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Assessment of intermediary GAINS emission reduction scenarios for Denmark aiming at the upcoming 2020 National Emission Ceilings EU directive

NERI Technical Report no. 746 2009

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Abstract:	The upcoming NEC-2020 EU directive sets up emission ceilings for NO_x, SO_2, NH_3, NMVOC and PM in order to meet the environmental exposure targets of the Thematic Strategy. This report contains an assessment of intermediary emission reduction scenarios for Denmark, computed by the GAINS model 2007, which serves as the basis for the pending negotiations in EU. The assessment is brought up to date by including a brief evaluation of the new reduction scenarios published in 2008, founding the European Commission NEC-2020 directive proposal.

Keywords:	National Emission Ceilings, NEC directive, GAINS, IIASA, European Commission, Thematic Strategy, emissions, NO_X, SO_2, NH_3, NMVOC, particulate matter, reduction scenarios, optimization.
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Preface

This report is prepared on the background of the ongoing negotiations in the European Union (EU) on the European Commission's (EC) proposal on a revised National Emission Ceiling (NEC) directive for the year 2020.

The present NEC directive is targeting 2010 and includes emission ceilings for the EU member states regarding the pollutants sulphur dioxide (SO_2), nitrogen oxides (NO_X), non-methane volatile compounds (NMVOC) and ammonia (NH_3). The upcoming NEC directive establishes new ceilings for 2020 and includes airborne particulate matter (PM).

This report presents, analyses and discusses the proposal for emission ceilings for Denmark computed by the International Institute for Applied Systems Analysis (IIASA) by their optimization model Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS).

The National Environmental Research Institute, Aarhus University (NERI) has carried out the work. The project has been financed by the Danish Environmental Protection Agency (EPA) and NERI.

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Summary

This report presents, analyses and discusses the proposal for emission ceilings for Denmark computed by the International Institute for Applied Systems Analysis (IIASA) by their optimization model Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS), as part of the ongoing negotiations on a revised national emission ceiling (NEC) directive aiming for the year 2020.

In a process running from the Gothenburg Protocol on Long-range Transboundary Air Pollution (LRTAP), via the Clean Air for Europe (CAFE) programme resulting in the Thematic Strategy (TS), IIASA has - in six reports (2006-2008) - provided the base for the EU proposal on a revised NEC directive, setting emission targets for 2020. The proposal is based upon various reduction scenarios established as result of consultations with stake holders and quantified by the GAINS optimisation model. Common for the scenarios is the demand meeting the objectives of the TS, regarding compounds effecting environment and human health (sulphur dioxide (SO_2), nitrogen oxides (NO_X), non-methane volatile compounds (NMVOC), ammonia (NH_3) and particulate matters (PM)).

Generally, the process computing a scenario is - first of all - to calculate the emissions levels in 2020 under the current legislation conditions, implying no new legislation adopted. Using results of the European Monitoring and Evaluation Programme's (EMEP) atmospheric transport model, GAINS calculates deposition or concentration of specific compounds and compares then to critical levels to establish critical loads. Thus environmental impact is assessed, e.g. exceedance of critical loads for acidification. In order to meet the environmental targets of the Thematic Strategy on Air Pollution (TSAP) reductions of emissions in several countries are needed. The optimization module of GAINS provides cost-effective solutions to reach the TSAP objectives for selected countries. As the assumption on energy demand and other activities is fixed for every single scenario, the only way to reduce is by implementing more efficient reduction technologies on emitting sources (e.g. de-NO_X equipment cleaning power plant flue gas) and changing production or operation methodologies (e.g. shifting from solvent based to water based products or methodologies). The marginal cost curves, which are included in the GAINS model, and which are determinant for the priority of reduction measures at the lowest marginal cost, follow the same principle for all scenarios. The environmental objectives determine the required reductions of emissions beyond current legislation. These reductions can be achieved by moving along the cost curve selecting the reduction options one by one - the most cost-efficient option first - and adding up their reduction potentials until the objectives are met.

This report focuses on analysing two specific scenarios computed by the GAINS model. They are run in parallel and were published by IIASA in the reports NEC-4 (IIASA, 2007a) and NEC-5 (IIASA, 2007b) in 2007. These two reports were the most recent when this project was commenced. Afterwards, IIASA has computed a new group of scenarios,

published in their NEC-6 report (IAASA, 2008f) which is the direct base for the EU proposal on a revised NEC directive. The main results from this latest scenario session are included in the present report and compared to the more in-depth analysed scenarios. The analyses of the NEC-4 and NEC-5 scenarios are quite easily compared to the NEC-6 scenarios as the differences between the scenarios, generally speaking, are the energy demand levels and the energy composition assumed for the year 2020, while the emission generating mechanisms are the same.

The analyses show fine agreement between the Baseline scenario of the GAINS model, based upon Danish reported activity data, and the latest emission projection from the National Environmental Research Institute, Aarhus University (NERI) from 2008, when adjusted for the use of two different energy projections from the DEA from 2005 and 2006, respectively. However, major differences occur for few activities and sectors. This applies for, among others, the cement industry and the gas and oil extraction industry. The possible reasons are the differences in classification of sources in the Danish inventory system and in the GAINS model, along with choice of emission factors not matching Danish conditions and also lack of detailed knowledge on specific Danish conditions.

The computed reduction scenarios propose implementation of reduction measures in various sectors suggesting specific types of reduction options. In general, these suggestions seem feasible. However, for a few sectors and pollutants the suggestions may be difficult to implement. This applies for e.g. the industrial sector where implementation of selective catalytic reduction (SCR) equipment may cause problems; the reason being that the daily operation and maintenance demands skilled and dedicated labour, a demand that may be too expensive to meet for small industries. However, technological development may simplify the operation of the equipment.

