REPORT

The climate impact of energy peat utilisation – comparison and sensitivity analysis of Finnish and Swedish results

Kristina Holmgren, Johanna Kirkinen & Ilkka Savolainen
B1681
2006-06-16

The report approved
2006-06-16

Lars-Gunnar Lindfors
Scientific Director

IVL Swedish Environmental Research Institute

Organisation

IVL Swedish Environmental Research Institute Ltd.

Address

P.O. Box 21060
SE-100 31 Stockholm

Telephone

+46 (0)8-598 563 00

Report Summary

Project title

The climate impact of energy peat utilisation – comparison and sensitivity analysis of Finnish and Swedish results

Project sponsor

Swedish part: Swedish Energy Agency, STEM and Swedish Peat Producers Association
Finnish part: Ministry of Agriculture and Forestry

Authors

Kristina Holmgren Johanna Kirkinen & Ilkka Savolainen

Title and subtitle of the report

The climate impact of energy peat utilisation – comparison and sensitivity analysis of Finnish and Swedish results

Summary

See the report for summary in English, Swedish and Finnish respectively.

Keyword

Peat, climate change, climate impact, radiative forcing, energy production, greenhouse gas emission, carbon dioxide, methane, nitrous oxide, life cycle analysis, coal

Bibliographic data

IVL Report B1681

The report can be ordered via

Homepage: www.ivl.se, e-mail: publicationservice@ivl.se, fax+46 (0)8-598 563 90, or via IVL, P.O. Box 21060, SE-100 31 Stockholm Sweden

Summary

The climate impact of energy peat utilisation have been studied both in Finland by VTT Technical Research Centre and in Sweden by IVL Swedish Environmental Research Institute Ltd. The main objective of this study is to compare the results of earlier studies by VTT and IVL and to perform a sensitivity analysis of previous and new results.

The scientific approach of the two studies is very similar. The climate impact of peat utilisation is considered from a life-cycle point of view by taking into account all phases of the peat utilisation chain (peat production, storing, transport, combustion and after-treatment of the peat production area). Peat reserves can be both sinks and sources of greenhouse gas emissions as well as there are both uptake and emissions of greenhouse gases during the utilisation chain. Both sinks and sources are considered in the calculations. The net impact of the utilisation chain is assessed as the climate impact due to the utilisation chain minus the climate impact of non-utilisation chain (i.e. the reference scenario where the peat reserve is left in its initial state).

The calculation methodology of the climate impact of energy peat utilisation is similar in the Swedish and the Finnish study. The instantaneous radiative forcing and accumulated radiative forcing are used in both studies as the indicator of the climate impact. Radiative forcing is calculated on the basis of the concentration changes due to emissions and uptake of greenhouse gases. The differences in the models for calculating concentrations and radiative forcing are minor.

There are some differences in the definitions and boundaries of the considered peat utilisation chains, although the differences in the results due to differences in the chain definitions are small. The main reason for the differences in results between the two studies is differences in emission (and uptake) estimates for the after-treatment phase and the non-utilisation chain (i.e. reference scenario).

There are many similarities between the results of Swedish and Finnish studies. Both Swedish and Finnish studies show that the use of cultivated peatland for energy peat utilisation results in lower climate impact than using coal (within 100 years). Both studies show that the use of pristine mires for peat production will result in larger climate impact than the use of already drained peatlands.

The climate impact of peat utilisation chains where fens and forestry-drained peatlands are used for peat production differs between the Finnish and the Swedish study. In the Finnish study average emission and uptake estimates for Finland based on the national measurement programme were used (variation ranges are used to consider the differences between regions). In the Swedish study emission estimates based on Swedish measurements were used. The Swedish results show lower climate impact than the Finnish results mainly due to different emission estimates for after-treatment and reference situation. The large differences in emissions estimates for forestry drained peatlands are not fully known. Explanations suggested are different management methods (ditching practices) and more southern location of Swedish sites. There might also be differences in the methodologies used for estimating the peat decay rates. The differences in emission estimates for forestry drained peatlands will have to be investigated further since in Finland forestry drained peatlands are the most commonly used peatlands and also in Sweden these areas are of great importance.

In the calculations made in this study we used a range of emissions estimates when calculating the uncertainty. Note that these uncertainty estimates show the range within which the climate impact of a certain peat utilisation chain lay. The size of the range depend both on uncertainty in the emission estimates and in natural variation of the emissions between different types of peatlands.

The size of the range also depends on how much the greenhouse gas emissions from the surrounding area (surrounding the peat cutting site) are affected by the drainage. The largest uncertainties of emission estimates is identified for the forestry drained peatlands (initial phase) and restored areas. There is also large variation in the emission estimate of cultivated peatlands, which has considerable impact on the total radiative forcing of the production chains.

The greenhouse impact of peat production (i.e. from cutting field, machinery, storage, ditches etc) and combustion is the most well known of the phases. The relative uncertainty of this phase is the smallest. The main part of the uncertainty arises from the emissions and uptake of after-treatment and non-utilisation chain (initial conditions at peat reserves).

In addition to the comparative study IVL investigated the climate impact of peat utilisation chains using the new production methodology developed by Vapo and also the risk for increased climate impact due to premature close down of peat cutting areas. This additional study was made from a Swedish perspective and for Swedish conditions.

According to the results in the new calculations in this study and in the results of Kirkinen et al (in press) the new production technology being developed by Vapo has the potential of reducing the climate impact of the peat utilisation chain significantly. The reduction potential is due to lower emissions from the production area, shorter production period, lower emissions from the combustion (due to drier peat), less residual peat etc. There are also other positive environmental effects with the new production technology compared to the conventional peat cutting methods such as: lower emissions of dust, enabling of utilisation of abandoned cultivated peatlands, simplification of restoration

The risk for increased climate impact due to premature close down of peat cutting areas, following a significant decrease in demand of energy peat is mainly caused by the choice of after-treatment. There might be a risk that it will take longer time until the after-treatment is completed. The main risk for increased climate impact due to premature close down of peat cutting areas is the risk for low forest productivity and high CO_2 emissions due to decomposition of residual peat in the case of afforestation. If the area is restored the risk of decomposition of the residual peat is diminished. Due to the Swedish laws of peat cutting it is not likely that closed down areas will be left without after-treatment.

Sammanfattning

Klimatpåverkan från energitorvanvändning har studerats både i Finland av VTT och i Sverige av IVL Svenska Miljöinstitutet AB. Huvudsyftet med denna studie är att jämföra resultaten av tidigare genomförda studier vid VTT och IVL och att genomföra en känslighetsanalys av gamla och nya resultat.

Det vetenskapliga tillvägagångssättet i de två studierna är mycket lika. Klimatpåverkan av energitorvanvändning bestäms ur ett livscykelperspektiv genom att ta hänsyn till emissioner och upptag av växthusgaser under samtliga faser av utvinning och användning (torvproduktion, lagring, transport, förbränning, och efterbehandling av skördeytan) av energitorv. Torvmarker kan vara både källor och sänkor för växthusgaser och i de olika faserna av energitorvanvändning förekommer både emissioner och upptag av växthusgaser. Både källor och sänkor inkluderas i beräkningarna av klimatpåverkan. Nettopåverkan av torvanvändningen beräknas som emissioner och upptag under produktion och användning (inklusive efterbehandlad yta) minus emissioner och upptag i referensscenario (då man ej utnyttjar torvmarken utan låter den vara i nuvarande skick).

Beräkningsmetodiken för klimatpåverkan för energitorvanvändningen är lika i de bägge studierna. Både momentan och ackumulerad radiative forcing (påverkan på strålningsbalansen) används som mått på klimatpåverkan i de bägge studierna. Radiative forcing är ett mått av påverkan på strålningsbalansen och beräknas med hjälp av koncentrationsförändringar som följer av emissioner och upptag av växthusgaser. De skillnader i beräkningsmodellerna för koncentrationsförändringar och påverkan på strålningsbalansen som finns mellan de bägge studierna är små.

Det finns en del skillnader i definitioner och systemavgränsningar mellan torvscenarierna i de bägge studierna, men också dessa skillnader har relativt liten betydelse för resultaten. Den huvudsakliga anledningen till skillnader i resultat är skillnader i uppskattningar av emissioner och upptag av växthusgaser för referensscenarierna (emissionerna på torvmarkerna före torvbrytning) och för de efterbehandlade ytorna.

Det finns många likheter mellan resultaten i den svenska och den finska studien. De visar bägge att användningen av uppodlade torvmarker för energitorvproduktion resulterar i lägre klimatpåverkan än motsvarande kolanvändning (i ett 100-års perspektiv). Bägge studier visar också att användningen av orörda myrmarker för energitorvutvinning resulterar i större klimatpåverkan än motsvarande användning av torv från redan dränerade marker.

Skillnaden i klimatpåverkan från energitorvscenarier där man utgår från kärr (fen) eller dränerade skogsbevuxen torvmark och klimatpåverkan från kolscenarier skiljer sig mellan den finska och den svenska studien. I den finska studien är klimatpåverkan från torvscenariet generellt sett högre än kolscenariet medan i den svenska studien så är klimatpåverkan från torvscenariet i samma storleksordning eller lägre än kolscenariet. I den finska studien har man använt sig av medelvärden för emissioner och upptag av växthusgaser baserat på det nationella mätprogrammet (variationen i emissionsdata speglar skillnader mellan olika regioner i Finland). I den svenska studien använde man sig av svenska mätdata. Resultaten från den svenska studien visar på lägre klimatpåverkan från användandet av torv från dessa marker jämfört med de finska resultaten. Huvudskälet till detta är skillnaden i emissionsuppskattningar för referensscenariet och den efterbehandlade ytan. Anledningen till skillnaderna i emissionsuppskattningarna för dränerade skogsbevuxna torvmarker är inte känd. Föreslagna förklaringar är dels skillnader i dikningsmetoder eller att många av de svenska mätstationerna är lokaliserade i södra och mellersta Sverige, och därmed skulle ha ett

varmare klimat. Men det kan också vara så att det finns skillnader i metodiken för hur man gör emissionsuppskattningarna av nedbrytningen av torv i dessa marker. Dessa skillnader i emissionsuppskattningar kräver vidare utredning eftersom dränerade skogsbevuxna torvmarker är de främst använda torvmarkerna för energitorvproduktion i Finland och de är dessutom viktiga även i den svenska produktionen.

För känslighetsanalysen i denna studie har vi använt oss av variationen i uppskattningarna på emissionsdata. Notera att osäkerhetsuppskattningarna visar inom vilket intervall klimatpåverkan från de olika torvanvändningskedjorna ligger. Storleken på intervallen beror både på osäkerheten i emissionsdata och i den naturliga variationen på emissioner från olika typer av torvmarker. Storleken på intervallen beror också på hur mycket växthusgaser som kommer från den omgivande ytan som också påverkas av dräneringen i samband med torvbrytningen. Den största osäkerheten i emissionsuppskattningarna identifierades för de dränerade skogsbevuxna torvmarkerna och för de efterbehandlade områdena. Det är också stor variation i emissionsuppskattningarna för de uppodlade torvmarkerna och det har stor betydelse för resultaten i de fall man använder sådana marker för energitorvproduktion.

Klimatpåverkan från torvproduktion (d.v.s. från täktytan, arbetsmaskiner, lagring, diken, etc) och förbänningsfasen är de som är bäst bestämda. Den relativa osäkerheten i resultaten för dessa faser är minst. Den största delen av osäkerheten i energitorvscenarierna härrör från emissioner och upptag från referensscenariet och den efterbehandlade ytan.

Utöver den jämförande studien så har IVL också tittat på klimatpåverkan från ett torvbruk som bedrivs med den nya skördetekniken som Vapo utvecklar. IVL har även tittat på risken för ökad klimatpåverkan från täkter som stängs i förtid på grund av dålig lönsamhet. Denna del av studien är gjord från ett svenskt perspektiv och svenska förhållanden.

Enligt de resultat som presenteras i denna studie och resultat från Kirkinen et al (i tryck) så har den nya produktionsteknik som utvecklats av Vapo potential att reducera klimatpåverkan från energitorvanvändning avsevärt. Reduktionspotentialen beror bland annat på lägre emissioner från produktionsytan, kortare produktionstid, lägre emissioner från förbränningen (på grund av torrare torv), mindre kvarlämnad torv efter skörd, etc. Det finns även andra miljöfördelar med den nya produktionstekniken, nämligen lägre emissioner av partiklar (damm), möjlighet att utnyttja övergiven uppodlad torvmark och bättre möjlighet till restaurering.

Den största risken för ökad klimatpåverkan från i förtid avslutade torvtäkter på grund av dålig lönsamhet ligger i valet av efterbehandling. Det kan finnas en viss risk för att det skulle dröja längre efter avslutad verksamhet tills dess att efterbehandlingen genomförs. Den största risken för ökad klimatpåverkan på grund av tidigare avslut av torvtäkter är risken för låg skogsproduktivitet (i de fall man efterbehandlar genom beskogning) och dessutom hög CO_2 avgång från marken på grund av nedbrytning av kvarvarande torv (som ju då är en betydligt större mängd än i de fall då täkten är färdigskördad). Om täkten istället efterbehandlas genom restaurering (återskapande av våtmark) är risken för sådan CO_2-avgång mycket liten. Dock är det inte troligt med dagens svenska lagar och regler för torvtäkt att någon av de i förtid avslutade täkterna skulle bli utan efterbehandling.

Yhteenveto

Turve-energian käytöstä johtuvaa kasvihuonevaikutusta on tutkittu sekä VTT:llä Suomessa että IVL:ssä (Swedish Environmental Research Institute) Ruotsissa. Tämän tutkimuksen päätavoite on vertailla VTT:n ja IVL:n aiempia tutkimuksia sekä analysoida aiempien ja uusien tuloksien herkkyyttä.

VTT:n ja IVL:n aiempien tutkimusten tieteellinen lähestymistapa on hyvin samanlainen. Energiaturpeen käytön kasvihuonevaikutusta tutkitaan elinkaarinäkökulmasta ottamalla huomioon kaikki turpeen hyödyntämisketjun vaiheet (turpeen tuotanto, varastoiminen, kuljetus, poltto ja turvetuotantoalueen tuotannon jälkeinen hyödyntäminen). Turvetuotantovarat voivat olla sekä kasvihuonekaasujen lähteitä että nieluja joten sekä sitoutumista että päästöjä voi tapahtua turvetuotantoketjun aikana. Molemmat, sekä kasvihuonekaasujen nielut että lähteet huomioidaan. Turpeen hyödyntämisen nettokasvihuonevaikutus lasketaan vähentämällä turpeen hyödyntämisen kasvihuonevaikutuksesta (tuotanto, varastointi, työkoneet, poltto) sen tilanteen jatkuminen, että turvevaraa ei oteta tuotantoon (referenssitila ts. tuotantovara jätetään nykyiseen tilaansa).

Turve-energian kasvihuonevaikutuksen laskentamenetelmä on samanlainen sekä ruotsalaisessa että suomalaisessa tutkimuksessa. Hetkellistä ja kumulatiivista säteilypakotetta käytetään kasvihuonevaikutuksen indikaattorina. Säteilypakote on laskettu kasvihuonekaasujen pitoisuuksien muutoksesta, jonka ovat aiheuttaneet kasvihuonekaasujen päästöt ja nielut. Erot malleissa, joita käytetään kasvihuonekaasujen pitoisuuksien ja säteilypakotteen laskemisessa, ovat vähäisiä.

Turpeen elinkaariketjun määrittelyssä ja rajoituksissa on joitain eroja. Määrittelyeroista johtuneet erot tuloksissa ovat kuitenkin pieniä. Pääsyyt ruotsalaisen ja suomalaisen tutkimuksien tulosten eroavaisuuksiin johtuvat turvetuotantoalueen jälkikäsittelyvaihtoehtojen sekä tuotantovarojen (ts. referenssitilanne) päästö- ja nieluarvioista.

Ruotsalaisessa ja suomalaisessa tutkimuksessa on monia yhtäläisyyksiä. Molemmat tutkimukset osoittavat, että hyödyntämällä maatalouskäytössä ollutta turvemaata (suopeltoa) turpeen tuotantoon on kasvihuonevaikutus alhaisempi kuin käyttämällä kivihiiltä energiantuotantoon (jo 100 vuoden ajanjaksolla). Molemmat tutkimukset osoittavat että käyttämällä jo kuivattuja soita turvetuotantoon aiheuttaa pienemmän kasvihuonevaikutuksen kuin käyttämällä turvetuotantoon luonnontilaisia soita.

Turpeen käyttöketjujen kasvihuonevaikutus, joissa turve on tuotettu luonnontilaisilta soilta (aapasuo) tai metsäojitetuilta soilta, verrattuna kivihiilen aiheuttamaan kasvihuonevaikutukseen eroaa suomalaisessa ja ruotsalaisessa tutkimuksessa. Suomalaisessa tutkimuksessa keskimääräiset päästö- ja nieluarvot perustuvat kansalliseen mittausohjelmaan (epävarmuuksia käytettiin ilmentämään eri alueiden eroja). Ruotsalaisessa tutkimuksessa käytettiin ruotsalaisiin mittauksiin perustuvia päästöarvioita. Ruotsalaisen tutkimuksen tuloksissa turveketjujen kasvihuonevaikutus on alhaisempi kuin suomalaisen tutkimuksen tulokset. Tämä ero johtuu pääasiassa erilaisista referenssi- ja jälkikäsittelytilanteen päästöarvioista. Syytä metsäojitetun suon päästöarvojen suurelle eroavaisuudelle ei täysin tiedetä. Ehdotetut perustelut ovat erilaiset hoitomenetelmät (ojituskäytäntö) ja ruotsalaisten turvetuotantoalueiden eteläisempi sijainti. Myös turpeen hajoamisnopeuden arviointimenetelmissä saattaa olla eroja. Metsäojitettujen soiden päästöarviointimenetelmien erot tullee tutkia tarkemmin, sillä Suomessa metsäojitetut suot ovat tärkeimmät turpeen tuotantoalueet, Ruotsissa nämä alueet ovat myös hyvin merkittäviä tuotantoalueita.

Tässä tutkimuksessa tehdyissä laskelmissa käytämme päästö- ja nieluarvioiden vaihteluväliä. Nämä epävarmuusarviot kuvaavat sen vaihteluvälin, jossa tietyn turpeen käyttöketjun kasvihuonevaikutus sijaitsee. Vaihteluvälin suuruus riippuu sekä päästöarvioiden epävarmuudesta että päästöjen luonnollisesta vaihtelusta erilaisten suomaiden välillä. Vaihteluvälin suuruus riippuu myös tuotantoaluetta ympäröivän alueen päästöistä, joihin turvetuotantoalueen ojitus vaikuttaa. Suurimmat päästöarvioiden epävarmuudet tunnistetaan olevan luonnontilaisilla metsäojitetuilla soilla sekä soistetuilla alueilla. Myös suopeltojen lähtötiedoissa on suuri vaihtelu, jolla on merkittävä vaikutus turpeen käyttöketjujen kasvihuonevaikutukseen.

Turpeen tuottamisen (aumat, turvetuotantoalue, työkoneet, ojat jne.) ja polttamisen kasvihuonevaikutus tiedetään tarkimmin. Tämän vaiheen epävarmuus on suhteellisesti pienin verrattuna muihin vaiheisiin. Suurimmat epävarmuudet liittyvät tuotantovarojen sekä turvetuotantoalueen jälkikäytön päästöihin ja nieluihin.

Vertailututkimuksen lisäksi IVL tutki myös turpeen käyttöketjun kasvihuonevaikutusta, jossa turve on tuotettu käyttäen Vapon kehittämää uutta turvetuotantomenetelmää, sekä myös ennenaikaiseen turvetuotantoalueiden sulkemiseen liittyvää lisääntyneen kasvihuonevaikutuksen riskiä. Tämä täydentävä tutkimus tehtiin ruotsalaisesta näkökulmasta ja ruotsalaisista olosuhteista.

Tämän tutkimuksen uusien laskelmien perusteella sekä Kirkisen et al (hyväksytty) mukaan uudella Vapon kehittämällä turvetuotantomenetelmällä pystytään turpeen käytöstä aiheutuvaa kasvihuonevaikutusta vähentämään merkittävästi. Tämä on mahdollista mm. tuotantoalueen päästöjen vähentymisen, lyhyemmän tuotantoajan, polton alempien päästömäärien (kuivempi polttoaine) sekä jäännösturpeen vähentymisen ansiosta. Uudella turvetuotantomenetelmällä on myös muita ympäristöystävällisiä vaikutuksia verrattuna normaaliin turvetuotantomenetelmään (mm. jyrsinturve) kuten mm. vähentyneet pölypäästöt, hylättyjen suopeltojen käyttöönoton tuleminen mahdolliseksi sekä soistamisen helpottuminen.

Turvetuotantoalueiden ennenaikaisen sulkemisen (johtuen energiaturpeen tarpeen merkittävästä vähentymisestä) aiheuttama kasvihuonevaikutuksen voimistumisen riski on olemassa pääasiassa tuotantoalueen jälkikäsittelyn valinnassa. Tuotantoalueiden jälkikäsittelyn loppuun viemisen viivästymisen riski on olemassa. Suurin riski ilmastovaikutuksen kasvulle on tuotantoalueilla, joilla metsitys-jälkikäsittelyvaiheessa metsän tuottavuus on pieni ja jäännösturpeen hajoamisesta johtuvat CO_2-päästöt ovat suuret. Riski jäännösturpeen hajoamisesta johtuvista päästöistä vähentyy soistettaessa alue. Ruotsin lakien mukaan on kuitenkin epätodennäköistä, että suljetut turvetuotantoalueet jäävät ilman jälkikäsittelyä.

Content

1 Introduction

Peatlands constitute a significant amount of the land area in both Sweden and Finland. Peatlands are known to be important storages of terrestrial carbon and sources of methane emissions. In Sweden and Finland peatlands have historically been considered to be useless and low productivity land. Therefore large areas of peatlands in both Finland and Sweden have been drained in order to increase forest productivity or in order to use the land for other purposes e.g. cultivation. At drained peatlands the methane emissions decrease but the net carbon sequestration ceases and the soil looses CO_2 due to decomposition of the peat. Research has shown that many drained peatlands are net sources of greenhouse gases.

Climate change, how to combat it and how to adapt to it are some of the most important environmental questions in most western industrialised countries today. Countries that have signed the Kyoto Protocol will have to report emissions and the Annex 1 countries will also have to reduce their emissions. Due to this it has become more important to make adequate estimates of emissions from peatlands and different management methods of them.

A number of life cycle analyses of the climate impact of energy peat utilisation have been performed by Finnish and Swedish researchers. The climate impacts from utilisation of different types of peatlands and with different after-treatment options have been calculated. Comparisons to the climate impact of fossil fuels, e.g. coal have also been made in the studies. Some of the results are very similar while others do not look the same. It is important to improve the uncertainty and to get better knowledge of reasons for differences and similarities.

2 Objectives

The main objective of this study is to compare the results of life cycle analyses of climate impact from energy peat utilisation performed by Finnish and Swedish researchers. The specific studies compared are Kirkinen et al (in press) and Nilsson & Nilsson 2004.

The following issues are handled in the comparative study:

- Similarities between the studies are pointed out and discussed
- Differences between the studies are pointed out and possible reasons for them discussed
- A sensitivity analysis of input data is performed
- Common conclusions on the results, uncertainty & the methodology are given
- In a separate chapter (no 5) the new scenario calculations performed with the Swedish model are presented together with the aspects on early close down of harvesting sites. This was studied by IVL from Swedish perspective.

2.1 Methodology

The Finnish and Swedish approaches to assess the climate impact are first compared and discussed, then the calculation models are compared. A detailed model comparison is also made by running the exact same scenario in both models (same input data). Then the system boundaries are discussed as well as the input data.

A sensitivity analysis showing the sensitivity of the results to uncertainty in emission estimates have been performed. Both models were used also in the sensitivity analysis.

3 Similarities and differences

In this chapter we show the differences and similarities between the studies Kirkinen et al (in press.) and Nilsson & Nilsson 2004. The comparison is divided into the following parts:

- Scientific approach and calculation model
- System boundaries
- Emission estimates (input data)

3.1 Scientific approach and calculation model

The Finnish model, refers in this report to the calculation model used by Kirkinen et al (in press) and the Swedish model, refers to the calculation model used by Nilsson & Nilsson (2004).

The scientific approach of the two studies is very similar. The climate impact of peat utilisation is considered from a life-cycle point of view by taking into account all phases of the peat utilisation chain. Peat reserves can be both sinks and sources of greenhouse gas emissions as well as there are both uptake and emissions of greenhouse gases during the utilisation chain. Both sinks and sources are considered. The net impact of the utilisation chain is assessed as the climate impact due to the utilisation chain minus the climate impact of non-utilisation chain (reference scenario where the peat reserve is left in its current state).

The calculation methodologies of greenhouse impact of energy peat used in the Swedish and the Finnish studies are similar. The radiative forcing and accumulated radiative forcing were used in both studies as the indicator of the climate impact. Radiative forcing was calculated on the basis of the concentration changes due to emission and sinks of greenhouse gases.

