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Nordic low CO2 emission scenarios – implemented in the GAINS model

Potential impacts on air pollution following Nordic low greenhouse gas emission initiatives. Scenario analysis performed with the GAINS model

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Nordic co-operation

Nordic co-operation is one of the world's most extensive forms of regional collaboration, involving Denmark, Finland, Iceland, Norway, Sweden, and three autonomous areas: the Faroe Islands, Greenland, and Åland.

Nordic co-operation has firm traditions in politics, the economy, and culture. It plays an important role in European and international collaboration, and aims at creating a strong Nordic community in a strong Europe.

Nordic co-operation seeks to safeguard Nordic and regional interests and principles in the global community. Common Nordic values help the region solidify its position as one of the world's most innovative and competitive.

Content

Preface

The Nordic countries have since many years been very active in the international work on protection of the environment from adverse effects of human activities. During the last years, there has been an increasing concern for effects of climate change and related issues. At the same time, the Nordic countries have strived to keep the air pollution issues in focus, mainly due to the sensitivity of the Nordic environment to air pollution The Nordic environment is still severely damaged by transboundary air pollution. Thus the many linkages between air pollution and climate change have recently gained more attention.

In 2006, the Nordic Council of Ministers – Air and Sea group agreed to finance a project that would clarify the potential impact on air pollution emissions and impacts following implementation of ambitious national climate change initiatives. In this report results and conclusions from the project are presented along with a discussion of important aspects for policy makers in the Nordic countries.

This project has been fully financed by the Nordic Council of Ministers. The project was performed in collaboration between the Center for International Climate and Environmental Research – Oslo (CICERO), Danmarks Miljøundersøgelser (DMU), IVL Svenska Miljöinstitutet AB (IVL), and Soumen Ympäristökeskus (SYKE). The project group would like to thank the GAINS modelling group at IIASA for their kind support to this project.

Stefan Åström, project leader

Summary

Main message from the study

The results from this study show that the technical measures to avoid Greenhouse gas (GHG) emissions and air pollutants in a Nordic energy system in many cases result in cost savings for society due to reduced expenses on energy.

Environmental benefits achieved due to energy demand savings and structural changes in the energy system would make it easier for the Nordic countries to reach the air pollution targets as well as post-Kyoto targets for GHG. Some of the measures would also make it easier to reach European Air Quality targets.

All strategies do not imply co-benefits between air pollution emission reduction and GHG emission reduction. For example, GHG emission reduction through increased use of bio fuels risk imposing a trade-off between air pollution and GHG emission abatement since increased use of bio fuels could risk increasing the emissions of air pollutants.

These co-benefits and the risk for conflicts between air quality and climate change should be more emphasised in the development of future Nordic low CO_2 energy and emission strategies. The project group also suggests that these Nordic strategies should be developed as joint efforts between the Nordic countries.

Introduction and background

Some of Europe’s most air pollution sensitive ecosystem areas are located in the Nordic countries. The Nordic countries have in general had a high priority on environmental protection. The challenge of air pollution and climate change is currently handled in separate political processes despite the obvious link between air pollution and climate change policy problems. Both problems arise primarily from the burning of fossil fuels and have a regional and global scale which requires international agreements and action. However, the problems are different since air pollution is mostly a local to regional scale problem, while climate change is a global environmental problem and policy challenge. Internationally, the questions related to air pollution and the impacts on the environment are mainly treated in the UNECE Convention on Long Range Transboundary Air Pollution (CLRTAP) and within the EU.

Emission abatement of Greenhouse Gases (GHG) is currently treated both in the UN system and within the EU. The United Nations Framework

Convention on Climate Change (UNFCCC) was established in 1992, and its Kyoto protocol was adopted in 1997 and entered into force in 2005. At the Copenhagen meeting COP15 in 2009, it was underlined that climate change is one of the greatest challenges of our time.

The Nordic perspective

In the Nordic countries, the long term policy work directed towards the phasing out of fossil fuels (together with a relative abundance of renewable hydro power, bio fuels and nuclear power) has resulted in more limited options for further implementation of measures that will lead to co-benefits for climate change and air pollution abatement. To ensure that future policies are developed with maximum exploitation of co-benefits for air pollution and climate, the remaining options need to be evaluated with this perspective in mind. If not, the risk of the future energy and climate policies to impose trade-offs, with negative impact on air pollution problems when reduction GHG emissions, will increase.

The aim of the study

The aim of this study has been to explore co-benefits and trade-offs between climate and air pollution policies, based on an analysis of national baseline and low-CO_2 energy scenarios for the Nordic countries. The GAINS model and cost database was used to estimate the cost of going from the national projected baseline scenario to a low CO_2 emission scenario. The model was also used to estimate the relative effects on selected elements of human health and the environment, both for the Nordic countries and for other European countries. Finally, a scenario analysis was made on the environmental benefits of replacing coal fired power production in Germany and Poland with electricity from Nordic power production.

Method, scenarios and data

This study was performed by implementing national low CO_2 emission scenarios into the GAINS model and separately into the GAINS model cost database. Main steps included converting of reported data into the GAINS model format; scenario calibration with official projections on air pollutant emissions; and calculation of abatement measure costs.

The low CO_2 emission scenarios analysed in this study were based on the following reports:

- Denmark: "Energy projection 2009", Denmark Energy Agency, 2009
- Finland: "World Wildlife Foundation energy scenario Finland", in Finnish, 2007
- Norway: "Lavutslippsutvalget", NOU 06:18, 2007
- Sweden: "Halva energin, hela välfärden", in Swedish Naturskyddsföreningen, 2008

The reports were the base for the national low CO_2 scenarios. These scenarios were compared with the national baseline scenarios for energy and air pollution as reported from the Nordic countries to the UNECE CLRTAP. The project analysed emissions, environmental impacts and abatement costs associated with moving from a national baseline projection to a low CO_2 emission projection.

Furthermore, a "what-if" scenario was constructed. In this scenario, "clean electricity" was exported from the Nordic countries to Poland and Germany in order to phase out some electricity production from condensing coal power plants in these countries. "Clean electricity" is in this report referring to electricity produced by using non-fossil fuels.

Results from the scenario analysis

In this chapter, results on emissions, environmental impacts and economic costs when moving from the national baseline scenarios to the national low emission scenarios are presented. All results presented are for the year 2020.

Emission reductions between the baseline and the low emission scenarios

Country / emission	Finland	Norway	Sweden	Denmark	Other*	Total Nordic	Unit
CO_2	28	21	29	20	3	25	%
Non-CO_2 GHG	12	1	4	3	1	4	%
SO_2	35	8	14	-5	3	18	%
NOx	25	25	37	-3	2	19	%
PM2,5	15	-18	13	-42	0	-8	%

*Other emissions are applicable in the "What-if" scenario. Germany and Poland are in the emission calculations included in the group "Other".

As can be seen from the table above, the low emission scenario implies different ambition levels with respect to CO_2 emission reductions for the Nordic countries. But what is more important in this study is the varying impact on air pollutant emissions. Both Norway and Denmark would experience increasing emissions of SO_2 and $PM_{2.5}$ as a consequence of the CO_2 emission abatement measures implemented in the national strategies to reach the defined low emission scenarios.

The results below show the impact on acidification, eutrophication and human health.

Impact on Acidification – % reduction in in areas with deposition exceeding Critical Load for acidification (- implies deterioration compared to baseline)

Country / Scenario	Finland	Norway	Sweden	Denmark	Other*	Total Nordic	Unit
BSL total	0.0	0.0	0.0	0.0	0.0	0.0	% from BSL
Low_em – BSL change	13.5	3.9	5.0	7.7	0.4	5.4	% from BSL
WHATIF – BSL change	13.5	5.2	5.0	15.4	1.4	6.1	% from BSL

* Other is in the case of environmental and health impact on all regions outside the Nordic countries described in the GAINS model

The scenario analysis shows improvements in terms of reduced acidification in the Nordic countries if implementing the low CO_2 emission scenario. The improvement on acidification damage will be even larger if the “clean electricity” were to be exported to Poland and Germany, as is done in the “What-if” scenario. For both the low emission scenario, and the “What-if” scenario, there are environmental benefits for the countries outside of the Nordic countries.

Impact on Eutrophication – % reduction in areas with deposition exceeding Critical Load for eutrophication (- implies deterioration compared to baseline)

Country / scenario	Finland	Norway	Sweden	Denmark	Other*	Total Nordic	Unit
BSL total	0.0	0.0	0.0	0.0	0.0	0.0	% from BSL
Low_em – BSL change	9.9	5.8	4.3	0.0	0.1	7.2	% from BSL
WHATIF – BSL change	10.3	5.8	4.5	0.0	0.2	7.5	% from BSL

* Other is in the case of environmental and health impact calculated from the “What-if” scenario, but on all regions outside the Nordic countries described in the GAINS model

The improvement potential for the Nordic eutrophication problem differ more than for acidification between the countries studied, according to the results. The improvement in eutrophication is similar to the improvement in acidification for the Nordic countries and the rest of Europe, with Denmark being the exception.

The GAINS model describes health impacts in terms of “million life years lost”. This unit measures how the remaining total life expectancy of a population would be affected by varying levels of $PM_{2.5}$ concentrations in air. In the table below the improvement is shown as improvement compared to the baseline.

Impact on health – % reduction in life years lost due to long term exposure of $PM_{2.5}$ (- implies deterioration compared to baseline)

Country	Finland	Norway	Sweden	Denmark	Other*	Total Nordic	Unit
BSL total	0.0	0.0	0.0	0.0	0.0	0.0	% from BSL
Low_em – BSL change	5.0	-4.8	3.0	-2.7	0.1	0.4	% from BSL
WHATIF – BSL change	5.0	-4.8	3.3	-2.4	0.5	0.6	% from BSL

* Other is in the case of environmental and health impact calculated from the "What-if" scenario, but on all regions outside the Nordic countries described in the GAINS model

As can be seen from the table above, Norway and Denmark could be negatively affected by their low CO_2 emission strategies. The negative impact is caused by increased use of bio fuels with the following risk for increase in $PM_{2.5}$ emissions.

The GAINS model is also used to calculate the incremental costs for society when moving from national baseline projections to the low CO_2 scenarios. The costs are presented as million € per year, and represent incremental costs associated with environmental and energy efficiency improvements for the different sectors represented in the GAINS model. The total costs include investments, operation, as well as fuel & electricity costs associated with the abatement measures introduced in the low CO_2 scenarios. These costs are annualised in order to estimate costs per year. In the table below, a negative sign implies savings for society.

The Nordic net incremental costs associated with the low CO_2 scenarios

Incremental cost on top of the baseline scenarios						
Country / Sector	Denmark	Finland	Norway	Sweden	Total	
Domestic sector	-367	-334	-75	-1231 (-574)*	-2007 (-1350)*	million €/year
Power Plants and Industry sector	488	427	284	-911 – 0	288 – 1199	million €/year
Transport sector	-394	-167	-705	794	-472	million €/year
Total costs on top of the national baselines	-273	-74	-496	-1348 – 220	-2191 – -623	million €/year

* The number within brackets show the costs if not including behavioural changes into the cost calculations

These results show that large air pollutant emission reductions can be associated with negative costs for society. The costs vary between sectors and countries.

Conclusions and discussion

This study shows that low energy pathways and low CO_2 emission strategies lead to cost effective reductions of greenhouse gases in most sectors. Also, in almost every case this also leads to a reduction in the emissions of traditional air pollutants. The supporting material to this study also indicates that there is no common Nordic strategy for how these reductions are achieved on a country level. And there is no indication that any of these strategies take into account another country's strategy. The same seems to be valid for the energy baseline emission projections.

All in all, the results from this study show that the technical costs of avoided GHG emissions and air pollutant emissions in a Nordic energy system would imply cost savings to the society due to reduced expenses on energy. Also, environmental benefits achieved due to energy demand savings and structural changes would make it easier for the Nordic countries to reach their air pollution targets as well as coming targets related to climate change. Some of the measures would also make it easier to reach European Air Quality targets. All strategies do not imply co-benefits between air pollution and climate. In this study it has been shown that increased use of bio fuels risk imposing a trade-off between air pollution and GHG emission abatement.

These co-benefits and the risk for conflicts between air quality and climate change should be more emphasised in the development of future Nordic low CO_2 energy and emission strategies.

Recommendations to policy makers

Nordic policy makers should increase their efforts on development of joint strategies towards a consistent Nordic energy policy. Recently finished projects such as "Nordic Energy Perspectives" might provide more useful input for the Nordic countries.

In this study it has been shown how effects on air pollutant emissions and environmental impacts can vary as a result of implementing different strategies for reduced national climate change impact. From this the project group can conclude that future designs of Nordic climate change strategies should take into account how air pollutant emissions are affected in order to increase co-benefits and avoid trade-offs. Although most of the national low emission scenarios analysed originated from special interest groups, this recommendation is still valid since these reports quite well formulate the public agenda.

The Nordic discussion on the benefits of exporting "green electricity" is, via the results of the analysis of a "what-if" scenario, supported. An export of electricity from the Nordic countries to Germany and Poland would have a beneficial impact on the Nordic environment, if certain requirements for foreign power production are met. These requirements thus allow for specification of suitable energy policies related to electricity exports.

First, it is important that the exported electricity replaces the most polluting type of electricity production. This could be done by contracting or branding of electricity.

Second, the Nordic electricity transfer grid must be considered so that the transfer capacity is ensured.

Svensk Sammanfattning

Huvudbudskap från studien

Resultaten från denna studie visar att tekniska åtgärder för att minska utsläpp av växthusgaser (GHG) och luftföroreningar i ett Nordiskt energisystem i många fall kan leda till kostnadsbesparingar för samhället till följd av minskade kostnader för energianvändning.

De miljömässiga fördelar som nås tack vare minskad efterfrågan på energi samt strukturella förändringar i energisystemet skulle göra det lättare för de Nordiska länderna att uppnå mål gällande utsläpp av luftföroreningar samt kommande mål för växthusgaser (efterföljande Kyotoprotokollet). Vissa av åtgärderna skulle även göra det lättare att nå Europeiska mål gällande luftkvalitet.

Det är inte alla strategier för att minska utsläpp av växthusgaser som innebär samverkansfördelar mellan utsläppsminskning av luftföroreningar och utsläppsminskning av växthusgaser. Till exempel så riskerar utsläppsminskning av växthusgaser genom ökad användning av biobränslen att en kompromiss mellan utsläpp av luftföroreningar och växthusgaser måste accepteras eftersom ökad användning av biobränslen riskerar öka utsläppen av luftföroreningar.

Dessa samverkansfördelar, samt risken för konflikter mellan luftkvalitet och klimatförändring, bör betonas mer i utvecklingen av framtida Nordiska strategier för energianvändning och minskning av växthusgasutsläpp. Projektgruppen föreslår dessutom att dessa Nordiska strategier skall tas fram gemensamt för de Nordiska länderna.

Inledning och bakgrund

Några av Europas mest luftföroreningskänsliga ekosystem finns belägna i de Nordiska länderna, och de Nordiska länderna har i allmänhet länge prioriterat miljöskydd. Utmaningarna kopplade till luftföroreningar och klimatförändring hanteras just nu i separata politiska processer trots de uppenbara sambanden mellan problem med luftföroreningar och klimatförändringar. Båda problemen uppstår främst vid förbränning av fossila bränslen och har en regional och global skala som kräver internationella överenskommelser och åtgärder. Men problemen är olika eftersom luftföroreningar oftast är ett problem främst på lokal och regional skala, medan klimatförändringen är ett regionalt och globalt miljöproblem och en global politisk utmaning. Internationellt så är frågor som rör luftföroreningar och påverkan på miljön främst behandlade i UNECE:s Konvention om långväga gränsöverskridande luftföroreningar (CLRTAP) och inom EU.

Det internationella arbetet med att minska utsläpp av växthusgaser (GHG) behandlas för närvarande både i FN-systemet och inom EU. FN:s ramkonvention för klimatförändringar (UNFCCC) inrättades 1992, dess Kyotoprotokoll antogs 1997 och trädde i kraft 2005. Vid det internationella klimatmötet i Köpenhamn COP15, 2009, betonades att klimatförändringen är en av de största utmaningarna i vår tid.

Det nordiska perspektivet

I de nordiska länderna så har det långsiktiga politiska arbetet, inriktat mot en utfasning av fossila bränslen (tillsammans med relativt lätt tillgänglig förnybar vattenkraft, biobränslen och kärnkraft), lett till något begränsade möjligheter till ytterligare genomförande av åtgärder som leder till samverkansfördelar mellan klimat och luftföroreningar. För att säkerställa att framtida strategier utformas med maximalt utnyttjande av samverkansfördelar mellan luftföroreningar och klimat, så måste de återstående alternativen för utsläppsminskningar utvärderas med detta perspektiv i åtanke.

Om inte, så riskerar framtida energi- och klimatpolicies att medföra en ökning av policies som medför kompromisslösningar, med negativ påverkan på utsläpp av luftföroreningar.

Syftet med studien

Syftet med denna studie har varit att utforska policies riktade mot växthusgaser och dess samverkansfördelar och kompromisser mellan utsläpp av växthusgaser och luftföroreningar, baserat på analyser av nationella huvudprognoser och utsläppsscenarier med mycket låga koldioxidutsläpp (CO_2) för de Nordiska länderna. GAINS-modellen och dess databas över åtgärdskostnader användes för att uppskatta ekonomiska kostnader för att minska utsläppen från nivåerna i huvudprognoserna till de i låg-CO_2-scenarierna. Modellen användes även för att uppskatta effekter på hälsa och miljö, både för de Nordiska länderna och för andra europeiska länder. Slutligen genomfördes en scenarioanalys där miljöeffekterna av att ersätta tysk och polsk elproduktion i kolkraftverk med el från Nordisk elproduktion undersöktes.

Metod, scenarier och data

Denna studie utfördes genom att implementera nationella låg-CO_2-scenarier in i GAINS-modellen och dessutom separat in i GAINS modellens databas över åtgärdskostnader. De huvudsakliga momenten inkluderade: konvertering av inrapporterade data till GAINS-modellens format; kalibrering av scenarier gentemot de officiellt rapporterade projektionerna avseende utsläpp av luftföroreningar; samt beräkning av kostnader för att minska utsläpp.

