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Analysing climate effect of agriculture and forestry in southern Sweden at Högestad & Christinehof Estate

Robert Paulsson

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Geobiosphere Science Centre
Physical Geography and Ecosystems Analysis
Lund University
Sölvegatan 12
S-223 62 Lund
Sweden

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Supervisor: **Thomas Hickler**

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Department of Physical Geography and Ecosystem Analysis, Lund University

Abstract

The Intergovernmental Panel of Climate Change (IPCC) estimates global warming caused by anthropogenic emissions of greenhouse gases (GHG) to 1.1-6.4 ° C in the year 2100. Agriculture is the source of 10-12 % of the global GHG emissions. Forests and other terrestrial ecosystems estimated to provide a sink affected by land use management. In this study, I estimate the sources and sinks in agriculture and forestry by using the methodology in the Swedish National Inventory Report of emissions made under the Kyoto protocol. Companies in these trades have an increasing demand for emission inventories of their businesses. Analysis of the Högestad & Christinehof Estate, situated in Scania in southern Sweden, serves as an example. The estate consists of some 6000 ha of agricultural land and some 7000 ha of forest. Within the business, there are also over 350 cattle and game. Estimates cover emissions from agriculture and removals in land use and forestry. The analysis shows that the most affecting part is the livestock and especially the manure management which stands for 90 % of the 45 000 TonCO_2-equivalents of GHG that is emitted annually. When forest harvest is not treated as a sink, data from Swedish forest carbon monitoring indicates a removal in the forest of only about 400 TonCO_2-eq/yr despite a substantial growth. Because some of the harvest is sequestered, I suggest a method where all saw log is considered an uptake and everything harvested for paper assumed oxidised within a year. This way of counting gives a removal of some 16 000 TonCO_2-eq/yr. Important sources are e.g. the use of synthetic fertilizer and animal manure that emit about 1000 TonCO_2-eq/yr, carbon loss from cropland that is almost 2000 TonCO_2-eq/yr. The removal in grassland is about 1600 TonCO_2-eq/yr.

The inventory provides the landowner with a good picture and an opportunity to take action despite estimated uncertainties in the analysis of 25-100%. Changed manure management, possibly through biogas production, could reduce emissions significantly. Late thinning, minimized disturbance and fertilization of the forest could increase the net uptake. The inclusion of harvested wood products, and especially long-term products, in the national inventory could be a way of affecting forest management toward more carbon storage. In the agriculture, about 90 % of the GHG emissions are CH_4 and N_2O and including them in the emission trading system could have positive effects.

Sammanfattning

Klimatanalysen av ett av Skånes största företag inom jord- och skogsbruk visade att kor är klimatbovar och att skogen kan hjälpa oss att sätta dit dem.

Under många år har forskarna förutspått att uppvärmningen till följd av människans utsläpp av växthusgaser kan få dramatiska konsekvenser. En global ökning av temperaturen ökar förekomsten av extrema väderfenomen som stormar, skyfall och torka. I Sverige kommer ungefär 13 % av växthusgasutsläppen från jordbruket medan skogen tar upp ca 6 % av de samlade utsläppen. Företag med verksamhet inom jord- och skogsbruk är intresserade av åtgärder för att minska utsläppen och eventuellt öka upptaget. I den här studien analyseras ett av Skånes största företag i branschen, Högestad & Christinehof Egendoms AB. Det här examensarbetet ingår som en del i samarbetet inom hållbar utveckling mellan Lunds universitet och Högestad. Med hjälp av resultaten kan företagets verksamhet bedrivas på ett mer klimatvänligt sätt. Av de totalt 13 000 hektar som ägs av Högestad är ca 7000 ha skog och 6000 ha jordbruksmark. I verksamheten ingår över 350 nötkreatur för köttproduktion och viltuppfödning för jaktverksamhet.

Sverige och andra länder har åtagit sig att minska sina utsläpp enligt Kyoto-protokollet och gör varje år en uppskattning av utsläppen inom olika branscher. Siffrorna för olika branscher sammanställs av Naturvårdsverket till en årlig rapport. Uppskattningarna av Högestads utsläpp och upptag baseras på samma metod som används i den rapporten. Analysen av Högestads verksamhet är begränsad till de tre viktigaste växthusgaserna, koldioxid, metan och lustgas. Metan (CH_4) och lustgas (N_2O) är det som släpps ut mest i jordbruket. Metan kommer till stor del från kors matsmältning och från nedbrytning av gödsel. Lustgas bildas när kemiska föreningar som innehåller kväve bryts ner under speciella förhållanden t.ex. vid gödselhantering och tillförsel av kväve till jorden. Kväve tillförs jorden genom konstgödsel och stallgödsel, men också genom att växter som binder kväve från luften odlas.

Undersökningen visar att 90 % av utsläppen kommer från gödselhanteringen. Andra stora källor är lustgas från konstgödsling och koldioxid från nedbrytningen av organiskt material i jordbruksmarken. Skogens upptag är mindre än 1 % av de totala utsläppen, vilket är förhållandevis litet. Förändrad gödselhantering eventuellt i form av biogasproduktion kan minska utsläppen. Minskad gallring och eventuell tillförsel av mineraler kan öka upptaget i skogen. Det mesta av tillväxten i skogen avverkas och räknas därför inte in i upptaget med den nuvarande metoden. De avverkade träden blir både kortlivade produkter som papper och långlivade produkter som byggnadsmaterial. Kol som är bundet i långlivade produkter anses vara borta från atmosfären i hundra år och därför inte bidra till växthuseffekten inom de närmaste decennierna. Därför föreslås de kunna räknas in i upptaget.

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1. Introduction

The human induced climate change is a symptom of unsustainable development in the world. Agriculture, forestry and other land use are in many ways contributing through unsustainable use of the ecosystems. The ecosystems provide 6.5 billions of people with food and energy and will hopefully be able to feed 9 billions in the future. The need for sustainable development in these sectors is large and increases with the population. Global temperatures are likely to increase by 1.1 to 6.4°C by the end of this century mainly due to anthropogenic emissions of greenhouse gases (GHG) (Meehl et al., 2007). Emissions from agriculture are estimated to 5.1-6.1 gigatons (Gt) CO_2-equivalents/yr or 10-12 % of the global GHG emissions (Smith et al., 2007). The sector of Land Use, Land Use Change and Forestry (LULUCF) contents both removals of CO_2 and emissions. Estimated removal is 3.1 GtCO_2-eq/yr, which mostly takes place in the temperate and boreal forests of the northern hemisphere (Nabuurs et al., 2007). Emissions estimated to 5.8 GtCO_2-eq/yr, mainly originate from land use change in the form of deforestation in the tropics. Some of these emissions are sequestered in the terrestrial ecosystems and it is difficult to estimate the net effect of this sector (Nabuurs et al., 2007).