The Swedish model

The Swedish calculation model is built by IVL (Uppenberg et al 2004 and Nilsson & Nilsson 2004) and is set up in Powersim (www.powersim.no). The time step used in the calculations is 1 year. The equations and input-data used in the model are described in the following sections.

The Finnish model

The Finnish model is built by VTT (Korhonen et al 1993, Monni et al 2003). The time step used in the calculations is 1 year. The equations and input-data used in the model are described in the following sections.

3.1.1 The energy peat utilisation chains

The two studies apply similar methodology for calculating the greenhouse impact of energy peat. The emissions and uptake of the three greenhouse gases carbon dioxide, methane and nitrous oxide were taken into account during all stages of energy peat production and utilisation. The following stages are defined within both studies:

- Pre-harvesting conditions at the peatland, the non-utilisation situation (R)
- Harvesting stage, when peat is being cut (H)
- Combustion phase (C)
- After-treatment phase (A)

The total emissions considered are:

$$E(t) = H(t) + C(t) + A(t) - R(t) \qquad \text{Equation 3.1}$$

The three first terms of the sum describe emissions and sinks due to peat utilisation chain and the last term describes emission and sinks of the non-utilisation chain. The description of the mechanisms within each phase is further described in section 3.2 (System boundaries) and section 3.3 (Emissions and uptake of greenhouse gases).

3.1.2 Equations for radiative forcing

In general the Finnish and the Swedish model use the same equations for calculating the radiative forcing. The equations are based on the information given in IPCC (2001). However in the Finnish model also the indirect radiative forcing of CH_4 is taken into account.

Radiative forcing describes the disturbance of the Earth's radiative energy balance. Increasing greenhouse gas concentrations leads to increased radiative forcing since thermal radiation emitted by the Earth is partly trapped by the greenhouse gases (Figure 3.1). Less energy is radiated to space, which raises the temperature of the atmosphere-surface system of the Earth. Each greenhouse gas absorbs radiation in a range of wavelengths. When the greenhouse gas concentrations increase sufficiently all radiation of particular wavelength is trapped, leading to a saturation of the radiative forcing.

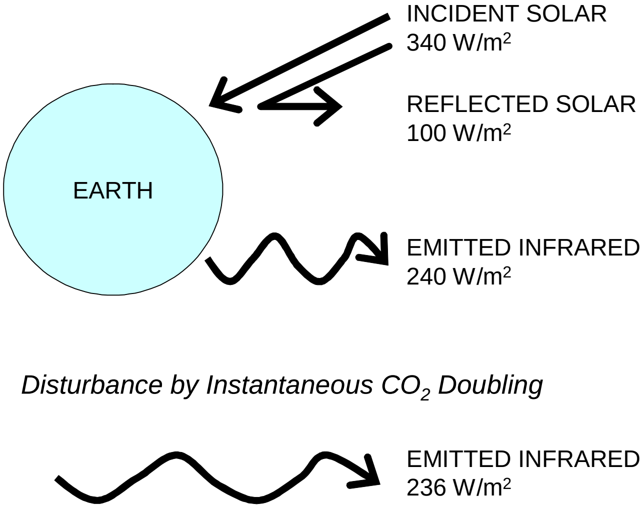

Figure 3.1 The increased greenhouse gas concentrations by human activities decrease the radiation from Earth to space. This will lead to disturbed radiation balance, which increases the temperature of the surface/oceans and the lower atmosphere. The doubling of CO_2 concentration would decrease the outgoing radiation by about 4 Wm^{-2}. (IPCC 1990)

According to IPCC (2001) the globally averaged radiative forcing due to an increase in CO_2 concentration is calculated according to the following equation:

$$\Delta F_{CO2} = 5.35 * \ln (C/C_0)$$ Equation 3.2

Where C is the atmospheric concentration of CO_2 and C_0 is the undisturbed concentration (background concentration). If we call the change in concentration due to a certain amount of emissions ΔC, the relation between background concentration and atmospheric concentration is described by $C = \Delta C + C_0$.

Direct forcing due to methane emissions is according to IPCC (2001) defined as:

$$\Delta F_{CH4} = 0.036 \cdot (\sqrt{M} - \sqrt{M_0}) - [f(M, N_0) - f(M_0, N_0)]$$ Equation 3.3

Where M is the atmospheric concentration of methane and N is the atmospheric concentration of nitrous oxide. The f(M,N) term considers the fact that methane and nitrous oxide party absorbs within the same wavelength area. According to IPCC the overlapping term is described according to Equation 3.4:

$$f(M, N) = 0.47 \cdot \ln\left[1 + 2.01 \cdot 10^{-5} \cdot (MN)^{0.75} + 5.31 \cdot 10^{-15} \cdot M(MN)^{1.52}\right]$$ Equation 3.4

The radiative forcing caused by nitrous oxide is according to IPCC (2001) described by the following equation:

$$\Delta F_{N2O} = 0.12 \cdot (\sqrt{N} - \sqrt{N_0}) - [f(M_0, N) - f(M_0, N_0)]$$ Equation 3.5

In the Finnish model also the indirect radiative forcing of methane has been taken into account (Monni 2002). In the case of CH_4, indirect forcing arises through the formation of stratospheric water vapour from oxidation of CH_4, and through effects on tropospheric O_3 (IPCC 1997). The term describing the forcing due to water vapour introduced into the stratosphere due to the decay of methane is calculated by Equation 3.6.

$$\Delta F_{CH4,ind,H2O} = 0.05\Delta F_{CH4pure}$$

Equation 3.6

According to IPCC (1997) the radiative forcing due to the increase in tropospheric ozone (O_3) associated with increasing CH_4 concentration is directly proportional to the increase in methane concentration. This radiative forcing has been approximately 0.11 Wm^{-2} during 1850–1992 (Lelieveld et al 1998). During this period atmospheric methane concentration has increased from 826 ppb_v (Etheridge et al 1994) to 1714 ppb_v (IPCC 1995). The indirect radiative forcing due to ozone is described by equation 3.7:

$$\Delta F_{CH4,ind,O3} = \frac{0.11Wm^{-2}}{1714\,ppb - 826\,ppb}(M - M_0)$$

Equation 3.7

The total radiative forcing of methane is then according to equations 3.5, 3.6 and 3.7:

$$\Delta F_{CH4} = 1.05 * 0.036(\sqrt{M} - \sqrt{M_0}) - (f(M,N_0) - f(M_0,N_0)) + 0.000124(M - M_0)$$

Equation 3.8

The effect of the difference between the Finnish and the Swedish consideration of radiative forcing due to methane will be shown in section 3.1.5 where the model comparison is presented.

3.1.3 Atmospheric lifetime of greenhouse gases

One of the most important model parameters is the atmospheric lifetime of the greenhouse gases. There are many parameterisations of the atmospheric lifetime of carbon dioxide (IPCC 2001) and different parameterisations have been used in the Finnish and the Swedish model.

The Swedish model

In the Swedish model an ocean-atmosphere box diffusion model developed by Oeschger et al (1975) and utilised as parameterisation of the response to a perturbation of atmospheric CO_2 in the first assessment report of the IPCC (Albritton et al 1995) is used. The parameterisation in the model is done by division of carbon dioxide emissions into three components with different atmospheric lifetimes, see equation 3.1. One fraction has a relatively short atmospheric lifetime, which is explained by biospheric uptake. The other two fractions are removed from the atmosphere by uptake to the ocean surface water and transfer to deep ocean water. Since these are quite slow processes these fractions remain for a very long time in the atmosphere.

In the Swedish model the atmospheric lifetimes of the greenhouse gases are constant throughout the calculation period.

$$f_{CO_2}(t) = a_1 \cdot e^{-t/\tau_1} + a_2 \cdot e^{-t/\tau_2} + a_3 \cdot e^{-t/\tau_3}$$ Equation 3.9

Where

$a_1 = 0.30036$	$\tau_1 = 6.993$
$a_2 = 0.34278$	$\tau_2 = 71.109$
$a_3 = 0.35686$	$\tau_3 = 815.727$

For methane and nitrous oxide the removal of gas from the atmosphere is described by a pulse-response function with one exponential only, see equation 3.10. This means that there is no division of the gases into different fractions. The atmospheric lifetimes used in the Swedish model are 12 years for methane and 114 years for nitrous oxide based on IPCC (2001).

$$f_{gas}(t) = e^{-t/\tau}$$ Equation 3.10

The Finnish model

In the Finnish model a parameterisation of the pulse response function of an increase of CO_2 into the atmosphere made by Maier-Reimer & Hasselmann (1987) is used. This models the transfer of carbon dioxide from the atmosphere to the oceans with a pulse-response function. The pulse-response function is a superposition of four exponentials with different relaxation times. The function is given in equation 3.11 and means that the emissions of carbon dioxide are divided into five fractions with different atmospheric lifetimes.

$$f_{CO_2}(t) = a_0 + a_1 \cdot e^{-t/\tau_1} + a_2 \cdot e^{-t/\tau_2} + a_3 \cdot e^{-t/\tau_3} + a_4 \cdot e^{-t/\tau_4}$$ Equation 3.11

According to equation 3.11 one of the fractions (a_0) will remain in the atmosphere indefinitely. The values of the parameters in equation 3.11 for different step-functions are given in table 3.1. In the Finnish model, the pulse-response functions for different step-function increases (1.25, 2 and 4) are weighted according to global atmospheric concentration. In the calculations made by Kirkinen et al (in press) the pulse-response 2 was utilised. For further explanation of the background concentration, see next section.

Table 3.1 Parameters of pulse-response function used in Finnish model (REFUGE 2).

Step function	**1.25**	**2**	**4**
a_0	0.131	0.142	0.166
a_1	0.201	0.241	0.356
a_2	0.321	0.323	0.285
a_3	0.249	0.206	0.130
a_4	0.098	0.088	0.063
τ_1 (years)	362.9	313.8	326.3
τ_2 (years)	73.6	79.8	91.3
τ_3 (years)	17.3	18.8	18.9
τ_4 (years)	1.9	1.7	1.2

In the Finnish model the carbon fluxes between the atmosphere and the terrestrial biosphere are considered as external input terms, to the model. It was also assumed that increased atmospheric concentration does not change the flux of CO_2 to the terrestrial biosphere. No CO_2 fertilisation is considered neither are mechanisms such as more rapid decay of organic material of the soil due to rising temperatures that might cancel some (or the entire) of the CO_2 fertilisation effect.

The retention of methane and nitrous oxide is described by pulse-response functions with a single exponential, just as in the Swedish model, see equation 3.10. However, in the Finnish model the lifetimes of methane and nitrous oxide are dependent on the concentration of the gas in the atmosphere and are not constant throughout the calculations. This dependency is described in table 1 in Appendix 3.

The change in the lifetimes of CH_4 and N_2O is taken into account in the Finnish model step by step approximately every 0.2 year. In the year 1990 the concentration of CH_4 was 1700 ppb_v which corresponds to an average lifetime of 8.4 years (IPCC 2001). The atmospheric lifetime of CH_4 increases by 2.8 %, when the concentration of CH_4 increases by 10 % from 1700 ppb_v. The atmospheric lifetime of methane at lower and higher concentrations are described in table 1 in Appendix 3. (Monni 2002)

For N_2O the decreasing lifetime is defined so that while concentration increases by 10 % the lifetime decrease by 0.5 %. At the concentration level of 1998, which was 314 ppb_v, the lifetime of N_2O is 120 years (IPCC 2001).

Summary of atmospheric lifetimes

The parameterisation of the CO_2 pulse response by Maier-Reimer & Hasselmann (1987) is used in one of the models (Wigley model) used by the IPCC (1995) when making forecasts of future CO_2 concentrations due to certain emission scenarios. The IPCC also frequently uses the Bern model in which the parameterisation is done by a box diffusion model, as in the Swedish model, with an additional advective component.

The parameterisation of the CO_2 pulse response used in the Swedish model is an older description and more simple than the one used in the Finnish model. However, Figure 3.2 show that the difference between the two models is limited and the main difference lies between 5–95 years after the perturbation.

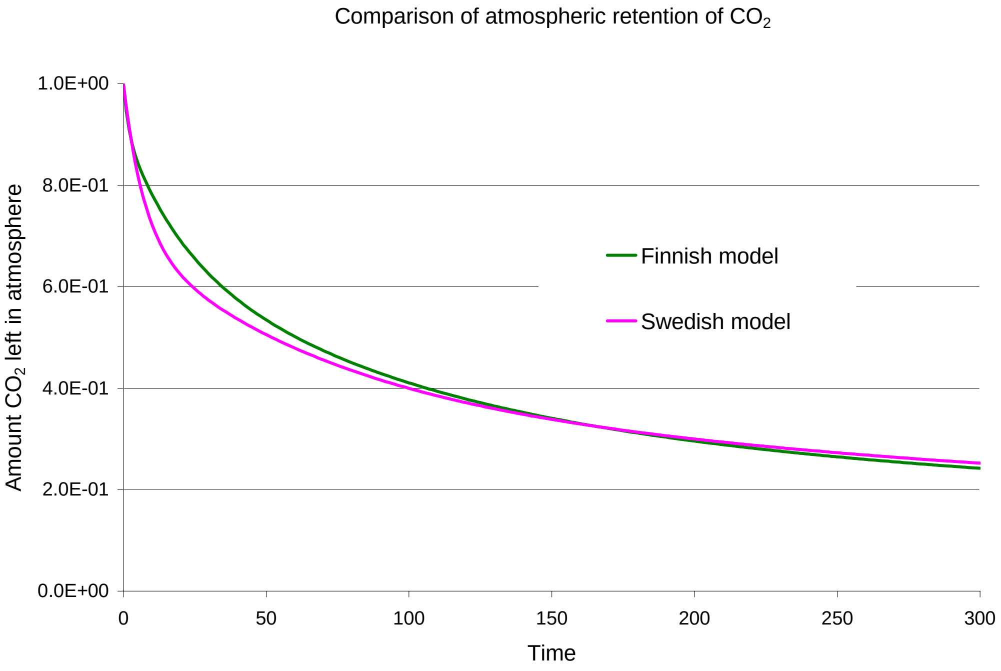

Figure 3.2 Atmospheric response to perturbation of CO_2 as described by the two models.

The Finnish model uses a pulse response function valid for a doubling of the CO_2 in the atmosphere. The emissions due to the peat utilisation in Finland do not correspond to a perturbation of that size but currently the atmospheric concentrations are increasing due to other human activity. The assumptions made concerning the background concentrations are described below.

3.1.4 Background concentration

The equations describing the radiative forcing caused by an increase of the atmospheric concentration of the greenhouse gases carbon dioxide, methane or nitrous oxide is not linear. For all three gases it means that the higher the atmospheric concentration the smaller additional radiative forcing is caused by further emissions. This is why the chosen background concentration is very important when calculating the radiative forcing from a specific activity or country.

The Swedish model

In the Swedish model the current global average background concentrations of carbon dioxide, methane and nitrous oxide are used throughout the calculations. The used values are given in Table 3.2. Since the calculation period is 300 years and the global emissions of greenhouse gases are increasing the global average concentrations during this time period it means that using current concentrations result in an overestimation of the climate impact of the emissions due to the saturation effect.

Table 3.2 Background concentrations used in Swedish model.

Gas	Concentration	Reference
CO_2	372 ppmv	CDIAC, Nov 2003,http://cdiac.esd.ornl.gov/pns/current_ghg.html
CH_4	318 ppbv	CDIAC, Nov 2003,http://cdiac.esd.ornl.gov/pns/current_ghg.html
N_2O	1843 ppbv	CDIAC, Nov 2003,http://cdiac.esd.ornl.gov/pns/current_ghg.html

The Finnish model

In the Finnish model the global average background concentrations of the three greenhouse gases varies over the calculation period. It has been assumed that the global background concentration increases according to the IPCC SRES Scenario A2 until the doubled level of the CO_2 concentration compared to the pre-industrial level is reached. This assumption is made due to "business-as-usual" development in the world, i.e. the emissions are increasing which affect the background concentrations. Then it is assumed, when the doubled CO_2 level is reached, strong mitigation of emissions is needed, otherwise the effect on the atmosphere is too strong and it will affect the life on Earth negatively. This means that the background concentration is increasing during the first 65 years of the calculation period until the doubled level of CO_2 is reached and then stays constant at a high level (CO_2 551 ppm, CH_4 2730 ppb, N_2O 392 ppb). The rise of the CH_4 and N_2O concentration is assumed to stop after the same time period, for simplicity.

Since we currently see increasing atmospheric concentrations this model seem to resemble the real case. This also results in the climate impact of the emissions in the energy utilisation scenarios to be smaller than in the Swedish model, since the atmosphere is getting saturated.

In the Finnish model it is also considered that as the concentrations of methane and carbon dioxide are getting higher the atmospheric lifetime is getting longer, cancelling out part of the saturation effect. However, the saturation effect is stronger than the increase in atmospheric lifetime (Monni et al 2003).

Summary of background concentration

For CO_2 the different assumptions of background concentrations means that the climate impact of the Swedish model would be higher. Since there are also differences in the assumed atmospheric lifetime of the gas the picture is more complex and initially the climate impact from the Finnish model is higher than the Swedish model, see Figure 3.5. Hence the impact of different background concentrations is cancelled out by the impact of the different atmospheric lifetimes. For methane the climate impact would be higher in the Swedish model since background concentration is lower and atmospheric lifetime is longer. However, since the Swedish model does not include the indirect effect of methane, the Finnish model proves higher climate impact of methane, see Figure 3.6. In the case of nitrous oxide the different assumptions of the background concentrations would result in the climate impact of nitrous oxide being higher in the Swedish calculations (due to the lower background concentration). Since the atmospheric lifetime of nitrous oxide is shorter in the Swedish model, the combined effect is still a higher climate impact in the Finnish model, see Figure 3.7.

3.1.5 Model comparison

This section was included in order to show that there are reasons for differences in results also when using the same input data on greenhouse gas emissions from the peat production chain. In order to show the comparability between the Finnish and the Swedish models we have made calculations using the exact same input data in the two models. The input data for these calculations are presented in Appendix 1. Scenarios for which calculations have been made are:

- a scenario where a fen is utilised for peat cutting and then after treated by restoration
- a scenario where a cultivated peatland is utilised for peat cutting and then after treated by restoration
- a coal scenario where coal is used instead of the peat in order to produce the same amount of energy that would be available in the peatland.

In the Figure 3.3 and Figure 3.4 both the instantaneous and the accumulated radiative forcing are presented. As can be seen in Figure 3.4, showing the accumulated radiative forcing, the difference in results between the two models is not substantial. Looking at the instantaneous radiative forcing the difference looks larger at least when emissions are large, i.e. during the combustion phase.

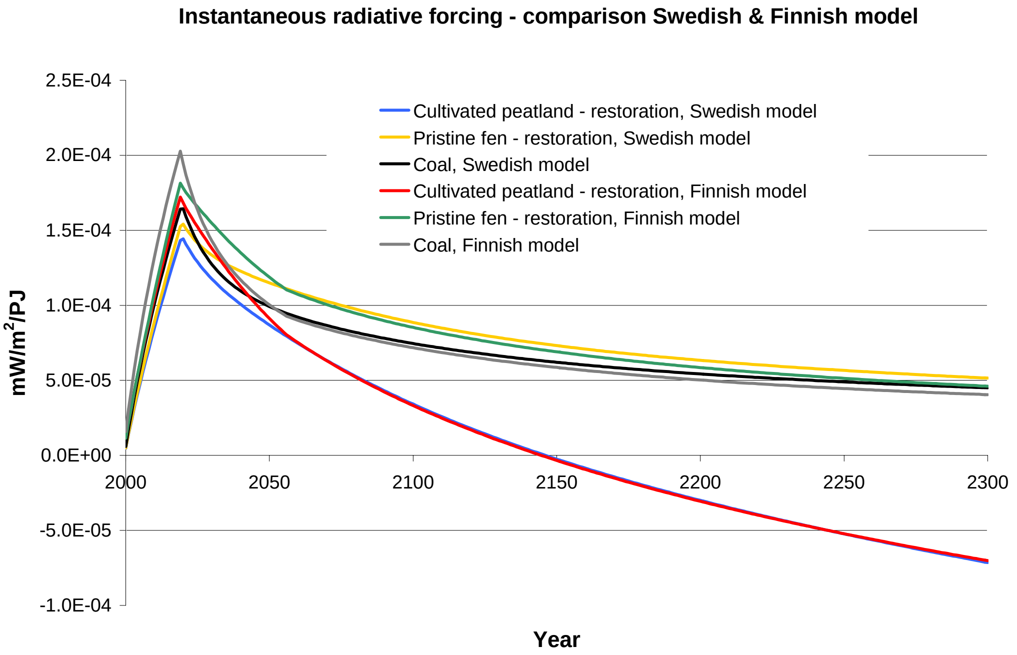

Figure 3.3 Instantaneous radiative forcing for the scenarios run in both models.

As can be seen in both Figure 3.3 and Figure 3.4 there are some differences which are due to the models and not to the input data. The differences are due to the effects already discussed, such as equations of radiative forcing (in the case of methane), utilised values of background concentrations and atmospheric lifetimes. In order to see the impact of each gas we also separated the instantaneous radiative forcing from the gases and plotted them in separate figures. This was done for the coal scenario and in Figure 3.5–Figure 3.7 the instantaneous radiative forcing is presented separately for each gas (CO_2, CH_4 and N_2O respectively).

Figure 3.5 shows that in the case of CO_2 the instantaneous radiative forcing is higher in the Finnish model and lower in the Swedish. One explanation to that is that the atmospheric lifetime of the gas is described differently in the two models. Figure 3.2 show the CO_2 retention time for an addition of one unit of CO_2 to the atmosphere as described in the two models. From that figure it can be seen that in the Finnish model there is during the first 5–100 years significantly more CO_2 in the atmosphere, causing a larger radiative forcing.

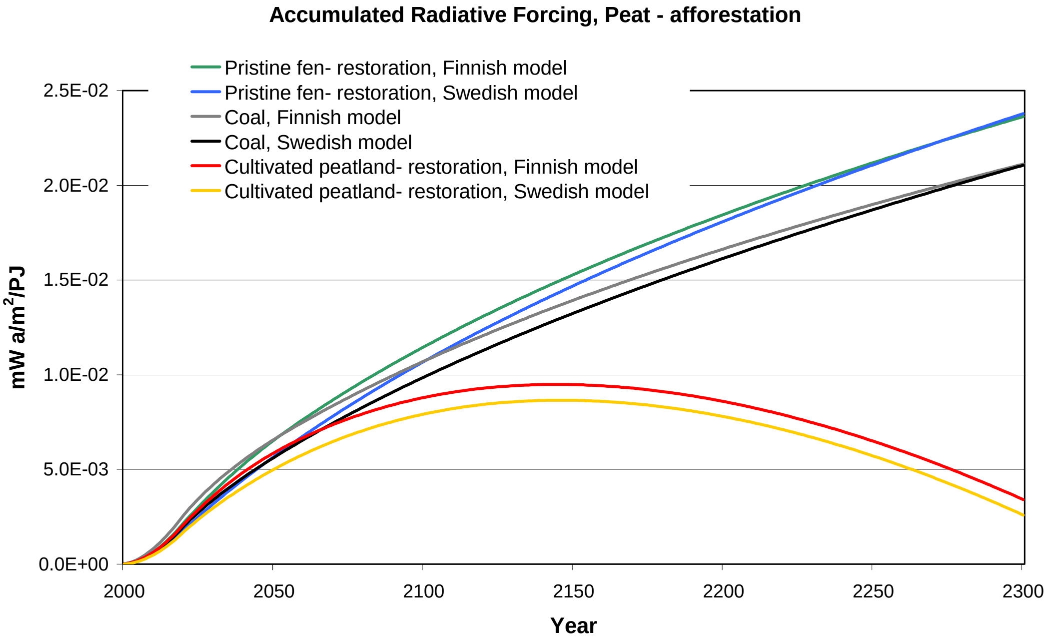

Figure 3.4 Accumulated radiative forcing for the scenarios run in both models.

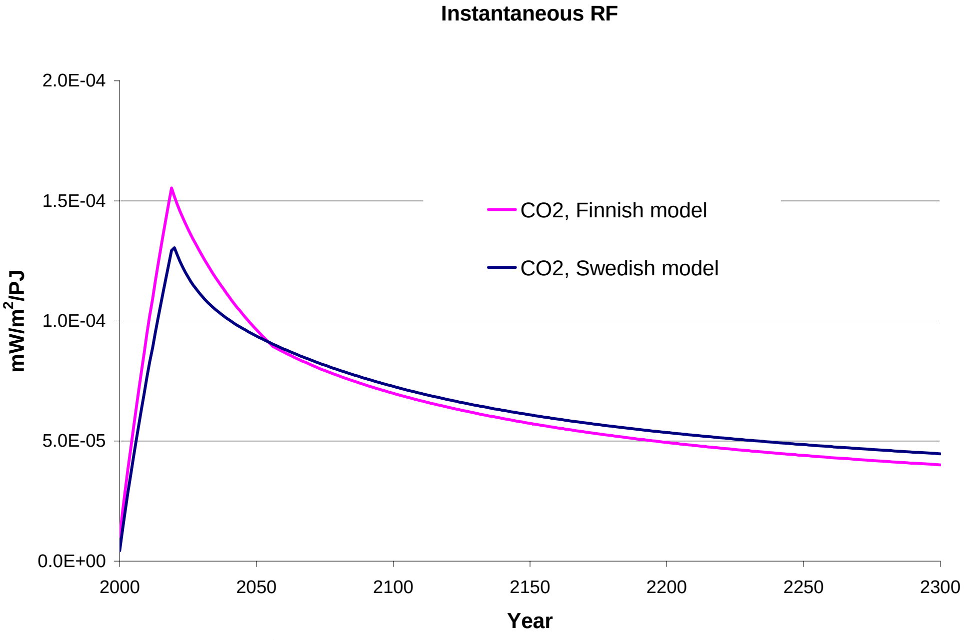

Figure 3.5 Instantaneous radiative forcing of the CO_2 emissions in the coal scenario run in the two models.