De låg-CO_2-scenarier som analyserats i denna studie baserades på följande rapporter / strategier:

- Danmark: "Energi prognos 2009", Danmark Energimyndigheten, 2009
- Finland: "Världsnaturfonden energiscenario för inland", 2007
- Norge: "Lavutslippsutvalget", NOU 06:18, 2007
- Sverige: "Halva energin, Hela välfärden", på svenska Naturskyddsföreningen, 2008

Rapporterna utgjorde grunden för de nationella låg-CO_2-scenarierna. Dessa scenarier jämfördes med de nationella huvudprognoserna för energi och luftföroreningar som rapporterats från de nordiska länderna till UNECE CLRTAP. Inom projektet analyserades utsläpp, miljöpåverkan och åtgärdskostnader som kan bli konsekvensen av en höjd ambitionsnivå: från en nationell huvudprognos till ett låg-CO_2-scenario.

Dessutom skapades ett "tänk om"-scenario. I detta scenario exporterades "ren el" från de nordiska länderna till Polen och Tyskland för att fasa ut viss elproduktion från kolkondenskraftverk i dessa länder. Med "ren el" syftar vi i denna rapport på el som produceras med hjälp av icke-fossila bränslen.

Resultat från scenarioanalyserna

I detta kapitel presenteras resultat för vilka utsläppsnivåer, miljöpåverkan och ekonomiska kostnader som skulle bli följden av ifall de nationella grundprognoserna ersätts med de nationella låg-CO_2-scenarierna. Samtliga resultat som redovisas är för år 2020.

Minskning i utsläppsnivåer mellan grundprognoserna och låg-CO_2-scenarierna

Land / utsläpp	Finland	Norge	Sverige	Danmark	Andra*	Totalt Norden	Enhet
CO_2	28	21	29	20	3	25	%
Andra växthusgaser	12	1	4	3	1	4	%
SO_2	35	8	14	-5	3	18	%
NO_x	25	25	37	-3	2	19	%
$PM_{2,5}$	15	-18	13	-42	0	-8	%

*"Andra" innefattar, vid beräkning av utsläpp, Tyskland och Polen i "Tänk-om" scenariot.

Som framgår av tabellen ovan så har de nationella låg-CO_2-scenarierna olika ambitionsnivåer med avseende på utsläppsminskningar av CO_2 för de nordiska länderna. Men vad som är viktigare i denna studie är de olika effekterna på utsläpp av luftföroreningar. Både Norge och Danmark skulle öka utsläppen av SO_2 och $PM_{2.5}$ som en följd av de åtgärder för att minska CO_2 som genomförs i de nationella strategier som ligger till grund för låg-CO_2-scenarierna.

Resultaten nedan visar effekten på försurning, övergödning och människors hälsa.

Påverkan på försurning – % minskning i arealer med försurande deposition överskridandes kritisk belastning för försurning (- innebär försämring i jämförelse med grundprognosen)

Land / Scenario	Finland	Norge	Sverige	Danmark	Andra*	Totalt Norden	Enhet
Grundprognos	0.0	0.0	0.0	0.0	0.0	0.0	% minskning från grundprognos
Skillnad (Låg-utsläpp – Grundprognos)	13.5	3.9	5.0	7.7	0.4	5.4	% minskning från grundprognos
Skillnad (“Tänk-om” – Grundprognos)	13.5	5.2	5.0	15.4	1.4	6.1	% minskning från grundprognos

*“Andra” innefattar, vid beräkning av miljö och hälsopåverkan, alla länder beskrivna i GAINS modellen utanför de Nordiska länderna.

Scenarioanalyserna visar förbättringar i form av minskad försurning i de nordiska länderna som en följd av om låg-CO_2-scenariot skulle förverkligas. Förbättringen med avseende på försurningsskador kommer att bli ännu större om “ren el” skulle exporteras till Polen och Tyskland, vilket görs i “Tänk-om”-scenariot. För både låg-CO_2-scenariot och “tänk-om”-scenariot finns det miljömässiga fördelar för länder utanför Norden.

Påverkan på övergödning – % minskning i arealer med övergödande deposition överskridandes kritisk belastning för övergödning (- innebär försämring i jämförelse med grundprognosen)

Land / scenario	Finland	Norge	Sverige	Danmark	Andra*	Totalt Norden	Enhet
Grundprognos	0.0	0.0	0.0	0.0	0.0	0.0	% minskning från grundprognos
Skillnad (Låg-utsläpp – Grundprognos)	9.9	5.8	4.3	0.0	0.1	7.2	% minskning från grundprognos
Skillnad (“Tänk-om” – Grundprognos)	10.3	5.8	4.5	0.0	0.2	7.5	% minskning från grundprognos

*“Andra” innefattar, vid beräkning av miljö och hälsopåverkan, alla länder beskrivna i GAINS modellen utanför de Nordiska länderna.

Förbättringspotentialen för övergödningsproblemet i de Nordiska länderna visar större nationell variation än för försurning mellan de studerade länderna enligt resultaten. Förbättringen i övergödningssituationen liknar förbättringen i försurningssituationen för de nordiska länderna och övriga Europa, med Danmark som undantag.

GAINS modellen beskriver hälsoeffekter i form av “miljoner förlorade levnadsår”. Denna enhet mäter hur den totala återstående förväntade livslängden för en befolkning skulle påverkas av olika nivåer av $PM_{2.5}$ halter i luft. I tabellen nedan visas förbättringen i procent jämfört med grundprognosen.

Påverkan på hälsa – % minskning i förlorade levnadsår p.g.a. långtida exponering av $PM_{2.5}$ (- innebär försämring i jämförelse med grundprognosen)

Land / scenario	Finland	Norge	Sverige	Danmark	Andra*	Totalt Norden	Enhet
Grundprognos	0.0	0.0	0.0	0.0	0.0	0.0	% minskning från grundprognos
Skillnad (Lågutsläpp – Grundprognos)	5.0	-4.8	3.0	-2.7	0.1	0.4	% minskning från grundprognos
Skillnad ("Tänk-om" – Grundprognos)	5.0	-4.8	3.3	-2.4	0.5	0.6	% minskning från grundprognos

*"Andra" innefattar, vid beräkning av miljö och hälsopåverkan, alla länder beskrivna i GAINS modellen utanför de Nordiska länderna.

Som framgår av tabellen ovan så kan Norge och Danmark påverkas negativt av deras respektive låg-CO_2-scenarier. De negativa konsekvenserna beror på ökad användning av biobränslen med påföljande risk för ökning av $PM_{2.5}$ utsläpp.

GAINS modellen används även för att beräkna merkostnader för samhället vid en ändring av utsläpp från grundprognosens nivå till låg-CO_2-scenariets nivå. Merkostnaderna presenteras i enheten miljoner Euro (€) per år, och utgör merkostnader i samband med miljö- och energieffektivitetsförbättringar i de olika sektorerna representerade i GAINS-modellen. De totala merkostnaderna inkluderar investeringar, drifts, liksom bränsle- och elkostnader i samband med införande av utsläppsminskande åtgärder i låg-CO_2-scenarierna. Dessa kostnader är annualiserade för att kunna jämförbara kostnader på årsbasis. I tabellen nedan, så innebär ett negativt tecken besparingar för samhället.

Netto-merkostnader för de Nordiska länderna till följd av låg-CO_2-scenairerna

Merkostnader utöver kostnader tagna i grundprognosen						
Land / Sektor	Danmark	Finland	Norge	Sverige	Total	
Hushålls- och service sektorn	-367	-334	-75	-1231 (-574)*	-2007 (-1350)*	miljoner €/år
El- och värmeproduktion samt industrin	488	427	284	-911 – 0	288 – 1199	miljoner €/år
Transportsektorn	-394	-167	-705	794	-472	miljoner €/år
Totala merkostnader utöver kostnader tagna i grundprognosen	-273	-74	-496	-1348 – 220	-2191 – -623	miljoner €/år

*Numret inom parantes visar kostnader ifall ändringar i beteende inte beaktas i kostnadsberäkningarna

Dessa resultat visar att stora utsläppsminskningar av kan förknippas med negativa kostnader för samhället. Kostnaderna varierar mellan sektorer och länder.

Slutsatser och diskussion

Denna studie visar att energieffektivisering och låg-CO_2-strategier kan leda till kostnadseffektiva minskningar av växthusgaser i de flesta sektorer. Och i nästan samtliga fall leder detta även till minskade utsläpp av traditionella luftföroreningar. Underlaget till denna studie tyder också att det saknas en gemensam Nordisk strategi för hur dessa minskningar uppnås på en nationell nivå. Och det finns inget som tyder på att dessa strategier beaktar ett annat lands strategi. Detsamma tycks gälla för ländernas grundprognoser för utsläpp.

Allt som allt visar resultaten från denna studie att de tekniska kostnaderna för att undvika utsläpp av växthusgaser och luftföroreningar i ett nordiskt energisystem skulle innebära besparingar för samhället på grund av lägre kostnader för energi. Dessutom, miljöfördelar som ges på grund av minskad efterfrågan på energi samt strukturella förändringar skulle göra det lättare för de nordiska länderna att nå sina utsläppsmål gällande luftföroreningar samt kommande klimatmål. Vissa av åtgärderna skulle även göra det lättare att nå Europeiska mål gällande luftkvalitet. Alla strategier innebär inte samverkansfördelar mellan luftföroreningar och klimat. I denna studie har det visats att en ökad användning av biobränslen riskerar införa en kompromiss mellan minskade utsläpp av luftföroreningar och växthusgaser.

Dessa möjligheter till samverkansfördelar och risker för konflikter mellan luftkvalitet och klimatförändring bör betonas mer i utvecklingen av framtida nordiska låg-CO_2-utsläppsstrategier.

Rekommendationer till beslutsfattare

Nordiska beslutsfattare bör utöka ansträngningar mot en utveckling av gemensamma strategier för en konsekvent nordisk energipolitik. Nyss avslutade projekt som “Nordic Energy Perspectives” kan ge mer värdefulla bidrag för de Nordiska länderna.

I denna studie har visats hur effekter på utsläppen av luftföroreningar och miljöpåverkan kan variera till följd av genomförandet av olika nationella strategier för minskad klimatpåverkan. Från detta kan projektgruppen dra slutsatsen att framtida utveckling av nordiska klimatförändringsstrategier bör ta hänsyn till hur utsläppen av luftföroreningar påverkas i syfte att öka samverkansfördelar och undvika kompromisser. Även om de flesta av de nationella låg-CO_2-scenarier som analyserats härstammar från intressegrupper är denna rekommendation fortfarande giltig eftersom dessa rapporter ganska väl samstämmer med den offentliga dagordningen.

Den nordiska diskussionen om fördelarna med att exportera “grön el” kan via resultaten från analysen av ett “tänk-om”-scenario stödjas. En export av el från Norden till Tyskland och Polen skulle ha en gynnsam effekt på den nordiska miljön, förutsatt att vissa krav för utländsk elproduktion är uppfyllda. Dessa krav möjliggör därmed specifikation av lämplig energipolitik relaterat till elexport.

För det första är det viktigt att den exporterade elen ersätter den mest förorenande typen av elproduktion. Detta kan ske genom avtal eller märkning av el.

För det andra måste det nordiska elnätet beaktas så att överföringskapaciteten är säkerställd.

1. Introduction

Some of Europe's most air pollution sensitive ecosystem areas are located in the Nordic countries. The Nordic countries have in general given a high priority to environmental and nature protection. The Nordic countries have been active as driving forces behind the establishment of the 1979 Convention on Long-range Transboundary Air Pollution (CLRTAP) and the reduction of European emissions of air pollution achieved through protocols under the Convention.

From the establishment of the 1999 Gothenburg protocol, the CLRTAP process to reduce emissions of air pollutants, has been paralleled with EU policies on air pollution, e.g. the National Emissions Ceiling (NEC) directive and Large Combustion Plant (LCP) directive. Both the CLRTAP Gothenburg protocol and the EU NEC directive are presently under revision. A proposal for a new "Industrial Emissions" directive is also being considered.

The United Nations Framework Convention on Climate Change (UNFCCC) was established in 1992, and the Kyoto protocol was adopted in 1997 entering into force in 2005. At the Copenhagen meeting COP15 in 2009, it was underlined that climate change is one of the greatest challenges of our time. The challenge of air pollution and climate change is currently handled in separate political processes, despite the obvious link between air pollution and climate change policy problems. Both problems arise primarily from the burning of fossil fuels, and require international agreements and action to be solved. However, the problems are different since air pollution is mostly a local to regional scale problem, where effects in a particular location are caused by emissions from a finite region. Climate change is a global environmental problem and a policy challenge. A key element in the implementation of the Kyoto protocol in EU has been flexible mechanisms, e.g. emission trading, which influences emissions of air pollutants.

The international agreements on air pollution have to a large extent been effect oriented and cost optimised. This approach has enabled differences in national emission targets through nationally binding emission ceilings, supplemented with specification of Best Available emission reducing Technologies (BAT) as well as sector specific regulations such as the LCP directive and the Auto Oil programme. Emission abatement measures, such as energy demand savings and fuel switching, imply co-benefits for climate change and air pollution since these measures reduce emissions of both GHG and air pollutants. The situation can be the opposite for some end-of-pipe (EOP) emission abatement measures. EOP measures were of highest priority in the early international agreements to curb air pollution emissions. EOP measures generally focus on one pollutant but can in some cases decrease fuel efficiency, and can therefore lead to increased energy consumption and thus higher emissions of other pollutants. This trade-off between air pollution and climate change is of concern both in the case of Carbon Capture and Storage (CCS) systems and for e.g. catalytic converters for NO_X reduction. Energy demand savings and fuel switching have gained increased attention during later protocols, partly thanks to the co-benefit with emissions of greenhouse gases.

The Nordic countries have since 1996 had a closely linked energy system through the Nord pool system for electricity exchange. A common Nordic resource pool for electricity helps to optimise the use of available power and reduce local deficits, and can enhance the use of non-fossil based power sources. However, the trade of electricity on a commercial market can affect both co-benefits and trade-offs between climate and air pollution, as well as the national implementation of environmental policies.

The aim of this study, on the basis of national baseline and low carbon dioxide (CO_2) scenarios for the Nordic countries, has been to explore co-benefits and trade-offs between climate and air pollution policies. The GAINS model was used to estimate the cost of shifting from the national projected baseline scenario to a low CO_2 emission scenario. The model was also used to estimate the change in air pollutant emissions and impacts on human health and the environment, both for the Nordic countries and for other European countries. Finally, a scenario analysis was made on the environmental benefits of replacing coal fired power production in Germany and Poland with renewable energy from Nordic power production.

2. Background

Air quality and climate change

There are clear links between air pollution and climate change policies because the burning of fossil fuels both causes CO_2 emissions and emissions of the conventional air pollutants, i.e.: carbon monoxide (CO), volatile organic compounds (VOC), carbonaceous aerosols (black carbon, BC), fine particulate matter (PM, PM_{10}, $PM_{2.5}$) nitrogen oxides (NOx) and sulphur dioxide (SO_2). In emission abatement strategies, there are also links where emission abatement strategies such as fuel switching and behavioural changes can work to control both climate change and air pollution. These measures will however not be exclusive since relatively low cost EOP measures exist for some of the conventional air pollutants, and 80 % of the world's energy consumption is still covered by fossil fuels. Fossil fuels still provide a cheap source of energy for all countries, which is especially important for developing economies.

Air pollution and climate change affect the earth system and human environment in different interlinked ways, especially through ozone (O_3) and PM interactions. O_3 is primarily formed in the atmosphere with VOC's and NOx as precursors, and is currently assessed to be the third most important greenhouse gas. O_3 also plays an important role for the oxidizing capacity of the atmosphere and thus the atmospheric lifetime and concentration of methane. Methane acts as a precursor for background tropospheric O_3.

Nitrogen (N) biogeochemistry is the main link between air pollution and climate change effects on ecosystems. N inputs will increase carbon (C) sequestration, at least for a period. N accumulation in non-agricultural ecosystems reduces biodiversity and increases the risk of nitrate leaching and N_2O emission causing a potential conflict between an interest in increased carbon sequestration and conserved biodiversity. N_2O is presently the main source of stratospheric ozone destruction.

Atmospheric particles (PM) also affect solar radiation. Depending on chemical composition, PM can either absorb or reflect solar radiation. Atmospheric particles (as aerosols) have an immediate effect on cloud and precipitation formation, and hence affect local and regional atmospheric circulation and the water cycle.

Climate change affects biodiversity by altering the basic conditions (temperature, precipitation) in ecosystems and thus favouring species capable of adapting to the new conditions. For individual ecosystems, climate change offsets the baseline conditions and can thus interact with the effects on biodiversity of air pollution.

Other research activities

The link between emissions of air pollutants and greenhouse gases has recently gained more interest in Europe. Several conferences, reports and publications have treated the same issue as the one in our report (although not in the same region). Examples include the Stockholm Co-benefits conference (September 2008) that concluded that integrate air pollution and climate change policies should be developed. Hammingh et al (2008) concluded that climate measures to a large extent are beneficial for air pollution, but that there are some climate measures that might have adverse effects in the Netherlands. For example, the use of 1st generation bio fuels in the transport sector and CCS might have negative impacts on air pollution.

The link between the environmental impact from emissions of greenhouse gases and air pollution is also fairly well described. Tagaris et al. (2009) showed that climate change could cause adverse health effects via the impact from PM and O_3 in several countries. Furthermore, Apsimon et al. (2009) showed that the link between greenhouse gases and air pollution is of concern both in terms of emission abatement technologies and policies as well as environmental and health impacts. Van Vuuren et al. (2004) stressed that the design of climate policies also has a large impact on the co-benefits and trade-offs between climate change. They showed that the use of flexible mechanisms in climate policies can increase co-benefits via CO_2 emission abatement in regions where air quality policies are less stringent. Countries in the former Soviet Union region have less stringent air pollution legislation than western European countries, which results in the co-benefits being higher when using flexible mechanisms as a mean to reduce CO_2 emissions. Similar results were shown in Rypdal et al. (2007).

The Nordic perspective

In the Nordic countries, the long term policy work directed towards the phasing out of fossil fuels (together with a relative abundance of renewable hydro power, bio fuels and nuclear power) has resulted in more limited options for further implementation of measures that will lead to co-benefits for climate change and air pollution abatement. To ensure that future policies are developed with maximum exploitation of co-benefits for air pollution and climate, the remaining options need to be evaluated with this perspective in mind. If not, the risk of the future energy and climate policies to impose trade-offs, with negative impact on air pollution problems when reduction GHG emissions, will increase.