In Sweden, 13 % of the emissions that drive global warming originate from the agricultural sector and consist mainly of CH_4 and N_2O. The LULUCF-sector contains a net removal corresponding to 6 % of the total emissions in the other sectors (NIR, 2007).

The Swedish cities of Stockholm and Malmö offer support to companies in analysing the climate effects of their businesses. This study deals with such an analysis for a large company in agriculture and forestry in southern Sweden. The Högestad-Christinehof Estate[1] in Scania has collaboration with Lund University within sustainable development since 2006 and serves as an example. Companies need a detailed view of the climate affect of their businesses to be able to take the right actions in their work towards climate change mitigation. To provide such a picture the work began with the structuring of an inventory tool. The inventory tool follows the same methodology as the Swedish reporting for the United Nations Convention on Climate Change (UNFCCC) made by the Swedish Environmental Protection Agency (EPA). The analysis covers the ecosystem parts of agriculture, land use, land use change and forestry. A modification of the forestry section deals with the issue whether harvest of the forest is a removal or an emission. In the discussion, there are possible actions to limit the emissions and enhance the removals.

This analysis does not include other sources related to agriculture and forestry e.g. energy consumption, production of synthetic fertilizers and transportation since the focus is on the ecosystem processes. To provide a more complete picture of the business there is a synthesis in the discussion with another master's dissertation containing a carbon budget for Högestad (Agardh, 2007).

1.1 Background

1.1.1 The IPCC and the Swedish assignment to the Kyoto protocol

The Intergovernmental Panel on Climate Change[2] (IPCC) consists of over 2000 scientists that submit reports and prognoses about the climate. United Nations Environment Programme (UNEP) and World Meteorological Organization (WMO) set up the panel in 1988. The IPCC recognized the climate change as a real problem and, in 1992, the United Nations Framework Convention on Climate Change (UNFCCC) was ready. The convention is a non-binding

[1] www.hogesta.se
[2] www.ipcc.ch

document with the intention to stabilize the quantities of greenhouse gases at such levels that the climate change will not be harmful.

The Swedish Environmental Protection Agency (EPA) makes an annual submission of the emissions and trends regarding greenhouse gases according to the IPCC-guidelines. This National Inventory Report (NIR) is along with the CRF-tables (Common Reporting Format) of greenhouse gas emissions obligatory reporting for all members of UNFCCC.

The most important addition to the convention is the Kyoto protocol in 1997; this binding document states that the industrialised countries should together reduce emissions with 5 % to 2012 compared to the 1990-level. The European Union (EU) acts as one part in the agreement and has a joint responsibility to reduce emissions with 8 %. Within the EU, the sharing of the burden allows Sweden to *increase* the emissions by 4 %. Sweden's national goal[3] is however a *decrease* of 4 % without accounting for the removal in the LULUCF or using the flexible mechanisms within the Kyoto protocol. Sweden has also joined the long-term goal of the EU that global temperatures should not increase by more than two degrees. The new goal for EU is to cut the GHG emissions by 20 % to the year 2020 and 30 %, if the rest of the industrial countries join them. The Swedish government supports the EU goal. The Swedish parliament has approved a proposition that Sweden's GHG-emissions should be reduced by 25 % until 2020 compared to 1990-level. In December 2007, the United Nations had a climate change conference on Bali. The meeting was the starting point of the negotiations about an agreement that will replace the Kyoto protocol in 2012. The successor of Kyoto most likely contains far stricter demands on the countries and probably even stricter then the EU goal.

1.1.2 Greenhouse gas emissions from Agriculture and LULUCF

The two most important greenhouse gases in agriculture are CH_4 and N_2O. Important sources for CH_4 are the decomposition of carbohydrates in the stomachs of ruminants (enteric fermentation) and in manure management (Westin, 2007). Application of nitrogen to the soil in combination with limited access to oxygen can lead to N_2O emissions. Synthetic fertilizers, animal manure, nitrogen-fixing plants and crop residues are adding nitrogen to the soil. N_2O emissions also originate from manure management.

The sector of LULUCF contains estimates of greenhouse gas emissions and removals within four different land use-categories: forest, cropland, grassland and settlements. Forest is the most important category in the LULUCF-sector since it contains both the largest carbon stocks and the biggest stock changes. The most important removal is in the living biomass in the forest. Drainage of histosols is the largest source of CO_2 due to increased decomposition rate when access to oxygen increases. Biomass burning releases both CO_2 and CH4, but is not a very common practice in Sweden. N_2O is emitted when forests are fertilized and when land is converted to cropland (NIR, 2007).

2. Material and methods

The aim was to estimate the climate influence of a company in agriculture and forestry and to provide accurate information to the company. Thereby making it possible to take efficient actions to limit the GHG emissions. Estimates of emissions and removals from Agriculture and LULUCF are according to a locally adapted variant of the Swedish NIR (NIR, 2007). Alternative estimate of forest removal is considering the retention time of wood products. All results converted to CO_2-equivalents using *Global Warming Potential* in a 100-year perspective, GWP_{100}. The GWP depends on the efficiency as a greenhouse gas and the lifetime in the atmosphere. Hence, it is important to state the time horizon. For CH_4 this

[3] www.miljomal.nu

means multiplying the amount with 20 and N_2O with 310. CO_2 has a GWP of one by definition (Forster et al., 2007).

In addition to the study of literature, visits at Högestad and interviews with the staff[4] has contributed to gain understanding of the business and to provide facts for the estimates.

2.1 Delimitation of the study

The estimates are only regarding the three most important greenhouse gases: CO_2, CH_4 and N_2O and deal with the emissions on a yearly basis.

All the emission factors and the methodology in the section 2.2 and 2.3 are from the Swedish National Inventory Report (2007).

In this particular case, the object of study is the Högestad & Christinehof Estate, situated in the eastern Scania and one of the biggest landowners in the region. The estate consists of about 7000 ha of forest and about 6000 ha of agricultural land.

Removals and emissions from the agriculture are only estimated on the land that is managed by Högestad & Christinehof Förvaltnings AB, about 1600 ha, and not the land managed by leaseholders. H-C Förvaltnings AB manages all the forest.