The table below compares the latest baseline emission projections from NERI (2006) with the two current legislation projections by the GAINS model. The projections by NERI and GAINS-NAT (NAT = national reported) are based on similar energy data from DEA (2005) while GAINS-COH (COH = coherent) is based on energy data from the common European model PRIMES. PRIMES is a modelling system that simulates a market equilibrium solution for energy supply and demand in the EU member states. The two former projections are quite similar in their totals when excluding NO_X emissions, which are partly caused by the interpretation of energy data reported from Denmark - to be elaborated in Chapter 4.

Baseline emission projections from NERI and the GAINS model, 2020.

ktonnes	NO_X	SO_2	NH_3	NMVOC	$PM_{2.5}$
NERI (2006)	115	21	55	74	16
GAINS-NAT-BL	126	21	53	71	15
GAINS-COH-BL	104	19	53	62	14

The next table below shows the GAINS model's suggested for emission reductions in order to meet the TS targets. Denmark has not conducted a similar kind of computation.

Emission reductions from the GAINS model, 2020.

Ktonnes	NO_X	SO_2	NH_3	NMVOC	$PM_{2.5}$
GAINS-NAT-TS	89	15	48	62	12
GAINS-COH-TS	87	16	50	59	13

For obvious reasons the outcome of the two reduction scenarios are quite similar since both aim at meeting the same targets for environmental and health exposure maximums as formulated in the EU Thematic Strategy. Differences are caused by a different distribution of energy data among the European regions in the model.

Compared to the NERI baseline projection, especially NO_X and SO_2 decrease towards 2020, which may be unrealistic. Energy related targets, among others formulated in the EU Climate and Energy Package, leads indirectly to NO_X and SO_2 reductions following CO_2 reduction efforts. However, increased use of biomass may cause problems when rinsing SO_2 and NO_X in the power and heating plants, since desulphurisation and de-NO_X technologies works more efficiently with emissions from uniform fuels like coal, oil or gas. The varying composition of biomass (waste, straw, wood etc.) may lead to management problems efficiently rinsing the emissions.

Regarding PM and NMVOC emissions, increased combustion of biomass - especially in the sparse controlled household sector (stoves, boilers, fireplaces) - may lead to increasing emissions in the future.

The reduction scenarios claim substantial NO_X and SO_2 reductions. Since the power and heating plants are already equipped with advanced de-NO_X and sulphurous flue gas rinsing technologies, the major reductions have to take place in the industrial sector. The industry structure in Denmark has few big and many small emitters and thus it may be difficult to achieve the reductions due to a lack of expert knowledge managing the rinsing technologies. However, manageable and automatic rinsing equipment for non-experts may be developed during the next ten years to 2020, paced by policy measures.

Livestock are the most important source to NH_3 emissions in Denmark. Suggested reductions are expected to be achievable with the present stock of animals. However, the potential is little since the Danish farming sector is already very advanced in curbing NH_3.

The underlying study to this report is, as mentioned, conducted pending the negotiation forming the final NEC-2020 directive. In the summer 2008, a new reduction scenario analysis, NEC-6 (IIASA, 2008f) was published, based on a new common European energy projection from the PRIMES model incorporating the effects of the EU Climate and Energy Package (EC, 2008). This scenario analysis is the basis for the negotiation proposal from the European Commission on emission ceilings for 2020 (unpublished).

The table beneath compares the new reduction scenario (GAINS EU proposal) with the two other mentioned reductions scenarios (GAINS-NAT-TS and GAINS-COH-TS) and with the Danish basic emissions projection (NERI, 2006).

Emission reductions of the GAINS model including the new EU proposal scenario - compare with the NERI baseline emission projection.

Unit: ktonnes	NO_X	SO_2	NH_3	NMVOC	$PM_{2.5}$
GAINS EU proposal	88	16	52	73	17
GAINS-NAT-TS	89	15	48	62	12
GAINS-COH-TS	87	16	50	59	13
NERI (2006)	115	21	55	74	16

The new GAINS reduction scenario does not change the levels much compared to the former GAINS scenarios regarding NO_X, SO_2 and NH_3, while the levels for NMVOC and PM has been lifted - now at level with the NERI baseline projections.

A new reduction scenario from the GAINS model is expected in 2010. The new scenario will to be based on new national reporting on activity data (energy, agriculture, transport etc.). This is in contrast to the NEC-6 scenario based on common European data on emission generating activities (PRIMES, CAPRI, etc.).

Sammenfatning

I denne rapport formidles, analyseres og diskuteres de forslag til emissionslofter for 2020 som the International Institute for Applied Systems Analysis (IIASA) via deres GAINS-model har beregnet for Danmark, i forbindelse med de igangværende forhandlinger om et revideret NEC-direktiv gældende for 2020.

I en proces, løbende fra Göteborgprotokollen om grænseoverskridende luftforurening, via CAFE-programmet (Clean Air for Europe) der mundede ud EU's temastrategi, har IIASA i seks rapporter (2006-2008) udarbejdet grundlaget for EU-kommissionens udspil til revidering af det oprindelige NEC-direktiv, der satte emissionslofter for 2010. Det reviderede NEC-direktiv vil således rette sig frem mod år 2020. Udspillet er baseret på forskellige reduktionsscenarier som er dannet på baggrund af konsultationer med interessenter og kvantificeret via GAINS-optimeringsmodellen. Fælles for scenarierne er, at de skal opfylde EU's Temastrategis grænseværdier for miljøpåvirkninger fra forsurende, eutrofierende og helbredstruende stoffer (SO_2 (svovldioxid), NO_X (kvælstofilter), NMVOC (andre volatile organiske forbindelse end metan), NH_3 (ammoniak) og partikler i luften (PM)).