Environmentally sensitive areas in the Nordic countries

The Nordic countries have some of the largest most sensitive ecosystem areas to air pollution in Europe. In EU27 there are 1.9 million km^2 nature areas susceptible to acidification and the corresponding area in Fennoscandia is 0.9 million km^2 (Hettelingh et al. 2008). More than 80 % of the European nature areas with low critical loads for acidity (CLmax(S) < 200 eq / ha and year) are located in Fennoscandia. In this region, some of the first and most severe occurrences of fish death were reported in the 70'-ties as a result of water acidification. To counteract acidification, liming of lakes and waterways is carried out on a large scale in Sweden and also to some extent in Norway. In Sweden around 7500 lakes and 11,000 kilometres of waterways are limed each year.

In the southern part of Scandinavia, particularly Denmark and southern Sweden, large scale exceedance of the critical loads for nutrient nitrogen is found. The major exceedances are particularly on naturally nitrogen poor habitats such as heath, mire, bog and fen, species rich grasslands, and some coastal habitats, and forests. North Scandinavian boreal and arctic ecosystems probably have low critical loads to eutrophication. However, the concern for these areas have been less because the current deposition levels of (1–3 kg N / ha and year) are well below earlier applied empirical critical load estimates in the range (5–10 kg / ha and year). It has been difficult to establish scientific evidence for eutrophication effects at lower deposition levels because of the slow pace of e.g. changes in vegetation species distribution. However, newer scientific findings points to a much higher vulnerability of some of the ecosystems in this region, and the critical loads and the air pollution problems in this region are currently being reassessed (Nordin et al. 2007).

The Nordic electricity market

The common Nordic electricity market might be under stress in the future, following ambitious plans to reduce the emissions of CO_2, while increasing the electricity production in the Nordic countries. In the official Swedish projection, the installed capacity of wind power increases from 3.6 PetaJoule (PJ) in 2005 to 25 PJ in 2020. This increase not only poses a challenge for the Swedish environmental legislation, but also increases the need for electricity storage capacity in Sweden and probably in other Nordic countries as well. Denmark is since long a larger producer of wind power than Sweden, and faces similar problems. Of special interest in our study is the potential to export "clean electricity" from the Nordic countries to central Europe. In order to allow a large scale export of "clean electricity", the transfer capacity from and between the Nordic countries needs to be considered.

3. The aim of this study

The aim of this study was to explore co-benefits and trade-offs between climate and air pollution policies, based on the national baseline and selected low CO_2 scenarios for the Nordic countries. By focusing on national scenarios for the Nordic countries, the study has enabled an analysis of effects of differences in energy and climate policies. Different designs of energy & climate policies have different effects on emission of air pollutants and GHG: s as well as environmental impacts. It is important that the policy makers who set energy and climate policy targets make well informed decisions so that the co-benefits between air pollution and climate change abatement measures can be maximised, and so that the trade-offs in environmental impacts can be minimised.

In this study, the project group analysed the potential impact of specific national low CO_2 emission scenarios, developed by national organisations and authorities, on air pollution and the environment. These low CO_2 scenarios are not official national projections but were produced in order to raise the awareness of the impact of alternative energy futures in the Nordic countries. The low CO_2 emission scenario reports did not take multi-pollutant effects of these CO_2 abatement measures into account. Neither did they assess the impact on national emissions of air pollutants and the potential impact on human health, acidification and eutrophication.

These national low CO_2 emission scenarios were in this study interpreted and compared with the national baseline emission projections as they are reported by the countries to the CLRTAP CIAM / EMEP. More specifically, analysis was made on the impact on emission abatement costs and the environment of the following low CO_2 emission scenarios:

- Denmark: “Energy projection 2009”, Denmark Energy Agency, 2009
- Finland: “World Wildlife Foundation energy scenario Finland”, 2007
- Norway: “Lavutslippsutvalget”, NOU 06:18, 2007
- Sweden: “Halva energin, hela välfärden”, Svenska Naturskyddsföreningen, 2008

It must be stressed that the project groups’ analysis was deeply dependent on the underlying assumptions made in the national low CO_2 emission scenarios. This dependency was of major importance in the estimates of abatement costs for reaching the CO_2 emission levels as specified in the scenarios. However, this dependency was less important for the calculation of air pollutant emission levels and environmental impacts. All the low CO_2 emission scenarios focused on abatement of CO_2 emissions only, and did not include other greenhouse gases (GHG) or conventional air pollutants. The scenarios are not necessarily produced using a cost-minimising approach. Furthermore, the low CO_2 emission scenarios vary in the level of detail in the scenario descriptions. Therefore it was necessary for the project group to interpret and make estimates on many of the results of the low CO_2 emission scenario reports. A final note is that these national low CO_2 emission scenarios give us an indirect insight into which national energy policies can be considered of special interest in each country. The national low CO_2 emission scenarios vary in terms of policy instruments and measures considered. To a certain extent, these variance shows both that the national circumstances for CO_2 emission reduction vary, but also that political priority is different in the different countries.

Guidance to the reader of this report

In this report, the method and data used in the study are presented. This is followed by a presentation of the results on emissions, costs and environmental effects following the scenarios. The results section is followed by an exploring scenario analysis in which more options for the Nordic energy policy strategies and the potential impacts are analysed and discussed. Finally, conclusions are drawn from the results together with policy recommendations. More detailed descriptions and data are found in the appendix to this report. The following abbreviations are used to describe the scenarios in the report:

Table 1: Description of scenarios presented in the report

Scenario abbreviation	Description
BSL-DK	The Danish baseline scenario in GAINS adopted from the national reporting to the GAINS modelling team in 2007
LE-DK	The Danish Energy Authority’s low emission scenario
BSL-FIN	The Finnish BSL scenario in GAINS in correspondence with the 2005 national reporting to IIASA
WWF-FIN	The Finnish low emission scenario developed by the Finnish branch of the World Wildlife Foundation
BSL-NO	The Norwegian baseline scenario in GAINS adopted from the PRIMES 2009 draft scenario calculations
LUU-NO	The Norwegian low emission scenario developed from the NOU 2006:18
BSL-SWE	The Swedish baseline scenario developed from the national projections on energy use and emissions, (Swedish Energy Agency (SEA) 2009a,b)
SNF-SWE	The Swedish Low emission scenario, adapted from the Swedish Society of Nature protection (Svenska Naturskyddsföreningen) in 2008
“What-if”	The Nordic low emission scenarios presented above together with the adjusted energy balance in Poland and Germany (more electricity import, less condensing coal power plant electricity production). Other countries are based on the PRIMES 2009 draft scenario

4. Method

4.1. A short description of the GAINS model

General introduction to the GAINS model

The Greenhouse gas – Air pollution Interactions and Synergies (GAINS) model has been developed by the International Institute for Applied Systems Analysis (IIASA), Austria. It uses a bottom-up approach for quantifying greenhouse gas and air pollution abatement potentials and costs for the countries in the UNECE region, and can also estimate co-benefits on air pollution from implementation of greenhouse gas abatement measures. The GAINS model approach provides a framework for a coherent international comparison of the potentials and costs for emission control measures, both for greenhouse gases and air pollutants. The model estimates by which measures in which economic sector the emissions of the six greenhouse gases can be reduced and to what extent. The costs for the measures are also estimated. The model identifies for each country the portfolio of measures that achieves a given reduction target in the most cost-effective way.

The model also provides national cost curves that allow a direct comparison of abatement potentials and associated costs across countries. By using a bottom-up approach that distinguishes a large set of specific emission abatement measures, relevant information can be provided on a sector by sector basis. Implied costs can be reported in terms of upfront investments, operating costs and costs (or savings) for fuel input.

The following sections provide a general outline of the basic rationale, the approach and data sources that have been employed for estimating abatement potentials and costs for the various countries. Adjustments of the general approach to address specific requirements for individual gases are described in the companion reports (Amann et al., 2008a, Borken-Kleefeld et al., 2008, Höglund-Isaksson et al., 2008, Böttcher et al., 2008).

Emission abatement cost calculations in the GAINS model

The cost functions in GAINS are based on a multi-pollutant approach, where each abatement measure affects one or more pollutants. However, abatement cost is calculated by the technical measure and later expressed as cost per avoided emission. This means that the costs are not directly calculated as a “cost curve” for each pollutant. In principle, the GAINS model applies the same concepts of cost calculation as the RAINS model, which allows consistent evaluation of emission abatement costs approximated by estimating costs at the production level. Any taxes added to production costs are similarly ignored in the cost calculations since they are considered as economic transfers within the society, not as a resource costs. A central assumption in the RAINS/GAINS cost calculation is the existence of a free market for (abatement) equipment throughout Europe that is accessible to all countries at the same conditions. Thus, the capital investments for a certain technology can be specified as being independent of the country. Simultaneously, the calculation routine takes into account several country-specific parameters that characterise the situation in a given region. For instance, these parameters include average boiler sizes, capacity/vehicles utilization rates and emission factors. The total expenditures for emission abatement are differentiated into: investments, fixed operating costs and variable operating costs.

From these elements GAINS calculates annual costs per unit of activity level. The activity level indicates the economic activity that causes pollution. For example the use of coal in the power sector is indicated with the activity PetaJoule (PJ) of coal use, and the number of cattle is an activity related to emissions of ammonia. In this study, the production and use of electricity, heat and transport were the activities of main consideration. Parameters used for calculating variable cost components such as the extra demand for labour, energy, and materials are also considered common to all countries. However, the unit prices for labour, electricity, fuel and other materials as well as cost of waste disposal are considered as country specific. Other country-specific parameters characterise the type of capacity operated in a given country and its operation regime. They include the average size of installations in a given sector, operating hours, annual fuel consumption and mileage for vehicles.

All costs in RAINS/GAINS are expressed in constant € (in this study, at year 2005 value). Although based on the same principles, the methodologies for calculating costs for individual sectors need to reflect the relevant differences (e.g., in terms of capital investments). Thus, separate formulas are developed for stationary combustion sources, stationary industrial processes and mobile sources (vehicles). Primarily, the GAINS model calculates *incremental costs* associated with abatement of emissions. This means that the model calculates costs for technologies specifically directed towards reducing emissions rather than calculating costs for technologies where emission reduction is only one of the utilities of the technology. The main exemption from this is when calculating costs for electricity and heat production using different fuels and technologies.

4.2. General methodology in this study

The starting point for this study was the independently created national low CO_2 emission scenarios for the Nordic countries presented above. These national approaches for low CO_2 emission scenarios were not based on similar assumptions or baselines, which as mentioned earlier has an impact on the results in this report. Some of the national low CO_2 emission scenarios were based on existing energy baseline scenarios. Others were just reported as lists of measures that were not fully congruent with any existing energy baseline scenario.

In an early stage of the project the GAINS model was chosen as a platform for common modelling framework. As a starting point the national baseline emission scenarios on emissions of air pollutants (other than GHG:s) were calibrated with the national energy baseline scenarios and the national low CO2 emission scenarios used in the analysis. The calculated emissions of air pollutants in the national energy baselines scenarios were calibrated with national emission baseline scenarios by implementing a set of air pollution emission reducing measures in the GAINS model. These measures were derived from the air pollution emission control strategies in the national scenarios so that they would fulfil current and planned legislation in 2020. This was done by using the latest control strategy set for GAINS Gothenburg Protocol revision scenario (PRIMES 2009 draft scenario).

When the low CO_2 emission scenarios resulted in fuel shifts, as was the case for Finland, the implementation of air pollution control measures in the GAINS model scenario was adjusted so that national legislation on control of air pollution was ensured. For Finland, this meant that the measures implemented to control air pollution differed slightly between the baseline and the low CO_2 emission scenario. The task of calibrating emissions of air pollutants enabled a coherent baseline for the calculation of air pollutant emission reductions following an implementation of national low CO_2 emission scenarios. These resulting energy & emission baseline scenarios were also compared with other scenarios developed by the GAINS modelling teams at IIASA.

The low CO_2 emission scenarios were created by interpreting the national low CO_2 emission scenario reports, and then estimate which of the CO_2 emission abatement measures available in the GAINS model database that should be implemented in the national low CO_2 emission scenario calculations. The final energy balance in the low CO_2 emission scenario, after implementing the CO_2 emission abatement measures in GAINS, should match the energy balance from the national low emission scenario reports. Some of the measures in the reports were however not included among the available CO_2 emission abatement measures.

For measures that were not included in GAINS, alternative assessments were made using data from other sources than the GAINS model. Abatement measures used for cost calculations were primarily based on CO_2 abatement measures in the GAINS model. The results from these scenario analyses provided quantified prognosis on how the developed Nordic low CO_2 emission scenarios could affect GHG emission levels, impacts on air pollutants, as well as economic costs for the Nordic countries.

The GAINS model cost optimisation routine specifies the desired emission target for CO_2 and abatement measures that are needed to reach this emission target. The model implements the emission abatement measures by starting with the most cost efficient measure first, and do not separate different sectors. In our study, the abatement measures implemented were specified already in the low CO_2 emission scenario reports. The implication of this was that the GAINS optimisation routine could not be used to represent the low CO_2 emission scenarios. Therefore, the data in the GAINS database on CO_2 abatement measures and emission factors (as of September 2009) was used to derive sector specific "non-optimal" CO_2 abatement strategies. These strategies better represented the measures proposed in the national low emission scenarios analysed in this study. This database is used in the GAINS model cost optimisation routine, but in the optimisation routine the database is applied without sector-specific restrictions on fuel use, which was needed in our study.

The work with compilation of the national scenarios and the breakdown of these scenarios into GAINS format was performed by the national institutions corresponding to the country-specific scenario.

4.3. Conversion of national data into GAINS format

Due to the different starting points and methodologies in how the national low CO_2 scenarios were reported, there was no common methodology used to convert national data into a format suitable for analysis with the GAINS model. The common methodology chosen to reach balanced scenarios was to let the energy balance in the low CO_2 emission scenario meet the energy balance in the BSL scenarios by using the GAINS model abatement measures, when suitable measures were available. If the measures available in the GAINS model database weren't sufficient to simulate the national measures in the low CO_2 emission scenarios, further adaptation was needed. As a final end point, energy balance data and data on implementation rates of air pollution control measures in GAINS format were developed for all countries and scenarios. These energy balances and air pollution controls were used for further analysis with the GAINS model. In the following text, the national specific methods for converting national estimates to the GAINS model format are described.

4.3.1. Denmark, data conversion method

For the description of the basic activity pathways, GAINS uses a combination of 19 different fuels and 14 sectors. For the Danish energy scenarios only 60 combinations of fuels and sectors are actually used. The Danish energy statistics are more detailed. They are based on a combination of 29 fuels and 52 sectors, of which 527 fuel-sector combinations are used. For the scenarios and projections made by the Danish Energy Agency (DEA 2009), 26 fuels and 25 sectors are used. Since both the national Danish statistics and projections are more detailed than what is required by GAINS, it could seem trivial to aggregate the national figures into GAINS format. This is, however, not quite the case. The GAINS classifications used for fuels and activities could not be generated as an aggregation of the classes used in the Danish national statistics and scenarios, because many of the classes are differently aggregated. This is also to some degree the case for the relationship between the national energy statistics and national scenarios. The relationship between the GAINS classification of fuels and the national Danish data is as follows:

Table 2: Fuel classification in the GAINS model and Danish statistics

GAINS	Danish
GAS	Refinery gas, LPG, natural gas, city gas
GSL	aviation gasoline, motor gasoline, JP1
MD	gas / diesel, ethanol, kerosene
HF	Heavy fuel oil, white spirit, lubricants, bitumen
DC	coke etc., petroleum coke
HC1	Coal for power plants, other
OS1	straw, wood, wood chips, wood pellets, wood waste, biogas
OS2	Waste
REN	solar, geothermal, heat pumps

When comparing sectors described in the GAINS model and in the Danish statistics and reporting, the conversion was more complicated. One challenge was that the non-road transport sub-sector, which in GAINS is separated into a number of activities (sector-fuel combinations), whereas this sub-sector is represented within the transport sector in the Danish national statistics and scenarios.

The fuel use in the agricultural, construction and industrial sectors has been converted from national estimates to GAINS by splitting the energy use in energy for transport and for other purposes. The split has been made based on more detailed national data with a relationship to fuel type, where e.g. gasoline is primarily used for transport purposes. Since both the national baseline scenario (BSL-DK), and the national low CO_2 emission scenario (LE-DK) were based on national statistics and projections using the same sector and fuel classifications, no further conversion efforts were needed for Denmark.

4.3.2. Finland, data conversion method

For Finland, the low CO_2 emission scenario was based on a report from the Finnish branch of the World Wildlife Foundation (WWF 2007, Lund 2007a). In this study, the Finnish low CO_2 emission scenario's (WWF-FIN scenario) fuel-sector activities were converted into GAINS format with help of the FRES-model (Finnish Regional Emission Scenario) (Karvosenoja 2008). By using this methodology, local energy balances and fuel logistics remained realistic for Finland. The maximum penetration rates of new abatement measures were based on Lund (2007b). The GAINS energy balance data created in our study for the BSL-FIN scenario was based on the 2005 baseline scenario energy balance as described in the FRES model. This energy balance was also the starting point for the WWF-FIN scenario. All industrial boiler or power plant sectors described in the GAINS energy balance data were linked to existing power plants in the FRES database (Karvosenoja 2007).

In the WWF-FIN scenario, these plants were "closed down" as a result of fuel saving measures, or "fuel" was substituted with carbon neutral fuel if a measure of CO2 abatement was based on fuel switches. Only realistic fuel substitutions and phase offs were allowed. As an example, gas turbine power plants couldn't switch from using gas to using partly biomass, and co-firing fluidized bed power plants could only replace e.g. peat with biomass to a certain limit. When a specific power plant could not be named, the average structure of power generation in Finland was used to describe the impact on the energy balance following energy demand savings and fuel shifts.

For the WWF-FIN scenario, several GAINS measures were identified and applied. However, some of the main measures listed in the low CO_2 emission scenario developed by WWF (2007) were not included in the list of measures in GAINS, only as a part of the model's optimization routine. These measures were used by calculating energy balance data outside the model and including them to the final energy balance data sheet which was uploaded into the GAINS model. The implementation of air pollutant control measures in the GAINS model was changed so that fuel gas cleaning system would meet the future emission limits set in Large Combustion Plant (LCP)-directive and the coming Industrial Emissions (IE)-directive.