2.2 Emissions in Agriculture

The emission factors used are from either national studies, studies performed in a country with similar climatic conditions or IPCC default values (NIR, 2007). All calculations are in an Excel-file and provided as an electronic appendix. Terms used in this section are summarised in the end of the section, see table 1. Facts from Högestad and a more explicit calculation of the emissions in agriculture are in the Appendix 1 and 2, see table 8 and 9. The CRF-code from the National Inventory Report makes it easy to connect the method with the result and tables in the appendix. The code is also convenient to get further information from the report.

2.2.1 Enteric fermentation CRF 4A

Bacteria active in the decomposition of mostly cellulose structures to carbohydrates produce methane (CH_4) e.g. in the stomach of grazers.

The emissions of CH_4 are as:

$$emissions = N_T \times EF_T$$

N_T = Number of animals in category T.

EF_T = Emission Factor for group T of livestock, based on energy intake and the methane conversion rate, e.g. cattle: 57 kg CH_4/head/yr

2.2.2 Manure management CRF 4B

CH_4 emissions from manure management

Methane emissions are also occurring in manure management and that includes excretion during grazing. The formula for the emissions is:

$$emissions = N_T \times EF_T$$

N_T = Number of animals in category T.

EF_T = Emission Factor, annual emission of methane from manure per head of livestock in category T, e.g. cattle:6,2 kg CH_4/head/yr

EF_T is more explicit:

$$EF_T = VS_T \times B_{0T} \times 0.67 \times \sum_{jk} MCF_{jk} \times MS_{Tjk}$$

[4] Charlotte Lindström, responsible for environmental issues at Högestad & Christinehof Förvaltnings AB.

VS_T = Volatile Substance excreted per year.
B_{0T} = Maximum methane production capacity for manure within the livestock group *T*.
MCF_{jk} = Methane Conversion Factor for the manure management system *j* in climate *k*.
MS_{Tjk} = Fraction of manure handled by system *j* in climate *k*.

N_2O emissions from manure management

Manure production, stable periods and the waste management system affect the emissions of N_2O as:

$$emissions = N_T \times Nex_T \times (365 - GrazPeriod) \times EF_{system} \times 44/28$$

N_T = Number of animals in category *T*.
Nex_T = Amount of N excreted per head by animals in category *T*.
GrazPeriod = Grazing period in days.
EF_{system} = Emission Factor for the used manure management system,
e.g. liquid manuresystem: 0,01 kg N_2O-N/kg N.

2.2.3 Agricultural soils, direct emissions CRF 4D1

N_2O emissions from agricultural soils derive mostly from N-fertilization. Other contributing factors are airborne nitrogen deposition, fixation by plants, excretion from grazing animals and the decomposition of crop residues.

N_2O from Synthetic fertilizers

N_2O Emissions originating from the breakdown of nitrogen compounds in synthetic fertilizers performed by bacteria in the soil:

$$emissions = N_{FERT} \times (1 - Frac_{GASF}) \times EF \times 44/28$$

N_{FERT} = Amount of applied nitrogen.
$Frac_{GASF}$ = 0.012, fraction of N from fertilizer that volatilises as ammonia, NH_3.
EF = Emission Factor, the amount of N emitted as N_2O, 0,008 kg N_2O-N/kg N.

N_2O from animal manure

The use of animal manure causes N_2O emissions that vary with (among other things) the grazing period:

$$emissions = N_T \times Nex_T \times (365 - GrazPeriod_T)/365 \times (1 - Frac_{GASM}) \times EF \times 44/28$$

N_T = Number of animals in category *T*.
Nex_T = Amount of N excreted per head by animals in category *T*.
GrazPeriod = Grazing period in days.
$Frac_{GASM}$ = 0.320, fraction of N from manure that volatilises as ammonia.
EF = Emission Factor, the amount of N emitted as N_2O, 0,025 kg N_2O-N/kg N.

N_2O from nitrogen fixing plants

Several kinds of plants can fix nitrogen. Examples are clover, peas and beans both grown in pure stands and in pasture grounds. The estimations here are **only** concerning leguminous plants grown as a part of the nutrient circulation in agricultural soils. Their adding of nitrogen to the soil causes N_2O emissions as:

$$emissions = area_{CROP} \times yield_{CROP\times} \times Nfraction_{CROP} \times EF \times 44/28$$

$Area_{CROP}$ = Area cultivated with specific crop.
$Yield_{CROP}$ = Yield of crop per area.
$Nfraction_{CROP}$ = Fraction of crop that consists of N.
EF = Emission Factor, the amount of N emitted as N_2O, 0,012 kg N_2O-N/kg N.

N_2O from crop residue

After the harvest, crop residues left in the fields decompose and add nitrogen to the soil, which causes emissions:

$$emissions = yield_{CROP} \times area_{CROP} \times Fracr_{CROP} \times FracN_{CROP} \times (1 - Fracrem_{CROP}) \times EF \times 44/28$$

$Fracr_{CROP}$ = Fraction of total yield consisting of crop residue.
$FracN_{CROP}$ = Fraction of crop residue consisting of N.
$Fracrem_{CROP}$ = Fraction of crop residue removed from the fields.
EF = Emission Factor, the amount of N emitted as N_2O, 0,012 kg N_2O-N/kg N.

N_2O from cultivation of organic soils

Background emission is present when cultivating both mineral and organic soils. The emissions from organic soils are:

$$emissions = area \times EF$$

Area = Area of cultivated organic soil.
EF = Emission Factor, amount of N_2O emitted per area, 8,0 kg kg N_2O-N/ha.

2.2.4 Agricultural soils, animal production CRF 4D2

N_2O emissions from pasture, range and paddock manure

Animals grazing excrete nitrogen, and the emissions are:

$$emissions = N_T \times Nex_T \times GrazPeriod_T / 365 \times (1 - Frac_{GASG}) \times EF_T \times 44/28$$

N_T = Number of animals in category *T*.
Nex_T = Excretion of nitrogen per head.
$GrazPeriod_T$ = Grazing period in days.
$Frac_{GASG}$ = 0.320, fraction of N excreted that volatilises as ammonia.
EF_T = Emission Factor, fraction of N emitted as N_2O by livestock in category *T*,
0,016 kg N_2O-N/kg N.

2.2.5 Agricultural soils, indirect emissions CRF 4D3

Atmospheric deposition

Atmospheric deposition of ammonia from the immediate surrounding has three origins: fertilizer, manure and grazing. They cause emissions of N_2O:

$$emissions = (N_{FERT} \times Frac_{GASF} + N \times Nex \times Frac_{GASM} + N \times Nex \times Frac_{GASG}) \times EF \times 44/28$$

N = Number of livestock.
Nex = Amount of N excreted.
EF = Emission Factor, the amount of N emitted as N_2O, 0,010 kg N_2O-N/kg N.