I store træk er processen omkring en scenarieberegning først og fremmest at bestemme, hvad emissionerne vil blive i 2020 under tilsvarende forhold som i dag - udtrykt i et baseline-scenarie. En sådan situation kaldes *business-as-usual* eller *current legislation*. Ved at anvende resultaterne fra den atmosfæriske transportmodel udviklet af European Monitoring and Evaluation Programme (EMEP), beregner GAINS spredningen af de specifikke forurenende stoffer i hvert enkelt område af Europa og sætter dem i forhold til hvad området maksimalt kan bære for at der ikke opstår uønskede miljøpåvirkninger. Dette kan for eksempel gælde den kritiske mængde for forsuring forårsaget af SO_2. For at overholde miljømålsætningerne i EU's temastrategi, er det i flere lande nødvendigt med reduktion af miljø- og helbredstruende luftemissioner. Optimeringsmodulet i GAINS beregner de mest omkostningseffektive måder at reducere på for de enkelte lande, så de kan leve op til Temastrategiens målsætninger. Da antagelserne om energiforbruget og andre aktiviteter i samfundet ligger fast i det givne scenarie, kan man kun reducere ved at implementere mere effektive rensningsteknologier på de forurenende enheder - f.eks. de-NO_X-anlæg på kraftværkers røg - eller ved at ændre produktionsmåder - f.eks. ved at gå fra anvendelse af opløsningsmiddelbaserede produkter til vandbaserede. GAINS-modellen rangordner reduktionstiltag efter deres marginalomkostning i omkostningskurver. Kurverne er bestemmende for hvilke tiltag modellen prioriterer først for at reducere emissionerne til det ønskede niveau. Der vælges således flere og dyrere tiltag jo større reduktionsbehovet er i et givent scenarie.

Denne rapport koncentrerer sig om at analysere to specifikke scenarier beregnet af GAINS-modellen. De er publiceret af IIASA parallelt i rapporterne NEC-4 og NEC-5, og var ved projektets igangsættelse de nyeste. Sidenhen har IIASA beregnet en ny gruppe scenarier publiceret i NEC-6-rapporten, som direkte ligger til grund for det af EU-

Kommissionen fremsatte forslag til direktiv. Hovedresultaterne fra NEC-6-scenarie-runden er inkluderet i denne rapport og sammenlignes med resultaterne fra de to dybdeanalyserede scenarier. Principperne fra analyserne af NEC-4 og NEC-5-scenarierne lader sig let overføre til det nye NEC-6-scenarie, idet forskellene imellem scenarierne i grove træk er, hvilket energiforbrugsniveau og hvilken energisammensætning man antager for 2020, mens de emissionsgenererende mekanismer er de samme.

Analysen viser at der er en rimelig god overensstemmelse imellem GAINS-modellens baseline-scenarie, baseret på dansk indberettede data, og DMU's (v/ Aarhus Universitet) seneste samlede emissionsfremskrivninger fra 2008, når der tages hensyn til, at de baserer sig på forskellige danske energifremskrivninger fra Energistyrelsen udført i hhv. 2005 og 2006. Omkring enkelte aktiviteter og sektorer tegner der sig dog nogen uoverensstemmelse. Dette gælder mht. cementproduktion og olie- og gasudvinding i Nordsøen. Årsagerne til sådanne forskelle kan være forskelle imellem GAINS og Danmarks kategoriseringssystem for emissionskilder, valg af emissionsfaktorer i GAINS der ikke matcher danske forhold, samt manglende detailviden om danske forhold.

De udregnede reduktionsscenarier, opstiller forslag til reduktionstiltag i forskellige sektorer, med forslag til specifikke reduktionsmetoder. I det store hele er disse forslag realistiske at implementere, ligesom potentialet for deres reduktionseffekt synes rimelige. Dog kan implementeringen af SCR (Selective Catalytic Reduction) i industrisektoren være problematisk, fordi den daglige drift af denne avancerede de-NO_x-teknologi kræver arbejde og ekspertise, som små og mellemstore virksomheder ikke nødvendigvis har kapacitet til.

Tabellen herunder sammenligner DMU's seneste fremskrivning af emissioner for 2020 (NERI, 2006) med GAINS-modellens to basisfremskrivninger. DMU's fremskrivning og GAINS-NAT er baseret på omtrent samme data fra Energistyrelsen 2005, mens GAINS-COH er baseret på en europæisk energifremskrivning fra PRIMES-modellen. For de to førstnævnte fremskrivninger ses en rimelig overensstemmelse, bortset fra NO_X-emissionerne som bl.a. skyldes fejlfortolkning af energidata leveret fra Danmark.

Basis-emissionsprojektioner, 2020, fra DMU (NERI, 2006) og GAINS-modellen.

ktonnes	NO_X	SO_2	NH_3	NMVOC	$PM_{2.5}$
NERI (2006)	115	21	55	74	16
GAINS-NAT-BL	126	21	53	71	15
GAINS-COH-BL	104	19	53	62	14

Tabellen herunder viser GAINS-modellens forslag til emissionsreduktioner for at imødekomme Temastrategiens målsætninger. Fra dansk side er der ikke lavet en tilsvarende beregning.