While processing the WWF-FIN scenario measures into GAINS data, a total of 12 PJ of primary energy could not be identified within the limits of the current energy infrastructure. This means that if all savings and substitutions in the WWF-FIN scenario would be implemented, extra cuts in fossil fuel use in the capital area of Finland would be needed. This would most likely mean logistical problems in fuel transport, because of a massive increase in biomass use. There has lately been a discussion of gasification of biomass outside metropolitan areas and transporting the produced biogas together with natural gas pipelines, which could be a way to solve these problems. No exact cost estimations of this kind of technique are published and the WWF-FIN scenario did not include this kind of measure.

The WWF-FIN scenario included significant amount of carbon neutral bio fuels. At the time of writing, bio fuel logistics are mainly directed to forest and pulp industry activities. Lately there has been decreasing utilisation of production capacity e.g. in saw mills and chemical pulp mills. If this trend continues it will have a large impact on the Finnish energy balance. Another topic raised into awareness lately is that not all forest residues is actually carbon neutral if the whole carbon cycle is taken into account. This will have an impact on the CO_2 emissions resulting from a bio fuel intensive energy future.

4.3.3. Norway, data conversion method

The conversion of data from the Norwegian NOU 2006:18 report into GAINS format was based on a comparison of the list of measures and activities described in the report and the national baseline scenario (BSL-NO scenario) submission of data to the GAINS model, which was the closest to NOU (2006) publication year. The BSL-NO scenario is described in the IIASA report "NEC Scenario analysis report nr 5" (Amann et al. 2007). Additional information was sought from IFE (2006) and Åvitsland (2006). The energy data conversion process was relatively simple, because of the unique structure of Norway's energy system, where electricity is mainly produced by hydropower and heat in natural gas boilers.

4.3.4. Sweden, data conversion method

Conversion of energy projections from the BSL-SWE scenario and the SNF-SWE scenario into the GAINS format is subject to a number of challenges. The main challenges involved the different perspectives on energy balance in other GAINS model scenarios and the national scenarios, as well as the different level of aggregation for fuels and sectors. This difference requires some adjustment of energy balances to achieve comparable values. In the BSL-SWE scenario for the year 2005, SEA (2006, 2009) energy estimations differ with 14 TWh (50,4 PJ) because of the difference in preliminary and final statistics. The Swedish reported energy balance data are adjusted by removing the energy supplied by heat pumps and residual heats as well as international shipping before introducing into the GAINS model format. The non-energy use of fuels is unspecified per fuels inputs in the Swedish baseline scenario, and the fuel distribution for non-energy uses is therefore balanced according to other GAINS model scenarios for Sweden. These scenarios are in turn based on reporting from the International Energy Agency.

The SNF (2008) projection only projects activities by 2030. Total fuel consumption by 2030 in the SNF-SWE scenario per sector is the sum of total fuel consumption from the SNF report. In the GAINS model, the total fuel consumption by 2030 in the SNF-SWE scenario is calculated by reducing primary fuel uses from the BSL-SWE scenario 2005 to meet the fuel consumption level by 2030. However, in order to adjust for the conversion of the energy balance between the years 2005 and 2020, 2030, the distribution of fuels in 2020 and 2030 in the SNF-SWE scenario follows the distribution in the BSL-SWE scenario. The fuel consumption for year 2020 is obtained by linear interpolation between 2005 and 2030 for the SNF-SWE scenario. For the BSL-SWE scenario, projections are given for both 2020 and 2030.

Specified descriptions of the conversion method for the industrial, transport, residential and service sectors are presented in the Appendix.

5. The scenarios and data

The data needed to perform the scenario analysis in this project were taken from the national energy and emission projections, national low emission scenarios, as well as the GAINS model database on emission factors and abatement measures. These have been described earlier in this report. The national energy and emission projections were used to describe the structure of the national energy systems in different scenarios.

The GAINS model and the GAINS model database on abatement measures were used both to calculate emissions and to calculate scenario abatement costs for the low CO_2 emission scenarios. In this chapter, not all data is presented. More national specific information can be seen in the appendix to this report and in the associated GAINS model reports. This chapter first presents the national scenarios and an exploring "what-if" scenario, followed by a presentation of the underlying GAINS model scenarios (PRIMES model scenarios) that provided energy and emission estimates for the other countries outside the Nordic countries. Finally, a brief presentation of the GAINS database for abatement cost calculations is given.

5.1 The national scenarios

The national scenarios are briefly presented for each country. Additional and more detailed information is to be found in the appendix to this report.

5.1.1. Denmark, the BSL-DK and LE-DK scenario

The vision for Danish energy policies is to reach 100 percent independence from fossil fuels. This is, however, a long term vision, and as yet, no national scenarios have been set up leading to this endpoint.

5.1.1.1 A short description of the BSL-DK scenario

Denmark has the following international binding targets for the energy policy:

- 30 percent renewables in final energy consumption in 2020, 10 percent renewable energy in transport
- 20 percent reduction in 2020 in non-trading greenhouse gas emissions compared to 2005
- 21 percent reduction in greenhouse gas emissions on average in 2008-2012 compared to 1990 (Kyoto).

The BSL-DK scenario in this study includes the above mentioned targets.

5.1.1.2 A short description of the LE-DK scenario

The Danish Energy Agency has created a new baseline projection for energy production, energy consumption and related greenhouse gas emissions by 2030 in Denmark. The projection is based on implementation of already adopted measures without additional instruments. DEA's baseline projection is not a forecast but describes the development of a number of assumptions about technological development, prices, economic development, etc. which may occur between now and 2030 if there, hypothetically assumed, was not to be undertaken new initiatives or instruments.

The latest energy plan (Energy projection 2009) has the following national targets:

- 20 percent renewable energy in gross energy consumption in 2011
- Annual energy demand savings of 1.5 percent of final energy consumption in 2006
- 4 percent reduction in gross energy consumption in 2020 compared to 2006

The Danish energy policies, and therefore the Danish projections and underlying analysis performed in this study, have been subject to review and adjustment in order for Denmark to meet national targets set in the Danish Allocation plan following the EU implementation of the Kyoto Protocol. Denmark has a GHG emission reduction obligation of 21 % by 2012 compared to 1990. However, the unsuccessfulness in meeting this obligation, the so-called climate gap, was in 2005 estimated at 8-13 million tonnes of CO_2 annually in 2008–2012. Therefore, since 2005, a number of political measures have been adopted to meet the target. The energy and emission scenarios have been revised, and now include new emission factors for emissions of GHG, particularly for some of the agricultural emissions, and for waste incineration. New estimates for the fossil content (e.g. plastic) in waste increased the GHG emissions with 600 000 tonnes per year, and new emission factors for CH_4 and N_2O increased the estimate on GHG emissions from agricultural sources with 400 000 tonnes per year. The newest scenario reported from the Danish Energy Agency (Energy projection 2009), reported in May 2009, still results in a climate gap of around 1 million tonne GHG emissions per year.

The Danish Government has announced several new initiatives to close the remaining climate gap. The following is a list of suggested initiatives:

- Change in car taxation: making it cheaper to buy but more expensive to drive a car
- A framework for support of electric cars
- Increased taxes on energy use
- Changes in agricultural legislation

- Changes in the building regulations: strengthening the regulation of material use and setting new rules for energy renovation of existing buildings
- More support for research, especially in the transport sector.

The newest official energy scenario (Energy Projection 2009) has been used as the LE-DK scenario in this study. Although this scenario is insufficient in terms of reaching national targets, it has been chosen for continued analysis in this study since no new, consistent and reliable scenarios are available with a higher GHG emission reduction ambition. The scenario has in this study been used as it was described in the national reporting (DEA 2009) without introducing the announced new measures listed above. The reason for this is that the exact implementation of these measures is not known, and the expected effect is within the uncertainty range of the scenario.

Table 3: Key parameters and assumptions in the BSL-DK scenario

Key parameters & assumptions:	2005	2020	Annual growth rate, %/a
Population, million	5.4	5.7	
GDP, 10^9 €	289	403.5	1.9
Imported electricity %-of total	3.8	11.9	
Renewables % -of primary	15	27	
Carbon price, €/t CO_2	11	31	
Oil price ($US / barrel)	69	110	

5.1.2. Finland, the BSL-FIN and WWF-FIN scenario

The Finnish baseline scenario (BSL-FIN) used in our study is based on the latest Finnish projections submitted to the GAINS model (2005). However, after the Finnish baseline was delivered, a new Finnish Energy and Climate strategy has been published in 2008. The difference between the Finnish baseline scenario (2005) and the new strategy from 2008 have an impact on the Finnish low emission scenario. In order to illustrate the impact of the new strategy, the 2008 strategy is presented as “2008 Strategy” in the tables below. To keep energy consistency between the Finnish low CO_2 emission scenario (WWF-FIN scenario) and the BSL-FIN scenario the WWF-FIN scenario is based on and comparable to the BSL-FIN scenario with projections based on the Finnish energy strategy from 2005 (2005 Strategy).

5.1.2.1 A short description of the BSL-FIN scenario

Finland’s GAINS baseline (used in the BSL-FIN scenario) was based on the year 2005 energy and climate strategy and the most ambitious “with additional measures” scenario for Finland. As mentioned, a new energy and climate strategy for Finland was published in 2008 (2008 Strategy). The key numbers of economical growth and population were similar in the two strategies. The CO_2 abatement potential reported in the WWF-FIN scenario was based on the energy balance in the BSL-FIN scenario (2005 strategy) and there are some important discrepancies between 2005 and 2008 Strategy. This could have an impact on the results when comparing the WWF-FIN scenario with the 2008 Strategy.

Some of the measures in WWF-scenario have already been adapted to 2008 Strategy. For example, the growth of the forest industry is smaller in the 2008 Strategy, which affects the energy use and availability of biomass. From table 4 it can be noted, that the level of bio fuel use is increased in the 2008 Strategy. Also, the energy and electricity use in the 2008 Strategy indicates, that some energy demand saving measures are implemented in the 2008 Strategy but not in the BSL-FIN scenario (2005 Strategy).

Table 4: Key parameters and assumptions in the BSL-FIN scenario and 2008 Strategy

Key parameters and assumptions:	2005	2020 (BSL-FIN)	2020 (2008 Strategy)
Population, million	5,2	5,3	5.3
GDP, 10^9 €	155	224	208
Nuclear	2660 MW	4250 MW	4250 MW
Imported electricity %-of total		5	0
Renewables %-of total primary	27	27	38
Carbon price, €/t CO_2	15	20	20

The 2008 Strategy would fulfil the Finnish obligations under the EU Climate and Energy package (C&E package) (EU 2008). The strategy also weighted energy structural policies differently from the BSL-FIN scenario (2005 strategy), meaning that fuels that are easy to store and handle were more preferred in the energy policies than the ones that are not. The 2008 Strategy also considered energy security and energy independency, no electricity import was included in the Finnish energy balance in the 2008 Strategy. The Finnish obligations under the approved EU C&E package included a 38 % share of renewable energy (and 10% of bio fuels in the traffic sector), improved efficiency of the energy systems and 16% cuts on GHG emissions from the sectors in Finland that are excluded from the EU GHG Emissions Trading System (EU ETS).

5.1.2.2. Structural differences between the Finnish 2005 Strategy (BSL-FIN scenario) and the 2008 Strategy.

The structural differences in the energy system between the two different national strategies have a quite large impact on the projected energy balance in Finland. In table 5, the difference in use of primary fuels between the 2005 and 2008 strategies are presented. The table shows how the projected use of combustible fuels changed from the 2005 Strategy to the 2008 Strategy. Hydro and nuclear power are remaining the same in both projections.

Table 5: How combustible fuel structure changes from the 2005 strategy compared to the 2008 strategy.

Primary combustible fuels	2005	2020 (2005 strategy)	2020 (2008 Strategy)
	(PJ)	(PJ)	(PJ)
Peat	68	63	70
Wood fuels (excluding black liquor)	97	181	127
Black liquor	132	187	144
Waste fuels	3	15	15
Coal	86	70	100
heavy oil	44	33	76
Diesel	8	11	11
Light oil	11	18	18
Natural gas	194	281	205
Total , energy sectors, excluding nuclear and hydro	642	859	777
Transport	196	226	214
Small combustion	105	94	85
Total fuel	958	1179	1064
Renewable [%] , including HYD, WIND, etc.	27	27	38
	2005	2020 (2005 Strategy)	2020 (2008 Strategy)
Total energy consumption	1366	1611	1548
Electricity consumption	295	356	353
Imported electricity (as PJ)	61	25	0
Imported energy described as primary condensing coal	160	66 (69)	0
Transport losses for electricity (as PJ)	2	1	0

In the 2008 Strategy electricity imports are reduced to zero and the maximum CO_2 emission abatement in terms of reduction of Condensing coal power plant use outside Finnish borders would be 66 to 69 PJ.

5.1.2.3. A short description of the WWF-FIN scenario

The WWF low-energy/CO_2 measures for Finland were published and presented on the 14th of February 2007 in a seminar in the Finnish Parliament, i.e. their political status is relatively high. The steering group to the WWF project included participants from energy industries, economical research centres etc., i.e. also their credibility is acceptable. The WWF report presented a number of measures and was therefore relatively easily adapted to the GAINS model approach.

WWF's low CO_2 measures included set of technical measures for (a) energy demand saving and (b) renewable energy. The technical measures include quantified estimates on implementation costs, effects on primary energy and electricity consumption. In the list of technical measures there are also two set of policy measures included. These policy measures would promote the implementation of the technical measures. The measures that were chosen for illustration in the report were based on interviews with decision-makers in both the private and public sectors. Only the first sets of measures were used in our study (energy demand saving measures). These energy demand savings were not only directed towards the Finnish energy system but also to the entire whole Nordic region and northern parts of Germany and Poland.

This international focus was chosen because the potential for large energy system changes could not be fully implemented in Finland. In order to get highest possible reduction of CO_2 emissions, Finnish measures should have an effect also on energy systems outside Finnish borders. Since all the measures presented in the report were based on maximal potentials with average costs of the measures, cost optimization was impossible to carry out when performing the abatement cost calculations in this study. During the presentation of the WWF scenario in 2007, there were uncertainties expressed whether the abatement costs and potentials reported were realistic.

In table 6, five different scenarios based on similar economic factors are presented. The PRIMES 2007 scenario is based on the PRIMES-model's supporting calculations for the negotiations of the EU's suggestion for a Climate and Energy package. The PRIMES C&E package (2008) scenario was delivered from the PRIMES model group and illustrates the impact on the agreed EU C&E package. By the time of this study, this PRIMES scenario was the latest finalised scenario delivered from the PRIMES modelling group to the GAINS modelling group. The PRIMES 2009 (draft) scenario is the draft version of the latest scenario delivered from the PRIMES model group. This scenario also includes the impact from the international financial crisis.

Table 6: Five different energy use outcomes in Finland based on similar economic factors

2020 projections	BSL-FIN Scenario (2005 Strategy)	WWF-FIN scenario (2007)	PRIMES 2007 Scenario	PRIMES – C&E package (2008)	PRIMES 2009 (draft)
Total energy demand	1611	1327	1547	1573	1542
Electricity consumption	356	251	329	355	376
Imported electricity (as PJ)	25	0 to -3	25	26	12
Imported electricity described as primary condensing coal (PJ)	66 -68	0	66 -68	68-70	32-34
Electricity transport losses for (as PJ)	1	0	1	2	1

Table 6 shows that the WWF-FIN scenario has the most ambitious targets for reducing the energy demand. The total cuts from the 2005 Strategy would be 259 PJ in Finland and maximum of 69 PJ Condensing coal equivalents outside Finnish borders, when imported electricity is converted to condensing coal. In the WWF-FIN scenario it could be possible to export 3 PJ of electricity if all fuel switches and fuel savings presented in the WWF report would be implemented at the same time. However, this would not lead to further CO_2 emission reductions, but would increase emissions of traditional air pollutants inside Finland's borders.

5.1.3. Norway, BSL-NO & LUU-NO scenarios

5.1.3.1. A short description of the Norwegian baseline scenario (BSL-NO)

The Norwegian baseline used in this study follows the latest Norwegian reporting to the GAINS model. This baseline is described in detail in Amann et al. (2007).

5.1.3.2. General comparison between the Norwegian baseline and the low emission scenario

Norway's Lavutsslippbanen (LUU-NO) scenario was based on 15 different emission reducing measures that were targeted either for the year 2020 or linearly from 2005 to 2050. This scenario was presented in the report "Et klimavennlig Norge" (NOU 2006). Almost all of the measures in Lavutslippsbanen were indentified in the GAINS model database as an emission abatement measure or as a fuel switch. This enabled a fairly easy conversion from the Lavutslippsbanen report to the GAINS model format. The LUU-NO scenario was compared to the latest national submission in GAINS (NEC5 or BSL-NO) and the baseline/Referansebanen described in the report "Et klimavennlig Norge" (2006).

The baseline scenario in "Et klimavennlig Norge" was created using the MARKAL model. The MARKAL model determines the end use of energy carriers given a projected final demand for electricity and heat. The LUU-NO scenario in our study was created by using a portfolio of measures determined by a Norwegian expert committee and described in NOU (2006).

5.1.3.3. General description of abatement measures the LUU-NO scenario

The abatement measures included in the LUU-NO scenario are fuel efficiency improvements in the on road and the off road transport sector and in the domestic sector. It also includes structural changes related to production of electricity and heat as well as increased use of wind and small hydro power. Norway's electricity generation is based on almost 100% hydropower. This implies that parts of the effect from the electricity savings measures and shifts in electricity production by further introduction of wind power and natural gas Combined Heat and Power plants (CHP) will lead to increased exports of electricity.

The LUU-NO scenario also included a remarkable use of carbon capture and storage (CCS). The implementation of CCS was targeted towards new power plants. In the GAINS model (as it was in August 2009), the implementation of CCS was difficult to estimate. So the effects on emissions from implementation of CCS were therefore not calculated in this report. The potential implementation of CCS in Norway was assumed to cover 85% of new power plants and all remarkable process industry emitters (NOU 2006).