Nitrogen leaching and run off

Nitrogen leaching in the form of ammonia also causes emissions of N_2O.

$$emissions = area \times leachfactor \times EF \times 44/28$$

leachfactor = 0.230, amount of N leaching from the soil.
EF = Emission Factor, the amount of N emitted as N_2O, 0,025 kg N_2O-N/kg N.

Cultivation of mineral soils

Background emission of N_2O is present when cultivating both mineral and organic soils. The emissions from mineral soils are:

$$emissions = area \times EF$$

area = Area of cultivated mineral soil.
EF = Emission Factor, amount of N_2O emitted per area, 0,50 kg kg N_2O-N/ha..

2.2.6 Uncertainty estimate for agriculture

Uncertainties are reported in the form of two relative standard error. The uncertainties in the reported emissions from the agricultural sector are among the largest contributors to the total uncertainty in the NIR. Examples are direct N_2O emissions from agricultural soils with an uncertainty at about 80% and N_2O from manure management with about 50 %. The uncertainties are combining uncertainties in activity data and emission factors. Generally, estimates of uncertainty are from the same source as the emission data. Uncetainties can also be from similar statistics or some times rough estimates of experts when other information is lacking.

Table 1. Terminology used in the agriculture part of the estimates.

Terms in alphabetic order	
$Area_{CROP}$	Area in hectare.
B_{0T}	Maximum methane production capacity for manure within the livestock group *T*.
EF	Emission Factor specific to each estimation.
EF_{system}	Emission Factor for the used manure management system
EF_T	Emission Factor for group *T* of livestock.
$Frac_{GASF}$	Fraction of N from fertilizer that volatilises as ammonia, NH_3.
$Frac_{GASG}$	Fraction of N excreted that volatilises as ammonia.
$Frac_{GASM}$	Fraction of N from manure that volatilises as ammonia.
$FracN_{CROP}$	Fraction of crop residue consisting of N.
$Fracr_{CROP}$	Fraction of total yield consisting of crop residue.
$Fracrem_{CROP}$	Fraction of crop residue removed from the fields.
GrazPeriod	Grazing period in days.
leachfactor	Amount of N leaching from the soil.
MCF_{jk}	Methane Conversion Factor for the manure management system *j* in climate *k*.
MS_{Tjk}	Fraction of manure handled by system *j* in climate *k*.
Nex_T	Amount of N excreted per head by animals in category *T*.
N_{FERT}	Amount of applied nitrogen.
$Nfraction_{CROP}$ =	Fraction of crop that consists of N.
N_T	Number of animals in category *T*.
VS_T	Volatile Substance excreted per year by animals in category *T*.
$Yield_{CROP}$	Yield in kg/ha.

2.3 Emissions/Removals in Land Use, Land Use Change and Forestry, LULUCF CRF 5

A summary of the terminology in this section is found in the end of the section, see table 2. Facts from Högestad about land use and forestry are in the Appendix 1, see table 8. The calculations in the Excel-file are provided electronically and in table 10 in the Appendix 3.

2.3.1 CO_2 emissions from carbon balance in Forest, Cropland, Grassland and Settlements CRF 5A, 5B, 5C, 5E

Sweden has chosen a national carbon pool method for estimating the carbon balance instead of the IPCC-default. Regularly monitoring about 18000 plots and measuring the living biomass, the dead wood and the soil organic carbon pool. Modelling replaces measurements in some cases, for example the soil organic carbon content in cropland. Estimate of the living biomass pool in the land use category *Forest* only includes biomass from trees more than 1.3 m high. The *annual net change* is the sum of these pools. The IPCC-default method bases on harvest figures. Categories 5D and 5F (wetlands and other land) are not considered managed and therefore not reported by Sweden.

Land use transfers can cause changes in the carbon stocks for a long time e.g. forest converted to cropland means carbon loss from the soil carbon pool due to increased decomposition and from decreased living biomass pool. A category of land converted to a different land use is in the conversion class for 20 years.

$$emission / removal = area \times netchange$$

area = Area of specific land use.
netchange = Net change in the three carbon pools per area.

2.3.2 CO_2 emissions from biomass burning

Contains information about the biomass carbon being burned in both controlled and wildfires. Fires assumed to take place on Forest remaining forest and on Grassland remaining grassland.

$$emissions = A \times EF$$

A = Annual burned area.
EF = Amount of carbon dioxide emitted per area burned, 15 Ton CO_2/ha.

2.3.3 CO_2 emissions from agricultural lime application

The carbon dioxide emissions calculated according to the formula:

$$emissions = (M_{LIME} \times EF_{LIME} + M_{DOL} \times EF_{DOL}) \times 44/12$$

M = Amount of either limestone or dolomite that is applied.
EF = Amount of carbon emitted as CO_2 per ton limestone or dolomite, e.g 0,12 Ton C/Ton of limestone

2.3.4 N_2O emissions from N-fertilization of forest

The application of synthetic fertilizer leads to emissions of N_2O originating from the breakdown of nitrogen compounds (denitrification) in synthetic fertilizers performed by bacteria in the soil:

$$emissions = F_{SYNT} \times EF \times 44/28$$

F_{SYNT} = Amount of nitrogen from applied synthetic fertilizer.
EF = Emission Factor, the amount of N emitted as N_2O, 0,011 kg N_2O-N/kg N.

2.3.5 N_2O emissions from disturbance at conversion to cropland

The conversion of land use to cropland causes a more rapid decomposition in the soil and the content of mineralised nitrogen increases. The fraction of that nitrogen emitted as N_2O is:

$$emissions = area_{CONV} \times EF \times 44/28$$

$area_{conv}$ = Area of land converted to cropland.
EF = Emission factor, 2,5 kg N2O-N/ha.
More in detail:

$$emissions = \Delta C_{MIN} \times \frac{1}{C:N_{RATIO}} \times EF \times 44/28$$

C_{MIN} = Annual emission of carbon due to soil mineralization.
C: N_{RATIO} = Ratio between carbon and nitrogen in the soil.

2.3.6 CH_4 emissions from biomass burning

Living and dead biomass burning on *Forest remaining forest* and on *Grassland remaining grassland* leads to emissions of CH_4 according to:

$$emissions = area_{FOREST} + EF_{FOREST} + area_{GRASS} \times EF_{GRASS}$$

area = Area of forest or grassland burned.
EF = Emissions per hectare of Mg CH_4, e.g. 0,066 Ton CH_4/ha.

2.3.7 Uncertainty estimate for LULUCF

Uncertainties are reported in the form of two relative standard errors. In the LULUCF part the figures are based on 18 000 surveyed plots and the uncertainties are statistically calculated and two standard errors are used in the reporting. In the Land Use and Land Use Change there are three different uncertainties, one for each carbon pool that has been combined in this work by using the share of each pool.