GAINS-modellens emissionsreduktioner for 2020.

Ktonnes	NO_X	SO_2	NH_3	NMVOC	$PM_{2.5}$
GAINS-NAT-TS	89	15	48	62	12
GAINS-COH-TS	87	16	50	59	13

Emissionsniveauerne er temmelig ens, idet begge scenarier sigter mod samme målsætning for miljø og sundhedspåvirkning udstukket af Temastrategien. Forskellene skal søges i forskellig relativ fordeling af energidata imellem de europæiske regioner som modellen opererer med.

Sammenlignet med DMU's basisfremskrivning for NO_X og SO_2, skal Danmark især reducere udledningerne af NO_X og SO_2 frem til 2020. Det vurderes umiddelbart ikke, at SO_2-reduktionerne vil volde problemer, mens det kan være sværere mht. NO_X. Energimæssige målsætninger udstukket over de seneste år, bl.a. udmøntet i EU's Klima- og Energipakke, medfører at der reduceres NO_X og SO_2 som indirekte gevinster af CO_2-reduktioner, selv om mekanismerne ikke er entydige. Et stigende forbrug af biomasse kan skabe problemer med røggasrensning i kraftvarmeværker, idet rensningsteknologierne kører bedst på entydige brændsler som kul, olie og gas; hvorimod biomassens varierende sammensætning (affald, træ, halm, etc.) kan skabe problemer med tilsodning o.a. Mht. partikelemissioner (PM) og NMVOC-emissioner vil disse øges ved en øget forbrænding af biomasse, især den ukontrollerede forbrænding i private hjem (brændeovne, biomassefyr, pejse). Dette forhold kan gøre forventningerne til fremtidens udslip af disse stoffer usikker.

Der tilstræbes en kraftig reduktion af SO_2 frem til 2020. Da kraftvarmeværker allerede har avancerede røggasrensningssystemer, vil de største reduktioner skulle finde sted i industrien. Imidlertid kan reduktionerne af både NO_X og SO_2 være vanskelige at opnå i den danske industristruktur med mange små virksomheder, hvor der kan mangle ekspertise til den daglige drift af katalysatorer og røggasrensning. Med passende politisk virkemidler kan det dog forventes, at der kan udvikles mere automatiserede teknologiske løsninger frem mod 2020.

Ud fra det nuværende antal husdyr, som er den vigtigste faktor for NH_3 udledning i Danmark, vurderes det muligt at nedbringe emissionerne som foreslået. Imidlertid er reduktionspotentialet meget lille idet Danmark allerede er meget avanceret i sin begrænsning af NH_3-emissioner.

Studiet bag denne rapport er som nævnt sket under en fortløbende proces frem mod en endelig opdatering af NEC-2010-direktivet til 2020-målsætninger, som ikke er nået endnu. I sommeren 2008 blev der publiceret et nyt reduktionsscenario NEC-6 (IIASA, 2008f), baseret på en ny fælleseuropæisk energifremskrivning fra PRIMES-modellen. Dette scenarie inkorporerer effekten af Klima- og Energipakken (EC, 2008), samt dannede grundlag for EU-Kommissionens forslag til emissionslofter for 2020.

Tabellen herunder sammenligner de ny reduktionsforslag (GAINS EU proposal) med de to andre ovenfor beskrevne reduktionsscenarier (GAINS-NAT og GAINS-COH), samt tal fra DMU's basisfremskrivning (NERI, 2006).

GAINS-modellens emissionsreduktioner for 2020 inklusiv NEC-6, samt DMU's basis fremskrivning (NERI, 2006).

Unit: ktonnes	NO_X	SO_2	NH_3	NMVOC	$PM_{2.5}$
GAINS EU proposal	88	16	52	73	17
GAINS-NAT-TS	89	15	48	62	12
GAINS-COH-TS	87	16	50	59	13
NERI (2006)	115	21	55	74	16

Som tabellen viser, er der ikke ændret meget ved niveauerne for NO_X, SO_2 og NH_3, mens niveauerne for NMVOC og PM er hævet til niveau med DMU's basisfremskrivninger. Dette betyder ingenlunde, at Danmark ikke vil skulle reducere NMVOC og PM, idet et øget forbrug af biomasse i husholdningssektoren vil føre til øgede emissioner her.

Primo 2010 forventes der at komme et nyt scenarie baseret på nyindberettede aktivitetsdata (energi, landbrug, transport etc.) fra nationale myndigheder, som, i en vis grad, vil være sammenlignelig med det nye NEC-6 scenario baseret på den fælleseuropæiske energimodellering PRIMES.

1 Introduction

1.1 Scope of the report

This report aims at providing background analysis related to the ongoing negotiations in EU that intent to establish an updated NEC directive for 2020 and onwards.

The existing NEC directive for 2010 (EC, 2001) sets emission ceilings for the pollutants NO_X, SO_2, NH_3 and NMVOC. Indirectly PM is also curbed to some extend since NO_X and SO_2 are precursors to forming fine particles. However, PM shall be included explicitly in the updated NEC-2020 directive.

The focus of the report is to analyse the results of the GAINS model on emission ceilings for Denmark, which is published in the NEC-4 (IIASA, 2007a) and NEC-5 (IIASA, 2007b) reports in 2007, and compare them and their underlying assumptions to the specific Danish emission projections and the Danish reduction potentials.

The GAINS model is operated by the International Institute for Applied Systems Analysis (IIASA) located in Austria, and is the leading model in the field of analysing and modelling long-range transboundary air pollutions.