Table 7: Four different energy use outcomes in Norway 2020 based on similar economic factors

Primary combustible fuels	2005	2020 (BSL-NO (NEC5))	2020 (BSL, NOU 2006)	2020 (LUU-NO, 2006)	2020 (PRIMES, 2007)
	(PJ)	(PJ)	(PJ)	(PJ)	(PJ)
Natural gas	175	248	233	193	248
Hard coal	31	5	4	4	4
Wood fuels (excl black liquor (bliq))	31	13	13	17	13
Waste fuels and bliq	0	16	16	16	16
Heavy oil	8	10	10	10	10
Diesel	12	9	9	9	9
Light oil and LPG	8	9	8	8	8
Hydro	480	529	450	464	442
Nuclear	0	0	0	0	0
Domestic combustion	60	61	61	61	61
Transport	237	300	300	246	298

The table 7 shows that combustion of wood fuels increase in the LUU-NO scenario compared to the BSL-NO scenario in 2020. For both scenarios, the combustion of wood fuels is smaller than in 2005.

Table 8: Comparisons of energy needs between the BSL-NO, LUU-NO and PRIMES scenarios

2020 projections	NAT 2005 (NEC05)	LUU-NO (2006)	PRIMES 2007	PRIMES 2009
Total energy demand	1145	994	1275	1387
Electricity consumption	497		488	523
Imported (exported) electricity (as PJ)	43	-26	-23	-12
Imported energy described as primary condensing coal (PJ)	113	-62	55	29
Electricity distribution losses for (PJ)	4	4	4	3

As can be seen in the table, large reductions in electricity and heat in the LUU-NO scenario implies that Norway can shift from being a net importer of electricity to a net exporter of electricity.

5.1.4. Sweden, the BSL-SWE and the SNF-SWE scenario

For Sweden two scenarios for 2020 were analysed; the baseline scenario and the low emission scenario. These scenarios are in this report abbreviated into BSL-SWE (baseline) scenario and SNF-SWE (Svenska Naturskyddsföreningen) scenario. These abbreviations are used to describe the scenarios in this report.

5.1.4.1. A short description of the BSL-SWE scenario

The total national energy demand in the baseline scenario is predicted to increase with 5 % from 2005 to 2020 (from 2318 to 2441 PJ), mainly due to increase of energy demand in the industrial sector and transport sector. The energy demand in the domestic sector remains on the same level from 2005 until 2020. The electricity and heat production in Sweden increase as a result of an increase in the use of bio fuel and natural gas in CHP plants. Net export of electricity in Sweden by 2020 is projected to be 83 PJ.

The main driver behind the increase in renewable electricity in Sweden is the Swedish system of certificate for electricity production. This system is projected to result in that electricity production from bio fuel CHP plants and wind power increases to 2020. The installed hydropower capacity is projected to be more efficient in 2020 compared to 2005. The net electricity production from nuclear power is projected to increase with 4% by 2020 as a result of the increased reactor production capacity (SEA 2009a).

The BSL-SWE scenario corresponds to the energy use and emission projections reported from Sweden to EMEP in March 2009, in accordance with the national obligations under the GHG projections and national programs (280/2004/EC); CLRTAP air emissions annual data reporting (CLRTAP/EMEP); and the NEC directive National inventories and emission projections (Directive 2001/81/EC).

Table 9: Key parameters & assumptions for the BSL-SWE scenario

Key parameters & assumptions:	2005	2020	Annual growth rate, %/a
Population, million	9	9.7	0.5
GDP, 10^9 €	289	403.5	2.3
Installed nuclear capacity	9 480 MW	10 080 MW	
Imported electricity %-of total			
Renewables % -of primary energy	39.8 %	47 – 48 %	
Carbon price, €/t CO_2	23	30	
Oil price ($US / barrel)	54.4	84	

5.1.4.2. Policies of concern for the BSL-SWE scenario

The BSL-SWE scenario took into account the Swedish policies related to electricity and heat production as decided and implemented in the national legislation in June 2008. This included the feed-in of renewable energy via the Swedish system of certificate for electricity production and CO_2 taxes inter alia. The use of renewable energy in Sweden was projected to be 48 %, which was almost in accordance with the Swedish obligations (49 %) as decided in the EU C&E package (Directive 2009/28/EC). The Swedish obligation to reduce CO_2eq emissions in the non-EU ETS sectors under the EU burden sharing agreement (part of the EU C&E package) was also met in the BSL-SWE scenario.

5.1.4.3. Economic growth and energy prices in the BSL-SWE scenario

In the BSL-SWE scenario, the national GDP was projected to increase by 2.25 %/year on average from 2005 to 2020. The projection did not consider the impact from the global financial crisis. In the BSL-SWE scenario, it was estimated that the price of oil should to $US 84 /barrel up until 2020 and 2030. The price of electricity was projected to increase with 23 % until 2030 because of the projected increase in fossil fuel price and the expected price of the CO_2eq emission permits (30 €/tonne CO_2eq). The price of electricity in the industry was projected to be 0.05 €/kWh by 2020 and 2030 (up from 0.03 €/kWh in 2005). The prices were higher for other industries and households. The price excluded distribution charges and taxes. For the domestic sector, the electricity price including distribution charges would be ~0.1 €/kWh. The price of district heating was projected to be 0.084 € / kWh for single houses by 2020, including value added tax (0.068 € / kWh in 2005). The Swedish nuclear rectors were estimated to have a 60 year's lifetime and no more reactors were to be shut down before 2030.

5.1.4.4. Original documentation for the BSL-SWE scenario

The BSL-SWE scenario was constructed from the projections from several governmental bodies (Sjöström & Östblom 2008; SEA 2009a; SEA 2009b; SRA 2009; SWEPA 2009). The BSL-SWE scenario as implemented in the GAINS model was based on the above mentioned sources, but with the following adjustments:

- The projection on energy use and cement and lime production for the Non-Metallic Minerals Industry (NMMI) in Sweden was taken from the International Energy Agency projections for Sweden (GAINS model scenario IEA 2008).
- Projections on fuel use activities in non-road mobile sources (NRMM) were taken from the latest reporting of the Swedish emission inventory program (SMED 2009).

5.1.4.5. A short description of the SNF-SWE scenario

The SNF-SWE scenario was based on the documentation supporting the SNF conference "Halva energin – hela välfärden", which was held in November 2008 (Ågren et al., 2008). The purpose of the conference and the supporting documentation was to show the potential for energy efficiency improvements in Sweden. The objective for the supporting documentation was to identify a pathway leading to a reduction of the final energy demand in Sweden (excluding aviation and shipping) from 1432 PJ in 2005 to ~720 PJ in 2030. The energy content of primary energy carriers in Sweden during 2004 (the base year for the scenario) was 2358 PJ, slightly higher than the year 2005 value given in the BSL-SWE scenario.

Table 10: Key parameters & assumptions for the SNF-SWE scenario

Key parameters & assumptions:	2005	2020	Annual growth rate, %/a
Population, million	9	9.7	0.5
GDP, 10^9 €	289	403.5	2.3
Installed nuclear capacity	9 480 MW	10 080 MW	
Imported electricity %-of total			
Renewables % -of primary	-	-	
Carbon price, €/t CO_2	23	25	
Oil price ($US / barrel)	-	-	

In the SNF-SWE scenario, the final demand for energy in Sweden was reduced from 1432 PJ in 2005 to 749 – 810 PJ in 2030 (dependent on the price for electricity). This reduction in final energy demand was reached by implementing existing energy efficiency measures; further development of new energy efficiency measures and by implementing specific policy instruments. A summary of the potential for final energy demand savings is shown in the table below:

Table 11: Potential for final energy demand savings in the SNF-SWE scenario

Potential savings per sector [PJ final energy]	Energy Efficiency measures	Policy instruments	Combined
Dwellings	216 – 234*	36 – 54	252 – 288
Industry	126 – 144	29 – 36	155 – 180
Transport	108 – 115	104	212 – 219
TOTAL	450 – 493	173 – 194	623 – 687

*The higher value is for the high estimate on electricity prices

Ågren et al. (2008) did not explicitly explore the impact on the Swedish energy system when implementing energy efficiency measures and policy instruments aimed at reducing the final energy demand. In our study the reduction in final energy demand is converted to a reduction in primary energy demand by using the GAINS database on abatement measures as well as our own calculations. The implementation of policy instruments was introduced as autonomous changes in the energy related activity data. This implied that some of the emission reductions were not associated with any specified technical costs.

5.1.4.6. Policies of concern for the SNF-SWE scenario

The policies implemented in the BSL-SWE scenario were also included in the SNF-SWE scenario. But in the SNF-SWE scenario there were more policy instruments introduced. As a first example, the EU ambition on increased energy efficiency by 2016 and 2020 was considered. This implied a 9 % improved efficiency, expressed as final energy, by 2016 and a 20 % increase in efficiency, expressed as primary energy, by 2020 compared to 2005 (EU 2008/2009). Another European policy instrument considered is the recently accepted ban on light bulbs in the EU. Other, more specific policy instruments included in Ågren et al. (2008) were:

- Improved education for maintenance personal (dwellings),
- Programs for improved energy efficiency in industry,
- Energy & climate advisors to corporations (industry),
- Research & Development for high efficiency engines,
- Improved legislation and regional planning,
- Modal shifts for heavy goods transports,
- Price setting of public transportation,
- Mobility management (transport).

As a final note to the scenario description, according to the SNF-SWE scenario, behaviour changes will reduce the energy consumption and create business opportunities and competitiveness.

5.1.4.7. Economic growth and energy prices in the SNF-SWE scenario

In Ågren et al. (2008), the macro economic growth and energy carrier prices were very similar to the SEA long term projection (2009a). The national GDP was projected to increase by 2.25 %/year on average from 2005 to 2030. The projection did not consider the impact from the global financial crisis. The SNF-SWE scenarios did not explicitly mention prices for oil, coal and gas. The electricity price was given in two price ranges that reflected the prices in the Nordic electricity market as well as the central European electricity markets. For the Nordic market, a spot market price of 0.05 €/kWh was assumed. This price is substantially lower than the price electricity price in SEA (2009a), even though SEA (2009a) did not present spot market prices. The spot price usually reflects the highest production cost for electricity and is usually representing the highest price for electricity.

In Ågren et al. (2008) the 0.05 €/kWh was considered as an increase in electricity price that motivated final demand adjustments due to high electricity prices. This situation could not be considered as motivated based on the electricity prices in SEA (2009a). So some of the energy demand savings presented in Ågren et al. (2008) remain to be solved.

For the European electricity market, a market spot price of 0.065 €/kWh was assumed, which reflects that electricity prices were considered to be higher in the central European region. The assumed price for a CO_2eq emission permit was set to 25 €/tonne. The electricity production from nuclear power plants was expected to increase slightly to 2030.

In this study, the electricity prices projected in SEA (2009a) were used when calculating emission reduction costs.

5.1.4.8. Original documentation for SNF-SWE

The supporting documentation for the SNF-SWE scenario was developed by Ågren et al. (2008). The SNF-SWE scenario involves implementation of energy efficiency with technical measures and policy instruments that will reduce the final energy use by half to 2030 while maintaining the welfare standard in Sweden. In the supporting documentation it was envisaged that the awareness of energy and climate related problems would increase in the future, and thereby the energy demand would decrease.

The projected national economic activities represented in the SNF-SWE scenario were stated to be the same as in the SWE-BSL scenario. In this study, the SNF-SWE scenario was based on the BSL-SWE scenario, but with the addition that the energy efficiency measures suggested in Ågren et al. (2008) were implemented by using the GAINS model database on energy efficiency measures (Sept. 2009 version). The policy instruments implemented in Ågren et al. (2008) had no corresponding data in the GAINS model database and were introduced as autonomous changes in the model by adjusting the assumptions on autonomous growth in final energy intensity for the specified energy needs. This would correspond to the increase in awareness towards energy and climate related issues.

5.1.5. The "What-if" scenario

During the course this study it became clear to the project group that the low CO_2 emission scenarios could increase the amount of electricity available for electricity export from the Nordic countries to central Europe. Such an export of "clean electricity" could be an effective way to reduce environmental impact in the Nordic countries. The topic of "clean electricity" has been a discussion topic over the last couple of years. This study provided us with a very good opportunity to explore the possibilities for a situation where the Nordic countries produce more electricity than what could be motivated by domestic demand. This surplus production would also have an impact on energy security in the European Union, which is a topic of concern in many countries and the EU.

In the "What-if" scenario the surplus electricity would be exported from the Nordic countries to Poland and Germany. It was then assumed that this electricity replaced some of the production of electricity from condensing coal power plants in these countries. The amount of surplus electricity generated and exported in the scenario was based on the surplus electricity produced in the national low emission scenarios. Poland and Germany were chosen instead of Russia because the electricity transfer grid from the Nordic countries is better developed towards these countries and because potential environmental benefits for the Nordic countries would larger due to the average atmospheric dispersion direction of air pollutants. In this scenario, the European electricity balance was kept consistent by adjusting the net Nordic export and Polish/German import so that the energy balance was kept identical to the GAINS model PRIMES 2009-draft scenario.

When studying the potential environmental of exporting Nordic "clean electricity', it was also of interest to study whether the existing and planned electricity transfer capacity from the Nordic countries would be sufficient to meet the demand for electricity export.

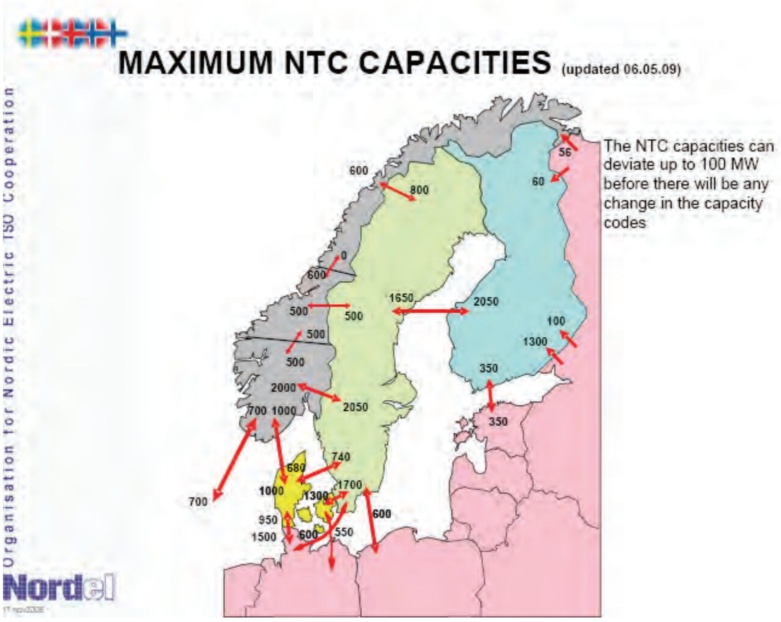

Figure 1: The 2005 electric Net Transfer Capacity in the Nordic region, source: Nordel

A reliable production of "clean electricity" within the Nordic countries, as well as the potential for export of the surplus production of "clean electricity" would need a continued co-operation within the Nordic countries. From this aspect the need for joined energy scenarios and common energy projections between the countries should be a high priority for the Nordic countries. In this study, the opportunity was given to make a joint study of national baselines as well as national low-emission scenarios. Large differences were seen in the assumptions underlying the scenarios, which suggest more attention could be paid towards joint energy strategies in the Nordic countries.

According to the current expansion plan of the transfer grid from the Nordic countries to central Europe, a maximum transfer capacity of 112 PJ of electricity would be possible. However, these 112 PJ of electricity would require a maximum capacity utilisation for all hours of the year (8760 hours per year). If actual export transfer demand would account for roughly 3000 hours per year (12 hours per day, 240 days per year) the actual transfer capacity should correspond to some 40 PJ of electricity from the Nordic countries to Poland and Germany.

Table 12: Potential electricity export when assuming full capacity utilization of the transfer grid from the Nordic countries

2015	Receiving country			
MWh max export capacity	Poland	Germany	The Netherlands	Estonia
Sweden	5 256 000	5 256 000		
Denmark		17 520 000		
Denmark		4 905 600		
Norway			6 132 000	
Finland				3 066 000
Total from the Nordic countries [MWh]		42 135 600		
Total from the Nordic to Poland and Germany [MWh]	32 937 600			
PJ	119	152		
Excluding 5% grid losses:	113	144		

According the expansion plans of the transfer grid to and from the Nordic countries to 2015, the maximum export capacity would correspond to 152 PJ if using the transfer capacity at full load during all hours of the year. This number includes all countries that are connected to the Nordic electricity grid. Potential maximum electricity export to Poland and Germany corresponds to 119 PJ.

Table 13: Potential electricity export when assuming 3000 hours of capacity utilization of the transfer grid from the Nordic countries

2015	Receiving country			
MWh max export capacity	Poland	Germany	The Netherlands	Estonia
Sweden	1 800 000	1 800 000		
Denmark		6 000 000		
Denmark		1 680 000		
Norway			2 100 000	
Finland				1 050 000
Total from the Nordic countries [MWh]		14 430 000		
Total from the Nordic to Poland and Germany [MWh]	11 280 000			
PJ	41	52		
Excluding 5% grid losses:	39	49		

If the potential electricity export in the “What-if” scenario would be higher than 40 PJ of electricity, then a discussion on extra transfer capacity would be motivated.

5.2. The PRIMES 2007 and PRIMES 2009 draft scenario

The PRIMES model is a pan-European Energy system model (NTUA 2008). The model allows for projections of energy needs on a European scale. The results are often used by the European Union for Impact Analysis of climate and air pollution policies suggested by the Commission. One of the major advantages of the model is that it keeps the energy balance consistent on a European scale, in contrast to the sum of the energy balances from the national member states. The results from the model can be used by the GAINS model to calculate emissions of greenhouse gases and air pollutants as well as environmental impacts.

The PRIMES 2007 scenario was used as the baseline emission scenario for the last version of the working documents supporting potential negotiations for a new National Emission Ceilings (NEC) directive produced by the EU Commission. The PRIMES 2009 draft scenario used draft energy projection received from the PRIMES model in August 2009. This was the first European emission scenario that took into account the impact of the global financial crisis. Agricultural activities included national data reported to EUROSTAT for the year 2005. Agricultural activity projections were based on trends estimated by the CAPRI model (September 2009). Assumptions about emission controls included full implementation of national legislation, relevant EU-wide directives as well as the ETS carbon trading system. A final version of this scenario, after including country comments, was delivered after the completion of this study (January 2010).

