management strategy implemented by SSL is a model strategy from a societal economic perspective with regards to wood production and climate mitigation. Climate benefit can really be done when a forest owner has a life cycle perspective and aim to have their wood end up in long lived products.

The key findings of the study are that there is no big difference between CCF and CF with regards to wood production and climate mitigation but in the baseline scenario the result was that CF had an 8 % higher NPV than CCF. However, in scenario 2 when the discount rate was changed from 2,5 % to 0 % the NPV was higher for CCF than CF by 2 %. We need a more multifunctional forestry, and we cannot afford to wait because species are dying, and the climate is changing. At the same time only 2-3 % is managed with CCF even though it has been shown to be more multifunctional and have about the same production levels.

For future studies it would be interesting to include more ecosystem services in the CBA. It would also be interesting to use a more accurate biomass growth curve maybe simulated in the system Heureka based on the composition and environmental conditions of the site forest stand.

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Appendix 1

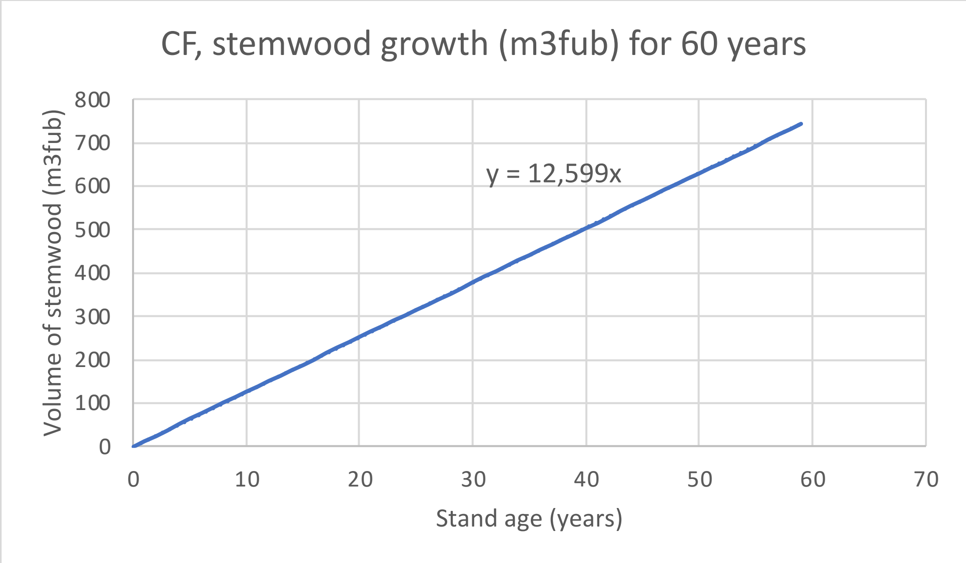

Figure
Shows the stemwwood growth rate for CF over one rotational period of 60 years, from year 0 to year 59. The slope of this line gives a constant growth rate of 12,599 m^3fub per year that will be used to calculate biomss growth per year.

Appendix 2

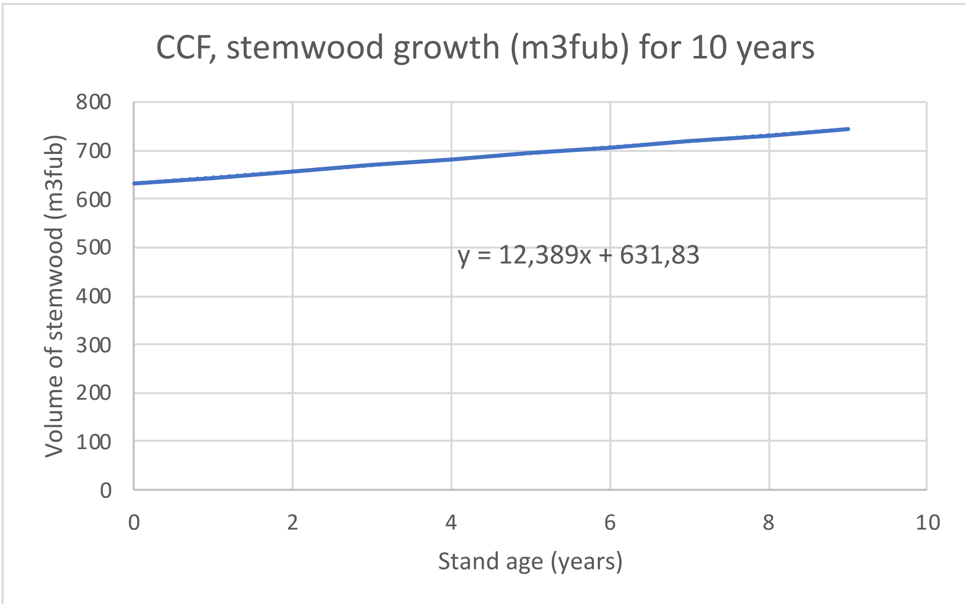

Figure
Shows the stemwwod growth for CCF over one roation perod of 10 years, from year 0 to year 9. The slope of this line gives a constant growth rate of 12,389 m^3fub per year that will be used to calculate biomss growth per year.