Suggestions to emission reductions and related costs are listed in various tables in the report. Besides the description of the cost calculation methodology of the GAINS model in Chapter 3, there has been no attempt assessing the costs in details, except from basic calculations of the unit cost of reducing emissions in the various sectors.

The assessments in this report serve as the foundation for assessing the official proposal of the European Commission (EC) on emission ceilings as of 2020. This proposal is based on a new set of GAINS emission reduction scenarios published in July 2008 in the NEC-6 report (IIASA, 2008f). The main figures of these scenarios are included in the overview tables in this report and briefly discussed in the final chapter.

1.1.1 Chapters walk through

The main part of the report is focussed on analysing GAINS model outcome from the NEC-4 and NEC-5 sessions, targeting the so-called Thematic Strategy (TS) reduction scenario, which is a forerunner to the July 2008 published reduction scenario underlying the EU proposal for NEC-2020 emission limits.

Chapter 2 describes the emissions scenarios developed and run by the GAINS model and presents the main findings relevant to the assessment.

Chapter 3 introduces the reduction cost calculation methodology used to find the optimal emission reduction solutions of the GAINS model.

Chapter 4 to 8 brings detailed assessment on the emission reductions suggested by GAINS. Each relevant sector/activity combination, e.g. power and heating plants running on natural gas are assessed. The assessments focus on the feasibility of the suggested emission reduction potentials and list the associated costs along with calculations of implied unit reduction costs.

Chapter 9 analyses the underlying energy projection data, which is one of the main drivers of the GAINS model. The outcome of GAINS is very sensitive to these energy data, because energy use is a main cause for pollution, directly and indirectly. Energy data to be assessed stem either from Danish national reporting or from the common European PRIMES model.

Chapter 10 briefly treats the EU proposal of June 2008 on emission ceilings for 2020, based on a new GAINS scenario session from IIASA.

Finally, Chapter 10 concludes.

1.2 NEC-2020 process

The EU NEC directive was adopted in 2001, aiming at limiting national and transnational emissions of acidifying and eutrophying pollutants and ozone precursors in the years to follow. As interim target the directive sets emission ceilings for the four pollutants NO_X, SO_2, NMVOC and NH_3 as by 2010. Emission scenarios computed by the RAINS model (IIASA, 2008a) form the background analysis leading to the ceilings.

In 2001, the CAFE programme was initiated with the aim of reviewing current air quality policies and assessing progress towards the long-term objectives of the 6th Environment Action Programme. This led to the EU adaptation of the TS on air quality in 2005. As part of the CAFE programme, a current legislation scenario was developed with the aim of showing the expected effects of current air quality policies on emissions up until 2020 (IIASA, 2008b).

As a consequence of the TS, a new series of emission scenarios were developed by the RAINS model - now GAINS - because of the inclusion of greenhouse gasses into the model.

This led to the publication of a series of NEC reports 1 – 5 (IIASA, 2008c). In the NEC-5 report two reduction scenarios were published. The first scenario, National Scenario, was based on national reporting on activity projections up until 2020 from the EU member states. The other scenario, Coherent Scenario, was based on common European activity models such as e.g. PRIMES and another model called Common Agricultural Policy Regional Impact Analysis (CAPRI).

Both reports took into account current legislation and current policy, especially regarding the upcoming but not adapted EU Climate and Energy Package. In other words, in the energy projections that drives the

GAINS model, the effect of the tighter CO_2 emission levels and higher share of renewable energy was taken into account. These CO_2 emissions directly and indirectly affect the emissions levels of the NEC pollutants.

These two scenarios are the basis for the assessments in Chapter 4 to 8.

In July 2008, new scenarios and a NEC-6-report for 2020 based on the 2008 EU Climate and Energy Package (IIASA, 2008f) was published, founding the EU proposal for emission ceilings as by 2020. The emission ceilings proposed by the EC is to be negotiated among the member states and eventually adopted in 2009 or later. As mentioned, main emission outcome of the new scenario is included in the overview tables of this report, in order to bring other figures into perspective. The subject is moreover assessed briefly in Chapter 10.

1.3 The GAINS model

The GAINS model is an integrated assessment model, which represents a further development of the well established RAINS model. The model now includes the greenhouse gasses: CO_2, N_2O, CH_4, HFC, PFC, SF_6 additional to the 'traditional' transboundary air pollutants NO_X, SO_2, NH_3, NMVOC and PM; although the latter are not directly relevant for the NEC.

The main objective of the RAINS model is to establish emission reduction strategies and to combine information on economic and energy development, emission control potentials and costs, atmospheric dispersion characteristics and environmental sensitivities towards air pollution. The model addresses threats to human health posed by fine particulates and ground-level ozone as well as risk of ecosystems damage from acidification, excess nitrogen deposition (eutrophication) and exposure to elevated ambient levels of ozone (Amman et al., 2004).

Figure 1.1 outlines the RAINS model. Economic activities serve as input to the model along with emission control policies, resulting in computed emission levels. The transport and dispersion of pollutants are calculated using transfer coefficients derived from the EMEP model (Meteorological Synthesizing Centre – West; Oslo). The GAINS model stores grid and ecosystem specific information on critical loads originating from the Coordination Centre for Effects (CCE) in Bilthoven. The information can be compared with the resulting deposition calculated by GAINS allowing for assessment of exceedances and comparison to environmental targets/objectives.

The spatial dispersion of the pollutants over Europe is modelled leading to calculations and determinations of critical loads in a grid cell defined Europe (50 x 50 km) and again leading to suggestions for environmental targets as output.