5.3. GAINS database description

The GAINS database and methodology has been presented in Amann et al., 2008a, Borken-Kleefeld et al., 2008, Höglund-Isaksson et al., 2008, Böttcher et al., 2008, Åström et al., 2009. The database contains information on costs associated with fuel shifts, technology improvements and efficiency improvements for several sectors. The transport-, industry-, household & services-, as well as power sector are all represented in this database. The GAINS model uses the database to optimise the lowest cost option to reach a certain ambition level on GHG emission reduction targets for a country or region. However, in this study, the CO_2 abatement measures were already specified. The implication of this determination of measures was that the optimisation routine in the GAINS model (run by IIASA) could not be used. Therefore, in this study the GAINS model database was used to calculate sector specific abatement costs associated with the low emission scenarios studied. The costs would therefore not necessarily illustrate a cost optimal solution.

6. Impacts of the low emission scenarios

In this chapter the results from this study are presented. The results show the differences between the Nordic BSL scenarios and the Nordic low emission scenarios. The potential impact from the "What-if" scenario is also presented. Since emission reductions in the Nordic countries affect other countries in Europe, these countries are also included in the results. The other countries (Poland and Germany, as well as all other countries in Europe) are summarised in the tables as "Other". When the tables present emissions, "Other" includes Poland and Germany. When the tables present environmental impacts, "Other" includes European countries outside of the Nordic countries. The results are presented in the following order: Impact on emissions, environmental impacts, and resulting abatement cost.

6.1. Emission changes in the Nordic countries

The following tables present the result on greenhouse gas (GHG incl. CO_2); CO_2; SO_2; NOx; and $PM_{2.5}$ emissions for the Nordic countries. Emissions for Germany and Poland in the "What-if" scenario are presented under the category "Other".

Table 14: Emission changes between the BSL scenarios and the low emission scenarios

Country / emission	Finland	Norway	Sweden	Denmark	Other*	Total Nordic	Unit
CO_2	-20	-5	-16	-10	-32	-65	MT CO_2-eq
Non-CO_2 GHG	-1	-0	-1	-0	-2	-1	MT CO_2-eq
SO_2	-16	1	-4	1	-23	-8	ktonne
NOx	-15	-40	-42	3	-22	-86	ktonne
PM2,5	-3	8	-4	7	-2	11	ktonne

*Other emissions are applicable in the "What-if" scenario. Germany and Poland are in the emission calculations included in the group "Other".

The table above shows emission reductions for all pollutants and greenhouse gases for Finland and Sweden. For Denmark and Norway, emissions of SO_2 and $PM_{2.5}$ increase as a consequence of the increase in bio fuel use in the low emission scenario studied.

Table 14: CO_2 and GHG emissions in the baseline and the low emission scenarios

GHG emissions	Finland	Norway	Sweden	Denmark	Other*	Unit
BSL tot GHG	78	61	73	64	1217	MT CO_2-eq
BSL CO_2	67	48	56	50	1054	MT CO_2-eq
Low em tot GHG	58	51	57	54	1183	MT CO_2-eq
Low em CO_2	48**	38	40	40	1022	MT CO_2-eq
% GHG reduction	25	17	23	16	3	%
% CO_2 reduction	29	21	29	20	3	%

* Emissions from "Other" countries are applicable in the "What-if" scenario. Germany and Poland are in the emission calculations included in the group "Other".

**The number also includes carbon neutral fuels in the traffic sector that are not included in GAINS model

The results in the table above show the relative impact on green house gas emissions of the low CO_2 emission scenarios in the Nordic countries. Again it should be clarified that the results are linked to the scenarios chosen for this study, while not necessarily representing an optimal solution for the countries. However, the results show that massive energy demand savings (as is the case in the Swedish low emission scenario) don't necessarily have a larger relative impact on GHG emissions than a combination of fuel shifts and energy demand savings. The reason for this difference is that the Swedish energy system already uses very little fossil fuels in the baseline scenario.

The reduction of non-CO_2 GHG varies between the Nordic countries following the low CO_2 emission scenarios. The GHG/CO_2 ratio is smallest for Finland and largest for Sweden.

In Table 16 the emission changes in percentage are presented to enable a comparison in terms of relative co-benefits or trade-offs between the low CO_2 emission scenarios and emissions of air pollutants shown in table 14.

Table 15: Emission reduction in percentage between the BSL scenario and the LE scenarios (- implies an increase in emissions)

% reduction	Finland	Norway	Sweden	Denmark
% SO_2	35	8	14	-5
% NOx	12	25	37	-3
% PM2,5	15	-15	13	-42
% CO_2 reduction	25	21	29	20

The results in Table 16 clearly show the impact of an energy system that keeps electricity production from "non-combustion sources", as in the case for Sweden. For Sweden, the CO_2 emissions would be reduced by 29 % while the NOx emissions would be reduced by 37 %. NOx is a pollutant mainly caused by the burning of fuels (both fossil and renewable).

Norway, with the increased used of renewable bio fuels would experience an increase in $PM_{2.5}$ emissions.

Country specific comments

Sweden

In absolute numbers, Sweden would reduce more emissions in comparison with the other Nordic countries when comparing the SNF-SWE scenario with the BSL-SWE scenario. This is a consequence of that the baseline emissions for Sweden in general are higher than for other countries in the baseline. In relative terms, Sweden would mainly reduce emissions of NOx, and smaller amount of $PM_{2.5}$ and SO_2. This difference in relative reduction is mainly caused by the project group's specification of the energy system in the SNF-SWE scenario. In this scenario, electricity production from combustion-based power is reduced more than non-combustion power, which results in relatively high NOx emission reductions. The relatively low reduction of SO_2 can mainly be explained by low sulphur content in the current Swedish energy system. In Sweden, the baseline emission level of SO_2 is quite low in 2020 and the largest emission source in 2020 will be shipping, a sector for which the SNF-SWE scenario does not include emission abatements. CO_2 emission reductions would contribute to almost the entire share of GHG emission reductions in the SNF-SWE scenario.

Finland

In Finland, the SO_2-reduction following the WWF-FIN scenario is driven by two factors: overall energy demand saving that cuts unabated sulphur emissions from small power plants and the domestic sector, and measures directed towards lesser use of medium distillates in the domestic sector. More efficient fuel use in the transport sector is the main contributor for reduced NOx emissions. Also, other fuel saving measures and introduction of "no-NOx" alternatives such as heat pumps and a massive increase of wind power will reduce the emissions of NOx.

In the WWF-FIN scenario, Finland would also invest in "GHG-neutral" fuels such as an increased use of wood chips. The amount of installed wind power would also be significant. From an energy demand savings perspective, Finland would be less ambitious than Sweden, but energy efficiency measures still contribute to almost half of the CO_2 emission reductions, due the carbon insensitivity of Finnish power generation. It should be noted that significant amount of energy demand savings based on CO_2 emission reductions in the WWF scenario are made outside the Finnish borders.

Norway

The total SO_2 emission was already very small in the BSL-NO scenario due the use of hydro power and natural gas as primary energy sources, which explains why the SO_2 emissions in the LUU-NO scenario are on the same level as in the BSL-NO scenario. "No-emission" hydro power produces almost 100% of all electricity in the country already in the BSL-NO scenario, and natural gas is the main source of the heat power.

In the case of the $PM_{2.5}$ emissions it must be emphasized that the scenario calculations were based on technical changes calibrated towards Norway's baseline emissions. This implies that small scale combustion emits more than the average stove in the Nordic countries. If increased use of bio fuels in the domestic sector would be based on e.g. pellet technologies, $PM_{2.5}$ emissions would not increase as drastic as they do in the LUU-NO scenario. As a continuation of this it must also be noted that the abatement costs were based on use of firewood instead of pellets. If pellets would have been used, the costs for reducing CO_2 emission in the LUU-NO scenario would have been higher.

Norway's LUU-NO scenario for the period 2020-2050 also included massive use of CCS, which was not taken into account in this study. One rationale for this is that the major impact of CCS use would be seen only after 2020.

Denmark

For Denmark, the emission levels of air pollutants increases by 2020 in the LE-DK scenario. In relative terms, the emissions of $PM_{2.5}$ increase more than increases of NOx and SO_2. This is largely an impact of the reliance of the introduction of bio fuels in the LE-DK scenario. As for most of the other Nordic countries, the highest reduction of the GHG emissions is CO_2 emission reductions.

Other countries: Poland and Germany versus the Nordic countries

In the "What-if" scenario, the use of sulphur intensive coal in condensing power plants in Poland and Germany would be phased out via an increased import of "clean electricity" from the Nordic countries. This was a condition specified in the scenario formulation by the project group, and should not be considered as a "natural" consequence of electricity export from the Nordic countries. The total CO_2 emissions from Poland and Germany would be reduced by ~1 % in the "What-if" scenario. And since fuels chosen to be phased out were the SO_2 intensive coal, SO_2 emissions were reduced quite much as well, 0.8 %. NOx and $PM_{2.5}$ are reduced to a smaller extent, which mainly reflects that SO_2 mostly origin from the power plant sector in these countries, while NOx and $PM_{2.5}$ also origin from many other sectors in society.

Final notes on emission results

The emission reductions of SO_2, NOx and $PM_{2.5}$ in the Nordic countries differ following the implementation of the national low CO_2 emission scenarios. Denmark would even increase their emissions of SO_2, NOx and $PM_{2.5}$. The basic reason for the differences in emission reductions is the difference in the energy systems of the studied countries. More carbon intensive counties benefit more from energy demand savings at a country level. Another point of view is that the emissions reductions for both the LE scenario and the BSL scenario are based on the total amount of the country emissions. As in the Kyoto protocol, it is important to point out that it would be a major difference in the results if the scenario where projected by emissions per person.

6.2. Acidification, eutrophication and health

Table 17 presents the environmental impact assessments following the low CO_2 emission scenarios as calculated with the GAINS model. The results show the impact on acidification, eutrophication and human health.

Table 16: Area and change in areas with deposition exceeding Critical Load for acidification (- implies improvement compared to baseline)

Country	Finland	Norway	Sweden	Denmark	Other*	Total Nordic	Unit
BSL total	3.7	15.4	24	1.3	112.2	44.4	1000 km^2
Low_em – BSL change	-0.4	-0.5	-0.5	-0.1	-0.3	-1.5	1000 km^2
WHATIF – BSL change	-0.5	-0.6	-0.6	-0.2	-1.3	-1.9	1000 km^2

* Other is in the case of environmental and health impact calculated from the "What-if" scenario, but on all regions outside the Nordic countries described in the GAINS model

There will be improvement in terms of reduced acidification in the Nordic countries if implementing the LE scenarios. And the impact on acidification will be even larger if the "clean electricity" were to be exported to Poland and Germany, as is done in the "What-if" scenario. For both the LE scenarios and the "What-if" scenario, there are environmental benefits for the countries outside of the Nordic countries.

The improvement potential for the Nordic eutrophication problem will differ more between the countries studied.

Table 17: Area and change in area with deposition exceeding Critical Load for eutrophication (- implies improvement compared to baseline)

Country	Finland	Norway	Sweden	Denmark	Other*	Total Nordic	Unit
BSL total	73.7	13.9	55.6	2.3	665.1	145.5	1000 km^2
Low_em – BSL change	-5.7	-0.7	-2.2	0	-0.6	-8.6	1000 km^2
WHATIF – BSL change	-6	-0.7	-2.4	0	-1.2	-9.1	1000 km^2

* Other is in the case of environmental and health impact calculated from the "What-if" scenario, but on all regions outside the Nordic countries described in the GAINS model

The situation is similar as for acidification in the Nordic countries and the rest of Europe, with Denmark being the exception. In Denmark, the eutrophication problem is so severe that much more emission reductions than the ones projected in the national low CO_2 emission scenarios are needed in order to reduce the impact on eutrophication significantly.

The GAINS model also calculates impacts on health following different emission scenarios. Long term exposure of high ambient concentrations of $PM_{2.5}$ is known to cause fatalities. The GAINS model measures this health impact in terms of million life years lost. This unit measures how the expected average lifetime of a population would be affected by varying levels of $PM_{2.5}$ concentrations in air.

Table 18: Number of life years lost due to long term exposure of $PM_{2.5}$ (- implies improvement compared to baseline)

Country	Finland	Norway	Sweden	Denmark	Other*	Total Nordic	Unit
BSL total	643	413	1250	1275	120597	3581	Thousand life years lost
Low_em – BSL change	-32	20	-38	35	-101	-15	Thousand life years lost
WHATIF – BSL change	-32	20	-41	30	-572	-23	Thousand life years lost

* Other is in the case of environmental and health impact calculated from the "What-if" scenario, but on all regions outside the Nordic countries described in the GAINS model

The health impact follows the impact on acidification. But in terms of health effects from long term exposure of $PM_{2.5}$, Norway and Denmark are the major exemptions, since the emissions and impact of $PM_{2.5}$ increase when implementing the LE-DK and LUU-NO scenario.

In the "what-if" scenario, due to emission reductions in Poland and Germany, the health improvements in the group "other" are widely dispersed geographically.

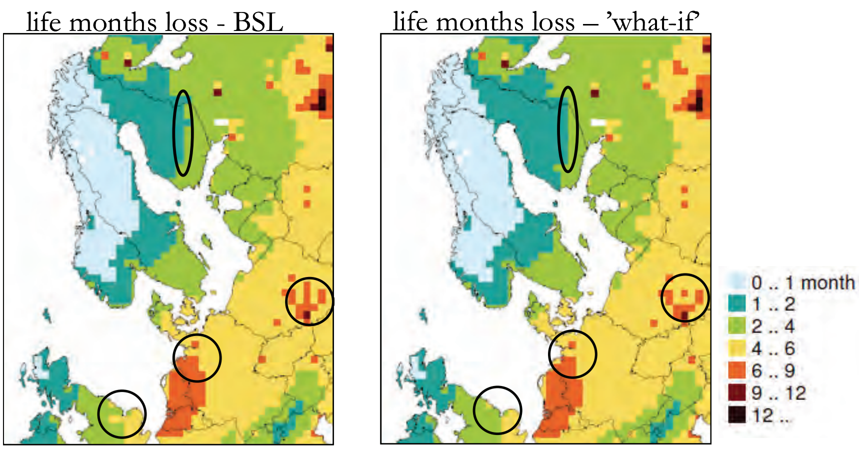

Figure 2: Geographical distribution of health improvements following the "what-if" scenario, [life month loss per capita]

The figure above shows potential for substantial health improvements in the United Kingdom, Germany, Poland, and Finland in the "what-if" scenario.

Furthermore, the GAINS model calculates health impacts from short term exposure of high concentrations of ozone. This impact is measured in the unit "premature fatalities".

Table 19: Number of premature fatalities caused by acute exposure to ozone (- implies improvement in comparison to baseline)

Country	Finland	Norway	Sweden	Denmark	Other*	Total Nordic	Unit
BSL total	47	82	163	153	18972	445	premature fatalities
Low_em – BSL change	-0.7	-0.9	-3.1	-1.6	-41	-6	premature fatalities
WHATIF – BSL change	-1	-1	-3	-2	-64	-7	Premature fatalities

* Other is in the case of environmental and health impact calculated from the "What-if" scenario, but on all regions outside the Nordic countries described in the GAINS model

The occurrence of premature fatalities from acute exposure to ozone is the only impact that shows a clear (but small) improvement in all countries.

6.3. Additional costs on top of the national baseline scenarios

A realisation of the national low CO_2 emission scenarios would be associated with implementation costs. These costs would be associated with the costs for using different fuels and technologies in order to reach energy demand savings or emission reductions. Up-front costs needed are in the text denoted "investments".

The costs presented in this chapter are:

- Annualised at a 4 % investment rate. Investment costs are distributed over the lifetime of the investment;
- Not including taxes, subsidies V.A.T. or other financial transfers within the society;
- Incremental costs. Incremental costs imply that only costs for the technology that cause reduced emissions are included in the cost calculations. For example, the cost estimate associated with refurbishment of buildings only includes the cost for insulation and other emission reducing (efficiency improving) measures, not the entire cost for refurbishing;
- Including costs savings in terms of reduced expenses for energy
- Given at a €$_{2005}$ value.

The total net costs presented in this report are including investments, fixed and variable operating costs, as well as savings on energy expenses. The tables presents costs associated with the purchase or investment of technologies needed (technology costs), cost associated with fuel use, as well as net incremental costs (environmental investment + energy costs). The costs are summarised as “costs on top of the baseline”. “Costs on top of the baseline” indicates that the costs estimate represents how much more expensive a low CO_2 emission scenario would be for the society compared to the baseline scenario. As was mentioned below, the costs do not include taxes. One implication of this is that the costs would not represent cost increases for individual consumers via increased taxes or other financial regulatory policy instruments.

The total net cost for all the Nordic countries:

The costs associated with an implementation of the national low CO_2 emission scenarios vary between countries as well as sectors. This variance is to a large extent a result of the emission abatement measures specified in the national low emission reports. It is also a result of how much the emissions are to be reduced in each sector.

The overall results show that for the Nordic countries as a group, the implementation of low CO_2 emission scenarios would result in cost savings for the countries. However, the power plants and industry sectors would experience increases in costs while the domestic and transport sectors would experience cost savings. For the power plants and industry, all countries except Sweden would experience cost increases. The emission reductions in the power plants and industry sector are driven by governmental interests, international policies and, of course, the incentives from the business organizations to develop new technology.

The largest savings in the domestic sector are to be found in Sweden and the smallest in Norway.

For the transport sector, most countries experience cost savings, while Sweden experience an increase in transport costs.