Table 2. Abbreviations used in the LULUCF part of the estimates.

Abbreviations in alphabetic order.	
A	Annual burned area.
$area_{conv}$	Area of land converted to cropland.
C_{MIN}	Annual emission of carbon due to soil mineralization.
C: N_{RATIO}	Ratio between carbon and nitrogen in the soil.
EF	Emission Factor specific to each estimation.
F_{SYNT}	Amount of the applied synthetic fertilizer nitrogen.
M	Amount of either limestone or dolomite that is applied.
netchange	Net change in the three carbon pools per area.

2.4 Estimates of the forest removal including harvested wood products

The method suggested here is a simple addition of the carbon stored in *harvested wood products* (HWP) to the result of the carbon pool method used in the NIR. Carbon stored in long-lived wood products such as buildings assumed to be out of the carbon cycle for 100 years (Houghton et al., 1983). With this carbon pool in the picture, it is clearer to a landowner how the purpose of the harvested wood affects carbon storage. The calculation is in the provided Excel-file and on paper, (Appendix 3, table 11).

The IPCC default assumption is that all HWP are oxidised within a year and that the change in the HWP carbon pool is small. Now there is some information about increasing carbon stocks in harvested wood products and suggestions to incorporate these in the national inventories somehow (Tonn & Marland, 2007). According to the *IPCC Good Practice Guidance,* there is such a possibility if the country can show increasing carbon pools. In the *IPCC Good Practice Guidance, 2003,* there are several methods suggested that incorporates import, export, wood used for fuel, paper, buildings etc. but the IPCC also opens for country specific methods if they are adequate.

Houghton et al. (1983) suggested that the retention time of products from forestry is important to estimate storage of carbon in the product pool. Houghton used three product categories. Category number one was the saw log with a retention time of 100 years meaning an annual emission of one percent. Number two was the paper with a ten-year retention time, thus an annual emission of ten percent. Category three was the one-year pool, which is already included in the estimate according to the Swedish national method. In this work, all the harvest for pulp and paper, about 60 %, considered an emission because of the relatively short retention time that causes a large debt from the past ten years. All the harvest for saw log considered a removal because the focus is on the present effect on the climate and not the very long-term. Estimates based on facts from Högestad about the harvested amount for each purpose. Assumptions that density is 0.5 and the carbon content is 50 % of the dry weight biomass are IPCC default.

$$removal = harvested\_volume \times density \times carbon\_content \times conversion\_factor$$

3. Results

All results displayed in ton CO_2-equivalent following the concept of GWP 100. The Excel-file provided is part of the results and designed for landowner use. For comparison is the annual emission per capita in Sweden 7.8 Ton CO_2-eq/yr according to the Swedish EPA[5].

3.1 The NIR based estimate

Estimates of the emissions and removals from the agricultural (tab 3) and the LULUCF sector (tab 4), including CRF-codes and uncertainties according to Sweden's NIR 2007. The uncertainties are, as mentioned in the method, combined of uncertainties in the activity data and in the emission factors.

Table 3. Emissions in agriculture according to Swedish NIR-methodology (summary of Table 9 in Appendix 2).

Source	CRF	Emission/Removal (Ton CO_2-eq/yr)	Uncertainty (%)
Enteric fermentation	4A	518	25
Manure management	4B	41418	54
Direct soil emissions	4D1	1749	71
Pasture, range and paddock manure	4D2	252	71
Indirect emissions	4D3	271	71
Other	4D4	303	71
	Total	**44511**	**54**

Table 4. Emissions and removals in LULUCF according to the Swedish NIR-methodology, also in table 10 Appendix 3.

Source	Area (ha)	Net change (Ton C/ha/yr)	Conversion C> CO_2	Emission/Removal (Ton CO_2-eq/yr)	Uncertainty %
Forest 5A	6983	-0,017	3 2/3	-435	40
Cropland 5B	1312	0,386	3 2/3	1857	40
Grassland 5C	284	-1,529	3 2/3	-1592	40
			Total	**-170**	**40**

[5] http://www.naturvardsverket.se/sv/EU-och-Internationellt/EU-arbetet-i-Naturvardsverket/EEA-bevakar-Europas-miljo/Belgradrapporten--Sverige-i-jamforelse/Klimatforandringar/

3.2 Removal including harvested wood products

Table 5 shows the net removal from LULUCF accounting for carbon stored in harvested wood products.

Table 5. Emissions and removals in LULUCF including harvested wood products, also in table 11 Appendix 3.

Sink	Volume (m3 solid i.b.)	Density (g/cm3)	C content (g/g)	Conversion C> CO_2	Removal (Ton CO_2-eq/yr)	Uncertainty %
Saw log	19670	0,5	0,5	3 2/3	-18031	8[6]
Removal acc. to NIR					-170	40
				Total	**-18201**	**9**

3.3 Summary of the results

Table 6. Net emissions with the two different methods used.

Method	Net emission (Ton CO_2-eq/yr)	Uncertainty (%)
Based on NIR	**44341**	**54**
Including HWP	**26310**	**41**

4. Discussion

The dominant source is emissions related to manure management, but enteric fermentation and the use of synthetic fertilizer contributes significantly. Changed manure management system and increased precision in nitrogen fertilizing suggested. Removal in forest is small with the carbon pool method, used in the national inventory, and this initiates a discussion about including some of the carbon stored in the harvest. Surprisingly the removal in grassland was larger than in forest. Carbon loss from cropland is large but is thought to be overestimated. Disturbance at minimum and enhanced growth can reduce the emissions and increase the removal. Earlier work on factors not estimated in this study e.g. fuel consumption and transports performed on Högestad is included in the discussion to give a more complete picture.

4.1 Agriculture

More than 90 % of the emissions are N_2O originating from manure management. The animal waste management system is the reason why this is so dominating. Handling the manure from 105 cattle on Högestad in a deep litter system causes large N_2O emissions. It causes 20 times more than handling in a liquid manure system. A liquid system handles the manure from the remaining 253 cattle. The deep litter and the liquid manure system stand for circa 80 % and 10 % respectively of the total emissions from agriculture.

The direct soil emissions stand for about 4 % and the biggest source in that is N_2O from the application of synthetic fertilizers. Animal manure as fertilizer causes another large part of the direct soil emissions.