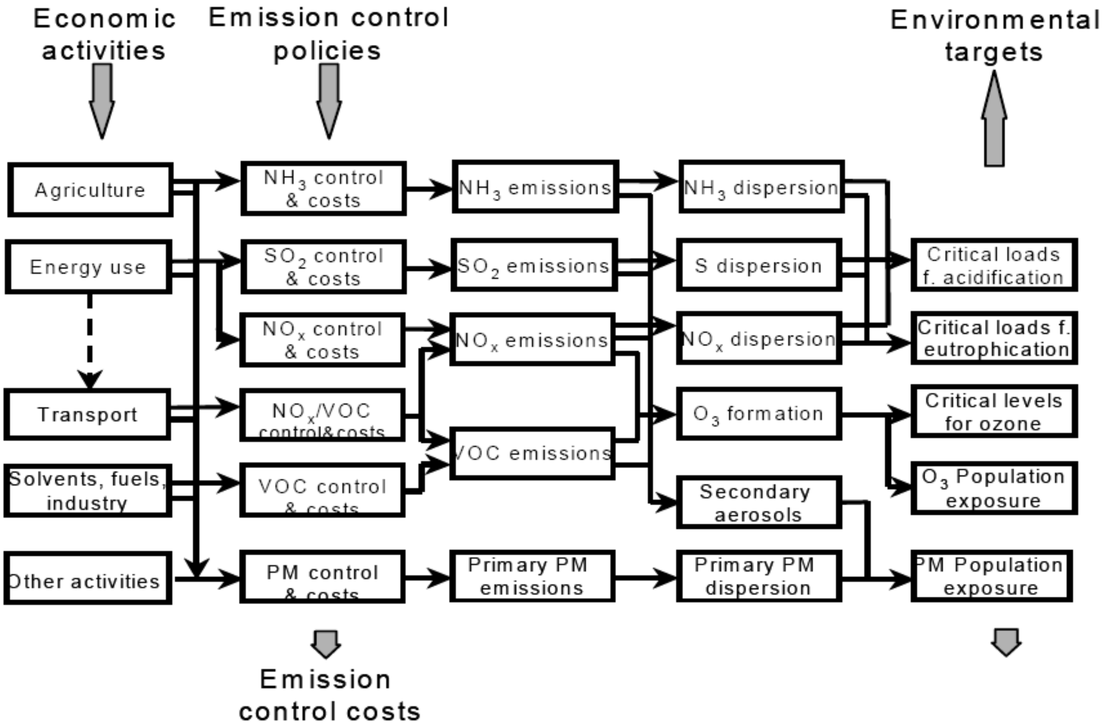

Figure 1.1 Flow of information in the RAINS model (Amman et al., 2004).

The model, which consists of modules working together, is able to compute straight forward emission projections based on input data on energy and agricultural activities, i.e. "simulation mode", but the model is also able to compute reduction scenarios based on exogenously defined environmental objectives by optimisation procedures.

For each emission scenario, marginal cost curves are created, which are determinant for the priority of reduction measures. Reduction measures are ranked by increasing cost-effectiveness, forming a stepwise upsloping curve, defined by aggregated reduction potentials. Refer to figure 1.2. When choosing reduction measures to implement the model moves up along the cost curve selecting the most cost-efficient option first. The reduction potential of each measure is limited by its inherent reduction efficiency and the emission level of the specific sector the measure is associated. This means, it is usually not sufficient choosing only the most cost-efficient measure, and therefore, the second most cost-efficient measure is also chosen, and so on, adding up until the desired reduction level has been reached.

GAINS focuses on technological add-ons, e.g. de-NO_X equipment at power and heating plants. It is not possible to take more advanced emission reduction measures into account. This goes for structural or behavioural changes. However, these changes can be reflected in the input data, e.g. the energy projections that drives the model.

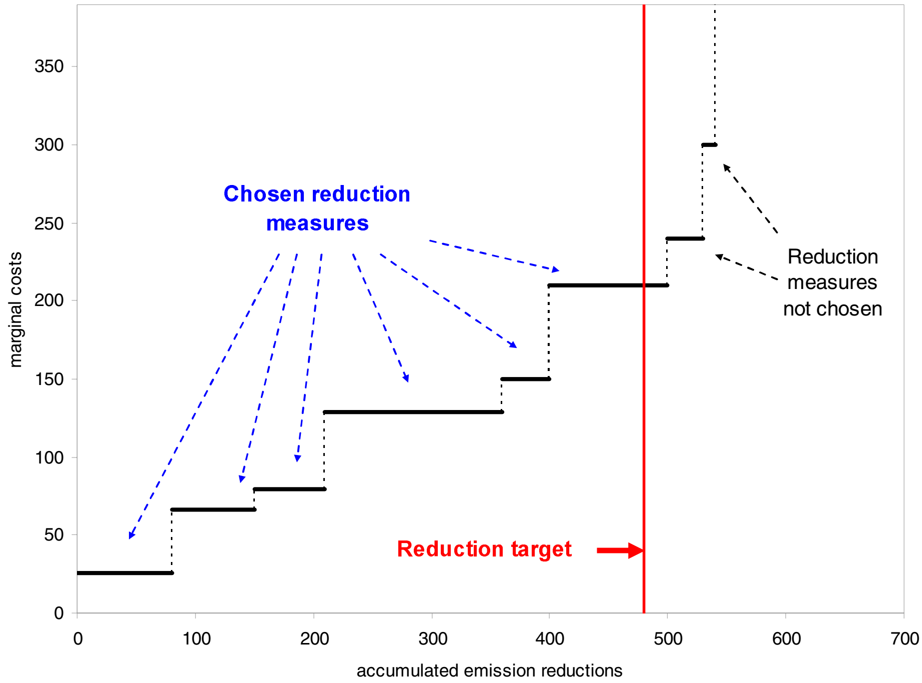

Figure 1.2 Conceptual graph on marginal cost curves for emission reduction measures.