In Figure 3.6 the calculated radiative forcing of the methane emitted in the coal scenario is showed. There is a substantial difference between the Swedish and the Finnish model. This is mainly due to the indirect forcing being considered in the Finnish model but not in the Swedish. Even when not considering the indirect effect of methane there is some difference between the Swedish and the Finnish models. This is probably due to differences in values used for the atmospheric lifetime and the background concentration. It should also be remembered that the radiative forcing of methane and nitrous oxide is interconnected by the overlap term.

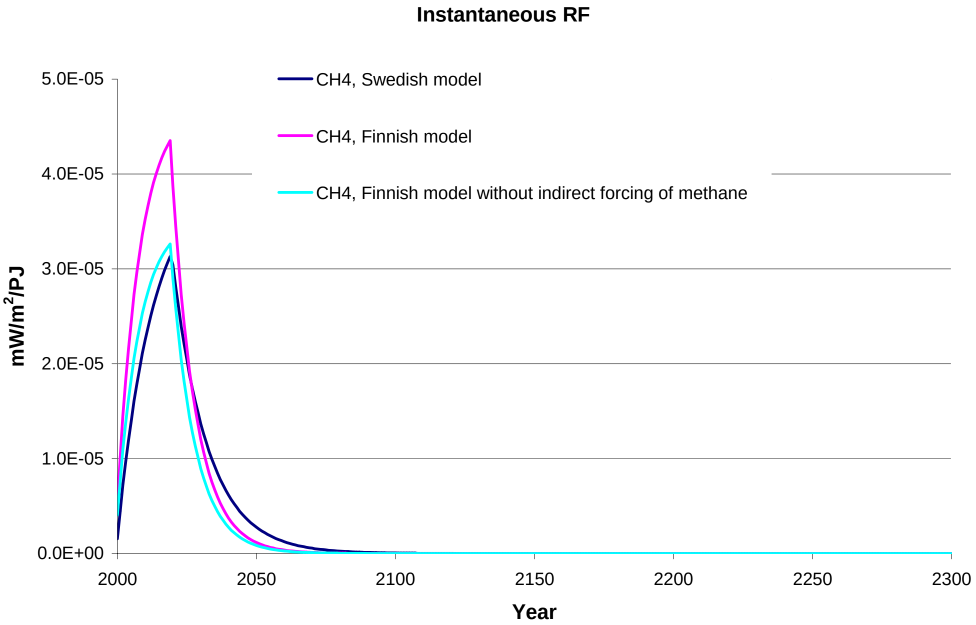

Figure 3.6 Instantaneous radiative forcing of the methane emissions run in both models. The radiative forcing is calculated twice with the Finnish model, once with and once without the indirect forcing of methane considered.

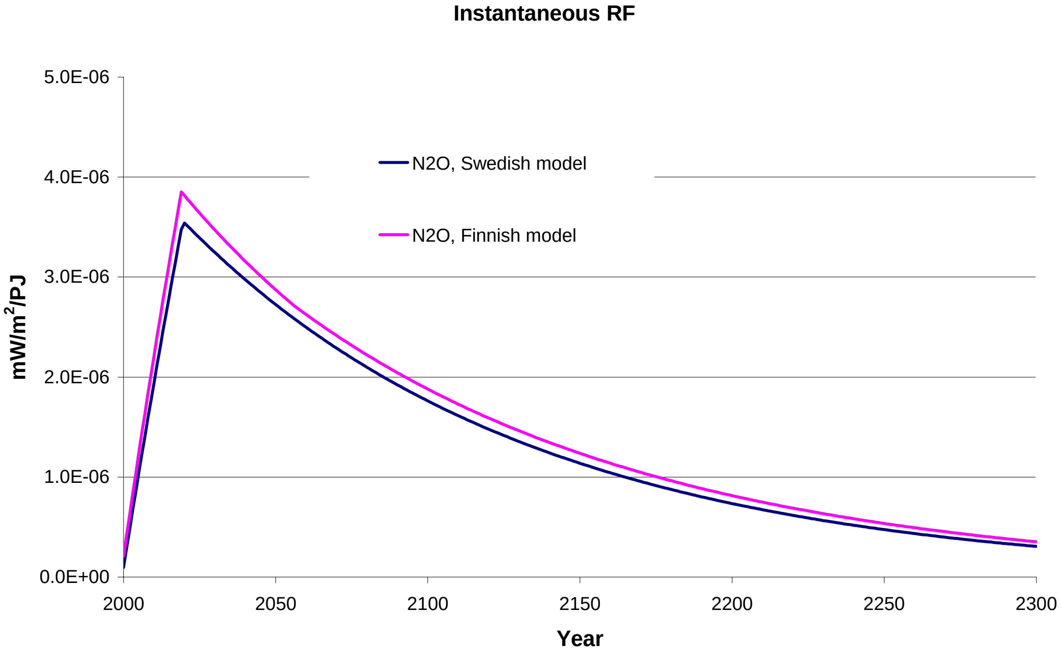

Figure 3.7 Instantaneous radiative forcing of the nitrous oxide emissions in the coal scenario run in the two models.

Even if the relative differences between the calculated radiative forcing caused by nitrous oxide emissions are not negligible the overall impact on total results are small since the emissions of nitrous oxide compared to the emissions of CO_2 are small (also when compared by CO_2 equivalents).

3.2 System boundaries

There are some differences in the boundaries set up in the Finnish and the Swedish studies but there are also many similarities.

3.2.1 The objectives

First of all, it is important to remember that the objective of the two studies where somewhat different.

The aim of the Finnish study was to:

1. Find an energy peat production and utilisation chain with as low climate impact as possible. The climate impact from the production and utilisation of the energy peat was to be considered from a life cycle analysis perspective. Specifically it was important to find what types of peatlands that were preferable to use and what after-treatment methods that were to be used

2. To assess the sensitivity and uncertainty of the results

3. To compare the greenhouse impact of energy peat utilisation with the climate impact of fossil fuels (mainly coal)

4. To produce new information on the climate impact of energy peat utilisation for the reporting of greenhouse gas emission according to the IPCC Guidelines for the UN Framework Convention on Climate Change.

The aim of the Swedish study was to:

- Estimate the climate impact of the current use of energy peat in Sweden and
- Investigate the potential to reduce greenhouse gas emissions by choosing harvesting sites and after-treatment methods
- Compare the climate impact of the use of energy peat to fossil fuels (coal and natural gas).

3.2.2 Surrounding area

In the Swedish study, the impact of drainage on the greenhouse gas balance at the surrounding area, i.e. the area nearby the harvesting site, was also considered. The reason for this was that drainage ditches are effective on both sides, and hence not only on the actual harvesting site. The resulting emissions will depend on the soil type of the surrounding area. If the circumference ditches are made at the border between mineral soil and peat soil, the drainage before harvesting might result only in minor emissions from the surrounding area. On the other hand if there is soil with shallower peat layer outside the circumference ditches there might be important emissions from the surrounding area. It can also be argued that at an already drained site (forestry drained or cultivated peatland) the effect of additional emissions from the surrounding area due to drainage might be insignificant. Another important issue is how large the impacted surrounding area will be, which is mainly dependent on the geometric form of the harvesting field (defined by the circumference ditches). If the harvesting site is large and has a simple geometrical form, the surrounding area will be relatively smaller compared to a case with a small harvesting area and/or a harvesting area with complex geometrical form.

In the Swedish study it was assumed that the surrounding area was as large as the harvesting site and that the peat layer was half as thick at the surrounding area as at the harvesting site.

In the Finnish study no emissions from the surrounding area were considered. One reason was that there are no studies on this subject and no reliable information. Peat production areas are mainly forestry-drained peatlands, which are drained anyway. During the Finnish work it was estimated that the potential impact of the surrounding area is relatively small

According to the previous calculations of energy peat utilisation chains and calculations made in this study (see Appendix 5) we can say that:

- considering the surrounding area will have important impact on the result
- the consideration of the impact on the surrounding area will strengthen the effect of peat utilisation. I.e. if peat cutting leads to a state with lowered emissions of greenhouse gases, the consideration of the impact on the surrounding area will result in a scenario with larger reduction of greenhouse gas emissions (smaller climate impact). On the other hand if peat cutting results in a scenario where emissions of greenhouse gases are increased (after treated state has higher emissions than initial state) considering the surrounding area will result in a scenario with larger increase of emissions (larger climate impact).

In conventional peat cutting ditches are made with 20 meters distance in order to get the land dry enough for machines and drying of the peat. The reason for having them so close is the low hydraulic conductivity of the peat. If they are further apart it will simply not be dry enough. According to Håkan Staffansson (personal communication) the convention at peat cutting in Sweden today is that the circumference ditches are dug at a site where the peat depth is approximately 2 m. The peat depth on the outside of the ditch can then of course be smaller. According to Staffansson the effect of the circumference ditch will not be more than 30 meters. If we get as far away as 30 meters the peat depth might be very shallow, 1–2 dm or even zero. The size of production areas varies greatly and we have no good average estimate of the size of the active areas. With the assumption of a simple geometrical form of the production area we get that a small area (20 ha) might have an impacted surrounding area 30% of the size of the production field whereas a larger area (100 ha) might have an impacted surrounding area 12% of the size of the production area. In Nilsson & Nilsson (2004) it was assumed that the peat depth at the surrounding area was half of that at the production area. The truth is probably that it is quite thick close to the circumference ditches (were it is also most affected by the drainage) and that the thickness decreases further away from the ditches.

Conclusion: The surrounding area will have some effect on the overall result but we need better information on sizes of the cutting areas and peat depths at the surrounding area in order to make good estimates of this. The relative impact from the surrounding area will be larger on undrained areas compared to already drained areas and on small production areas compared to large production areas. Currently there are no measurement data on emissions from the surrounding areas.

3.2.3 Carbon sequestration at after-treated area – afforestation

In the Swedish study the carbon sequestration into the growing forest at the after-treated area during one rotation period (70–90 years) was considered. After the full rotation period it was assumed that the forest had matured, the emissions from decomposition were equally large as the sequestration into new biomass, and hence a steady state was reached. This was assumed both for the tree biomass and for litter.

In the Finnish study, carbon sequestration into the growing forest was only considered until the average amount of a rotation period was sequestered. This since it was assumed that the forest would be harvested when mature and on average the carbon storage during coming centuries would best be described by this average value. For above ground litter it was assumed that the forest accumulates litter until a certain value is reached (1.8 kg C/m^2). The rates were estimated in the Finnish study so that the value was reached in approximately 45 years, i.e. half the time of a rotation period. For the below-ground litter it was assumed in the Finnish study that carbon will be sequestered for a long time period at a very slow rate.

Conclusion: We have come to the conclusion that since we are looking at the peat system and want to know what climate impact the peat production has, what should be considered is the change in carbon stock due to the peat cutting. This means that if the productivity of the forest is changed, it is the change that should be considered. Depending on what you want to study there are a few options on how to consider this.

1. If you only want to consider the climate impact of the peat, only the change in carbon stock should be considered. E.g. if the forest productivity is increased corresponding to an annual uptake of XX g CO_2/m^2 this is what is considered. (Note: this can be determined differently either you do it as it is done in the Finnish study where only the average value over the rotation period is used or you do it as in the Swedish study where the entire carbon stock for one whole rotation period is considered or other option)

2. If you have a land-use perspective and also want to avoid the problem of how much of the carbon stock to consider, you consider the forest system as it grows, i.e. the carbon stock builds up but is then released as the forest is cut. Of course you then need to make some assumption on how fast the carbon is released when the forest is cut. One way is to look at wood and its utilisation today. In that case some of the carbon is emitted relatively fast corresponding to the fraction of wood that is used for fuel or paper meaning that it is burnt relatively soon after cutting. Some of the carbon is emitted later (after some years) corresponding to fraction used for other purposes such as construction etc. Another way is to consider a special utilisation, e.g. fuel. Then all the carbon is released at once when cutting the forest.

3.3 Emissions and uptake of greenhouse gases

In this section all the different assumptions concerning uptake and emissions of greenhouse gases during the different stages of energy peat production are presented. Description of what differences are due to (new measurement data, differences in climate conditions between countries, different scope of studies, etc) is given.

3.3.1 Initial stage

Estimated emissions and uptake of greenhouse gases at the initial stage of the peatlands, e.g. at pristine mires, cultivated peatlands and forestry drained peatlands. In Table 3.3 the values used in the Swedish and Finnish study for different types of peatlands utilised for peat cutting are presented.

Table 3.3 Emissions from peatlands in initial stage before peat harvesting.

Gas	**Swedish study**	**Finnish study**
	Pristine Fen[1,2]	
CO_2	–51 g CO_2/m^2a	0– –147 g CO_2/m^2a
CH_4	6–23 g CH_4/m^2a[3]	15–31 g CH_4/m^2a
N_2O	0.02 g N_2O/m^2a	0
	Bogs and other peatlands	
CO_2	–62– –77 g CO_2/m^2a	n.a.
CH_4	3.5–8 g CH_4/m^2a[3]	n.a.
N_2O	0.02 g N_2O/m^2a	n.a.
	Cultivated peatland	
CO_2	1100–7000 g CO_2/m^2a	705–2815 g CO_2/m^2a
CH_4	0 g CH_4/m^2a	– 0.26– –0.03 g CH_4/m^2a
N_2O	1.0–2.5 g N_2O/m^2a[4]	0.46–2.13 g N_2O/m^2a
	Forestry drained peatlands	
CO_2, emissions from decomposition of peat	0–2300 g CO_2/m^2a	0–448 g CO_2/m^2a
CO_2, uptake in growing forest	231–347 g CO_2/m^2a	not considered
CH_4	0 g CH_4/m^2a	0 g CH_4/m^2a
N_2O	0.08–0.9 g N_2O/m^2a	0 g N_2O/m^2a

The CO_2 estimate in the Swedish study for fen is an estimate based on Turunen & Tolonen (1996). Note that the methane emission estimates for pristine fens used in the Swedish study are not averages for all Swedish fens. According to the study it was based on (Nilsson et al 2001) the methane emissions from Swedish fens rather varies between 8–40 g CH_4/m^2yr. The CO_2 emission estimates given in Kirkinen et al (in press) for pristine fens are based on more recent measurements than in the Swedish study.

The Finnish study did not include other pristine mires than fens and that is the reason for data missing in the Table 3.3 under "Bogs and other peatlands". It is mainly there to show the values utilised in the Swedish study.

For cultivated peatlands the variation in CO_2 emissions is large. In the Swedish study the cultivated peatlands had been divided into different categories depending on what crop that was cultivated. This since the management and cropping methods has great impact on the emissions. The three different categories were; grass, barley and row-crops. Grassland or other perennial crops had the lowest emission estimate in the Swedish study, i.e. CO_2 1100 g CO_2/m^2yr. Barley and other cereals had the medium level emission estimate of 2000 g CO_2/m^2yr whereas row crops had the highest emission estimate of 7000 g CO_2/m^2yr. This means that for grassland and barley estimates are

---

[1] Note that the Swedish values are estimated average values. No measure of variation is given.

[2] Note that the Finnish values are upper and lower limits of measured/estimated emissions.

[3] Note that the Swedish interval is an indication of the variation of average values between sites of different trophy. For an estimate of the variation in methane emissions from Swedish pristine fens, please consult Nilsson et al 2001 on which Nilsson & Nilsson 2004 based their estimates.

[4] Note that these values represent average values for cultivated peatlands with different crops.

similar to the range given in the Finnish study, whereas the row-crops estimate is significantly higher. The high values for row crops like potato were excluded from the Finnish study. It was seen extremely unlikely that such conditions would stretch for 300 years[5]. In fact the average value of 1760 g CO_2 / m^2 per year used in the Finnish study would deplete the carbon pool in peat soil in about 200 years. In the Finnish study some estimates of methane uptake at cultivated peatlands were utilised whereas in the Swedish study this uptake was considered negligible. The estimates of N_2O emissions between the two studies are quite similar. In the Swedish study also the N_2O emissions estimates were correlated to the crop.

3.3.2 Drainage stage

In the Swedish study it was considered necessary with a drainage period for the peatlands, prior to peat harvesting. It was considered to be 5 year long for all types of peatlands (both pristine and previously drained sites). Of course there will be differences between sites, but this parameter was the same for all peat harvesting scenarios. The reason for assuming that also at already drained sites a drainage period would be needed was that peat harvesting was considered to require further drainage. For forestry drained sites which first will have to be clear cut this seems reasonable.

In the Finnish study no drainage period was considered. Most of peat reserves used for fuel production are forestry-drained peatlands. During the Finnish work, the emission changes during drainage for peat production were estimated to be of minor importance.

Table 3.4 Emissions from drained peat production field before peat cutting (5 year period).

Gas	Swedish study
CO_2	Linear increase to 1000 g CO_2/m^2a At both harvesting and surrounding area
CH_4	0–2.3 g CH_4/m^2a, depending on initial methane emissions
N_2O	0.15 g N_2O/m^2a, for pristine and forestry drained sites. For cultivated peatlands higher emission estimates were used.

Conclusion: Probably the need for a drainage period is higher at initially undrained sites. Considering a drainage period or not will not have a significant impact on the overall results.

3.3.3 Peat cutting

Emissions from land area

The peat cutting period was equally long in both studies, i.e. 20 years. According to Table 3.5 there are differences in emissions from the peat field during harvesting.

---

[5] Note that it was considered in the Swedish study that the reference case could not go on for 300 years when the rate of peat decomposition was very high. Instead it was assumed that all peat available would decompose and then the emissions would cease.

Table 3.5 Emissions from peat field during peat cutting period (20 year period)[6].

Gas	**Swedish study**		**Finnish study (only average value presented)**	
	Harvesting area	**Surrounding area**		
	g gas/m²a	**g gas/m²a**	**g gas/m²a**	**g CO_2/MJ**
CO_2	1000, includes emissions from stockpiles	1000 during first years then declining to 300 at end of harvesting period	6.84 g CO_2/MJ from peat field 1.48 g CO_2/MJ from stockpiles In total 8.32 g CO_2/MJ which corresponds to 1408 g CO_2/m²a	
CH_4	0–2.5 depending on initial emissions (valid for both harvesting and surrounding area)		0.0039 g CH_4/MJ from peat field corresponds to 0.65 g CH_4/m²a	
N_2O	0.08–2.5 depending on initial emissions (valid for both harvesting and surrounding area)		Emissions considered negligible	

In the Swedish study it was assumed that the surrounding area is equally large as the harvesting area, this means that during the first year of peat harvesting the emissions in the Swedish case equals 2000 g CO_2/m^2a if only considering the harvesting area. The emissions from the surrounding area are assumed to decline linearly and at the end of the harvesting period the total emissions (counted per m^2 of harvesting area) is then 1300 g CO_2/m^2. The Finnish variation in CO_2 emissions from peat field is 3.42–10.25 g/MJ and for stockpiles 0.74–2.23 g/MJ which corresponds to a total variation between 704–2112 g CO_2/m^2a.

Also in the emission estimates for methane there seems to be some differences between the two studies. In the Finnish study the variation in methane emissions from the peat field is 0.0019–0.0058 g CH_4/MJ (0.32–0.98 g CH_4/m^2a). In the Swedish study emissions are assumed to occur both at the harvesting area and at the surrounding area which means that the interval given should be doubled in order to be comparable to the Finnish values, hence 0–5 g CH_4/m^2. In the Swedish study the higher values have only been used for peat cutting areas that were previously pristine mires with high methane emissions. For peat cutting areas that prior to the cutting already were drained, the lower value has been used.

Also the N_2O emissions differ between the two studies. In the Finnish studies it was assumed that the N_2O emissions from the production field were negligible. The value 0.08 g N_2O/m^2 that was used as lower value in the Swedish study is based on Nykänen et al (1996) and is stated to be a typical value for a forestry drained site. At cultivated peatlands the N_2O emissions are high and in the Swedish study it was assumed that the nitrous oxide emissions during peat cutting would stay the same as in the initial stage. During the Finnish study it was assessed that the impact of the N_2O emissions from the peat production area are much less than the uncertainty of the CO_2 emissions.

Conclusion: The emissions during the harvesting period have a limited impact on the total result since the time period is limited to 20 years (see also sensitivity analysis in Kirkinen et al (in press) and in this study). Due to this reason the differences in CO_2 and CH_4 emissions from the peat field can be considered to have limited effect. The differences in estimated N_2O emissions at cultivated peatlands are large, but probably still have a limited effect due to the limited period.

Emissions from working machines

In both studies also emissions form working machines were considered. As can be seen in Table 3.6 the values used in the two studies are very similar. The CO_2 emissions are exactly the same and the values used in the Swedish study for methane and nitrous oxide are so small they should not

---

[6] In this table only average values are presented. For a full overview of the emissions during the different stages of peat production in the Swedish and Finnish studies, please see Appendix 1.

result in any significant difference compared to the Finnish assumptions. It was assessed during the Finnish work that the impact of CH_4 and N_2O emissions is much smaller than the uncertainty of the CO_2 emissions.

Conclusion: The small difference in emission estimates from working machines will have no effect on the results of the studies.

Table 3.6 Emissions from working machines during peat harvesting.

Gas	Swedish study	Finnish study
CO_2	1 g CO_2/MJ	1 g CO_2/MJ
CH_4	0.7 mg CH_4/MJ	Emissions considered negligible
N_2O	0.025 mg N_2O/MJ	Emissions considered negligible

3.3.4 Combustion phase

According to the sensitivity analysis in Kirkinen et al (in press) and in this study, the emissions during the combustion phase have the largest impact on the overall climate impact of all phases of the production and utilisation chain. Approximately 90 % of the greenhouse impact of the peat fuel lifecycle is formed by the combustion phase. For this reason small differences in emission factor can be important. The greenhouse gases of the combustion phase are relatively well known compared to the emissions from pristine situations. The uncertainty of the combustion phase is in relative measures the smallest compared to the uncertainties of other phases.

The greenhouse gas emissions of the combustion phase have been studied in Finland by Vesterinen (2003) and in Sweden by Nilsson (2004). IPCC also has recommendations for the emission factors of the combustion. The combustion technology, the type of peat and the moisture content affects the emission factor. Mainly peat is combusted in large installations. In Finland, peat is mainly combusted using FBC (Fluidised Bed Combustion), the use of which has increased significantly. Peat is often combusted together with biomass or coal. To some extent, peat is combusted using pulverised firing, and grates are used in smaller boilers. Also a minor use of peat with gasification technology occurs. The emissions of peat combustion has changed during the last decades due to the decrease of moisture content of supplied peat (decreased by 2–3 mass-%) (Tsupari et al 2005). In Finland about 90 % of the utilised energy peat was in the form of milled peat and 10 % as sod peat (Leijting 1999).

According to Table 3.7 the carbon dioxide emission factors used in the Swedish and the Finnish study are very similar. The value of the carbon dioxide emission factor for combustion of energy peat can be considered to be well known and connected with low uncertainty. Both studies use a value of the combustion emission factor for peat valid for peat with an approximate moisture content of 45%.

Table 3.7 Greenhouse gas emissions due to combustion of peat.

Gas	Swedish study	Finnish study (variation given within parenthesis)	
CO_2	105.2 g CO_2/MJ	105.9 g CO_2/MJ	(105.3–106.5)
CH_4	0.005 g CH_4/MJ	0.0085 g CH_4/MJ	(0.0064–0.0106)
N_2O	0.006 g N_2O/MJ	0.0128 g N_2O/MJ	(0.0032–0.0224)

The methane emission factor differs to some extent between the two studies. However, the Swedish value is well within the interval given in the Finnish study.

The Swedish value is valid for combustion in co-generation plants in Sweden, the value is an average value for production units utilising peat in Sweden.

The nitrous oxide combustion emission factor also differs to some extent between the two studies. Again the Swedish value is within the interval given in the Finnish study. In the Swedish reference from which the value is taken (Uppenberg et al 2001a) it is stated that 6 mg N_2O/MJ is the average value for utilisation in large co-generation plants. Large plants are defined as production units with capacity of 50–300 MW. In Uppenberg et al (2001a) there is also a value given for small co-generation units, i.e. 11 mg N_2O/MJ. Small installations are defined as <50 MW. The value for these installations is similar to the average value used in the Finnish study. Nitrous oxide emissions are very dependent on the technology used in the combustion units.