Table 20: The Nordic net incremental costs associated with the low emission scenarios

Incremental cost on top of the baseline scenarios						
Country / Sector	Denmark	Finland	Norway	Sweden	Total	
Domestic sector	-367	-334	-75	-1231 (-574)*	-2007 (-1350)*	million €/year
Power Plants and Industry sector	488	427	284	-911 – 0	288 – 1199	million €/year
Transport sector	-394	-167	-705	794	-472	million €/year
Total costs on top of the national baselines	-273	-74	-496	-1348 – 220	-2191 – -623	million €/year

* The number within brackets show the costs if not including behavioural changes into the cost calculations

In the table above the national cost estimates as costs on top of the baseline are summarised. As is seen from the scenario, the low emission scenarios would be less expensive than the baseline scenarios, mainly due to reduced expenses on energy. The costs for the Swedish domestic sector (household

& services) varies dependent on whether cost savings due to behavioural and structural changes are included or not. The GAINS model do not estimate costs for behavioural or structural changes, but these are described in the SNF SWE scenario. The total economic savings due to behavioural and structural changes in the SNF SWE scenario amounts to ~657 million euro per year. The costs for the Swedish power and industry sectors range from -911 to 0 million €/year, the cost range representing the range in production capacity that would be installed for the Swedish power production in the Swedish SNF-SWE scenario. The cost range reflects which assumptions are made for how power production capacity would be adjusted to reduced electricity and heat demand from other sectors, as discussed in an earlier section of this report. A cost of 0 for the power sector, indicates that the electricity and heat production is kept constant despite the demand reduction in the SNF-SWE scenario. This would in turn imply even larger potential for electricity export than in the "what-if" scenario.

The following section presents the results per country.

Denmark

The cost estimation for Denmark has been performed by using the GAINS methodology and database as presented earlier in the report. The input fuel prices and production prices for heat and electricity has to a large extend been based on Danish estimates. The comparable national cost estimates performed in the DEA reports (DEA 2009) were based on detailed data for the electricity and heat production system and macroeconomic modelling, and might be expected to give estimates better adapted to Danish circumstances. However, even for the Danish estimates, uncertainty ranges are large, and the GAINS approach has been used here for comparison between the countries.

Table 21: Total technical and energy use and costs for all sectors between the LE-DK and BSL-DK scenario,

Costs (million €/year)	Change in energy demand (PJ)	Change in total technical abatement cost	Change in energy cost	Net cost
Energy efficiency improvements	18.72 PJ	268.82	-418.38	-149.57
Fuel switches	71.30 PJ	537.63	-661.24	-123.61
Cost on top of the national baseline				**-273.18**

Overall, if the Danish low CO_2 emission scenario would be realised, the results indicate that this would result in annualised net savings corresponding to some ~270 million €/year by 2020. The largest savings are a result of fuel switches. As is seen in table 21, the Danish power plant and industry sectors would experience cost increases, while the domestic and transport sector would experience cost reductions.

Finland

For Finland the GAINS database on CO_2 emission abatement costs was complemented with cost estimates from the WWF (2007) report. The costs estimates from the WWF report were calculated with the same methodology as used in the GAINS model. A 4 % interest rate and 20 years economic lifetime was used for the new technologies in the economic analysis based on the WWF report. The cost of primary energy was difficult to assess because of the different sources used, but the project group used the costs as suggested by the GAINS database. However, benefits in terms of energy demand savings have been calculated using average consumption or energy system analysis. In the WWF report, a large part of the environmental benefits would be associated with measures taken outside of the Finnish borders. These "foreign" costs were disregarded in this report.

Table 22: Total technical and energy cost between the WWF-FIN and the BSL-FIN scenario in domestic sector in Finland

Costs (million €/year)	Change in energy demand (PJ)	Change in total technical abatement cost	Change in energy cost	Net cost
Energy efficiency improvements	43 PJ	219	-336	-117
Fuel switches	68 PJ	440	-667	- 227
Cost on top of the national baseline	111 PJ	659	-1003	-334

*includes also technical renovation of oil boilers

Both energy demand savings and fuel switches are economically beneficial in the Finnish domestic sector. The main contributing parts of the energy demand savings are more energy efficient appliances and lighting and a large increase in the use of heat pumps (which to this date constitute a minor portion of the heat supply in Finland).

Table 23: Total technical and energy cost between the WWF-FIN and the BSL-FIN scenario in power and industry sector in Finland

Costs (million €/year)	Change in energy demand (PJ)	Change in total technical abatement cost	Change in energy cost	Net cost
Energy efficiency improvements	76 PJ	333	-378	-45
Fuel switches, industry	19 PJ	0	-7*	-7
Fuel switches, power	80 PJ	1235	-756*	479
Costs on top of the baseline:	175 PJ	1568	-1141	427

*cost difference of fuels and production cost

The WWF-FIN scenario energy demand saving measures implemented in the industrial sector have negative costs, mainly due to the expensive wind power being used less in the industry. It must be remembered that the price for wind power varies a lot. During the recently experienced economic crisis, materials such as steel were significantly more expensive than in a more stable economic situation. This affects the costs for wind power. The costs for wind power installations varied some 100 % in the literature reviewed. In this study, the higher price range for wind power in the GAINS database was used.

Table 24: Total technical and energy cost between the WWF-FIN and the BSL-FIN scenario in the transport sector, Finland

Costs (million €/year)	Change in energy demand (PJ)	Net cost
Fuel switches	16 PJ	16
Energy efficiency improvements	7 PJ	-183
Costs on top of the baseline:	-	-167

The economic benefits (cost savings) of the WWF-FIN scenario changes in the transport sector depend a lot on the assumed gasoline and diesel prices in 2020. However, even with lower fuel prices, energy demand savings would imply cost savings. For "CO_2-neutral" bio fuels, fuel costs varied even more. The total cost for emission reduction depends on the supply of inexpensive raw materials for bio fuel production.

Norway

Table 25: Changes in technical and energy costs between the LUU-NO and the BSL-NO scenario in the domestic sector

Costs (million €/year)	Change in energy demand (PJ)	Change in total technical abatement cost	Change in energy cost	Net cost
Energy efficiency improvements	22 PJ	155	- 210	-55
Fuel switches	11 PJ	118	- 137	-19
Costs on top of the baseline	-	273	- 347	-75

*cost difference of fuels and production cost

Both energy demand savings and fuel switches imply net cost savings in the domestic sector for Norway when following the LUU-NO scenario. More effective insulation and switch from fossil fuels to bio fuels are the main contributors to domestic sector CO_2 emission reduction in Norway.

Table 26: Changes in technical and energy costs between the LUU-NO and the BSL-NO scenario in the power and industry sectors in Norway

Costs (million €/year)	Change in energy demand (PJ)	Change in total technical abatement cost	Change in energy cost	Net cost
Energy efficiency improvements	33 PJ	98	-308	-210
Fuel switches	42 PJ	826	-332	494
Costs on top of the baseline	-	924	-640	284

*this number also includes exported wind power

Both for energy demand savings and fuel switches in the LUU-NO scenario the result leads to increased electricity export from Norway. The changes in energy costs are partly calculated by using condensing coal electricity prices in Poland and Germany in accordance with the GAINS database.

Table 27: Changes in technical and energy cost between the LUU-NO and the BSL-NO scenario in the transport sector in Norway

Costs (million €/year)	Change in energy demand (PJ)	Change in total technical abatement cost	Change in energy cost	Net cost
Costs on top of the baseline	27 PJ	137	- 837	-705

Sweden

The costs of electricity, district heating and primary energy:

The cost estimations made for the domestic, transport and power plant sectors in Sweden were made by using data from the GAINS database. The fuel price projections were taken from the GAINS database. When possible, the fuel price estimates given by the GAINS model were compared to the national fuel price projections from SEA (2009a,b). The GAINS model database allows for calculation of production costs for electricity and heat. When comparing the electricity production costs as calculated with the GAINS database with the electricity costs projected by SEA (2009a) it was clear that the costs were similar when calculated as production costs. However, SEA (2009a) also presented costs for transmission of electricity. When calculating cost estimates for Sweden, the electricity and heat costs projected by SEA (2009) were used in this study. The electricity costs for private consumers were estimated to around ~28 million €/PJ by 2020. In the SNF (2008) report, the spot price was assumed to be 14 million €/PJ, which was not introduced in our costs estimations. This price difference could not be explained by the project group, and would affect the cost calculation results for Sweden. The projected costs for district heat was ~17 million €/PJ (SEA 2009a).

Costs for emission reduction in the Household and Service sectors

Following a very strong implementation of energy efficiency measures in households and the service sectors, the domestic sector in the SNF-SWE scenario has a higher technical cost than the in the BSL-SWE scenario. The net cost in the SNF-SWE scenario is 1 231 million € less than in the BSL-SWE scenario following the large reduction in energy demand.

Table 28: Total technical and energy cost between the SNF-SWE and the BSL-SWE scenario in Sweden

Costs (million €/year)	Energy demand (PJ)	Total technical abatement cost	Energy cost	Net cost
BSL-SWE scenario	472	2 246	10 086	13 052
SNF-SWE scenario	349	3 542*	8 279 (8937)**	11 821 (12478)**
Costs on top of the baseline:	-	1 296	-2 527 (-1870)**	-1 231 (-574)**

*total technical costs underestimated due to large scale implementation of energy efficiency and behavioural changes
**numbers within brackets show energy costs if not including the effect of changes in energy demand behaviour

The energy demand savings in Sweden are very large, which is mainly a result of the large scale introduction of energy efficiency measures and changes in energy demand behaviour in these sectors. The costs for changes in energy demand behaviour was not possible to quantify in this study, but these changes are likely to be associated with high taxes on electricity in order to induce energy demand savings. The energy cost savings associated with changes in energy demand behaviour were however possible to estimate. It was estimated that the changes in energy demand behaviour would imply energy savings corresponding to some ~657 million euro per year. Financial incentives like energy taxes are not visible in the GAINS model. In a sensitivity analysis, it was indicated that if the net costs for the households and service sectors were to be zero (cost neutral), the final consumer electricity price would have to increase some 25 % in the SNF-SWE scenario compared to the BSL-SWE scenario, all else being equal.

In the SNF-SWE scenario, many of the energy efficiency measures available in the GAINS database were implemented to a larger extent than was estimated as feasible in Åström et al. (2010). This implies that the total technical abatement costs calculated in this study are represent a low estimate since larger technical efforts would be needed than the ones described in the GAINS database.

Costs for emission reduction in the road transport sector

The SNF-SWE scenario specifies large energy efficiency improvements in the road transport sectors for Sweden. This is to a large extent performed via the introduction of plug-in hybrid vehicles in the light duty car and heavy duty vehicle segments.

Table 29: Scenario costs for road transports in the transport sector in Sweden

Costs (Million €/year)	Total technical abatement cost	Total energy cost	Net costs
BSL-SWE scenario	580	10 425	11 005
SNF-SWE scenario	6 632	5 167	11 799
Costs on top of the baseline	6 052	-5 258	794

In the SNF report, the introduction of plug in-hybrid will make a large-scaled difference in the emissions level. The fuel prices are important for the end results of the calculations. In these cost calculations, an electricity price of ~28 M€/PJ was used.

Costs for emission reduction in the power sector

The total net cost in the Power plant sector is calculated using the GAINS database electricity and heat production cost data. This data specifies the production costs per sector and fuels. The difference in production costs depends on the difference in energy balance between the SNF-SWE and the BSL-SWE scenario. The costs per fuel inputs in the existing power and district heat plant sub-sector of other boilers type includes operation and maintenance (O&M), as well as fuel and fuel gas cleaning costs. The costs per fuel inputs in the new power and district heat plants sub-sector includes investments, O&M as well as fuel and fuel gas cleaning.

Table 30: Total energy cost in the power sector in Sweden

Costs (million €/year)	Change in fuel use (PJ)	Net cost
Costs on top of the baseline:	-148 PJ – 0 PJ	-910 – 0

The cost savings in Swedish power plants were associated with the project groups' interpretation of the SNF (2008) report. The project group has in the analysis assumed that electricity and heat production is reduced in accordance with decreased electricity and heat demand in other sectors. It must be mentioned that the power sector and industry in Sweden could just as well keep the electricity and heat production constant and export the surplus electricity to other countries outside the Nordic countries. If so, the not cost would equal zero for the power sector.

The fuel prices used in the cost calculations were based on the GAINS database fuel cost projections as they were in September 2009.

7. Discussion of the results

The GAINS database offers a unique collection of cost factors for a wide selection of emission abatement measures, including scenario specific fuel prices and (energy) production costs. The GAINS model technical measures and their costs are updated continuously to the database. Despite this, it still lacks some of the measures used in this study. This means that complete cost estimates can be calculated only by using both national data and GAINS data. In some cases, the applicability of certain abatement measures available in GAINS did not cover all needed savings or applied measures exceeded applicability rate in GAINS. In these cases it was necessary to increase the extent to which the GAINS measures are applied far beyond what should be considered as practically feasible. Alternatively put, the GAINS model database is more conservative in its assumptions on realistic abatement measures available until 2020 than the national low CO_2 scenario reports have been.

Furthermore, many of the measures suggested in the national reports include "soft measures", such as behavioural changes, which are yet to be quantified. It must be stressed that many of the energy demand savings suggested are not empirically verified as of yet. This has an impact on the credibility of the national low emission scenarios, as well as on the total emission abatement costs estimates in this study.

In this study, the marginal electricity production is assumed to be produced by condensing coal power plants in all the Nordic countries, except for Norway. This will cause a minor error in the emission and cost estimates, since the economic benefits (cost savings) gained from energy demand savings are, in the case of electricity savings, depending on the production costs for marginal electricity. It is also unclear, without having a more energy system oriented analysis available for forecasts, how the electricity market and energy system would react to large scale system changes. In at least two of the national low emission scenarios studied, there are large scale system changes present. The energy system is moving towards higher energy efficiency, and towards emitting less CO_2 and using carbon neutral fuels. This could lead to a situation, for example, where Norway's natural gas reserves would last longer or where the country could increase the export of natural gas.

A significant increase of carbon neutral technologies with a wide variety of production capacity, such as wind power, must be taken into account when energy security is concerned. Would there be a possibility to stabilize the trade of hydro power in the Nordic countries, thereby securing a back-up capacity for the increase in wind power production in the Nordic countries? This could be a cheap and sustainable way to stabilize low CO_2 energy demand peaks and intermittent supply in northern Europe. The cost of keeping hydro power partly as a reservoir for balancing the capacity of Nordic electricity production from wind power and other renewable fuels is unclear. The flexibility of low CO_2 energy systems will need stabilising mechanisms that are not currently included in the Nordic energy market (Nordpool).

Of interest from a Nordic perspective is also the potential for a joint Nordic approach to emission reduction. Could there be a neglected potential for further emission reductions if a "portfolio of low CO_2 measures" would be applied to all Nordic countries?

The "what-if" scenario showed clear potentials for environmental benefits for the Nordic countries following an export of surplus electricity to Europe. A condition for this benefit is that the exported electricity is balanced with reduced production of the most polluting type of electricity production in the countries importing electricity. This would require special agreements between regions/countries, and would therefore be subject to political negotiations rather than market mechanisms. Furthermore, the electricity transfer capacity in the grid between central Europe and the Nordic countries would probably need a review

In this study, emissions, environmental impacts, and abatement costs were calculated for the scenarios studied. However, saved costs for society from avoided environmental damages and achieved health benefits were not calculated. These types of calculations are only available when performing cost benefit analysis for energy system changes. It should therefore be mentioned that there are many more benefits for society than the co-benefits from joint air pollution and GHG emission reductions studied in this report. This was however, outside the scope of this study.

Finally, the development of the national baseline energy projections is important for the long term planning in the Nordic countries. The energy, industry and domestic sectors are sectors subjected to long term investment lifetimes. In this study we have been able to compare the national baseline energy projections and the assumptions made when performing them. It has been clear that the macro economic assumptions and fuel prices supporting the national baseline projections differ between the Nordic countries. The impact of these differences is unclear, but there is a risk that the countries, by using different assumptions in the baseline projections, imply uncertainties in the other countries' energy projections. A more harmonised approach to projections would enable less uncertainty in the national projections.

8. Conclusions

This study shows that low energy pathways and low CO_2 emission strategies lead to cost effective reductions of greenhouse gases in most sectors. Also, in almost every case this also leads to a reduction in the emissions of air pollutants. This study also shows that there is no common pathway to how these emission reductions are achieved on a country level. There is no indication that any of these strategies take into account another country's strategy. The same seems to be valid for the energy baseline projections.

A comparison of the technical measures selected in the low emission scenarios in the different countries would be beneficial for further analysis. It seems likely that the energy demand saving and emission reducing measures are both a reflection of national specific circumstances as well as a reflection of national "political preferences" at the time of the writing of the reports. As always when studying national energy baselines and the impact on CO_2 emissions, it is unclear why the most cost efficient measures are not already implemented. One conclusion is that some of the most cost effective measures may be associated with hidden costs or other structural constraints. Another reason could be that most of the energy saving measures are associated with relatively high investment costs, which makes them less attractive at higher interest rates than assumed in this study.

Energy demand savings and structural changes are cost effective ways to reach tightening targets of air pollution emissions. The measures presented in this study are targeted towards CO_2 reduction. These low CO_2 strategies will in most cases also lead to reduced emissions of air pollutants in significant amounts and thereby contribute to improving the state of the nature and quality of the air. The exception is increased use of bio fuels, which risks increasing emissions of particulate matter and thereby increasing adverse health impacts associated with air pollution.

The existence of the Nordic electricity market makes it important to coordinate national assumptions on macro-economics and expected electricity and natural gas trade. It is also important to analyze electricity trade outside Nordpool and environmental impacts of this trade.

In the Nordic countries, a Nordic trade of electricity from hydro power could be a cheap and sustainable way to stabilize low CO_2 energy production in northern Europe. The hydro power is also an ideal partner to wind power, since the production capacity in wind power varies more than in the conventional electricity production. Further introduction of electricity saving measures increase the availability of the stabilizing hydro power capacity.

All in all, the results from this study show that the technical costs of avoided GHG emissions and air pollutants in a Nordic energy system remain negative to the society due to reduced expenses on energy. Also, environmental benefits achieved due to energy demand savings and structural changes would make it easier for the Nordic countries to reach the air pollution targets as well as post-Kyoto targets. Some of the measures would also make it easier to reach European Air Quality targets. All strategies do not imply co-benefits between air pollution and climate. In this study it has been shown that increased use of bio fuels risk imposing a trade-off between air pollution and GHG emission abatement.

These co-benefits and the risk for achieving trade-offs between air quality and climate change should be more emphasised in the development of future Nordic low CO_2 emission strategies.