1.3.1 Optimisation principle

Figure 1.3 presents the concepts of optimization used in GAINS using energy input as an example on activity input.

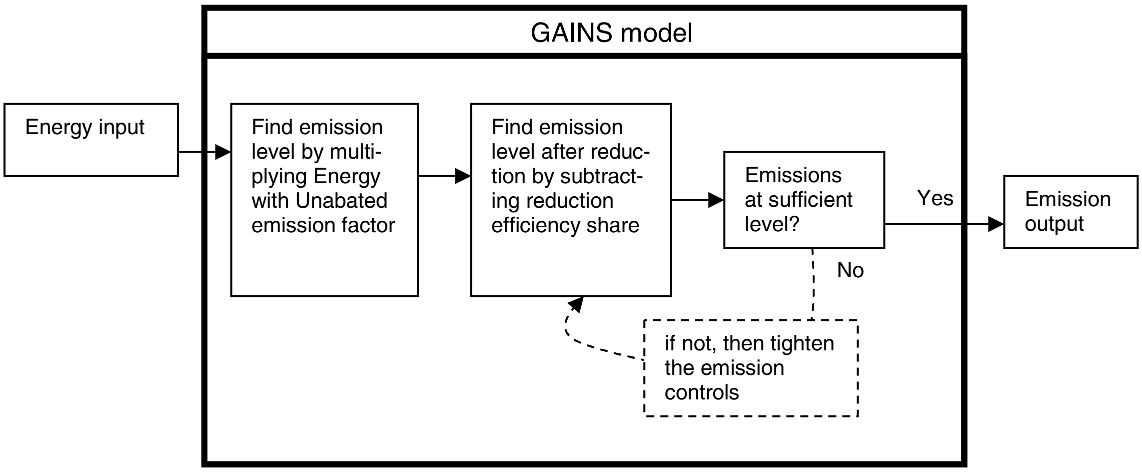

Figure 1.3 Conceptual diagram on the optimisation principle of the GAINS model.

Energy input data is multiplied by the unabated emission factor specific for the technology and activity, e.g. power and heating plants (technology) combusting coal (activity). This results in an unabated emission level before passing emission reduction technologies (e.g. combustion modification).

The resulting emission level - after passing reduction technology - is found by subtracting the reduction efficiency share (e.g. 60 %). If the aim is simulating current legislation, making a baseline scenario, this would be the end result.

If the aim is a reduction scenario - reducing emission to a certain level - the resulting emissions level is checked up against any exogenous standard, e.g. environmental critical load. If there is no exceedance the projection is secured and no further computation is necessary. If not, the computation procedure returns and tightens the reduction control by implementing a more cost-effective reduction technology.

1.3.2 Further on GAINS

The results of the GAINS model are accessible at the GAINS internet page hosted by IIASA (IIASA, 2008d). With special privileges it is possible to upload activity data and compute baseline scenarios.

For a more detailed description of the RAINS/GAINS model, refer to various documentations at the IIASA internet homepage (IIASA, 2008e) among others “Rains review 2004” by Amman et al. (2004).

Also refer to Chapter 2 for a description of the GAINS scenarios, and to Chapter 3 for a description of the cost calculation principles of the model.

1.4 Terms and abbreviations

1.4.1 Terms

Baseline scenario, current legislation scenario and business-as-usual scenario. All these terms are used in this report as alternating terms for scenarios projecting futures assuming implementation of current legislation and current estimates about future socioeconomic development.

- BL scenario: Baseline scenario

The **Reduction scenario** describes a future where emission reductions occur additional to current legislation and policy in order to meet certain objectives. In the case of TS scenarios the environmental objectives (ecological and health related) are formulated in the TSAP adapted by the EU.

- TS scenario: Thematic Strategy scenario.
- MRR scenario: Maximum Reductions included in the RAINS model scenario (and also the GAINS model).

The **NAT (national reported) and COH (coherent) scenario group** refers to two sets of scenarios run by the GAINS model operated by IIASA. These two groups of scenarios contain various scenarios, among others a baseline scenario (BL), a reduction scenario (TS) and another reduction scenario showing maximum achievable reductions within the GAINS model. The NAT group refers to scenarios driven by input data reported from the individual EU states while the COH group refers to input data coherent in a European perspective, generated by common European models like PRIMES, CAPRI and others.

NEC directive: National Emission Ceiling directive, adapted by the EU 2001, is setting emission ceiling targets as of 2010 for certain pollutants

(NO_X, SO_2, NMVOC, and NH_3). Ceilings are to be revised regarding pollution levels as of 2020 including $PM_{2.5}$, which is the subject of this report.

TSAP - Thematic Strategy on Air Pollution: Adapted by the EU, leading to a revised air quality directive and updated NEC directive by defining reduction targets for environmental effects of certain pollutants as of 2020.

Removal efficiencies and reductions efficiencies are terms for the same: the efficiency of a technological measure implemented to bring current emissions down from an emission source.