Conclusion: There are differences in the CH_4 and N_2O combustion emission factors used in the Finnish and Swedish studies respectively. However, the Swedish values are within the interval of the emissions factors in the Finnish study. The differences are probably due to different combustion technologies, since the emissions factors are very dependent on it.

3.3.5 Restoration

Estimated values of emissions and uptake of greenhouse gases at restored cutaway areas utilised in the Swedish and the Finnish study are presented in Table 3.8.

Table 3.8 Emission estimates from restored cut away peatlands.

Gas	Swedish study	Finnish study
CO_2	363 g CO_2/m^2a	+28– -271 g CO_2/m^2a
CH_4	10–23 g CH_4/m^2a	15–31 g CH_4/m^2a
N_2O	0.02 g N_2O/m^2a	0 g N_2O/m^2a

The differences in methane emission and nitrous oxide emission estimates are minor. The Swedish estimates for methane emissions are rather estimates for average values at sites of different trophy. The assumption made in both studies is that the methane emissions at the restored site will probably be similar to the initial emissions (if it was a pristine mire). The value of CO_2 uptake was in the Swedish study assumed to be reached in five years after restoration and then stay constant at that level throughout the calculation period. The Swedish estimate is based on Tuittila (1999) whereas the Finnish estimate is based on more recent research by Tuittila & Alm (2005).

Conclusion: The difference in CO_2 emissions is due to new research results and the Finnish values are probably more certain since they represent the results from a few more years of measurements.

3.3.6 Afforestation

Emission and uptake estimates of greenhouse gases at afforested cutaway areas in the Swedish and Finnish studies respectively are given in Table 3.9.

Table 3.9 Emission estimates from afforested cut away peatlands.

	Gas	Swedish study	Finnish study
Sequestration of carbon in growing forest	CO_2	- 520– -1155 g CO_2/m^2a	-359– -505 g CO_2/m^2a
Decomposition of residual peat	CO_2	1000 g CO_2/m^2a[7] (during 22 years, thereafter 0. Only 50% assumed to be decomposable).	Amount of C is decreasing exponentially from 15 000 g C/m^2
Accumulation of above-ground litter	CO_2	2.0–3.5 kg C/m^2 the amount is sequestered during one rotation period	-122– -155 g CO_2/m^2a (Assumption made: Forest sequesters litter carbon until 1.8 kg C/m^2 is reached)
Accumulation of below-ground litter	CO_2	N.a.	0– -6 g CO_2/m^2a

As can be seen in Table 3.9 there are large differences in the estimates of the amount of carbon sequestered in the growing forest. One reason for this is that in the Finnish study it was assumed that carbon is only sequestered until the average value of the total for a rotation period is reached, while in the Swedish study the entire rotation period was considered. The assumptions made for the aboveground litter is similar as is the assumption concerning total emissions due to decomposition of residual peat. In total, the decomposition of residual peat will produce 11 kg CO_2 m^{-2} in the Swedish study and about 50 kg in the Finnish study. However, uncertainty range assumed in the Finnish study is 0–83 kg CO_2 m^{-2}. The dynamics of the decomposition of the residual peat is somewhat different since the Swedish decomposition rate is faster. The Finnish description with an exponential decrease of the decomposition rate might be more realistic. In the Swedish study there was no distinction between below and above ground litter accumulation. The Finnish estimate for the below ground litter accumulation is very low and will not have a significant impact on the overall result.

3.3.7 Emissions from fossil fuels

In the two studies also the greenhouse impact of comparative fuels i.e. coal was calculated. Coal has a relatively large greenhouse impact. The combustion phase of coal utilisation chain has the largest greenhouse impact. Other phases of coal lifecycle are mining, coal transportation and coal processing. The emission estimates for the different phases are listed in a summary table (Table 3.10)

The different phases of the coal utilisation chains are:

1. Mining

   Coal mining releases methane emissions. The methane is generated in coal formation (coalification). The methane will stay stored in coal until the pressure on the coal is reduced, which can occur e.g. during coal mining. Once methane has been released it flows into the atmosphere (IPCC 1996). Most of the methane released is from underground mining. Methane is vented from the mines due to safety reasons. Collected methane can be combusted to produce energy or just flared to destroy it. Generally, the collection and combustion of methane in coal-mines can be seen as normal practice.

---

[7] This is the assumption made for the peat cutting area. In the Swedish study it is also assumed that the peat layer at the surrounding area will continue to decompose during a very long time.

2. Post-mining activities (inc. coal processing, transportation and utilisation)

   Methane in post-mining activities is mainly released because the increased surface area allows more CH_4 to desorb from the coal. Transportation of the coal contributes to CH_4 emissions, because CH_4 desorbs directly from the coal to the atmosphere during transportation. Coal may also release methane while being prepared for final use (for combustion).

   There also are CO_2 and N_2O emissions from transportation by train, ship or truck. The coal imported to Finland is mainly from Russia (80 %) and Poland (20 %) (Statistics Finland 2005). Coal imported to Sweden mainly comes from Poland, U.S.A. and Australia but also from Russia, Venezuela, Canada and Estonia (Rena kolfakta 2000).

3. Combustion

   Combustion phase of coal life cycle has the largest greenhouse impact compared to the other phases of the life cycle. The emissions from coal combustion vary greatly due to different combustion technologies. In Finland mainly the pulverised combustion technology are used for coal (approximately 90 %) (Kari Grönfors personal communication). The used combustion technology affects the emission factors greatly.

Table 3.10 Emission of coal utilisation chain.

Gas	Swedish study	Finnish study
CO_2	94.2 g CO_2/MJ	95.18 g CO_2/MJ
CH_4	1.1 g CH_4/MJ	0.34 g CH_4/MJ
N_2O	0.012 g N_2O/MJ	0.002 g N_2O/MJ

The information about the emission factors of coal utilisation chain of Finnish and Swedish studies were mainly from the ExternE-studies (Pingoud et al 1997, Nilsson & Gullenberg 1997 respectively). The differences in the emissions factors are mainly due to differences in taking account the CH_4 emissions of transportation and the N_2O emission factor of the combustion (different combustion technology).

Conclusion: The greenhouse gas emissions of coal utilisation phase need more detailed research, especially concerning the CH_4 emissions of mining and transportation phases. It also should be noticed that the emissions of the coal utilisation can be different in each country due to different combustion technologies and that the coal can be exported from different countries, which has impact on the emissions of the coal extraction and transportation parts of the life-cycle. The CH_4 emissions of the coal mining may differ greatly depending on where the coal is extracted, is it a new or old coal mine etc. Spath et al (1999) have assessed the CH_4 emissions of the coal mining to be about 0.17 g CH_4/MJ (underground mining). According to Olendrzyński et al (2003) and information from BP (2005) the average fugitive emissions from coal mines in Poland are about 0.14 g CH_4/MJ. In Russia the average fugitive methane emissions from coal mines are app. 0.25 g CH_4/MJ (CENEf 2003).

In the German ExternE-study by Krewitt et al (1997) have assessed the CH_4 emissions of the coal transportation to be 0.002 g CH_4/MJ, while in Swedish study (Nilsson & Gullenberg 1997) the CH_4 emissions of the transportation were assumed to be about 0.37 g CH_4/MJ. In Finnish ExternE-study (Pingoud et al 1997) the methane emissions from transportation were not taken into account. According to IPCC (1996) the methane emissions from post-mining activities are at the typically of the order of about 50 % or less of the emissions from mining activities. The information shows that the variety of the emissions data is broad.

4 Sensitivity analysis

In order to show the variation in result due to differences in input data (emission estimates) we have made a sensitivity analysis. The results are presented in the figures of this section. The input data used in the sensitivity analysis is presented in Appendix 2. In the Swedish model for these calculations, no consideration was taken to the surrounding area except where explicitly indicated. Further the Swedish model does consider a 5 year drainage period before the start of peat cutting. In the Swedish calculations there is about 10% lower energy content (per m^2) in the peat reserves than in the Finnish case. This means that in the Swedish case the emissions in the reference case is somewhat larger than in the Finnish case. We have calculated the variation of the climate impact of each phase using the maximum and minimum emission estimates. We estimated the maximum climate impact by combining the minimum emissions from the reference situation with the maximum emissions of the peat utilisation chain (production, combustion and after-treatment phase). The minimum climate impact was estimated by combining maximum emissions from the reference situation with the minimum emissions from the utilisation chain. This could be viewed upon as worst-worst and a best-best case scenario respectively. It gives the total range of the climate impact from the energy peat utilisation chain based on the emission estimates given in Appendix 2. The scenarios which we have calculated are the following:

- a scenario where a fen is utilised for peat cutting and then after treated by restoration
- a scenario where forestry drained peatland is utilised for peat cutting and then after treated by afforestation
- a scenario where a cultivated peatland is utilised for peat cutting and then after treated by afforestation
- a coal scenarios where coal is used instead of the peat in order to produce the same amount of energy that would be available in the peatland

As can be seen in all the figures of this section the uncertainty of the climate impact is smaller for the coal utilisation chain than for any of the peat utilisation chains. In Figure 4.1 and Figure 4.2 it can be seen that the differences in results are small between the two models. In Figure 4.3 the importance of the surrounding area is shown. As concluded earlier the surrounding area is a large addition to the uncertainty. However we can conclude that in relative terms the impact of the surrounding area will be smaller at large peat cutting areas and larger at small areas.

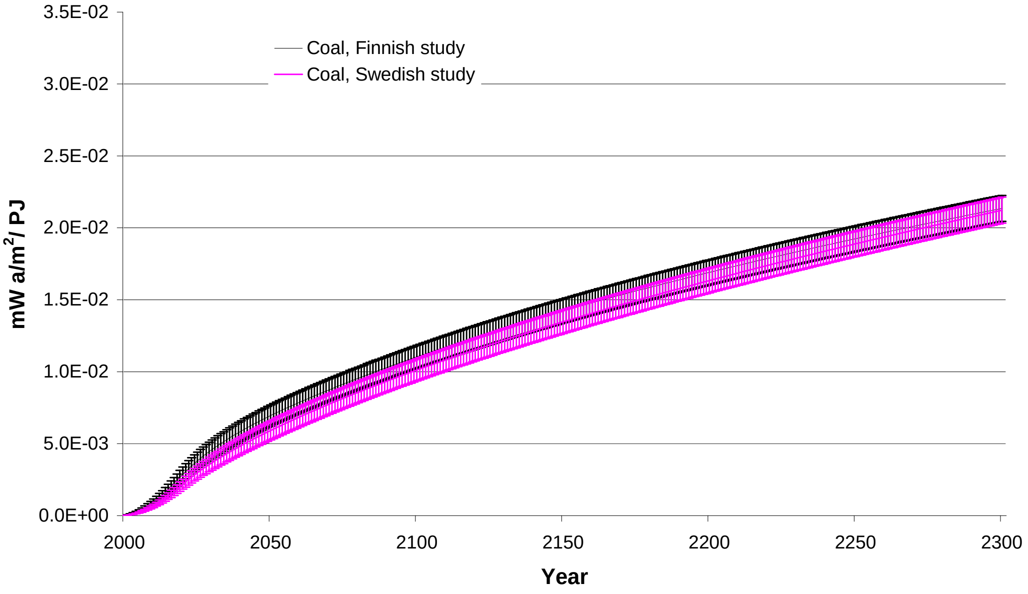

Figure 4.1 Variation analysis for the coal chain. The black curve is the result of the calculations with the Finnish model, whereas the pink curve is the result by the calculation with the Swedish model.

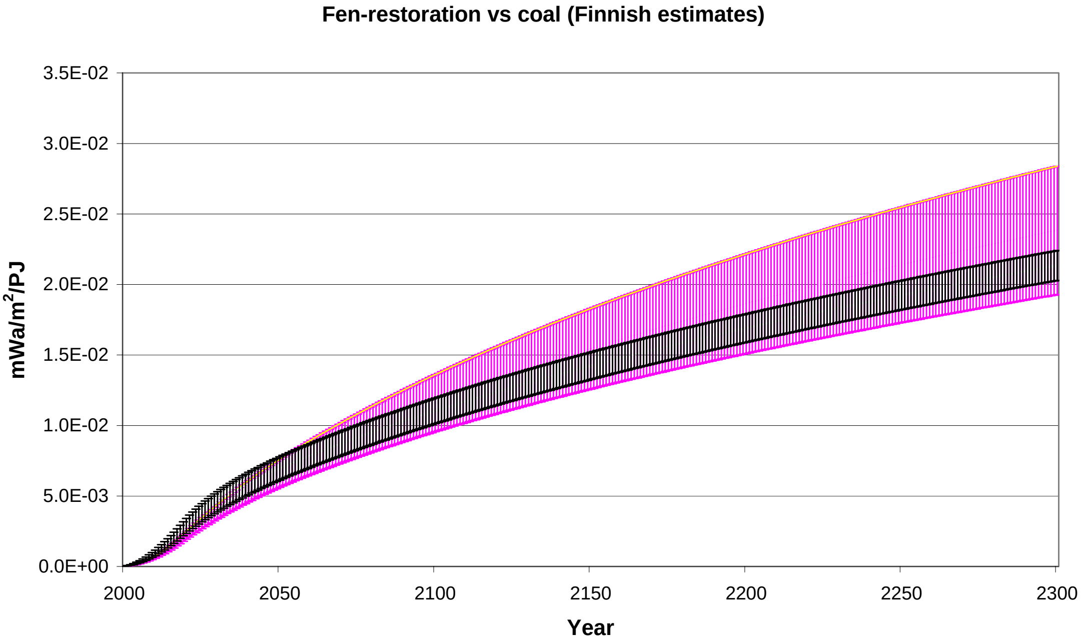

Figure 4.2 Variation in radiative forcing for the fen – restoration utilisation chain and for the coal chain. These calculations were made by the Finnish model.

This figure show that in most cases the peat utilisation chain starting with fen results in a climate impact higher or similar to that of coal. Only when the surrounding area is considered (Figure 4.3) the impact might be somewhat lower in the long run.

In Figure 4.3 the fen – restoration scenario was calculated both with and without consideration of the drainage impact on the surrounding area. In the case of the surrounding area it was assumed that the affected area was the same size as the cutting area. This is a very high estimate and will probably only be valid for very small peat cutting areas. However it shows that it can be of importance to consider also the surrounding area.

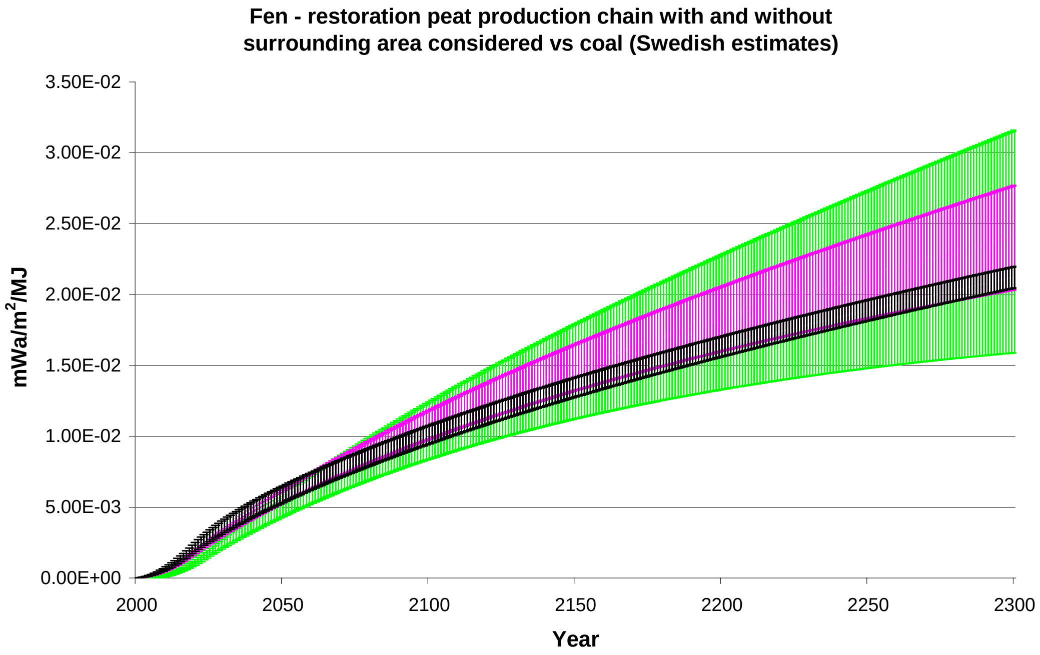

Figure 4.3 Variation range for the peat scenarios where pristine fens are used and after-treated by re-wetting. The pink range shows the results when calculating without considering the surrounding area whereas the green range shows the result when considering the surrounding area. The surrounding area is assumed to be of equal size as the production area itself. The black range shows the climate impact of coal utilisation chain.

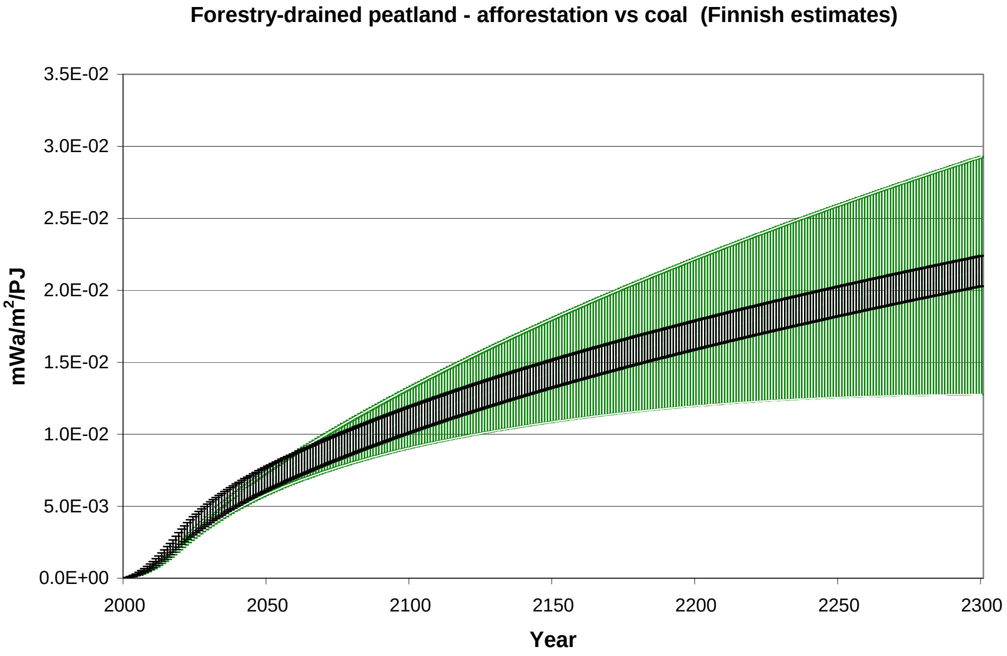

Figure 4.4 Variation range for the peat scenarios where forestry drained peatlands are used and after treated by afforestation. The uncertainty range for the coal scenario is also shown. These calculations do not consider the surrounding area. The calculations were made by the Finnish model.

We made two different assumptions for the afforestation phase. In the average scenario we consider the sequestration of carbon of the increase in forest productivity (3.9 m^3sk/ha) during 45 years, that is until the average value over the rotation period is reached. In our maximum scenario we consider the sequestration of carbon of the increase in forest productivity (3.9 m^3sk/ha) during the entire calculation period of 300 years. This corresponds to an assumption that the wood will be used and remain in constructions or that it will be utilised as fuel and replace some fossil fuel (e.g. coal). For the cultivated peatland – afforestation utilisation chain the increase in forest productivity was assumed to be double (7.8 m^3sk/ha) since there were no forest on the land area before peat cutting.

The uncertainty range for the forestry drained peatlands scenarios as shown in Figure 4.4 and Figure 4.5 is very large. The main reason is the large span for input data on the emissions from the forestry drained areas due to decomposition of peat. Also the variation range (shown in Figure 4.6 and Figure 4.7) for the cultivated peatlands is quite large. The main reason is also the wide range in input data for the initial stage of this utilisation chain.

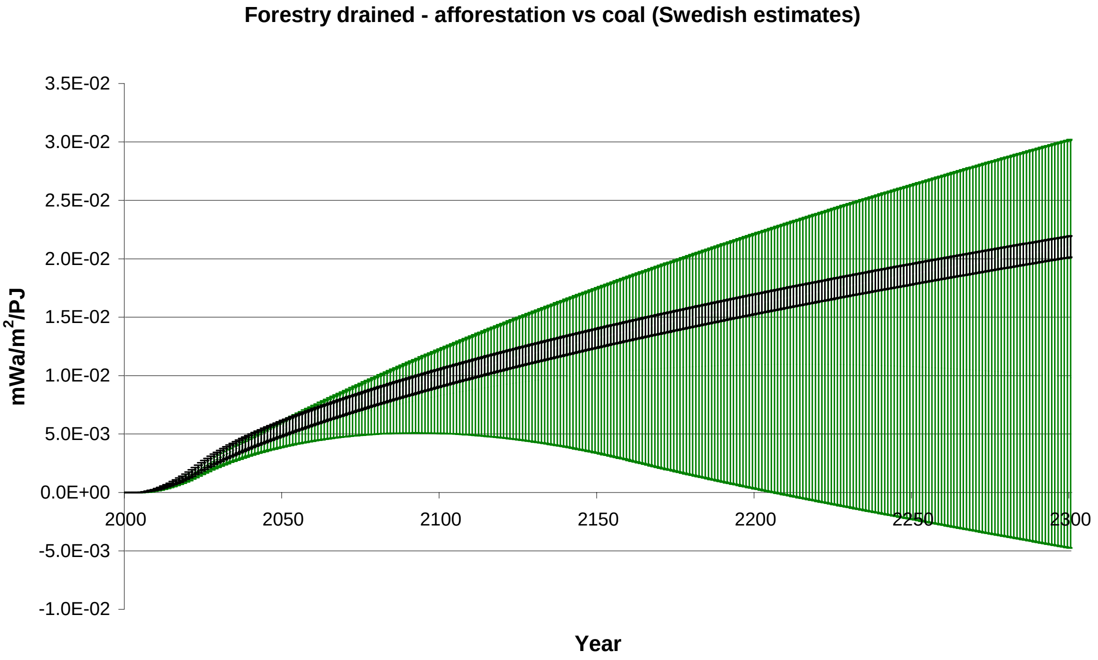

Figure 4.5 Variation range for the peat scenarios where forestry drained peatlands are used and after-treated by afforestation. The uncertainty range for the coal scenario is also shown. These calculations do not consider the surrounding area. These calculations were made by the Swedish model.

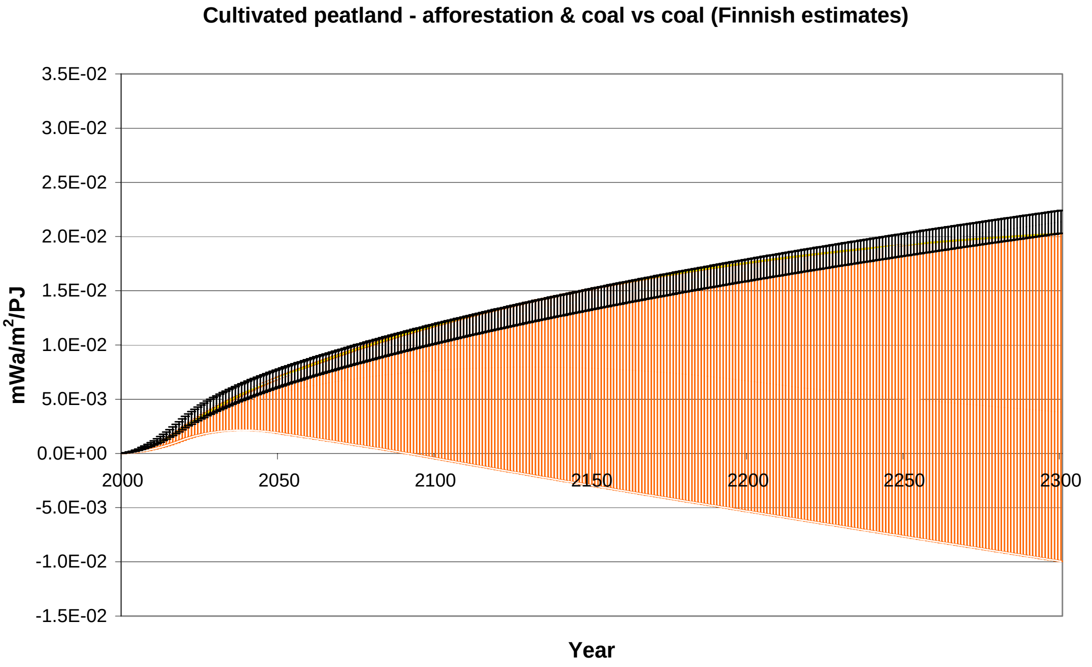

Figure 4.6 Variation range for cultivated peatland – afforestation and the coal chain. The calculation was made with the Finnish model.