4.1.1 Management options

The change from deep litter to a liquid manure system could reduce the agricultural emissions with about 75 % due to the twenty times smaller N_2O emissions. Capped slurry containers suggested to reduce CH_4 emissions that otherwise could increase (Jordbruksverket,

[6] Uncertainty according to the Timber Measurement Association of South Sweden www.vmfsyd.se

2004). Capped slurry containers are common in Sweden to reduce the ammonia emissions but often with a porous lid of chopped straw. The chopped straw permits air to reach the manure, which could lead to N_2O emissions. Thus, the recommendation is a solid lid.

Increased efficiency in the application of N to the soil can reduce N2O emissions. The emission factors used for N_2O are constant, but modelling has showed that the emission factor increases rapidly when the applied amount exceeds the plants demand (Grant et al., 2006). In addition, other factors e.g. high soil water content creates the right conditions for N_2O production. Timing with both weather conditions and plant demand are crucial to reduce the emissions. Economic reasons and prevention of nutrient leakage promotes high precision in nitrogen application as well.

An alternative way to handle the manure and to decrease both CH_4 and N_2O emissions could be through a farm-based biogas production (Jordbruksverket, 2004). This animal waste management system has the following advantages. Reduced N_2O emissions due to the limited access to oxygen. Decreased CH_4 emissions that require prevention of gas leakage. Higher content mineralized N in the produced fertilizer, which can lead to better precision in the N-application to the soil and finally the methane, can also be an energy resource (Svensson et al., 2005). GHG emissions from undigested manure than from digested can be almost twice as a high (Amon et al., 2006). Eighteen per cent of Högestads agriculture is organic and uses no synthetic fertilizers or pesticides. A common practice to replace synthetic fertilizers in organic farming is green manuring. This is the ploughing down of crop residues for nutrient recirculation and is common when lacking animal manure. Green manuring could cause leaching of nitrogen though the plants do not take up nitrogen in organic compounds so easy. Digesting crop residues in a biogas reactor, makes the nitrogen more easily accessible for plants and the yield in organic farming can increase (Gunnarsson et al., 2005).

Another very direct action to reduce N_2O and CH_4 emissions is to reduce the number of ruminants; alternatively increase productivity per intake or change the intake (Jordbruksverket, 2004).

To increase the carbon content in agricultural soils there are two ways; either the decomposition rate is decreased or the input of carbon is increased. No-till management can reduce the decomposition and more perennial plants and increased used of stable or green manure can increase the carbon input (Paustian et al., 2000).

4.2 LULUCF

With the NIR-based method, the removal is only 435 Ton CO_2-eq/yr from almost 7000 ha of forest. There are two likely causes for this rather small uptake. First, the carbon pool method implies that all carbon in harvested wood is back in the atmosphere within one year and secondly loss in the soil carbon pool largely offsets uptake in the living biomass pool.

Assuming no storage in harvest together with harvesting most of the growth makes the removal small in the forests living biomass pool. The storage in harvested wood products can be substantial. According to estimates of European carbon storage, 8 % is stored in wood products (Janssens et al., 2003). The alternative method, suggested in this study, considering everything harvested for long-lived wood products an uptake, makes the annual removal 18 201 Ton CO_2-eq. The method is one way to estimate the removal embedded in the harvested wood products. The atmosphere receives carbon stored in wood products from harvest earlier years now. To give a somewhat realistic picture of the removal, large quantities of the wood products already in circulation must be recycled. The next coming decades are a crucial period in mitigating climate change and therefore it might be interesting to look at the storage in HWP in this time perspective. There is political interest to be able to use more of the ecosystem carbon sinks to achieve reduced emissions, but this option is very limited. Estimates show that storage in European ecosystems is only 7-12 % of the emissions

(Janssens et al., 2003) and might be as small as 1.9-2.9 % during this decade (Zaehle et al., 2007).

In the national inventory, great loss of carbon from the soil largely offsets uptake in the living biomass pool. The values in the study are national means and losses are mostly emissions from forests on drained histosols. 5 % of Swedish forestry is on drained histosols (NIR, 2007) while Högestad have no forests on this type of soil, this probably makes the net uptake larger per area than the national average. Assuming carbon loss from soil in Högestads forest is negligible would make the removal in the forest about ten times larger or circa 4000 Ton CO_2-eq/yr.

In relation to the uptake in the forest, there is a net loss of 1857 Ton CO_2-eq from the cropland despite the smaller area of some 1300 ha. 9 % of the cropland in Sweden is drained histosols (NIR, 2007) while only 5 % of Högestads. The lesser proportion of histosols probably leads to an overestimation with possibly up to 100 % of the carbon loss from cropland. Janssens et al. (2003) estimate the net uptake in European forests to 0.363 Gt C/yr while the carbon loss in cropland is 0.300 Gt C/yr, a result that supports that carbon loss from land use can be significant.

Grasslands covering only 284 ha take up 1592 Ton CO_2-eq. Janssens et al. (2003) support that grasslands can be a significant sink and estimate the carbon removal in European grasslands to 0.100 Gt C/yr compared to the forest uptake of 0.363 Gt C/yr.

Storage in European terrestrial ecosystems is limited and predicted to decline in the future, but still it is important to promote uptake and reduce carbon losses. Present-day estimates show storage of 7-12 % of the annual emissions (Janssens et al., 2003). Estimates of future carbon storage show that the terrestrial ecosystems in Europe will store only 1.9-2.9 % of European CO_2-emissions between 1990-2100 (Zaehle et al., 2007). The increased decomposition rate in the second half of the twenty-first century may almost offset the increased productivity caused by CO_2-fertilization and climate change (Zaehle et al., 2007). Some of the main points in climate mitigation through forestry are maintained or increased forest area through reduction of deforestation and through afforestation. Forests preservation achieved through longer forest rotation and disturbance control. Increasing the living biomass, increasing carbon storage in harvested wood products and replacing fossil fuels with bio energy (Nabuurs et al., 2007).

4.2.1 Management options

At least two carbon pools are of importance when discussing enhancement of carbon storage in forests and other terrestrial ecosystems. The long-term sequestration in the soil carbon pool is the most difficult to affect through management. In the short-term perspective, it is the living biomass pool, especially important in forests, that is possible to affect. Because input to the soil carbon pool comes from the living biomass pool via the dead biomass pool there is of course strong linkage between them.

It is hard to determine in a general way what effect a certain management practice will have on carbon sequestration in soil. Jandl et al. (2007) thoroughly examined the experimental evidence for the effects of forest management practices. The main conclusions are that high production guarantees a large input of litter to the soil and a small degree of disturbance can reduce the carbon loss. Disturbances are e.g. harvest, thinning, soil preparation for planting, fires and pests. Stabilization of carbon in the soil is a long-term process and the effects of present management and historic is difficult to separate.