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Appendix A – Scenario details

Finland

Summary of abatement measures in the WWF-FIN scenario

Table A1: Actions of energy efficiency and policy instruments in the domestic and service sector

Energy efficiency - current technology	Primary energy (PJ) Electricity (TWh)	Sector	Energy carriers
Heat savings	5	Average heat (Power and Domestic)	Average
Electrical appliances, pumps, lightning (several measures):	27 (3)	Power	Coal
Low-energy house:	11 (1)	Domestic	

Table A2: Actions of fuel switches in the domestic sector

Fuel switches- current technology	Primary energy (PJ) (Electricity, TWh)	GAINS Sector	Switch
Oil boiler renovation and supplementary RES	23 (0)	Domestic	Oil to REN
Heat pumps (switch from electricity heating):	45 (5)	Power	Coal to REN
Solar heating:	2 (0)	Domestic	Oil to REN
Pellets	18 (0)	Domestic	Average heating to BIO

Table A3: Actions of energy efficiency and policy instruments in the industry sector

Energy efficiency – current technology (PJ)	Primary energy (Nordic, PJ)	GAINS sector	Switch from
Recovery of heat and cold through improved internal processes and improver	13	Power	Oil, peat, coal
Dimensioning and optimization of pumps, motors and peripheral systems: Electricity	63 (7)	Power	Coal

Table A4: Actions of fuel switches in the power sector

Fuel switches- current technology (PJ)	Primary energy (PJ), (electricity, TWh)	Sector	Switch from
Wind	22 (6)	Power	Coal
Small-scale hydro	7 (2)	Power	Coal
Biogas	8 (1)	Power	Average
REC	14 (2)	Power	Average
Wood chips	42 (6)	Power	Peat
Agrobiomass	16 (1)	Power	Peat

Table A5: Actions of energy efficiency and fuel switches in the transport sector

Fuel switches- current technology (PJ)	Primary energy (Nordic, PJ)	Sector	Energy carrier
Biofuels	16	Traffic	GSL
More effective combustion engine	7	Traffic	GSL

Table A6: Actions of energy efficiency improvements

Energy demand savings (PJ): 2005-2020	Energy efficiency (GAINS format)
Domestic	47
Electricity (as primary fuel)	27
Heat (as primary energy from Power Sector)	9
Primary fuels (from domestic sector)	11
Industry	72
Electricity (as primary fuel)	63
Heat (as primary energy from Power Sector)	9
Power plant	-18
Heat	-18
Heat	-18
Transport	141,26
Electricity	-23,76
Oil (HF, MD and GSL)	164,44
Gas	0,58
Total reduction	327

Summary of emissions in Finland

Table A7: Emission changes from the BSL-FIN scenario

Sector (in GAINS	CO2 [Mt]	CH4 [kt]	N2O [kt]	NOx [kt]	SO2 [kt]	PM2.5 [kt]
Domestic	-2,1	-0,92	0,07	-0,48	-0,16	-1,09
Power and industrial sectors (fuel)	-15,7	-0,46	-3,78	-15,61	-15,5	- 0,79
Traffic	-1,22-1,1=2,32	-0,05	0	-5,38	0	0,55
Others	0	0	0	0	0	-0,02
Total as CO2-ekv, , SO2, PM2.5 and NOx						

Norway

Description of the BSL-NO scenario

Table A8: Energy parameters in the scenarios for Norway

2020 projections	2005 values	LUU-NO scenario 2020	PRIMES 2020 (2007 scenario)	PRIMES 2020 (2009 scenario)
Total energy consumption	1255	1176	1255	1387
Electricity consumption	520	487	515	523
Imported electricity (as PJ)	27	-28	28	-12
Imported electricity described as primary condensing coal (PJ)	66	-68	67	29
Electricity transport losses for (as PJ)	4	4	4	3

Summary of abatement measures in the LUU-NO scenario

Table A9: Actions of energy efficiency and policy instruments in the domestic and service sector

Energy efficiency - current technology	Primary energy (PJ) Electricity (TWh)	Sector	Energy carriers
Low-energy house:	29 (4,6)	Average heat (Power and Domestic)	Average

Table A10: Actions of fuel switches in the domestic sector

Fuel switches- current technology	Primary energy (PJ) (Electricity, TWh)	GAINS sector	Switch
Supplementary RES	11 (0)	Domestic	Oil to REN

Table A11: Actions of energy efficiency and policy instruments in the industry sector

Energy efficiency – current technology (PJ)	Primary energy (PJ), (Electricity, TWh)	GAINS sector	Energy carriers
Dimensioning and optimization of pumps, motors and peripheral systems	13 (4,2)	Power	hydro, export
Process changes in aluminium industry	6 (1,7)	Power	hydro, export
Fuel switches in metal industry	3	Power	Coke to wood coke

Table A12: Actions of fuel switches in the power sector

Fuel switches- current technology (PJ)	Primary energy (Nordic, PJ)	Sector	Switch
Wind and small hydro	24,48 (6,8)	Power	GAS to wind, export
Biofuels	17,8 (0)	Power	GAS to bio, export
Switch from heat only to CHP	9,6 (0,88)	Power	GAS, export
CCS use in new power plants and industrial processes	not estimated		

Table A13: Actions of energy efficiency and fuel switches in the transport sector

Fuel switches- current technology (PJ)	Primary energy (PJ)	Sector	Energy carriers
More effective diesel engines in vessels	14	Traffic	MD
More effective combustion engines and road infrastucture	41	Traffic	MD, GSL

Table A14: Other measures

Fuel switches- current technology (PJ)	Primary energy (PJ), (electricity TWh)	Sector	Energy carriers
Improvements in the national grid	3,6 (1)	Power	Hydro,export

Summary of emissions in Norway

Table A15: Emission changes from the BSL-NO scenario

Sector (in GAINS	CO2 [Mt]	CH4 [kt]	N2O [kt]	NOx [kt]	SO2 [kt]	PM2.5 [kt]
Domestic	-0,94	+0,66	+0,03	-0,33	-0,03	9,34
Power and industrial sectors (fuel)	-3,1	+0,04	+0,06	-0,85	-0,68	-0,02
Traffic	-5,97	-0,93	0	-38,48	0	-1,04
Others		*			0	
Total as CO2-ekv, , SO2, PM2.5 and NOx						

Sweden

Detailed descriptions of the GAINS data conversion method

The industry sector

Some adjustments of energy balance from the SEA (2009a) reporting have been done within the industry sector to achieve comparable values in the GAINS format.

- Petroleum coke is moved from coal balance to balance oil,
- Blast furnace gas is moved from coal balance to balance gas,
- Peat is moved from biofuels balance to balance coal,
- "City" gas is included in the natural gas balance.
- The energy use input in the non-metallic minerals industry (other than combustion) is distributed according to the PRIMES 2009 scenario split.
- The PRIMES 2009 scenario split between renewable and non-renewable waste fuel is used for the sectors that burn waste fuel. The exception is the chemical industry that is assumed to only use non-renewable waste fuels.

Heat production from the industrial processes produced by industrial boilers is calculated by adding the district heating per sub-sector plus the sum of the primary fuels input with a conversion efficiency of 0.85. Heat in the other combustion sub-sector is considered as district heating.

In the SNF-SWE scenario, energy efficiency improvements in the industry sector in the SNF report is split into three sectors in the GAINS format: the industry sector, the power plant sector and the fuel production and conversion other than in power plant sector. The split between the sectors is according to the PRIMES 2009 scenario split. The amount of primary fuels in the PP sector is correlated to the heat and electricity production to meet the demand of electricity and heat consumption in the other sectors.

The transport sector

Some adjustments of energy balance from the SEA long term projection (BSL-SWE scenario) have been done within the transport sector to achieve comparable values in the GAINS format.

- All diesel oil and liquefied petroleum gas is moved from domestic sector to transport sector.
- "City" gas is included in the natural gas balance, within the transport sector.
- International shipping is excluded and international aviation is included in the GAINS format.

The number of electricity vehicles in the scenarios only corresponded to PHEV-vehicles, and was calculated by assuming an electricity consumption of 0.24 kWh/km and an annual vehicle usage of 15 000 km/vehicle according the SEA projection. In the BSL-SWE scenario, the use of 1.84 PJ gasoline was projected to be replaced by 0.61 PJ electricity by 2020. By 2030 in the BSL-SWE scenario, the project group made the assumption that the electric consumption in the transport sector will be doubled compared to 2020. In comparisons, the electricity use in the SNF report was five times more by 2030, compared to the SEA projection. In the SNF prognosis 75% of all personal vehicles and 20% of the heavy duty vehicles will be PHEV-vehicles by 2030. The diesel oil and gasoline use for vehicles in the road transport sub-sector is reduced with the corresponding amount of electricity use for the PHEV-vehicles.

The residential and service sector:

Some adjustments of energy balance from the SEA projection have been done within the domestic sector to achieve comparable values in the GAINS format.

- All diesel oil and liquefied petroleum gas is moved from domestic sector to transport sector.
- City gas is included in the natural gas balance, within the domestic sector.
- Ethanol and FAME is moved from the bio fuel balance to balance oil.
- Biogas is moved from bio fuels balance to balance gas.

In-house consumption in power production was given from the Swedish Energy Agency for 2005. The project group assumed that the growth of the in-house consumption should be corresponding to the growth in the power production to 2020 and 2030. The sub-sector and fuel specific split used in the GAINS model scenarios for Sweden (PRIMES 2009 scenario) was used to split the fuel input into the three sub-sectors: “residential”, “commercial” and “other” within the BSL-SWE scenario. In the SNF-SWE scenario the sub-sector and fuel specific share from the BSL-SWE scenario was used. Heat consumption in the domestic sector was the sum of district heating use in the sector plus the primary fuel use, according to the SEA (2009a) projection.

Specification of the energy balance in the Swedish scenarios

Table A16: Energy demand savings with Nordic electricity prices, SNF-SWE scenario

Energy demand savings (PJ): 2005-2020	Energy efficiency improvements by 2020 (GAINS format)
Domestic	126,31
Electricity	43,20
Heat	72
Primary fuels	11,12
Industry	59,06
Electricity	25,90
Heat	1,63
Heat and policy instruments	31,53
Power plant	**54,89**
Electricity	52,16
Heat	-73,44
Heat and policy instruments	76,18
Conversion (losses)	**8,11**
Electricity	7,75
Heat	-0,19
Heat and policy instruments	0,54
Transport	141,26
Electricity	-23,76
Oil (HF, MD and GSL)	164,44
Gas	0,58
Total reduction	327

Table A17: Energy efficiency improvements by 2020, SNF-SWE scenario

Electricity savings (PJ): 2005-2020	Energy efficiency (GAINS format)
Electricity	52,16
Wind power:	-62,64*
Bio-fuel district heating	0,00
Water and nuclear power	0,00

*increased use of wind power

Summary of abatement measures in the SNF-SWE scenario

The industry and power plant sectors

Table A18: Energy use in the industry sector, GAINS format

Energy use in the industry sector per scenario and year (PJ)	BSL-SWE 2005	BSL-SWE 2020	SNF-SWE 2020
Industry sector			
Coal, coke: HC1 and DC	56,70	61,56	46,50
Bio-fuels, peat etc: OS1, OS2 and BC1	143,23	153,60	127,18
Oil: HF, MD, GSL and LPG	62,81	56,15	52,03
GAS:	21,24	23,40	26,72
District heating	15,8	16,6	14,21
Electricity	201,2	209,5	175,34
Total energy use	**558**	**580**	**521**
Power plant			
Coal, coke: HC1 and DC	12,43	14,29	7,89
Bio-fuels, peat etc: OS1, OS2 and BC1	203,04	268,97	148,57
Oil: HF, MD, GSL and LPG	19,54	8,19	4,52
GAS:	23,64	38,91	21,49
District heating	-190,10	-208,21	-116,66
Electricity	-570,53	-635,27	-622,69
Wind power	3,60	25,20	66,24
Hydro power	262,80	248,40	262,80
Nuclear power	774	806,40	774
Total energy use	**538,42**	**566,88**	**546,17**
Conversion			
Coal, coke: HC1 and DC	8,80	8,80	8,11
Bio-fuels, peat etc: OS1, OS2 and BC1	5,14	5,44	5,01
Oil: HF, MD, GSL and LPG	49,88	56,00	51,58
GAS:	18,00	18,00	16,58
District heating	21,33	23,36	21,52
Electricity	72,29	70,07	64,54
Total energy use	**175,44**	**181,67**	**167,33**
Total	**1271,86**	**1328,55**	**1234,50**

Table A19: Actions of energy efficiency and policy instruments in the industry and power plants, SNF-SWE scenario

Energy efficiency: (PJ) Nordic price	**SNF-SWE-scenario: 2005-2030**		**SNF-SWE-scenario: 2005-2020 in the GAINS format**			
Total reduction per sector and scenario	**Total reduction**	**Pay-off time**	**TOT**	**IND**	**CON**	**PP**
Total reduction:	154.8		122.1	59.06	8.11	54.9
Energy efficiency current technology	115.2					
Electricity:	**43.20**		**85.80**	**25.90**	**7.75**	**52.16**
Electricity and heat: Lighting, ventilation and compressed air	21.60	<5				
Electricity: Pumps, motors and peripheral systems	10.80	<5				
Electricity: Process improvement in production processes.	10.80	<5				
Heat	**72.00**		**-72.00**	**1.63**	**-0.19**	**- 73.44**
Heat (oil): Improved internal processes and improve climate scale:	72.00	<5				
Primary fuels	**39.60**		**108.3**	**31.53**	**0.54**	**76.18**
Energy Efficiency Technology	10.80					
Process improvements of technology and process-development	10.80	<5				
Policy instruments	28.80					
The Program for electricity efficiency for energy intensive industries (PFE).	7.20					
New PFE programming period between 2009-2014	3.60					
Program outside the PPE-industries: height energy tax, deduction of tax or contribution, and tax credits for energy efficient investments	3.60					
Municipal energy and climate advice to companies for energy usage and energy-saving.	14.40					

The transport sector

Table A20: Energy efficiencies in the transport sector, SNF-SWE scenario

Energy efficiency due to technical improvements and fuel substitutions	
Technical improvements	Vehicles going on both electricity and combustion engines are projected to be introduced at the market by 2010, but will not become conventional vehicles before 2020.
Policy measure implementation	The use of bio-fuels is increasing as a result of the adoption of continued exemption from fuel tax. By 2020, the bio-fuels share are projected to be around 11% of the total energy use, which meet the EU target of 10% bio-fuels by 2020.
Transport substitution	Domestic aviation is projected to increase in view of the fact that the train is replacing the domestic travels. The assessment in the prognosis is that bio-fuels will not have a significant share in the aviation fuel. Rail-traffic is supposed to increase during the whole period, depending on the increased freight and personal traffic.
Fuel substitution	If electricity are replaced with gasoline, than en increase of 0,6 PJ electricity correspond to 1,8 PJ gasoline. The shipping sector is expected to use change from heavy oil to more use of light oil.

Table A21: Energy use in the transport sector, GAINS format

Energy use in the industry sector per scenario and year (PJ)	BSL-SWE 2005	BSL-SWE 2020	SNF-SWE 2020
Oil: HF, MD, GSL and LPG	373,68	416,48	209,24
GAS:	1,44	6,48	0,86
Electricity	10,08	13,68	33,84
Total	**385,20**	**436,64**	**243,94**

Table A22: Actions of energy efficiency and policy instruments in the transport sector, SNF-SWE scenario

Energy efficiency: (PJ) Nordic price	SNF-SWE-scenario: 2005-2030	SNF-SWE-scenario: 2005-2020
Total reduction per sector and scenario	**Total reduction**	**GAINS format**
Total reduction:	212,40	141,26
Oil and gas	252	165,02
Electricity	-39,60	-23,76
Energy efficiency current technology	**25,20**	
Tire pressure and tire quality: Oil	7,20	
Eco-driving: Oil	10,80	
Paving: Oil	7,20	
Energy Efficiency Technology	**82,80**	
Hybrid electric:	-32,40	
Electricity	115,20	
Oil		
Policy instruments	**104,40**	
Effective combustion engine: Restrictions on EU-level is proposed: Limit CO_2 emissions for new cars: 130gCO2/km by 2012, and 95 gCO2/km by 2020: Oil	39,60	
Enhanced plan legislation and binding regional planning: Oil	28,80	
Infrastructure and public transport: Half the long-distance	-7,20	
transport of freight can go from road to rail transport.	28,80	
Electricity		
Oil		
Tax: co-ordination and subversive	7,20	
Mobility management:	7,20	
mobile information		

The domestic sector:

Table A23: Energy efficiencies in the domestic sector, SNF-SWE scenario

Energy efficiency due to technical improvements and fuel substitutions	
Technical improvements	District heating replace some of the electric heating in dwellings, since the low price of district heating compared to other energy uses. Electric appliances are replaced with new appliances that are more energy efficient, which lower the energy consumption in households. The EU directive "Eco-design" entered into force in May 2008 that makes an effect on the energy consumption.
Fuel substitution	Conversion from electric heating to heat pumps. Heat pumps in dwellings reduce the electricity use for heating. The use of oil decreases in favor for heat pumps and district heating. Bio-fuels uses are projected to increase with 14% and seem to be competitive compared to other use of heating.

Table A24: Energy use in the domestic sector,

Energy use in the industry sector per scenario and year (PJ)	BSL-SWE 2005	BSL-SWE 2020	SNF-SWE 2020
Bio-fuels, peat etc: OS1, OS2 and BC1	48.60	56.16	55.52
Oil: HF, MD, GSL and LPG	39.60	11.16	11.16
GAS:	7.92	10.80	9.45
District heating	152.93	168.29	80.93
Electricity	260.28	258.84	217.08
Total	413.21	5050.25	383.01

Table A25: Actions of energy efficiency and policy instruments in the domestic sector, SNF-SWE scenario

Energy efficiency: (PJ) Nordic price	SNF-SWE-scenario: 2005-2030		SNF-SWE-scenario: 2005-2020
Total reduction per sector and scenario	**Total reduction**	**Pay-off time**	**GAINS format**
Total reduction:	252		126,31
Electricity	75,60		43,20
Heat	140,40		72,00
Primary fuels	36,00		11,12
Energy efficiency current technology	**198**		
Climate scale: heat	57,6	~10	
Ventilation, pumps, fans:	25,2	~5	
Electricity	82,8		
Heat			
Lighting: Low-energy lamps etc: Electricity	18	<5	
Electrical appliances: Electricity	14,4		
Energy Efficiency Technology	**18**		
Low-energy house: Electricity, heat, fuel	7,2	>10	
Lighting, LEDs: Electricity	10,8	<5	
Policy instruments	**36**		
Integrate information into the education system: Sustainable approach to the younger generation	36		