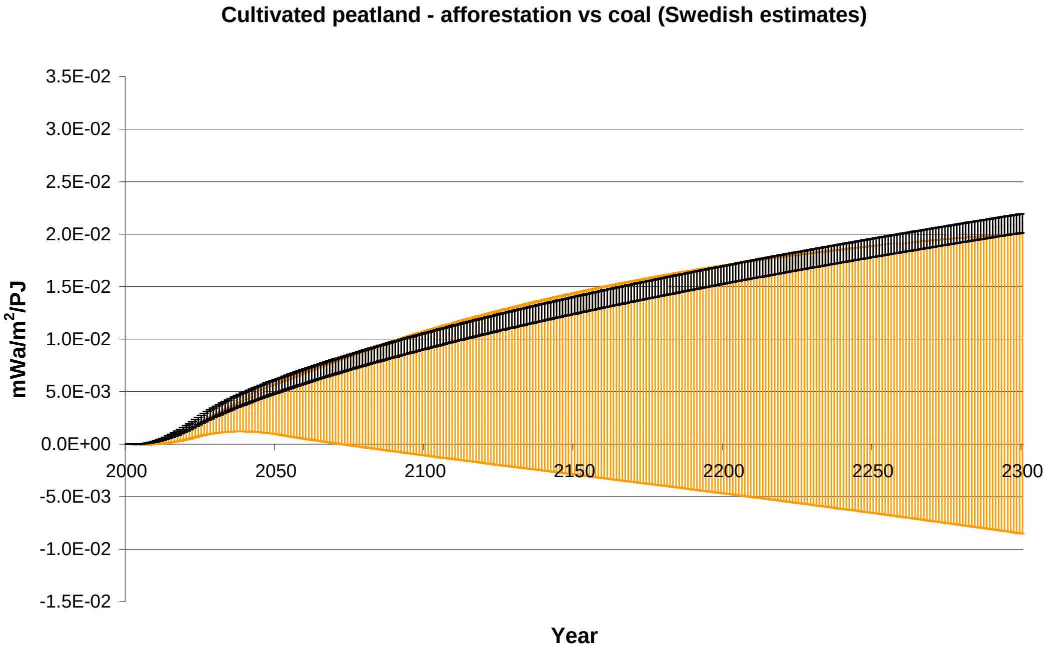

Figure 4.7 Variation range for cultivated peatland – afforestation and the coal chain. The range was calculated without consideration taken to the impact on the surrounding area. The calculation was made with the Swedish model.

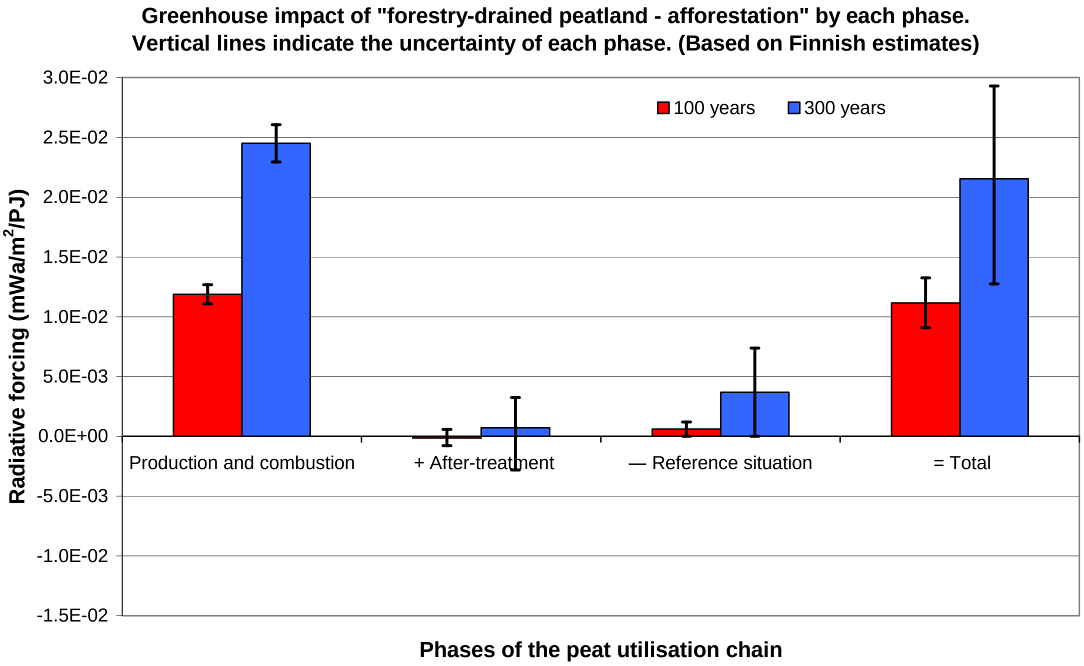

Figure 4.8 Accumulated radiative forcing of forestry drained peatland – afforestation utilisation chain by each phase. Vertical lines indicate the uncertainty of each phase. The largest contribution to the total uncertainty comes from the reference situation and the after-treatment. The relative uncertainty increases with time. These results are based on the Finnish values and model.

The variation of the accumulated forcing due to the emissions in the different phases is shown in Figure 4.8 and Figure 4.9. Both figures are based on the Finnish values and model. In Figure 4.8 it can be seen that the production and combustion phase are responsible for the main greenhouse impact during the first 100 years. The uncertainty of the total greenhouse impact increases over time. The impact of the reference situation and in the after-treatment phase is more important in the longer run. The reason for a positive climate impact from the after-treatment phase is the decomposition of residual peat. Negative value is due to sequestration of carbon into growing forest. With the Swedish values the variation of the greenhouse impact in the reference situation is much larger than in Figure 4.8 due to larger variation in emission estimates for the reference situation. In Figure 4.9 the effect of larger variation in emission estimates for the reference situation can be seen.

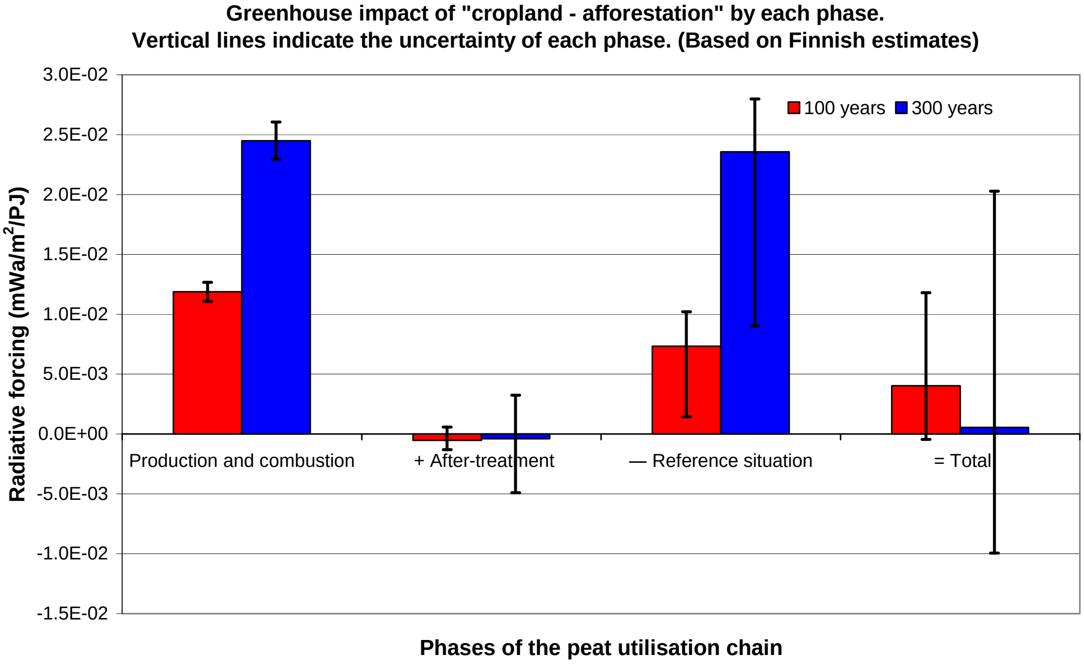

Figure 4.9 Accumulated radiative forcing of cultivated peatland – afforestation utilisation chain by each phase. Vertical lines indicate the uncertainty of each phase. The largest contribution to the total uncertainty comes from the reference situation and the after-treatment. The relative uncertainty increases with time.

In Figure 4.9 it can be seen that the climate impact from the reference situation to a large extent is cancelling out the climate impact from the production and combustion phase during 300 years. However the variation range is very large. The large range of variation is mainly due to large variation in peat decay rate in the cultivated peatland. The asymmetry of the variation range of the reference situation is due to the limited carbon pool of the soil. In the scenarios with the highest decomposition rate of peat, the carbon pool is completely depleted within 52 years. Also in the scenarios with average decomposition rate the entire carbon pool will be released during the studied period. Hence the total amount of carbon emitted due to peat decomposition is not dependent on the decay rate in those cases. However in the scenarios with the lowest peat decomposition rate approximately 60% of the total carbon stored in the peat reserve is depleted during the 300 years. So in this case, the change of the decay rate has impact on the total amount of carbon emitted from the soil. The results in Figure 4.9 are based on Finnish values and model but the results for the Swedish case will look similar.

5 Issues of special interest

Two issues were considered of special interest for this project. The special issues considered were from a Swedish perspective and for Swedish conditions. First of all there is a new production technology under development which has the potential of significantly reducing the emissions of greenhouse gases during the production stage and from the after-treated area. Secondly the peat industry has found it self in a serious situation due to lower demand for energy peat. This is mainly due to high prices of emissions allowances for emitting CO_2, which since January 2005 is mandatory for heat and power installations to surrender in equal amounts to their actual emissions. Due to this situation this project also aimed at briefly discuss the risks of increased climate impact due to premature close down of peat cutting areas due to lost profitability.

5.1 Calculations for production chains with new production methodology

5.1.1 Description of the technology

Vapo Ltd, (the largest peat producing company in Sweden and Finland) has been developing a new production methodology, which will increase the production capacity and decrease the environmental effects, including emissions of greenhouse gases. The new production methodology has been tested in field in Finland during 2004 and 2005 and will be further tested during the cutting season of 2006 both in Finland and Sweden. The new technology is schematically described in Figure 5.1.

The peat cutting area is to the left in Figure 5.1, whereas the drying area is to the right. Only a small area (compared to the drained area at a conventional cutting site) is drained at the time. Peat is cut with an excavator and pumped from the cutting area to the drying area. The drying area is constituted by a solar heated asphalted area. In Figure 5.1 the solar panels can be seen surrounding the drying area. The pumped peat is spread over the asphalted area and under optimal drying conditions the peat will dry in approximately 24–36 hours compared to a drying time of 1–2 weeks with traditional milling methods. The new drying technology thus means significantly decreased weather dependency. With the new cutting technology it is also possible to remove more of the peat layer. At conventional harvesting sites approximately 20–30 cm of residual peat is left when peat cutting is finished (the thickness of the residual peat layer can vary significantly depending on the topography of the under laying layer). With the new method it is estimated that the residual layer can be reduced significantly. Removing more of the peat means lower emissions from the after treated area, especially in the case of afforestation or other after-treatment where there is a possibility of decomposition of peat. Restoration will in most cases hinder such decomposition due to the water logged conditions.

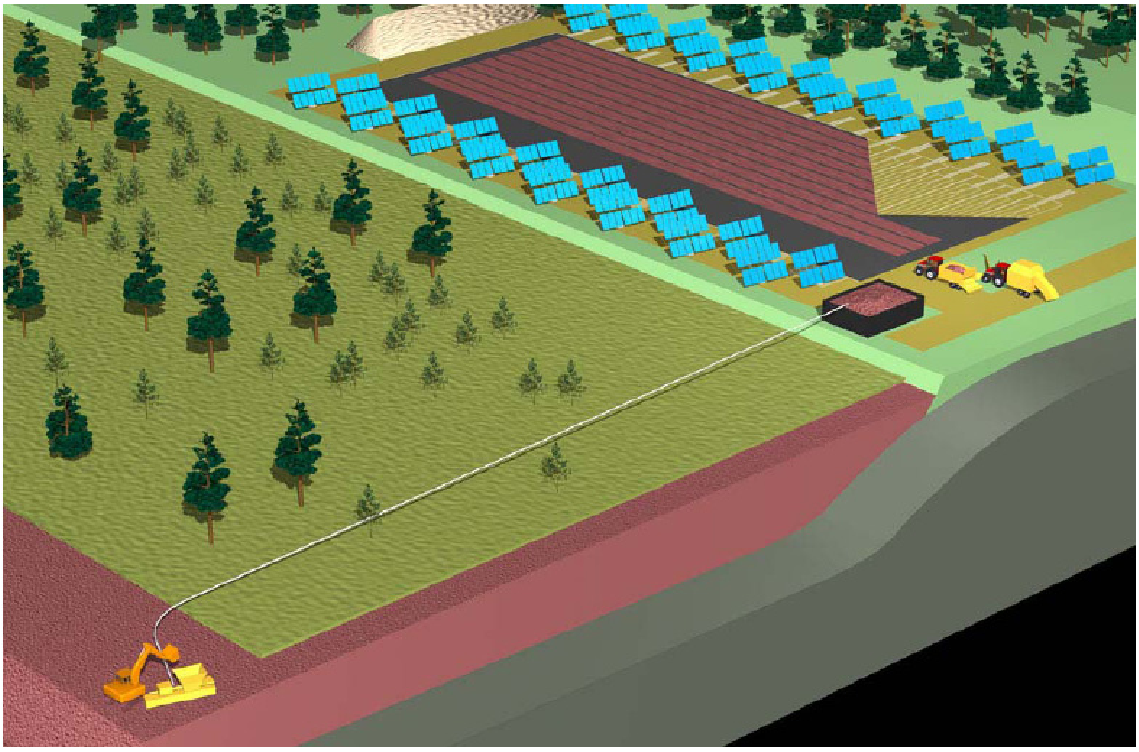

Figure 5.1 Schematic picture of new production methodology. Source: Niko Silvan Finnish Forest Research Institute, Parkano Finland.

According to Silvan (2005) there are several advantages with the new production technology;

- less greenhouse gas emissions from the production area since a much smaller area will be drained at the time and also a smaller vegetation-less area (as small area as 5% of that required in the milling method might be needed)
- the enabling of utilisation of abandoned cultivated peatlands
- lowered emissions from stockpiles
- restoration is easier than at conventional harvesting sites (due to high water level and remaining species bank in the edges of production area
- lower emissions of dust

Hence the new production methodology is promising; however it has only been tested at limited areas and only for a short time period.

5.1.2 Calculation of energy peat utilisation chains with new production technology

In this study a few calculations with the new production technology have been performed. The production chains for which calculations have been made are presented in Table 5.1. The calculations were made in the Swedish model after the following adjustments;

- the indirect forcing effect of methane used in the Finnish study was added
- the radiative forcing calculations are made per PJ of produced peat. (Assumption of energy content is same as in Nilsson & Nilsson 2004)

Table 5.1 Scenarios for which radiative forcing calculations have been performed.

Scenario no	Pre-peat extraction land-use	Peat extraction methodology	Restoration method	Scenario length [yr]	Energy production
1	Forestry drained peatland	Conventional Peat harvesting	Restoration	300	Peat production during 20 and 300 years respectively
2	Forestry drained peatland	Conventional Peat harvesting	Afforestation[8]	300	Peat production during 20 and 300 years respectively
3	Forestry drained peatland	New production technology	Afforestation[8]	300	Peat production during 20 and 300 years respectively
4	Corresponding amount of energy as in scenario 1 is produced by coal				
5	Corresponding amount of energy as in scenario 1 is produced by natural gas				

Emission estimates were selected in order to represent Swedish conditions. The emission estimates utilised are presented in detail in Appendix 4. Some of the important assumptions utilised were:

- new estimates of greenhouse gas emissions and uptake from restored areas utilised by Kirkinen et al (in press)
- emission estimates for the initial area of forestry drained peatlands are based on Klemedtsson et al (2002), average and lower estimate
- with new production methodology there will only be 5 cm left after peat cutting
- residual peat will decompose exponentially (similar assumption as in Kirkinen et al (in press)
- conventional forestry was assumed both for initial and after-treated area (in the case of afforestation). Thus sequestration of carbon was considered during growth period and emissions of carbon were assumed to occur at felling stage.

5.1.3 Results of calculations

In the scenarios presented in the figures below no consideration was made to the surrounding area. There are however figures in Appendix 5 where also the surrounding area have been considered. The main reason for not including the surrounding area was that the effect is assumed to be smaller when the initial stage is already drained areas (compared to pristine mires). The effect of the surrounding area is higher climate impact when conditions are not improved compared to initial situation and lower climate impact when it is (compared to the scenarios where the surrounding area was not considered), see Appendix 5.

In Figure 5.2 and Figure 5.3 the accumulated radiative forcing of scenarios 1a–5a are presented. In these scenarios 1PJ of peat is produced during 20 years. In Figure 5.4 and Figure 5.5 scenarios 1b–

---

[8] Normal forestry was considered both before and after peat cutting. Accumulation of carbon considered during growth period and emissions assumed to occur in same year as fellings.

5b are presented and in these scenarios corresponds to continuous peat production during 300 years, where 1 PJ is produced in each 20 year period.

In Figure 5.2 the decomposition rate of the peat layer in the initial forestry drained peatland is equal to the average estimate for Swedish forestry drained peatlands as made by Klemedtsson et al (2002). In Figure 5.3 the decomposition rate of the peat layer in the initial forestry drained peatland is equal to the lower estimate for Swedish forestry drained peatlands as made by Klemedtsson et al (2002), which is close to the average value for Finnish sites (Kirkinen et al (in press)). Figure 5.4 and Figure 5.5 are corresponding figures for the 300 year production scenarios. In all figures it is assumed that the forest productivity in scenario 2 and 3 is not changed due to peat cutting (this is indicated by "no prod" = no production increase).

According to Figure 5.2 the coal scenario has the highest climate impact. Only scenario 3a is initially higher, which is the scenario with the new production method. The reason for this is that in scenario 3a all peat is produced and burned during 1 year. Scenario 1a, the restoration scenario has the highest climate impact of the peat scenarios. The reason is that the total greenhouse gas balance after peat cutting is higher in the restoration scenario. This is mainly due to the high methane emissions at the after-treated area. Scenario 3a has somewhat lower climate impact than scenario 2a mainly due to the lower emissions from decomposing residual peat. In the coal scenarios we made the same assumptions on the emissions of combustion and production as in Nilsson & Nilsson (2004). In appendix 5 we also present the results where the methane emissions of the coal scenario are lower than assumed in Nilsson & Nilsson (2004).

In Appendix 5 further variations of the scenarios are presented. Note that we have not considered different levels of N_2O emissions from the initial forestry drained peatland. According to von Arnold (2005b), there are sites with significantly higher N_2O emissions than the emission estimates utilised in the present scenarios. If such areas are used and most of the peat is removed (lowering the N_2O emissions) it will probably result in lower climate impact than the scenarios presented here and in Appendix 5.

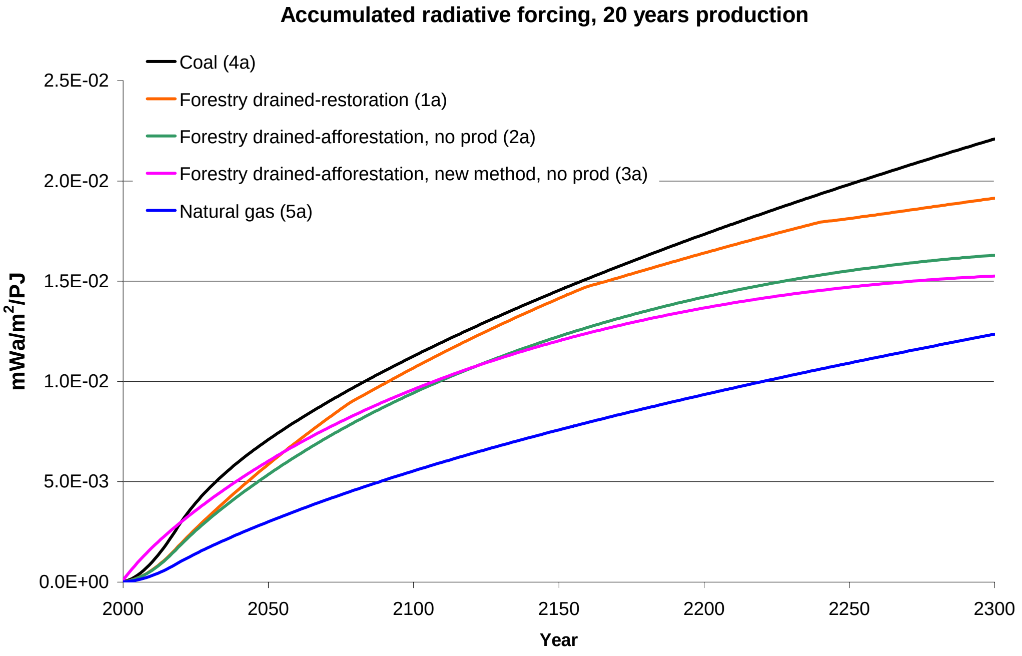

Figure 5.2 Accumulated radiative forcing for energy peat production scenarios. Initial stage of the peatland is forestry drained and the oxidation rate is the average estimate based on Klemedtsson et al (2002).

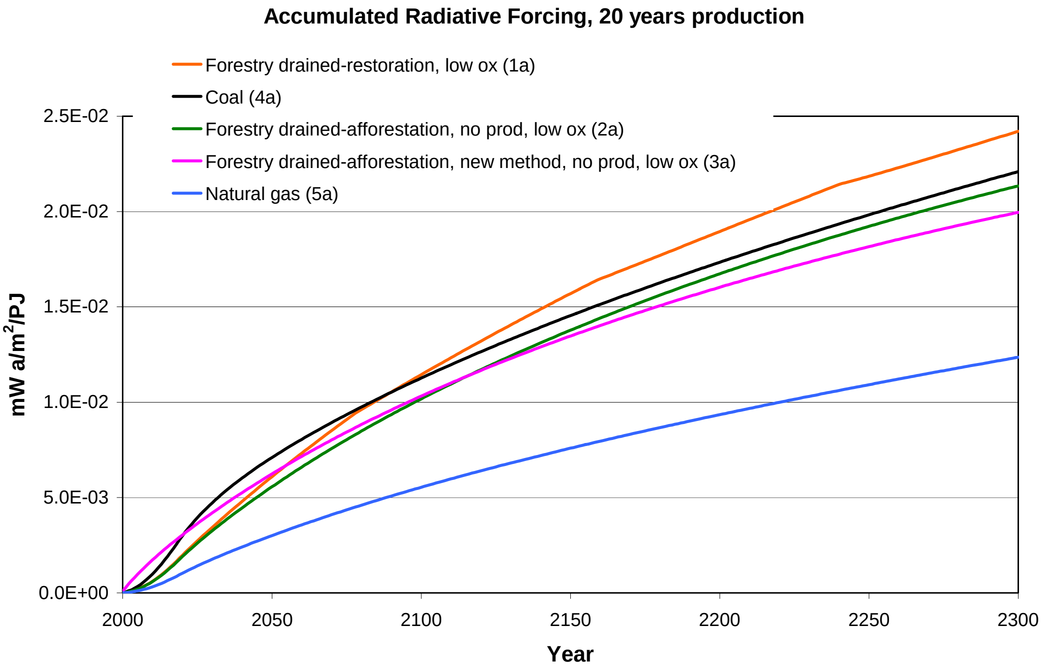

Figure 5.3 Accumulated radiative forcing energy peat production scenarios. The initial stage of the peatland is forestry drained and the oxidation rate is equal to lower estimates for Sweden (close to average Finnish estimates). No prod = no productivity increase in afforestation, low ox = low peat oxidation rate, new method = new peat production technology used.

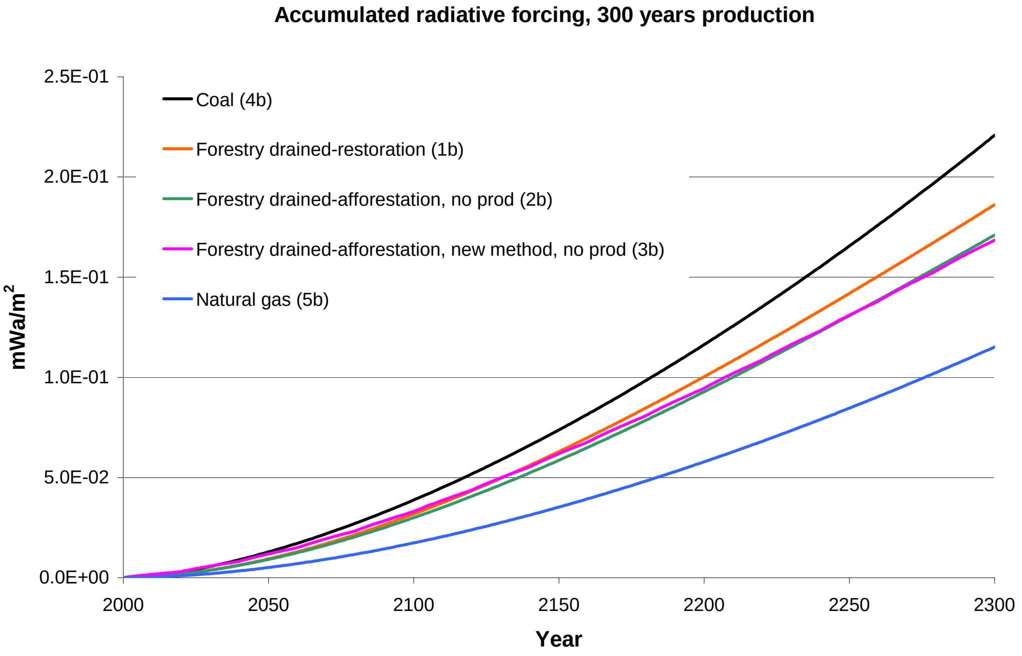

Figure 5.4 Accumulated radiative forcing for energy peat production scenarios. Initial stage of the peatland is forestry drained and the oxidation rate is the average estimate based on Klemedtsson et al (2002). The scenarios correspond to production of 1 PJ during every 20 year period. The production continues during 300 years.