Management practices are more rapidly affecting the living biomass pool. Adding nutrients is one example. Nitrogen limited growth in most of the Swedish forests before the industrialization and still is in the northern part. A study of optimised fertilization of Norway spruce in northern Sweden, showed that the annual production of biomass increased by a factor three and that the respiration from the soil *decreased* (Olsson et al., 2005). This means that carbon storage increased both in the standing tree biomass and in the soil. In the southern parts of Sweden, where Högestad is situated, the situation is different. Because there are substantial deposition of nitrogen and acidifying substances, nitrogen is no longer limiting. However, the acidification combined with the large growth and outtake have made other nutrients (Ca, Mg, K and P) limiting (Sverdrup et al., 2006). Fertilization with ashes to maintain a high production can be a good alternative since ashes contain the desired nutrients but are nitrogen poor. This is an advantage though the adding of nitrogen to the forest can lead to emissions of N_2O.

Storage can be significant in long-lived wood products and it can be of importance in mitigating climate change in the time perspective of the coming decades. Reduced and later thinning would increase the storage in standing biomass and leaving more trees to reach mature age and harvest for saw log. For a local landowner it has to be economically viable and that in turn depends on the market demand for such products.

4.3 The overall picture

Emissions from agriculture are dominating the picture and removal in forest is almost negligible in comparison. Including storage in HWP as suggested would increase the estimated uptake significantly. Delimitation of the study is the sectors of agriculture and LULUCF as defined by the IPCC, but sources outside these sectors can be important in the analysis.

A company with business in agriculture and forestry causes emissions of GHG in several other sectors. To provide a more complete picture of the climate effects of Högestads business the ecosystem processes have to be completed with the more technical aspects. In this case, that means; fuel consumption in both agriculture and forestry, energy consumption for heating and electricity at the farm, production and transports of products used within the estate and transports of the staff. All of the above estimated in a master's dissertation presented in 2007 (Agardh, 2007), see table 7.

Table 7. CO_2 emissions on Högestad estimated by Agardh (2007)

Source	Emission (Ton CO_2-eq /yr)	Reliability
Transport of products	2679	+
Production of synthetic fertilizer	1400	-
Fuel consumption, agriculture, forestry	708	++
Electricity	81	+
Transport of staff	37	++
Waste incineration	6	+
Production of pesticides	5	-
Heating	3	+
Total	**3520**	

The diagram below illustrates the estimated emissions and removal from both this study and the study by Agardh (2007). Agriculture is still the largest source with manure management absolutely dominating. Direct emissions mostly from application of synthetic fertilizer are the second largest in agriculture and emissions from cropland are almost as much. The dominant part of the emissions estimated by Agardh (2007) consists of transports outside the estate of for example synthetic fertilizer, pesticides and seed. The second largest is emissions related to production of synthetic fertilizers. Agardh´s study only focused on the CO_2 emissions associated with the production of synthetic fertilizer but corresponding amounts of N_2O (in

CO_2-eq) are also emitted according to manufacturer[7]. This would make emissions from fertilizer production of the same size as import and export of products to the estate. The third biggest are emissions from consumption of fossil fuels in machinery in agriculture and forestry.

Without considering carbon storage in harvested wood products, the removal in LULUCF is very small. The source of CO_2 from cropland almost offsets both the removal in forest and grassland.

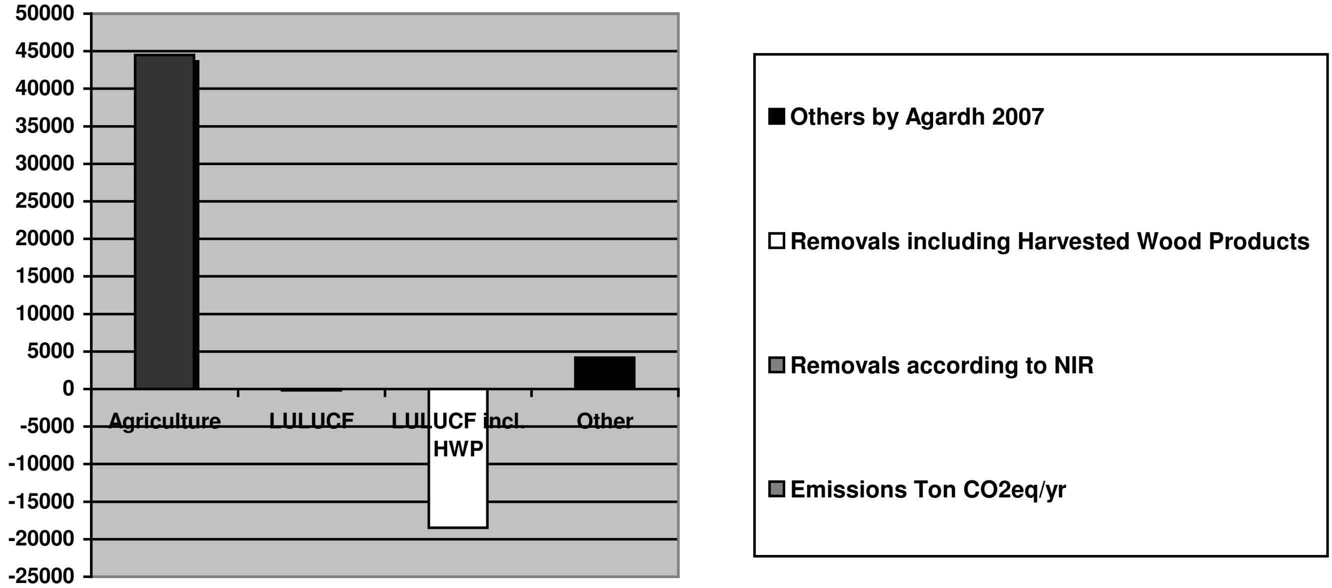

Figure. 1 Emissions and removals at Högestad.

Widening the analysis further could include production and transports of a variety of products used in agriculture and forestry. The processes involved can be analysed through the used energy. Assuming that the energy consumed corresponds to the same amount of energy in diesel. Then the consumed diesel is translatable to emissions. Nilsson et al. (2006) estimates the consumed energy in producing and transporting a tractor to be corresponding to 1.92 litres of diesel per kilogram. Högestad has roughly 80 000 kg tractors with an average age of 16 years. The amount of energy in the machinery corresponds to consuming 9600 l diesel annually. With an emission factor of 2,540 kg CO_2/l that would be about 24 Ton CO_2-eq. Comparably small but valuable information when considering purchase of new machinery to reduce fuel consumption. In a global perspective, emissions related to the ore mining for making machinery can be relevant. Transports and refining of oil for fuel and synthetic fertilizers have not been estimated but certainly have its place when comparing the fossil-based products with bio fuel and stable manure.