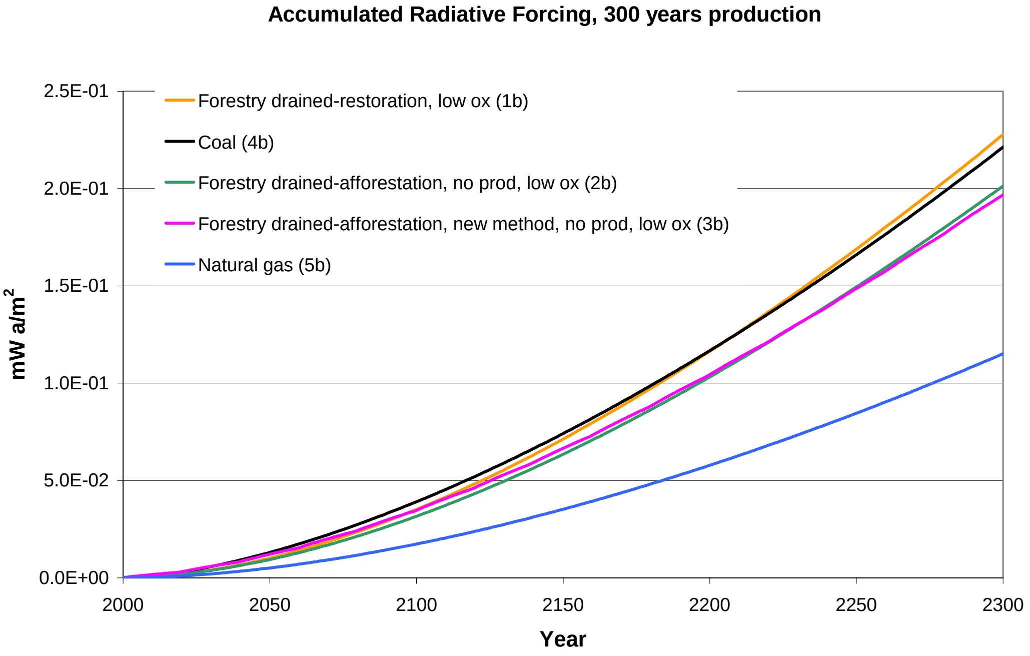

Figure 5.5 Accumulated radiative forcing energy peat production scenarios. The initial stage of the peatland is forestry drained and the oxidation rate is equal to lower estimates for Sweden (close to average Finnish estimates). The scenarios correspond to production of 1 PJ during every 20 year period. The production continues during 300 years.

As can be seen in Figure 5.2 and Figure 5.3 the climate impact of scenario 3 (new production method) is somewhat lower than the conventional peat cutting in scenario 2. The reason is the lower emissions from machines and production area as well as the lower emissions from decomposition of residual peat. If also other possibly positive effects of the new production technology such as lower water content of the peat, which leads to lower combustion emission factor, is added the scenarios with the new production method, it will have even lower climate impact. This can be seen in Figure 6.3 from Kirkinen et al (in press). In that figure scenario 3) forestry drained peatland – afforestation and scenario 3*) forestry drained peatland – afforestation should be compared. The first scenario show conventional peat cutting with 30 cm of residual peat whereas the second scenario show conventional peat cutting with no residual peat. The reduction of residual peat is one of the gains with the new technology. Also scenario 4) cultivated peatland – afforestation and scenario 5) Vision chain could be compared. In the vision chain the reduced amount of residual peat, lower emissions from working machines, lower combustion emission factor due to dryer peat and in addition also lower combustion emissions of methane and nitrous oxide due to improved combustion technology. These results show that there is a significant potential in the new production technology of reducing climate impact.

In Figure 5.4 and Figure 5.5 the positive effect of the new production technology can not be seen, mainly, since the peat cutting is continuous and the climate impact is dominated by the combustion phase, in which we did not consider any changes due to the new production technology. The calculations of the climate impact of energy peat utilisation chains in this study consider the lifecycle. The lifecycle includes emissions before, during and after peat cutting. In the 300 year scenarios only part of the life cycle is considered. This is also why the reduced climate impact is not visible in these scenarios. For instance the effect of reduced emissions due to the thinner layer of residual peat is not seen completely in these scenarios.

5.2 Risk of climate impact due to premature close down of peat cutting areas

As discussed previously there are a few factors determining the emissions/uptake of greenhouse gases from the after-treated area. For restored sites, CO_2 uptake will be dependent of the growth of the new vegetation and methane emissions will be very dependent on what species that are present. For afforested sites the decomposition rate of the residual peat layer and the productivity of the new forest are important factors.

Generally if there is a substantial residual peat layer and the after-treatment chosen would be afforestation there is a risk for substantial and long-term emissions of CO_2 due to decomposition of residual peat and the risk of low productivity of the forest. Of course all this is also dependent on what type of land the cutting area was before the start of peat cutting. The risk for low productivity of the forest is due to the fact that a thick residual peat layer will hinder the trees from getting minerals from the mineral soil and hence they might lack some nutrients. A less risky alternative of after-treatment at areas with substantial layers of residual peat is probably to restore the site. Of course there is always a risk for high methane emissions depending on what type of vegetation you get on the restored area, but the risk for decomposition of the residual peat and thereby emissions of CO_2 will be low. If the after-treatment is done in a good way there is also a possibility for a net uptake of CO_2 due to the new plants.

This means that if peat cutting areas are closed down in advance, with peat left, the choice of after-treatment will be more important. According to Östlund 2006 (personal communication) it is more probable that the land-owner would prefer afforestation if peat cutting was finished in advance.

However the final decision on what option that should be used for the after-treatment is in Sweden made by Länsstyrelsen.

According to Östlund (2006) (personal communication) it is also more probable that premature close down would occur in remote areas. In peat cutting areas situated close to densely populated areas there would probably still be a demand for horticultural peat so that peat cutting at least would continue to a lesser extent even if energy peat cutting would not be profitable.
What could be a risk is also that premature close down would result in areas being left without after-treatment resulting in high emissions of greenhouse gases. Peat cutting areas have in general quite high emissions of greenhouse gases, CO_2 emissions from the decomposition of the peat and methane emissions from stockpiles and ditches. In Sweden it is necessary to have a concession in order to cut peat. Normally these concessions are valid for 25 years and if the peat cutting is not finished by then a new application will have to be made. Production breaks during this period are allowed. There is no deadline set for when after-treatment will have to be finished but the contract guarantee securing the after-treatment will not be returned until the restoration has been approved. The peat cutting is considered finalised when the after-treatment has been approved. This could mean that if the demand for energy peat is low, producers might wait a few years to see if the market turns (production break) and then finalise the cutting or the after-treatment. In either case this might result in the cutting area being open for a longer time period resulting in higher emissions of greenhouse gases. Due to the rules of the producer being responsible for after-treatment there should be no risk (or a very small risk) for areas being left without after-treatment.

6 Results of the Finnish and Swedish studies

6.1 Similarities and differences

The following differences and similarities between the results of our studies were found:

- To use pristine mires for energy peat harvesting results in higher climate impact than using already drained areas. (Similarity)

- Using cultivated peatlands for energy peat production results in significantly lower climate impact then corresponding utilisation of coal. (In a 100-year perspective or longer). (Similarity)

- Using forestry drained peatlands for energy peat production does in most cases result in higher climate impact then corresponding utilisation of coal according to the Finnish study; according to the Swedish study the forestry drained peatlands result in most cases in lower climate impact then the coal utilisation. (Difference)

Figure 6.1 and Figure 6.2 below show the earlier results of the Swedish study (Nilsson & Nilsson, 2004) and Figure 6.3 show the results of the Finnish study (Kirkinen et al in press).

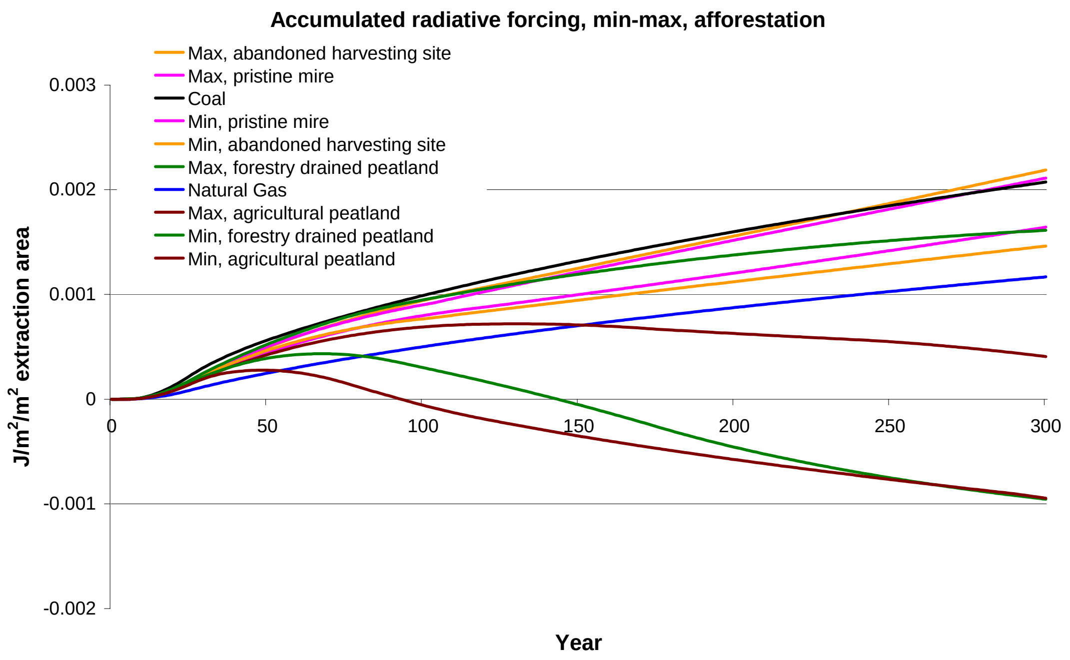

Figure 6.1 Accumulated radiative forcing of some energy peat production scenarios according to Nilsson & Nilsson 2004. In all of these scenarios the after-treatment was afforestation. For each type of peatland a maximum and minimum climate impact production chain is presented.

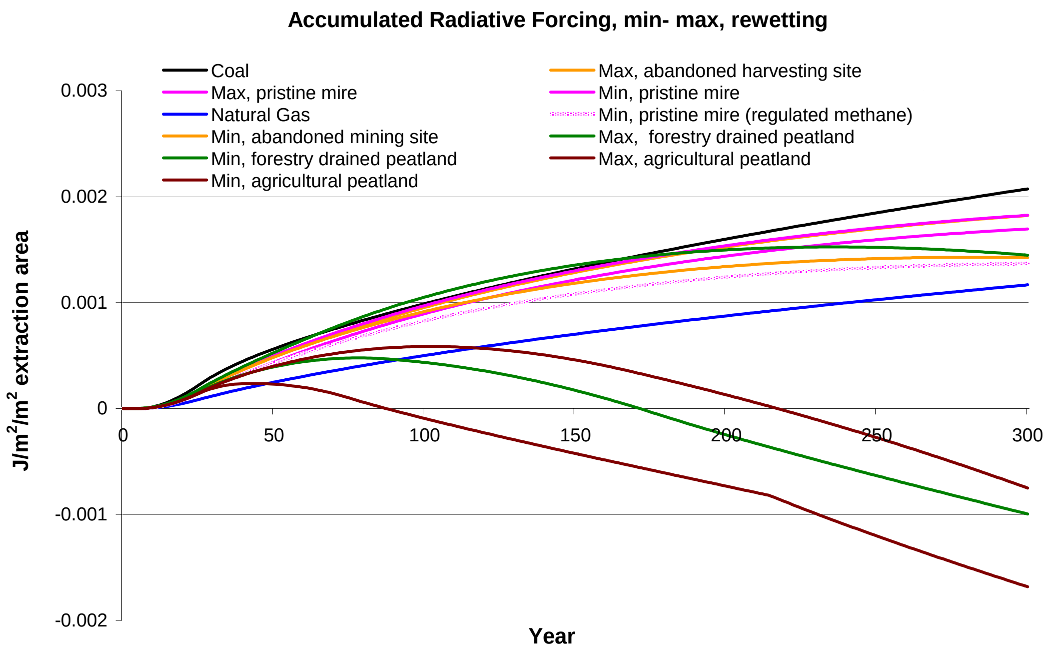

Figure 6.2 Accumulated radiative forcing of some energy peat production scenarios according to Nilsson & Nilsson 2004. In all of these scenarios the after-treatment was restoration (re-wetting). For each type of peatland a maximum and minimum climate impact production chain is presented.

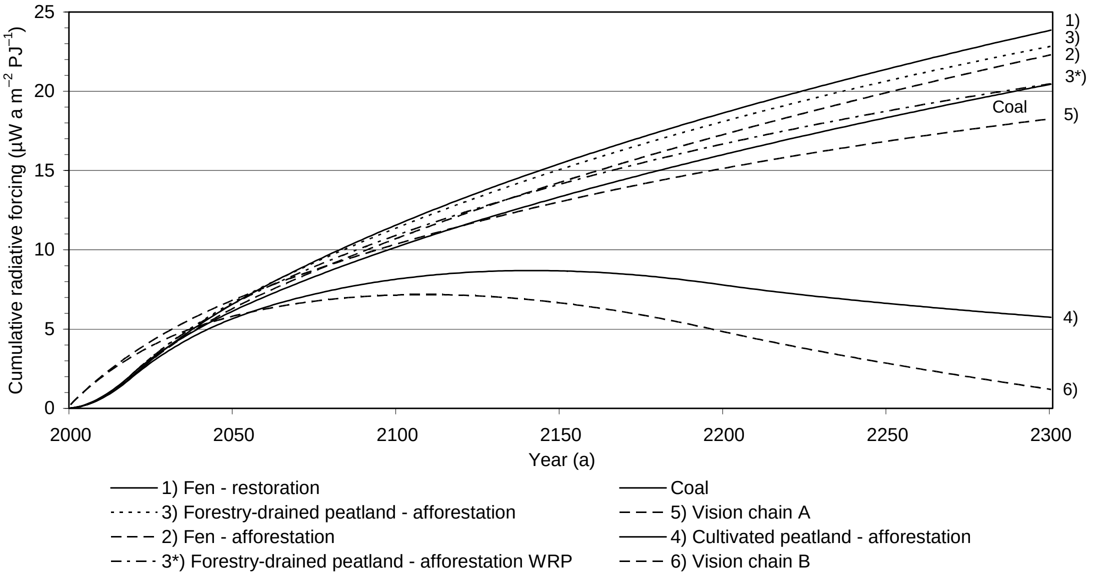

Figure 6.3 Accumulated radiative forcing of the peat and coal utilisation chains according to Kirkinen et al (in press)

Vision chain A in Figure 6.3 shows the climate impact of peat utilisation where forestry drained peatland is harvested with the new technology and then is afforested. Vision chain B in the same figure shows the climate impact of a peat utilisation chain where a cultivated peatland is harvested by the new peat cutting technology and then is afforested.

The main differences between Finnish and Swedish results are the forestry drained peatland utilisation chains. (Note that the scales on the Swedish and the Finnish figures are different.) The main reason here is the difference in input data. Finnish estimates of CO_2 emissions from forestry drained peatlands are lower than corresponding Swedish estimates compared to the coal chain (and other chains).

When the fen – restoration scenario in the Finnish study (scenario 1, figure 6.3) is compared to the Swedish scenarios for pristine peatlands and rewetting (pink lines in figure 6.2) it seems that the Swedish results are lower than coal and the Finnish are higher. One reason for that are the estimates of the uptake of CO_2 at the restored (rewetted) site. In the Finnish study more recent data was available and utilised. The earlier estimate used in the Swedish study is probably too high.

Another reason is the differences in emission estimates for the coal production chain. In the Swedish estimate the methane emissions were significantly higher than in the Finnish study. The reason for the high methane emissions connected to coal utilisation the Swedish study is due to the estimated emissions during transport. Considered in the Swedish study was that when transporting (and possibly also during grinding) the coal, methane trapped in the structure will be released.

An important difference between the results is also that in the Swedish study the surrounding area was considered. As we have seen in the study, considering the surrounding area results in a strengthening of the effect of the peat cutting. Hence if emission balance of greenhouse gases is improved (lower emissions from the land area) after peat cutting considering the surrounding area will lead to lower climate impact than if not considering the surrounding area. And opposite if the emission balance gets worse (higher emissions from the land area) after peat cutting, considering the surrounding are will lead to higher climate impact than if not considering the surrounding area.

7 Discussion

Scientific approach and calculation models:

The scientific approach in the two compared studies is similar. In both studies the same phases of peat production and utilisation is considered and compared to a reference scenario which is the non-utilisation of the peat resource, leaving it in its current state. There are some differences in how the calculation models are built up but the comparative study show that these differences will have only minor impact on the results. The differences also show that it is important to remember that a model is just a model and that there are uncertainties connected also to the models describing the radiative impact due to the increases of concentrations of greenhouse gases in the atmosphere. The uncertainty in the radiative forcing models and in the carbon cycle models and other models describing the atmospheric retention of the greenhouse gases are probably larger than the differences between the Swedish and the Finnish model (IPCC 1997). Models will have to be developed and improved as the scientific knowledge of these processes get better.

System boundaries:

There were some differences in the system boundaries used in the two studies. The most important differences are the consideration of the surrounding area and the consideration of carbon sequestration into growing biomass at afforested cut-away areas. When cutting peat, there will be impact of drainage not only at the production area but also at the surrounding area. The size of the impacted surrounding area depends on both the size of the production area and the geometrical form of it. The impact on total greenhouse gas emissions will also depend on the properties and peat depth of the affected surrounding area. We found that all these parameters are not very well known and this will have to be investigated further since it can have important impact on the results.

In the utilisation chains where afforestation is the chosen after-treatment there are different options on how to consider the carbon sequestration into the growing forest. Compared to the restoration alternative, where it can be assumed that the sequestered carbon will be stored for a long time, we know that the carbon bound in growing trees might not stay for long in the tree biomass. There are many possible pathways for this carbon:

- it can stay for very long time in the tree biomass if the forest is not utilised for conventional forestry but left to be a natural forest (this might not be a very likely scenario in Sweden or Finland today due to the great demand for biofuels)
- it can be used as a fuel (considering that the forest is used for conventional forestry)
- it can be used in the pulp and paper industry
- it can be used in constructions
- etc

The list can be made long and we think that it is best to make the decision on how to consider this in each study. It is important to describe how it is considered since it has impact on the results and the comparability with other studies. However the greenhouse impact of afforestation is only moderate compared to the impact of the combustion & production and reference case, see Figure 4.8 and Figure 4.9. However with other assumptions and input data the impact might be more substantial, in Uppenberg et al (2004) for instance the consideration of forest growth and utilisation of biomass for fuel had a significant impact on the overall results. The climate impact of considering biomass production at cutaway peatlands is currently being investigated both in Sweden and Finland and we have not investigated that further in this report.

Emission estimates:

The main reason for differences in results in the two studies is due to differences in input data (emission estimates). For the peat utilisation chain the main differences were found in the emission estimates of the initial/reference phases and the after-treatment phases.
For the initial phase the emission estimates at pristine mires (fen) were quite similar.
For cultivated peatlands the emission estimates were also quite similar with the exception of the high emission estimates utilised in the Swedish study for areas utilised for row-crops.

For the forestry drained peatlands there were large difference in the emission estimates of the initial phase. The Finnish emission estimates of CO_2 emissions due to the decomposition of peat at these areas are much lower than the Swedish estimates. We tried to get a better understanding of these differences and according to the researchers of LUSTRA (Per Weslien, personal communication) who have made the Swedish estimates one explanation is that there are differences in management methods used in Sweden and Finland respectively. In general the Swedish forestry drained sites seems to be more "severely drained", i.e. the Finnish ditches are in general shallower than the Swedish ones. This means that in the Swedish case a lower ground water table, more aerated peat and hence larger emissions. Another reason would be climatic differences. The two measuring stations that the Swedish estimates are based on are located in southern Sweden (Asa, Småland) and Norunda north of Uppsala respectively. Norunda is on the same latitude as the southern parts of Finland whereas Asa is much more south. However the latitude might not be the best indicator of differences in climatic conditions since other climatic factors such as precipitation is more important than for instance temperature. There might also be difference in the methodologies used in Finland and Sweden for assessing the carbon fluxes and decay rates from the forestry drained peatlands.

In the restoration phase there were also differences and the Finnish estimates were based on more recently updated data. Therefore we think that these are more relevant to use. The new data indicate that the carbon sequestration in the restored area is significantly lower than previous estimates. This means that the results in the Swedish study (Nilsson & Nilsson 2004) where restoration was used as after-treatment would result in somewhat higher climate impact since less carbon is sequestered into the restored wetland/peatland.

In the afforestation phase the main difference was the consideration of carbon sequestration. In the Finnish study sequestration was considered until the average value over a rotation period was reached whereas in the Swedish study sequestration was considered during one whole rotation period. We have in this study suggested another option of how to consider the sequestration into the growing forest. The new option is to consider only the increase in forest productivity. Still the question remains of how long sequestration will be considered. That depends on what you want to study and will have to be decided in each new study.

The emission estimates from the combustion phase of peat is very similar and also the emission estimates from the production phase.

There are also some differences in the emission estimates of the coal scenario. The main difference is the estimate of methane emissions during production and transportation. We have tried to find better data on this but we think this is an area that has to be investigated further.

Uncertainty:

The uncertainty estimates show the range within which the climate impact of a certain peat utilisation chain lay. The size of the range depends both on the variation in emission estimates and in natural variation of the emissions between different types of peatlands. The size of the range also depends somewhat on how much the greenhouse gas emissions from the surrounding area (surrounding the peat cutting site) are affected by the drainage. The largest uncertainties of emission estimates is identified for the forestry drained peatlands (initial phase) and restored areas. The uncertainty for the combustion phase (both for coal and peat) is quite small. Also the uncertainty for the initial phase of the fen chain is quite small.

New peat production technology:

The new production technology for energy peat has been tested in Finland with good results during two seasons. During this season (2006) it will be tested both in Finland and Sweden. These tests will improve the data available for this technology and the practical use of it. How much the climate impact will be reduced with the new technology depends on how much the residual peat layer is reduced, how much smaller area that needs to be drained and for how long as well as if the combustion emission factor of the peat can be lowered due to lower water content.

Risk for climate impact due to premature close down:

If the demand for energy peat gets very low it might become uneconomical to continue with energy peat cutting. In theory this might lead to peat cutting areas being prematurely closed down. According to Swedish peat producers close-down is more likely to happen in remote areas since the more centrally located peat cutting areas probably would continue to produce horticultural peat. However due to the rules of peat cutting it is not likely that closed down areas will be left without after-treatment. There might be a risk that it will take longer time until the after-treatment is completed (since there might be reasons for waiting to see if the price and demand of the energy peat rises again). What after-treatment that is chosen for a peat cutting area that is not completely cut will have importance on the total greenhouse gas emissions from the site. If it is afforested and there is a thick peat-layer left there is an increased risk of low forest productivity and high emissions due to decomposition of peat. If the area is restored the risk of decomposition of the residual peat is diminished.

8 Conclusions

Scientific approach and calculation models:

There are some minor differences in the models used in the Finnish and the Swedish studies but using one model for making comparison between different utilisation scenarios will not result in very different conclusions. More important is the input data.

System boundaries:

- There are differences in how the sequestration of carbon in growing forest is considered. We conclude that a more appropriate way is to consider the changes in carbon stock before and after peat cutting. For how long carbon sequestration into the growing forest should be considered will have to be decided in each study but is very important to describe since it will have significant impact on the results.

- There are also differences in the consideration of the surrounding area. The Swedish estimate of the size of the impacted surrounding area is probably high and the Finnish estimate is probably low. This parameter will have some effect on the overall result and need further investigation. In general the impact of surrounding area will strengthen the effect of peat cutting. This means that if the emission balance of the land area is improved (lower emissions of greenhouse gases) after peat cutting compared to before, the climate impact will be lower if also considering the surrounding area. On the other hand if the emissions are higher after peat cutting than before the climate impact will be higher if the surrounding area is included. Further the relative impact from the surrounding area will be larger on undrained areas compared to already drained areas and on small production areas compared to large production areas.

Emission estimates:

The emission estimates used in the Finnish and the Swedish studies respectively are quite similar, with some exceptions:

- The CO_2 emissions from decomposing peat at forestry drained areas. The Swedish emission estimates are significantly higher than the Finnish emission estimates. This is currently explained by differences in management methods (Finnish ditches shallower than Swedish) but other factors like climate and methods used for making the estimates might also affect. This will have to be investigated further since in Finland forestry drained peatlands are the most commonly used peatlands and in Sweden these areas are also of importance.

- The emission/uptake estimates for restored areas. We think the new data used in the Finnish study should be used also in future studies.

- The litter production and decomposition in forestry drained peatlands and afforested cutaway peatlands. This is probably closely related to the determination of the decomposition rate of the peat layer in these areas.

Uncertainties:

The largest uncertainties are in the emission estimates of the initial phase of the forestry drained peatlands and in the after-treated phases. The interval of radiative forcing for different types of cultivated peatlands utilised for energy peat production is also large but is rather due to the large range in emissions for these sites than uncertainty in the emission estimates. The uncertainty for the combustion phase (both for coal and peat) is quite small. Also the uncertainty for the initial phase of the fen chain is quite small.

Peat utilisation

Comparing our studies we can conclude that using already drained peatlands for energy peat production is better from a climate point of view than using pristine mires. Peat utilisation chains where cultivated peatlands are used result in lower climate impact than corresponding coal utilisation after approximately 50–70 years after peat cutting. Whether the climate impact of peat utilisation at forestry drained peatlands is higher or lower than coal is difficult to determine. It depends a lot on the initial rate of decomposition of the peatland (decomposition rate in reference case).

New production technology:

According to the results in the new calculations in this study (chapter 5.1 and Appendix 5) and in the results of Kirkinen et al (in press) (also presented in Figure 6.3) the new production technology being developed by Vapo has the potential of reducing the climate impact of the peat utilisation chain significantly. As emphasised by the developer there are many positive environmental effects) with the new production technology compared to the conventional peat cutting methods, such as:

- less greenhouse gas emissions from the production area since a much smaller area will be drained at the time and also a smaller vegetation-less area (as small area as 5% of that required in the milling method might be needed)
- the enabling of utilisation of abandoned cultivated peatlands
- lowered emissions from stockpiles
- restoration is easier than at conventional harvesting sites (due to high water level and remaining species bank in the edges of production area
- lower emissions of dust

Risk for climate impact due to premature close down:

The main risk for increased climate impact due to premature close down of peat cutting areas is the risk for low forest productivity and high CO_2 emissions due to decomposition of residual peat in the case of afforestation.

9 Further research

We want to emphasise that there is a need of further research in the field of emissions from the peatlands in the different stages. Further measurements of initial situations/after-treated areas especially during long time periods is needed to gain more detailed understanding of the complexity of natural processes. One important question is the rates of peat oxidation in forestry drained peatlands. It is very important to understand the mechanisms and decrease the uncertainty of these estimates. Further research is needed for understanding the emissions of cultivated peatlands and the correlation between emissions and cultivation practices. We also think that a better understanding of the decomposition of the residual peat is important to gain as well as getting better data on the amount of residual peat. The development of greenhouse gas balances at restored areas is being investigated and emission estimates are being improved but this process will have to continue.

Measurements on the surrounding areas of peat cutting sites would be informative as well as estimates on average relative sizes of the surrounding area. The emissions data from peat production fields and storages also need more studies.

10 Acknowledgements

We wish to acknowledge the Ministry of Agriculture and Forestry of Finland, the Swedish Energy Agency and the Swedish Peat Producers Organisation for the financial support. We also want to acknowledge Prof. Jukka Laine and Dr. Kari Minkkinen for valuable comments and contributing to this work. We wish to thank Dr. Niko Silvan for the information concerning the new peat production technology. We also wish to thank all those who have contributed to this work by giving valuable comments or information on this subject.

11 References

11.1 Literature

Albritton, D.L, Derwent, R.G, Isaksen, I.S.A., Lal, M., Wuebbles, D.J., 1995. Trace Gas Radiative Forcing Indices. In: Climate Change 1994: Radiative Forcing of Climate Change and An Evaluation of the IPCC IS92 Emission Scenarios. Reports of Working Groups I and III of the Intergovernmental Panel on Climate Change [Hougthon, J.T., Meira Filho, L.G., Bruce, J., Hoesung, L., Callander, B.A., Haites, E., Harris, N., Maskell, K. (eds.)]. Cambridge University Press, Cambridge, United Kingdom, New York, NY, U.S.A and Melbourne Australia.

BP 2005. Statistical Review of World Energy 2005. [http://www.bp.com/genericsection.do?categoryId=92&contentId=7005893]

CENEf 2004. National Inventory of Energy-Related Emissions of Greenhouse Gases in Russia. Pacific Northwest National Laboratory. Center for Energy Efficiency, Moscow, Russia. Supported by Environmental Protection Agency (U.S.A), Moscow. [http://www.cenef.ru/info/Climate/natinventory.pdf]

Etheridge D.M., Pearman G.I., Fraser P.J. 1994. Concentrations of CH4 from the Law Dome /East side, "DE08" Site) Ice Core. Commonwealth Scientific and Industrial Research Organisation, Aspendale, Victoria, Australia. Available [http://cdiac.esd.ornl/ftp/trends/methane/lawdome.259]

IPCC 1990. Climate change 1990: Scientific Assessment of Climate change – Report of Working Group I JT Houghton, GJ Jenkins and JJ Ephraums (Eds.). Cambridge University Press, UK. pp 365

IPCC 1995. Climate Change 1994:Radiative Forcing of Climate Change and an Evaluation of the IPCC IS92 Emission Scenarios. Cambridge Universitys Press, United Kingdom. 584 pp.

IPCC 1996. Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories. JT Houghton, LG Meira Filho, B Lim, K Treanton, I Mamaty, Y Bonduki, DJ Griggs and BA Callender (Eds) IPCC/OECD/IEA. UK Meteorological Office, Bracknell

IPCC 1997. An introduction to Simple Climate Models used in the IPCC Second Assessment Report. Eds. Houghton, J.T., Filho, I.G.M., Griggs, D.J. & Maskell, K. ISBN: 92-9169-101-1. [http://www.ipcc.ch/pub/IPCCTP.II(E).pdf].

IPCC 2001. Climate change 2001: The Scientific Basis. Contribution of Working Group I on the Third Assessment Report of the Intergovernmental Panel on Climate Change. [Houghton, J.T., Ding, Y., Griggs, D.J., Nouger, M., Linden van der, P.J., Dai, X., Maskell, K., Johnson, C.A. (eds)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, U.S.A.

Kasimir-Klemedtsson Å., Klemedtsson, L., Berglund, K., Martikainen, P.J., Silvola, J., Oenema, O., 1997. Greenhouse Gas Emissions from farmed organic soils: a review. Soil Use and Management, no 13 1997, pp 245–250.

Kirkinen, J., Minkkinen, K., Sievänen, R, Penttilä, T., Alm, J., Laine, J., & Savolainen, I., in press. Greenhouse gas impact due to peat fuel use – A life cycle approach. To be published in Boreal Environmental Research vol 11.

Klemedtsson, L., Weslien, P., von Arnold, K., Ågren, G., Nilsson, M. & Hånell, B. 2002. Greenhouse gas emissions from drained forests in Sweden. Chapter 2.3 in LUSTRA progress report for 1999–2002, "Land-Use Strategies for reducing net Greenhouse Gas Emissions", Uppsala 2002.

Korhonen, R. Savolainen I. & Sinisalo J. 1993. Assessing the impact of CO_2 emission control scenarios in Finland on radiative forcing and greenhouse effect. Environmental Management Vol. 17, No. 6, (1993) pp. 797–805.

Krewitt W. Mayerhofer, P., Friedrich, R., Trukenmüller, A., Heck, T., Gressmann, A., Raptis, F., Kaspar, F., Sachau, J., Rennings, K., Diekmann, J. & Praetorius, B. 1997. National Implementation Germany, Final Report. Prepared by IER, University of Stuttgart. [http://externe.jrc.es/]

Leijting, J. 1999. Fuel peat utilization in Finland: resource use and emissions. The Finnish Environment Institute. Oy Edita Ab. Helsinki. 94 pp.

Leinonen, A. & Hillebrand, K. 2000. Turpeen asema bioenergiana, loppuraportti. Finbio, Publication 15. Jyväskylä.

Lelieveld J, Crutzen P, Dentener F. 1998. Changing concentration, lifetime and climate forcing of atmospheric methane. Tellus. 50B pp 128–150.

Meier-Reimer, E. & Hasselmann, K. 1987. Transport and storage of CO_2 in the ocean an inorganic ocean-circulation carbon cycle model. Climate Dynamics 2 pp 63–90.

Monni S. 2002. A calculation model concerning warming effect of greenhouse gas emissions and its application to international comparisons. Master's Thesis. Mechanical Engineering, Helsinki University of Technology. 82 pp. [In Finnish with English summary]

Monni S., Korhonen R. & Savolainen I. 2003. Radiative Forcing due to Anthropogenic Greenhouse Gas Emissions from Finland: Methods for Estimating Forcing of a Country or an Activity. Environmental Management Vol 31, No 3, pp 401–411.

Nilsson K. 2004. The carbon dioxide emissions factor for combustion of Swedish peat. IVL B-report 1595.

Nilsson M & Gullenberg M. 1997. ExternE National Implementation Sweden, Final Report. Stockholm Environment Institute, Stockholm. [http://externe.jrc.es/]

Nilsson K. & Nilsson, M. 2004. The climate impact of energy peat utilisation in Sweden – the effect of former land-use and aftertreatment. IVL B-report 1606.

Nilsson M., Mikkelä, C., Sundh, I., Granberg, G., Svensson, B.H., & Ranneby B., 2001. Methane emissions from Swedish mires: National and regional budgets and dependence on mire vegetation. Journal of Geophysical Research Vol. 106, No D18 pp 20 847 – 20 860.

Nykänen H., Alm J., Lång K., Silvola J., Martikainen P.J. 1995. Emissions of CH_4, N_2O and CO_2 from a virgin fen and a fen drained for grassland in Finland. Journal of Biogeography 22, pp. 351–357.

Oeschger H., Siegenthaler, U., Schotterer U. & Gegelmann A. 1975. A box diffusion model to study the carbon dioxide exchange in nature. Tellus 27, 168–192.

Olendrzyński,K., Kargulewicz, I., Skośkiewicz, J. Dębski, B., Cieślińska, J. Radwański, E., Galiński, W., Kluz M. 2005. National Inventory Report 2003.. Poland. Institute of Environmental Protection, National Emission Centre. http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/2761.php

Pingoud K, Mälkki H., Wihersaari M., Siitonen S., LehtiläA., Johansson M., Hongisto M., Pirilä P. & Otterström T. 1997. ExternE National Implementation Finland, Final Report. Technical Research Centre of Finland, VTT, Espoo. [http://externe.jrc.es/]

Rena kolfakta, Svenska kolinstitutet. 2000.

Silvan, N., 2005. Reduced Environmental Effects Using the New Method for Energy Peat Production.

Spath P.L., Mann M.K. & Kerr D.R. 1999. Life Cycle Assessment of Coal-fired Power Production. National Renewable Energy Laboratory; Golden. C.O. U.S.A. www.osti.gov/bridge

Sundh, I., Nilsson, M., Mikkelä, C., Granberg, G. & Svensson B-H. 2000. Fluxes of methane and carbon dioxide on peat mining areas in Sweden. Ambio vol. 29, no 8, pp 499–503.

Statistics Finland 2005. Energy Statistics 2005. [www.stat.fi/energia]

Tuittila, E.-S., Komulainen, V.-M., Vasander, H. and Laine, J. 1999. Restored cut-away peatland as a sink for atmospheric CO_2. Oecologia. 120: 563–574. Springer-Verlag

Tolonen, K., & Turunen, J. 1996. Carbon accumulation in mires in Finland. In R. Laiho, J., Laine & H., Vasander (eds.), Northern Peatlands in Global Climatic Change, Proceedings of the International Workshop held in Hyytiälä, Finland October 1995. The academy of Finland, Helsinki pp. 250–255.

Tsupari, E, Monni, S. &Pipatti, R.. 2005. Non-CO2 greenhouse gas emissions from boilers and industrial processes. Evaluation and update of emission factors for the Finnish national greenhouse gas inventory VTT Prosessit, Espoo. 82 pp. + app. 24 pp. VTT Tiedotteita - Research Notes : 2321

Uppenberg, S., Zetterberg, L., Åhman, M., 2004. Climate impact from Peat Utilisation in Sweden. Mitigation and Adaptation Strategies for Global Change, 9, 37–76, Netherlands.

Uppenberg , S., Almemark, M., Brandel, M., Lindfors, L-G., Marcus, H-O., Stripple, H., Wachtmeister, A. & Zetterberg L., 2001a. Miljöfaktabok för bränslen. Del 2 Bakgrundinformation och Teknisk bilaga. IVL B-report 1334–2, Stockholm

Uppenberg, S., Zetterberg, L., Åhman, M., 2001b. Climate Impact from Peat Utilisation in Sweden. IVL B-1423. Stockholm, Sweden. [http://www.ivl.se]

Vesterinen R. 2003. Estimation of CO_2 emission factors for peat combustion on the basis of analyses of peat delivered to power plants. Research report PRO2/P6020/03. VTT Processes, Energy Production. Jyväskylä. 25 pp. + app. 5 pp.

Von Arnold, K., Weslien, P., Nilsson, M., Svensson B. H., Klemedtsson, L., 2005a. Fluxes of CO_2, CH_4 and N_2O from drained coniferous forest on organic soils. Paper I in von Arnold, Forests and Greenhouse Gases – Fluxes of CO_2, CH_4 and N_2O from drained forests on organic soils. Dissertation Linköping Studies in Arts and Science No 302.

Von Arnold, K., Nilsson, M., Hånell, B., Weslien, P., Klemedtsson, L., 2005b. Fluxes of CO_2, CH_4 and N_2O from drained organic soils in deciduous forests. Paper II in von Arnold, Forests and Greenhouse Gases – Fluxes of CO_2, CH_4 and N_2O from drained forests on organic soils. Dissertation Linköping Studies in Arts and Science No 302.

11.2 Personal communications

Eeva-Stina Tuittila and Jukka Alm J. 2005. Preliminary results from the Research Programme on Utilisation of Peat and Peatlands in Finland.

Håkan Staffansson, Geologist 2006-05-30

Kari Grönfors, Statistics Finland 2006-02-14

Per Weslien, Gothenburg University 2006-05-10

Stefan Östlund, Råsjö Torv, 2006-05-11.

Appendix 1

The following values of input data were used in the model comparison presented in section 3.1.5. These were chosen in order to make the model comparison and should not be viewed upon as average or best estimate values.

The energy content in these calculations were 3384 MJ/m^2, 1 PJ is produced in 20 years. The energy content per square metre is based on Finnish estimates and corresponds to a thickness of the peat layer of 2 m. (Leinonen & Hillebrand 2000) and was used in order to have the same figures. After-treatment is considered during 280 years and the total study period is 300 years. The peat production area is approximately 29.55 ha.

Production Reserve

Pristine mire	***Fen***	**Unit**	**Reference**
Carbon dioxide, CO_2	-73	g/m^{2}a	Saarnio & Alm 2005
Methane, CH_4	23	g/m^{2}a	Nilsson et al 2001, Saarnio & Alm 2005
Nitrous oxide, N_2O	0.02	g/m^{2}a	von Arnold 2005a

Cultivated peatlands		**Unit**	**Reference**
Carbon dioxide, CO_2	1800	g/m^{2}a	Kasimir-Klemedtsson et al 1997, Lohila et al 2004, Maljanen et al 2005
Methane, CH_4	0	g/m^{2}a	Kasimir-Klemedtsson et al 1997, Maljanen et al 2003
Nitrous oxide, N_2O	1.3	g/m^{2}a	Maljanen et al 2005

Peat Utilisation

Emissions of peat production field (including emissions from stockpiles and other losses)		**Unit**
Carbon dioxide, CO_2	1400	g/m^{2}a
Methane, CH_4	1	g/m^{2}a
Nitrous oxide, N_2O	0.08	g/m^{2}a

Combustion of Peat		**Unit**
Carbon dioxide, CO_2	105	g/MJ
Methane, CH_4	0.008	g/MJ
Nitrous oxide, N_2O	0.011	g/MJ

Working machines		**Unit**	**Reference**
Carbon dioxide, CO_2	1	g/MJ	Uppenberg et al 2001b
Methane, CH_4	0		
Nitrous oxide, N_2O	0		

Combustion of Coal		**Unit**
Carbon dioxide, CO_2	95	g/MJ
Methane, CH_4	0.5	g/MJ
Nitrous oxide, N_2O	0.01	g/MJ

After-treatment

Restoration		**Unit**
Carbon dioxide, CO_2	-120	g/m^{2}a
Methane, CH_4	23	g/m^{2}a
Nitrous oxide, N_2O	0.02	g/m^{2}a

Appendix 2

The tables in this section present the interval of emission estimates used in the sensitivity analysis.

The energy content in the calculations made with the Finnish study was 3384 MJ/m², and in the Swedish study it was 3030 MJ/m². In the calculations we assumed that the thickness of peat layer is 2 m. In both models 1 PJ is produced in 20 years, which means that the area is somewhat larger in the Swedish model. Also here the after-treatment is considered during 280 years and the total study period is 300 years.

Table 1 Emissions from peatlands in initial stage before peat harvesting.

Gas	Pristine Fen	Comment
CO_2	0 – -147 g CO_2/m^2a	This is the range given by Kirkinen et al (in press) and is based on more recent measurements then the values used in the Swedish study.
CH_4	8–40 g CH_4/m^2a	This is based on Nilsson et al (2001), which was the source in Nilsson & Nilsson (2004). The range is somewhat larger than the range given in Kirkinen et al.
N_2O	0 – 0.02 g N_2O/m^2a	Based on both the Swedish and the Finnish study

Note that pristine fen was the only pristine peatland considered in the Finnish study. In the Swedish study also other types of pristine peatlands were considered.

Table 2 Emissions from cultivated peatlands (before peat cutting).

Gas	Emissions	Comment
CO_2	700 – 7000 g CO_2/m^2a	Based on Finnish and Swedish figures. The higher range might be to high since it was based on subsidence estimates and not direct measurements of gas fluxes.
CH_4	- 0.26 – -0.03 g CH_4/m^2a	We use these values although omitting them and assuming the uptake/emissions to be 0 would not have a significant impact on the overall result.
N_2O	0.5 – 2.5 g N_2O/m^2a	Based on both Swedish and Finnish emission estimates.

The emissions from cultivated peatlands vary a lot between areas utilised for different type of cropping. Emissions of CO_2 are generally higher at areas with a lot of working of the ground such as row-crops and lower at areas of perennial crops such as grassland.

Table 3 Emissions from forestry drained peatlands.

Gas	Emissions	Comment
CO_2, emissions from decomposition of peat	0 – 2300 g CO_2/m^2a[9] 0 – 448 g CO_2/m^2a	Swedish estimates Finnish estimates
CO_2, uptake in growing forest	0 – 3.9 m^3sk/ha a	Only increase in forest productivity is considered, see afforestation phase
CH_4	0 g CH_4/m^2a	Based on both Finnish and Swedish estimates
N_2O	0 – 0.9 g N_2O/m^2a	Based on both Finnish and Swedish estimates. The higher values are valid for rich, deciduous sites, while lower values are better estimates for coniferous sites.

We made two different scenarios for the afforestation phase. In the average scenario we consider the sequestration of carbon of the increase in forest productivity (3.9 m^3sk/ha) during 45 years, that is until the average value over the rotation period is reached. In our maximum scenario we consider the sequestration of carbon of the increase in forest productivity (3.9 m^3sk/ha) during the entire calculation period of 300 years. This corresponds to an assumption that the wood will be used and remain in constructions or that it will be utilised as fuel and replace some fossil fuel (e.g. coal). For the cultivated peatland – afforestation utilisation chain the increase in forest productivity was assumed to be double (7.8 m^3sk/ha) since there were no forest on the land area before peat cutting.

Table 4 Emissions from peat field during peat cutting.

Gas	Emissions	Comment
CO_2, emissions from cutting area and stock-piles.	704 – 2112 g CO_2/m^2a	Based on Finnish and Swedish estimates
CH_4	0 – 2.3 g CH_4/m^2a	Based on Finnish and Swedish estimates
N_2O	0 – 0.15 g N_2O/m^2a	Based on Finnish and Swedish estimates

---

[9] These are the estimates used in Nilsson & Nilsson (2004). These estimates are based on Klemedtsson et al (2002) and other sources. According to those studies there is a clear relation between peat decomposition rate and ground water level, the lower groundwater level, the higher decomposition rate. According to Klemedtsson et al (2002) approximately 10-15% of the forestry drained peatlands are wet and these areas were considered to be in balance (neither sources nor sinks of CO_2). Since it is not possible to directly measure only peat decomposition, but rather soil fluxes, different sources has to be estimated. The different sources; dark respiration, root respiration, aboveground litter, root litter and oxidation of peat are all connected to large uncertainties why it is not possible to say very much for certain concerning the peat oxidation. Still Klemedtsson et al estimates that the non-wet Swedish forestry drained peatlands have net losses from soil of between 70-250 g CO_2/m^2yr.

Table 5 Emissions during combustion of peat – values used in sensitivity analysis.

Gas	Emissions	Comment
CO_2	105.2 – 106. 5 g CO_2/MJ	Based on Nilsson 2004 & Vesterinen 2003
CH_4	0.005 – 0.0106 g CH_4/MJ	Based on both Finnish and Swedish estimates
N_2O	0.0032 – 0.022 g N_2O/MJ	Based on both Finnish and Swedish estimates.

Table 6 Emissions from working machines – values used in sensitivity analysis.

Gas	Emissions	Comment
CO_2	0.5 – 1.5 g CO_2/MJ	Based on Finnish and Swedish estimates
CH_4	0 – 0.7 mg CH_4/MJ	Based on Finnish and Swedish estimates
N_2O	0 – 0.0025 mg N_2O/MJ	Based on Finnish and Swedish estimates.

Table 7 Emissions at restored site.

Gas	Emissions	Comment
CO_2	+28 – -271 g CO_2/m^{2}a	Based on Tuittila & Alm 2005.
CH_4	8–40 g CH_4/m^{2}a	Based on both the Finnish and Swedish estimates. Nilsson et al 2001.
N_2O	0 – 0.02 g N_2O/m^{2}a	Based on both Finnish and Swedish estimates.

Table 8 Emissions at afforested site.

Gas	Emissions	Comment
CO_2, decomposition of residual peat	0 – 22 500 g C/m^2	Combination of Finnish and Swedish estimates. The dynamics will be exponential, just as in the Finnish study.
CO_2, sequestration of carbon in growing forest	3.9 m^{3}sk/ha a[10] (45 years)	This reflects the difference in productivity
	3.9 m^{3}sk/ha a (300 years)	(variation)
	0 m^{3}sk/ha a	(variation)
CO_2 accumulation of above-ground litter	1.8 – 3.5 kg C/m^2	The values are the upper limits reached after 45 years
CH_4	0 g CH_4/m^{2}a	Based on both Finnish and Swedish estimates
N_2O	0 – 0.08 g N_2O/m^{2}a	Based on both Finnish and Swedish estimates

We have chosen not to include the accumulation of carbon in below-ground litter since we have made the assumption that there will be no significant change in the rate between the pre peat cutting and post peat cutting stage.

---

[10] Corresponds to 450 g CO_2/m^{2}a.

Table 9 Emissions from coal utilisation[11] chain.

Gas	Emissions	Comment
CO_2	94.2 – 95.2 g CO_2/MJ	Based on Finnish and Swedish estimates
CH_4	0.345 – 1.1 g CH_4/MJ	Based on Finnish and Swedish estimates
N_2O	0.002 – 0.012 g N_2O/MJ	Based on Finnish and Swedish estimates

---

[11] This includes both emissions from combustion phase and emissions from other phases of coal utilisation chain.

Appendix 3

Table 1 Lifetimes of methane and nitrous oxide according to a specific atmospheric concentration (adjusted from Monni et al 2003).

CH_4 concentration (ppb_v)	CH_4 lifetime (years)	N_2O concentration (ppb_v)	N_2O lifetime (years)
723	6.7	270	120.9
813	6.9	284	120.6
903	7.1	293	120.4
1004	7.3	302	120.2
1115	7.5	314	120
1239	7.7	324	119.8
377	7.9	333	119.6
1530	8.2	346	119.4
1700	8.4	357	119.2
1870	8.6	368	119
2057	8.9	383	118.8
2489	9.4	395	118.6
2738	9.6	411	118.4
3012	9.9	423	118.2
3313	10.2	436	118
3644	10.5	454	117.8
4009	10.8		

Appendix 4

Emission estimates utilised in calculations for new production methodology

The emissions from cultivated peatlands vary a lot between areas utilised for different type of cropping. Emissions of CO_2 are generally higher at areas with a lot of working of the ground such as row-crops and lower at areas of perennial crops such as grassland. Since we start with an already drained area we have assumed that there is no need for an initial drainage period.