[7] http://fert.yara.se/se/our_commitment/sustainability/our_environmental_goals/non_polluted_production.html
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5. Conclusions

This study shows the most important processes that account for the loss or uptake of GHG in farming and forestry companies in southern Sweden. Identifying these processes can help focusing efforts for climate change mitigation. Changed manure management could achieve very substantial emission reduction, in the case of Högestad. The magnitude of the forest uptake depends crucially on the way of accounting for the harvested biomass. Minimizing disturbance and maximizing the standing biomass are the most important ways of increasing carbon storage in the forest. Soil characteristics are important when estimating forest uptake from national means. The amount of histosols largely decides if the method is applicable.

Estimates show that manure management is the most important source in agriculture. Changing the deep litter system to a liquid manure system could reduce the emissions from agriculture with 75 %. Processing all manure in a biogas reactor could reduce the GHG emissions by 50 % (Amon et al., 2006). The precision in the fertilization would probably increase because of the more accessible nitrogen compounds in the processed manure and this could lead to reduced direct soil emissions of N_2O. Present machinery converted to biogas would reduce another large part of the total emissions. The emissions from agriculture and related industries mostly consist of N_2O and CH_4 and it would be relevant to include also these gases in the trading system for rights of emissions within the EU.

Considering all harvest an emission makes the removal in the forest surprisingly small because most of the growth harvested, in Högestads case 99.5 %. Emissions from drained histosols largely contribute to offsetting the remaining net uptake on a national scale. Högestad has less histosols than the national average and thus the removal is underestimated. Considering the saw log an uptake makes the removal in the forest forty times larger. Possible ways to increase carbon storage: Changed thinning routines, fertilization, reducing disturbance and grow forest for saw log instead of paper.

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Appendix 1

Table 8. Facts from Högestad & Chrisitinehof Förvaltnings AB

Category	Description	Amount
Agriculture		
	Livestock	**(nr)**
	Cattle non-dairy	358
	Wild boar (Swine)	250
	Fallow dear (Reindeer)	502
	Agricultural soils	**(ha)**
	Cropland	1312
	(mineral soil	1246)
	(organic soil	66)
		(kg N)
	Synthetic fertilizer	51563
	Solid manure	59856
	(cattle	3306)
	(poultry	56550)
	Liquid manure, cattle	4092
	Silt from sugar mill	4672
Land Use Land Use Change and Forestry		
	Land use	**(ha)**
	Forest	6983
	Cropland	1312
	Grassland	284
	Forestry	**(m^3 (solid i.b.))**
	Harvest	33811
	(saw log	19670)
	(paper	28344)
	(splinter	1862)

Appendix 2.

Table 9. Emissions in agriculture according to Swedish NIR-methodology.

Source	**Description**	**Amount**		**Emission factor**			**Conversion**	**Conversion**	**Emission**	**Emission**
Enteric	**CRF 4A**			**(kgCH_4/head/yr)**					**(kg CH_4/yr)**	**(Ton CO_2-**
fermentation		**(nr)**								**eq/yr)**
cattle	non-dairy	358		57,010					20409	429
swine	wild boar	250		1,500					375	8
reindeer	wild deer	502		7,700					3865	81
Manure	**CRF 4B**									
management										
cattle	non-dairy	358		6,219					2226	47
swine	wild boar	250		3,360					840	18
reindeer	wild deer	502		0,190					95	2
			N excreted	**Grazing**						
			(kgN/head/yr)	**period (days)**			**(kg N_2O-N/kgN)**	**(N>N_2O)**	**(kgN_2O/yr)**	
cattle	liquid manure	253	185,000	170			0,001	1 4/7	14342	4446
cattle	deep litter	105	185,000	170			0,020	1 4/7	119047	36905
Agricultural soils CRF 4D										
Direct soil emissions 4D1		**(kg N)**		**Fracgasf**						
	synt.fert	151563		0,012			0,008	1 4/7	1882	584
		(nr)								
	cattle	358	170	185,000			0,025	1 4/7	945	293
	poultry	46375	0	1,200			0,025	1 4/7	1510	468
		Area (ha)	**Yield (kg/ha)**	**Fracres**	**Fracresrem**	**FracN**				
	crop residues	1109	14128	0,800	0,900	0,020	0,012	1 4/7	472	147
	cultivation						**(kgN_2O-N/ha)**			
	of histosols	66					8,000	1 4/7	830	257
Pasture,range and paddock			**N excreted**	**Grazing**		**Fracgasg**	**(kg N_2O-N/kgN)**			
manure 4D2		**(nr)**	**(kgN/head/yr)**	**period (days)**						
cattle	non-dairy	358	185,000	170		0,320	0,016	1 4/7	528	163
swine	wild boar	250	1,500	365		0,320	0,016	1 4/7	200	62
reindeer	wild deer	502	7,700	365		0,320	0,016	1 4/7	86	27
Indirect emissions 4D3		**N-fertilizer(kg)**	**N excreted(kg)**	**Fracgasf**	**Fracgasm**					
atmospheric deposition		151563	82950	0,012	0,320	0,320	0,010	1 4/7	863	267
		Area (ha)	**leachfactor**							
N-leaching and run-off		1312	0,230				0,025	1 4/7	12	4
							(kgN_2O-N/ha)			
Other 4D4 mineral soil cultivat.		1246					0,500	1 4/7	979	303
									Total	**44511**

Appendix 3.

Table 10. Emissions and removals in LULUCF according to Swedish NIR-methodology.

Source	**Amount**	**Emission Factor**	**Conversion**	**Conversion**	**Emission/ Removal**
LULUCF CRF 5	**(ha)**	**Ton C/ha**		**C>CO_2**	**(Ton CO_2-eq/yr)**
Forest CRF 5A					
remaining forest	6983	0,017	-1	44/12	-435
Cropland CRF 5B					
remaining cropland	1312	-0,386	-1	44/12	1857
Grassland CRF 5C					
remaining grassland	284	1,529	-1	44/12	-1592
				Total	**-170**

Table 11. Removal incuding Harvested Wood Products (HWP).

	Volume	**Density**	**Carbon content**	**Conversion**	**Conversion**	**Removal**
	(m^3 solid i.b.)	**(g/cm^3)**	**(g/g)**		**C>CO_2**	**(Ton CO_2-eq/yr)**
HWP	19670	0,5	0,5	-1	44/12	-18031
NIR-methodology						-170
					Total	**-18201**

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