Table 1 Emissions from forestry drained peatlands.

Gas	Emissions	Reference
CO_2, emissions from decomposition of peat	660 g CO_2/m^2a (257 g CO_2/m^2a)	Klemedtsson et al 2002
CO_2, uptake in growing forest	Only the increase in forest productivity is considered	See afforestation phase
CH_4	0.8 g CH_4/m^2a	von Arnold 2005a, b
N_2O	0.06 g N_2O/m^2a (coniferous site) 0.08 g N_2O/m^2a (surrounding area)	von Arnold 2005a Nilsson & Nilsson 2004

Table 2 Emissions from peat field during peat cutting.

Gas	Emissions	Reference
CO_2, emissions from cutting area and stock piles	1000 g CO_2/m^2a	Nilsson & Nilsson 2004
CO_2 emissions from surrounding area	300 g CO_2/m^2a	Nilsson & Nilsson 2004
CH_4	2.5 g CH_4/m^2a extraction area 0 g CH_4/m^2 a surrounding area	Sundh et al 2000 Nilsson & Nilsson 2004
N_2O	0.15 g N_2O/m^2a	Nilsson & Nilsson 2004

Table 3 Emissions during combustion of peat – values used in sensitivity analysis.

Gas	Emissions	Reference
CO_2	105.2 g CO_2/MJ	Nilsson 2004
CH_4	0.005 g CH_4/MJ	Uppenberg et al 2001b
N_2O	0.0056 g N_2O/MJ	Uppenberg et al 2001b

Table 4 Emissions from working machines – values used in sensitivity analysis.

Gas	Emissions	Reference
CO_2	1.0 g CO_2/MJ	Uppenberg et al 2004
CH_4	0.7 mg CH_4/MJ	Uppenberg et al 2004
N_2O	0.0025 mg N_2O/MJ	Uppenberg et al 2004

Table 5 Emissions at restored site.

Gas	Emissions	Comment
CO_2	-122 g CO_2/m^2a	Kirkinen et al (in press)
CH_4	23 g CH_4/m^2a	Kirkinen et al (in press)
N_2O	0.02 g N_2O/m^2a	von Arnold 2005a

Table 6 Emissions at afforested site.

Gas	Emissions	Reference
CO_2, decomposition of residual peat	2500 g C/m^2	The dynamics will be exponential, just as in Kirkinen et al (in press) (Assume that 5 cm is left)
	10 000 gC/m^2	In conventional peat cutting where 20 cm is left.
CO_2, sequestration of carbon in growing forest	0–7 m^3sk/ha a corresponds to 0–810 g CO_2/m^2a	Note that only the difference in productivity will be considered.
CO_2 accumulation of above-ground litter	2.0 kg C/m^2 (3.5 kg C/m^2)	The values are the upper limits reached after 80 years.
CH_4	0 g CH_4/m^2a	Nilsson & Nilsson 2004
N_2O	0.06 g N_2O/m^2a	Nykänen et al 1996

We have chosen not to include the accumulation of carbon in below-ground litter since we have made the assumption that there will be no significant change in the rate between the pre peat cutting and post peat cutting stage.

Table 7 Emissions from coal utilisation chain.

Gas	Indirect emissions	Direct emissions	Total emissions	References
CO_2	3.2 g/MJ	91 g/MJ	94.2 g CO_2/MJ	Uppenberg et al 2004
CH_4	1.1 g/MJ (0.5 g/MJ)	0.0005 g/MJ	1.1 g CH_4/MJ 0.5 g CH_4/MJ	Uppenberg et al 2004 variation
N_2O	-	0.012 g/MJ	0.012 g N_2O/MJ	Uppenberg et al 2004

Table 8 Emissions from natural gas utilisation chain.

Gas	Indirect emissions	Direct emissions	Total emissions	References
CO_2	4.3 g/MJ	56 g/MJ	60.3 g CO_2/MJ	Uppenberg et al 2001a
CH_4	0.012 g/MJ	0.0001 g/MJ	0.0121 g CH_4/MJ	Uppenberg et al 2001a
N_2O	0.0001 g/MJ	0.0005 g/MJ	0.0006 g N_2O/MJ	Uppenberg et al 2004

Appendix 5

Below you will find additional calculations made for peat production scenarios with the new production method. Figure 1 and Figure 2 show the same scenarios as Figure 5.2 and Figure 5.3 with the only difference that coal production and utilisation (scenario 4) has lower emissions of methane in Figure 1 and Figure 2 than in pervious figures. Figure 3 and Figure 4 show the same scenarios as Figure 5.4 and Figure 5.5 with the only difference that coal production and utilisation (scenario 4) has lower emissions of methane in Figure 3 and Figure 4.
As can be seen from Figure 1–Figure 4 the coal scenario will be lower if the methane emissions during the production and transportation of coal are lower and this will make some of the peat scenarios having higher climate impact than the corresponding coal scenario.

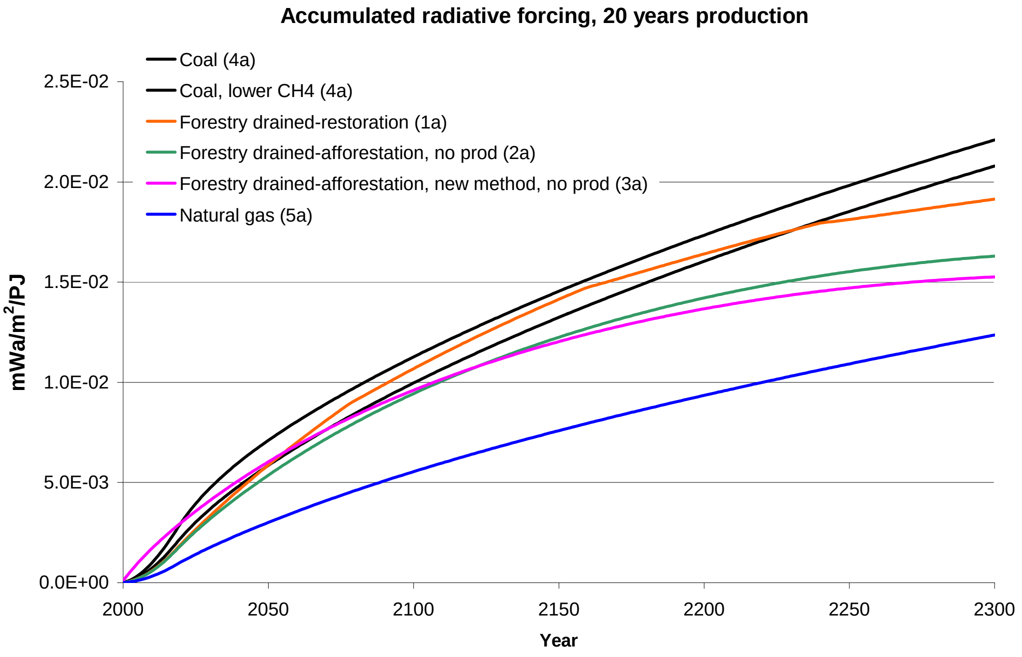

Figure 1 Accumulated radiative forcing, 20 years peat production. Same scenarios as in Figure 5.2 with exception for the coal scenario, scenario 4, in which methane emissions are lower. No prod = no increase in productivity of afforestation, new method = new production technology of peat.

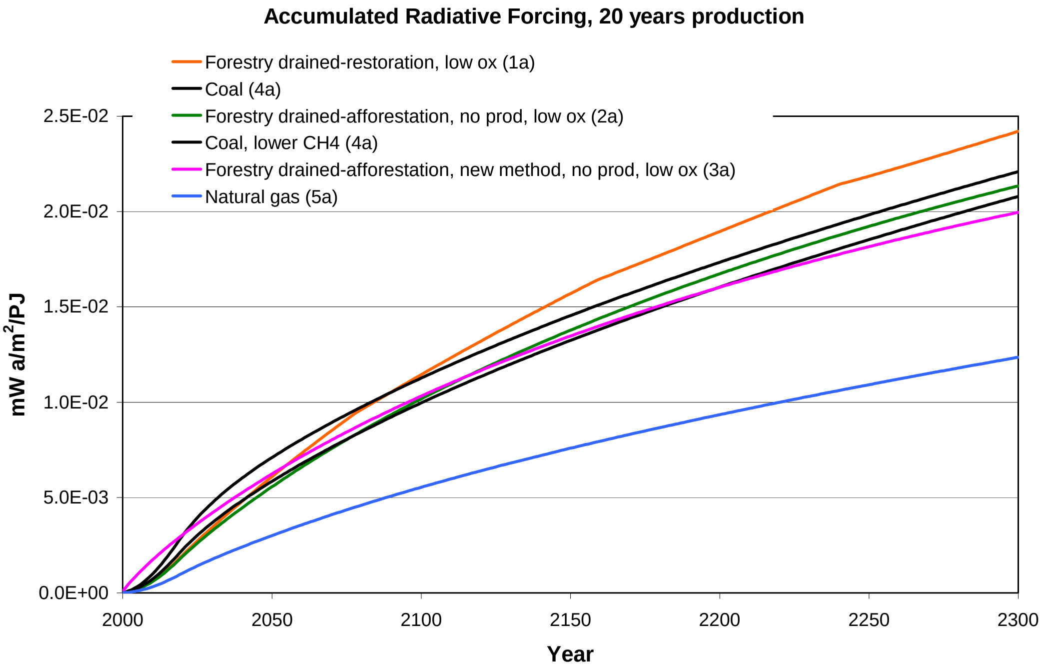

Figure 2 Accumulated radiative forcing, 20 years peat production. Same scenarios as in Figure 5.3, with the exception of coal scenario, scenario 4, for which methane emissions are lower.

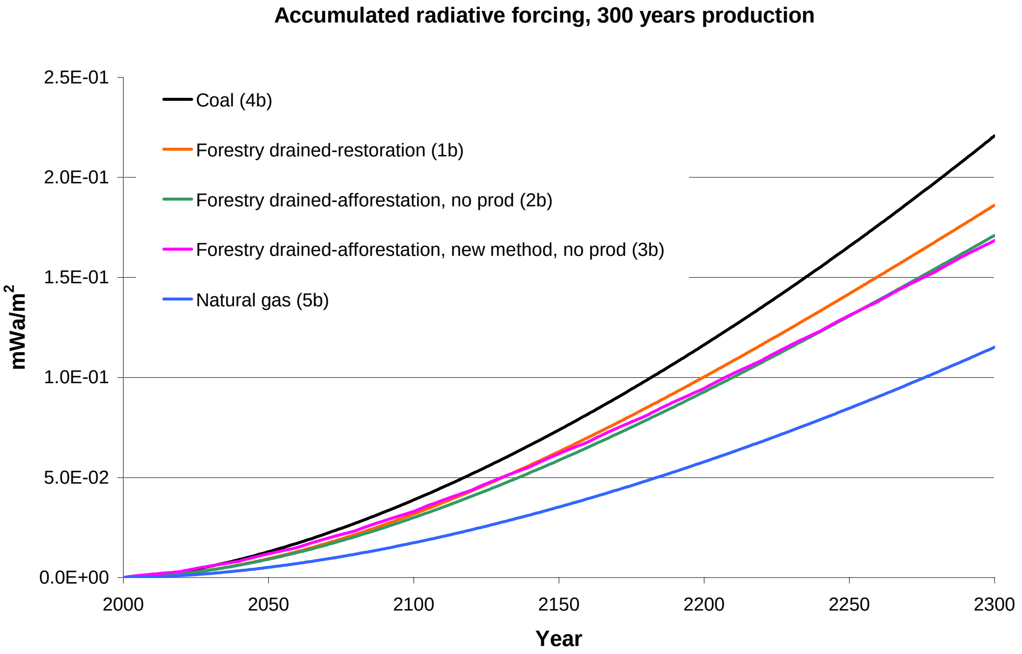

Figure 3 Accumulated radiative forcing, 300 years peat production. Same as Figure 5.4 only coal scenario (scenario 4) different. Lower methane emissions in connection to production and transportation of coal.

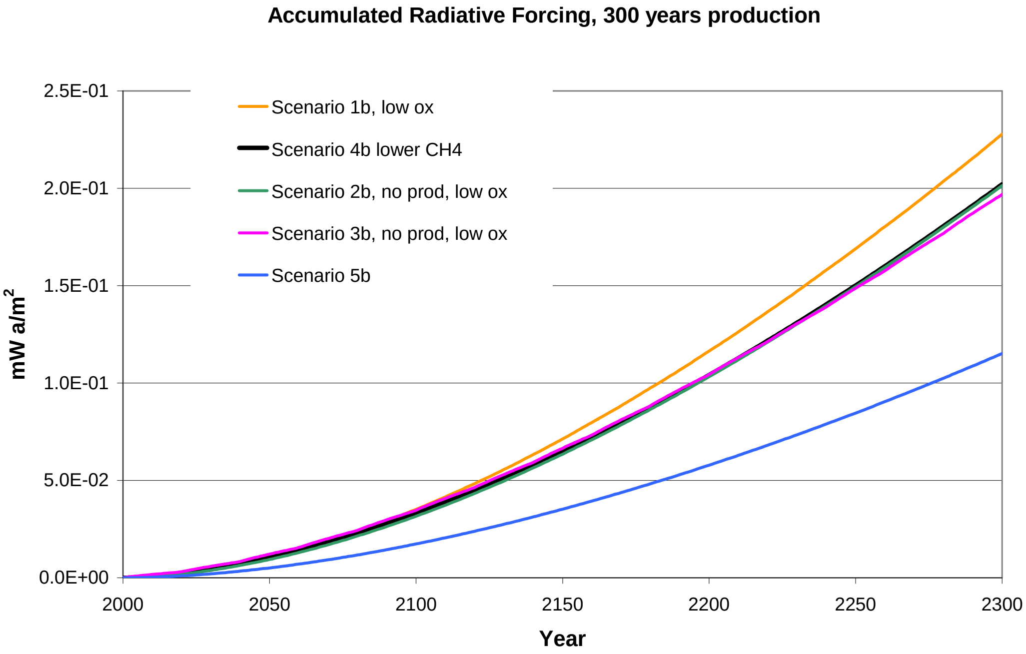

Figure 4 Accumulated radiative forcing, 300 years peat production. Same as Figure 5.5 only coal scenario (scenario 4) different. Lower methane emissions in connection to the production and transportation of coal.

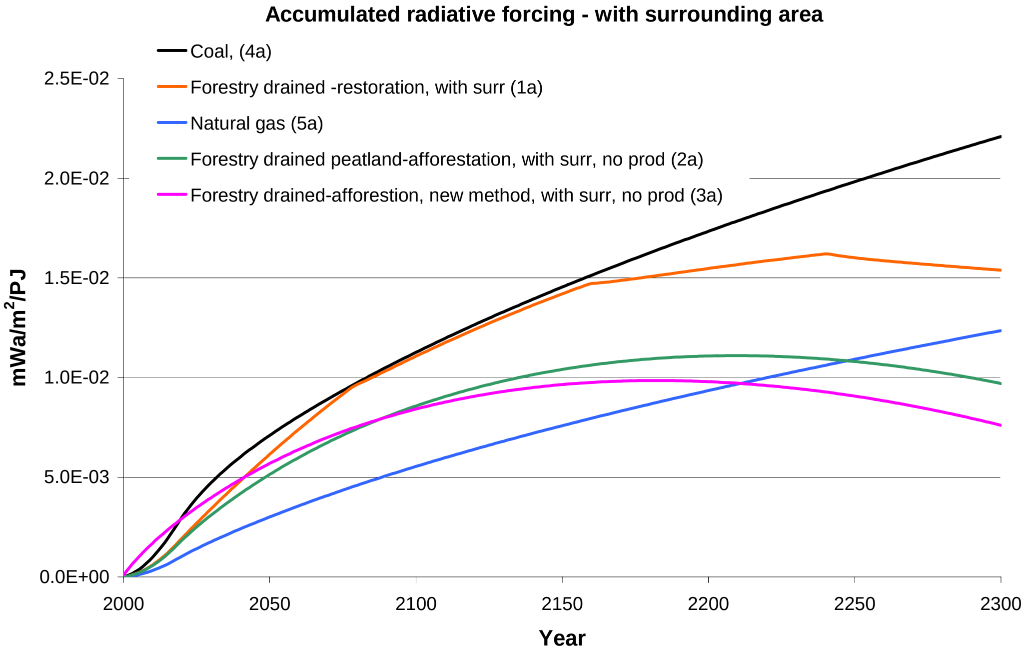

Figure 5 Accumulated radiative forcing, 20 years peat production. Same scenarios as in Figure 5.2 but surrounding area considered. With surr = surrounding area considered, no prod = no increase in forest productivity.

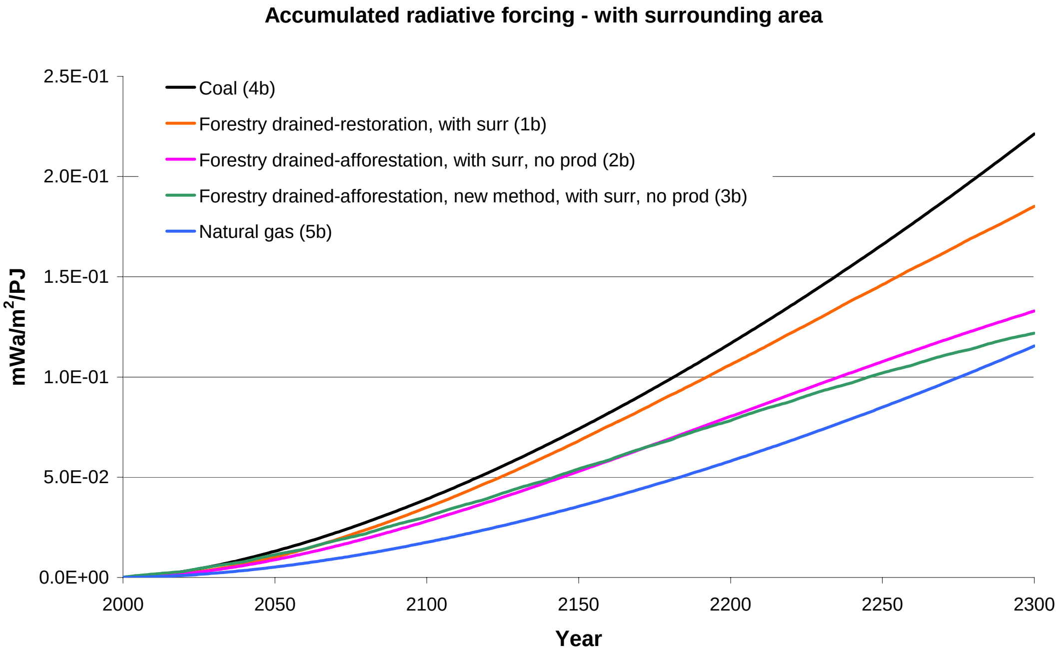

Figure 6 Accumulated radiative forcing, 300 years peat production. Same scenarios as in Figure 5.4 but surrounding area considered.

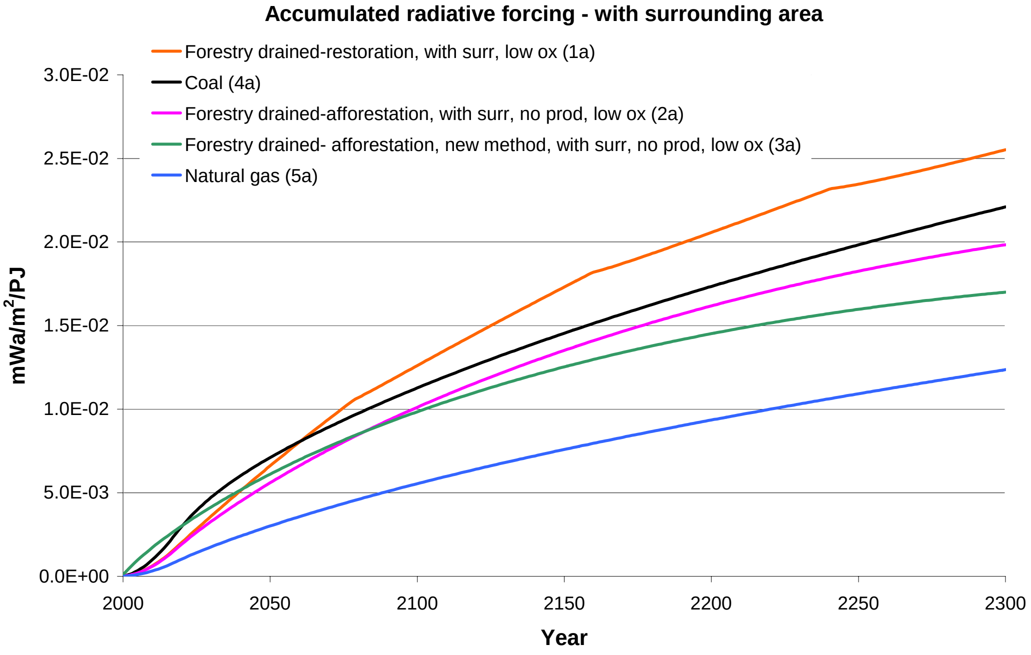

Figure 7 Accumulated radiative forcing, 20 years peat production. Same scenarios as in Figure 5.3 but with surrounding area considered. With surr = surrounding area considered, no prod = no increase in productivity, low ox = low oxidation rate of peat, new method = new production methodology for peat.

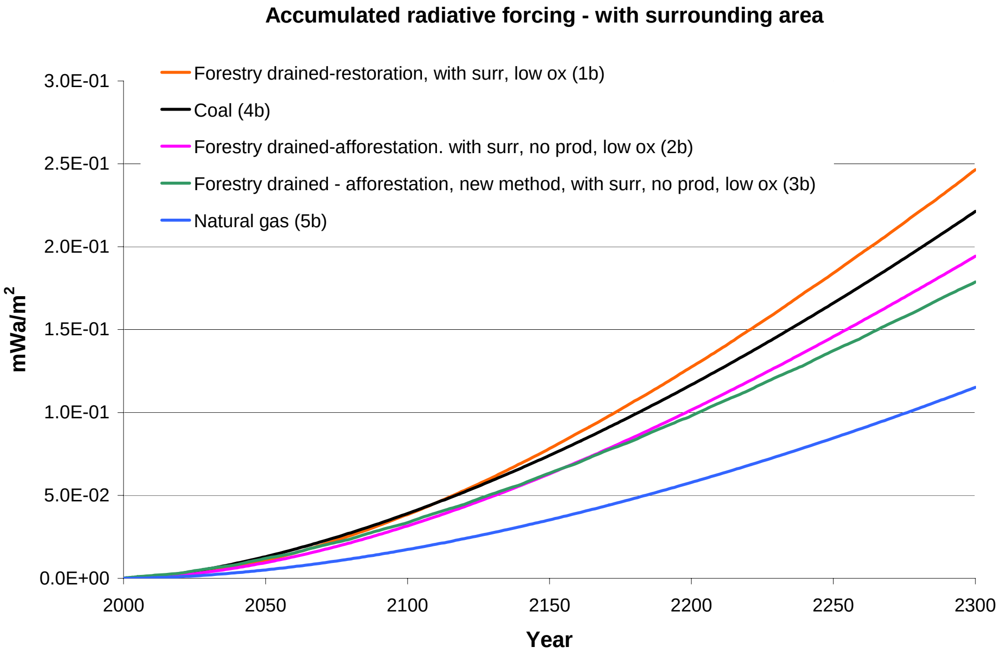

Figure 8 Accumulated radiative forcing, 300 years peat production. Same scenarios as in Figure 5.5 but with surrounding area considered. With surr = surrounding area considered, no prod = no productivity increase in forest growth, low ox = low rate of peat oxidation.

Figure 5 and Figure 6 show the same scenarios as in Figure 5.2 and Figure 5.4 respectively. The only difference is that in these figures the surrounding area of the peat cutting area was considered. That means that in the scenarios in Figure 5 and Figure 6 similar assumptions as in Nilsson & Nilsson 2004, where it was assumed that also the surrounding area will be affected by the peat cutting, were made. We assumed that an area equal to that of the cutting area is affected. In the same way Figure 7 and Figure 8 show the same scenarios as in Figure 5.3 and Figure 5.5 respectively. As can be seen the peat scenarios in Figure 5 and Figure 6 have lower climate impact than the corresponding peat scenarios in Figure 5.2 and Figure 5.4. At the same time the peat scenarios in Figure 7 and Figure 8 that have higher climate impact than the coal scenario (scenario 1) also have higher climate impact than corresponding scenarios in Figure 5.3 and Figure 5.5. Hence adding the surrounding area to a scenario where the greenhouse gas emissions after peat cutting is higher than before increases the climate impact of the scenario, whereas adding it to a scenario where the greenhouse gas emissions are lower after peat cutting decreases the climate impact.