The **technological measure** to reduce emissions is also referred to as **Control technology.**

1.4.2 A comprehensive list of abbreviations

EPA - Danish Environmental Protection Agency

BF - Bio filtration – air purification

BL -Baseline

Ca - Calcium

CAFÉ - Clean Air for Europe

CAPRI - Common Agricultural Policy Regional Impact Analysis

CCE - Coordination Centre for Effects

CDM/JI - Clean Development Mechanism/Joint Implementation

CH_4 - Methane

CHP - Combined heating and power plants

COH - Coherent

COH-BL - Coherent Baseline

COH-TS - Coherent Thematic Strategy

CORINAIR - CORe INventory AIR emissions

CS - Covered Storage

DEA - Danish Energy Agency

DKK - Danish Kroner

DLE - Dry Low Emission

DNV - Det Norske Veritas

EC - European Commission

EEA - European Environmental Agency

EGR - Exhaust Gas Recirculation

EMEP - European Monitoring and Evaluation Programme

ETS - European Emission Trading system

EU - European Union

EUR - Euro

GAINS - Greenhouse Gas and Air Pollution Interactions and Synergies

IEF - Implied Emission Factor

IIASA - International Institute for Applied Systems Analysis

IMO - International Maritime Organisation

Ind.Process - Industrial processes

LCP - Large Combustion Plants

LNA - Low ammonia application

LNF - Low Nitrogen Feed

LRTAP - Long-range Transboundary Air Pollution

M - Million

MRR - Maximum Reductions included in the RAINS model scenario (and also the GAINS model)

Mtonnes - Million tonnes

N_2O - Nitrous Oxide

NAT - National reported

NAT-TS - National reported Thematic Strategy

NEC - National Emission Ceiling

NERI - National Environmental Research Institute, Aarhus University

NH_3 - Ammonia

NMVOC - Non-methane volatile compounds

NO_x - Nitrogen Oxides

PM - Particulate matter

PRIMES - PRIMES is a modelling system that simulates a market equilibrium solution for energy supply and demand in the European Union (EU) member states.

RAINS - Regional Air Pollution Information and Simulation

rem. eff. - Removal efficiency

SCR - Selective Catalytic Reduction

SECA - SO_2 Emission Control Area

SNAP - Selected Nomenclature for Air Pollution

SNCR - Selective Non-Catalytic Reduction

SO_2 - sulphur dioxide

TCE - Total Cement Equivalent

TS - Thematic Strategy

TSAP - Thematic Strategy on Air Pollution

TSP - Total Suspended Particulate Matter

tTCE - Tonnes Total Cement Equivalent

WFGD - Wet Flue Gas Desulphurisation

2 The GAINS emission scenarios

During the NEC-2020 preparation process IIASA has presented various baseline and reduction scenarios computed by the GAINS model, reflecting comments, changes and new constraints emerging from the ongoing negotiation process. These are presented in the NEC report series NEC-1 to NEC-6 (IIASA, 2008c). The scenario data can be viewed in detail and downloaded from the GAINS online version (IIASA, 2008d).

This present report assesses the scenarios presented in the NEC-4 (baseline scenarios) and NEC-5 (reduction scenarios) reports. Two parallel scenario groups are generated. They are different in their input activity data. The figure below shows the relations between the scenarios.

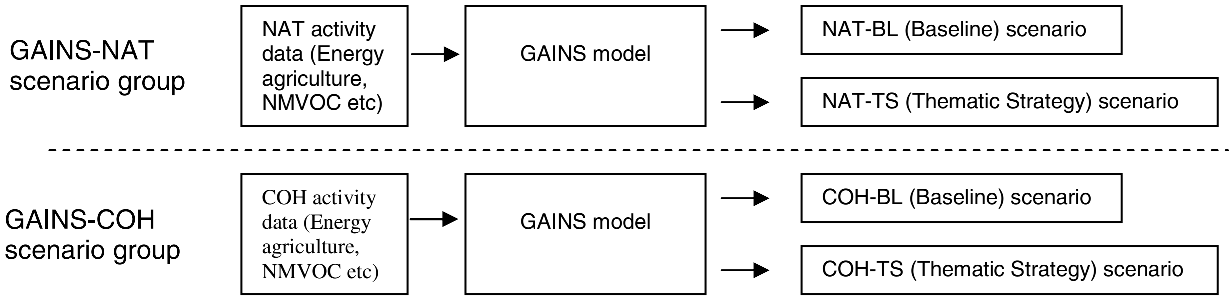

Figure 2.1 Overview on the flow from input of activity data, via model computation, to output of emission scenario data for the two scenarios groups "GAINS-NAT" and "GAINS-COH".

The one group, NAT ("national"), builds on activities reported from national authorities, while the other COH ("coherent"), builds on activities from the common European energy model PRIMES, incorporating constraints on CO_2 emission level (20 % as compared to 1990) and a certain share of renewable energy (17 %) in 2020. Refer to Chapter 9 for a detailed description of the energy input data that drives the two reduction scenarios.

The computations within each scenario group results (among others) in two scenarios, the Baseline Scenario (BL) and a reduction scenario, named Thematic Strategy (TS).

2.1 Baseline scenarios

The BL scenario describes, or simulates, the future projection based on current legislation. The scenarios explore how the emission future will evolve according to current legislation. It is of course not a plausible future that no further legislation will be adapted over the years, but it founds the basis for further analyses. The scenario calculates the future emissions simply by multiplying input data on activities with abated emission factors.

As a variant, a baseline scenario based on not only current legislation, but also current policy, can be established. This is the case in the COH scenario group. Here current EU policy about climate change and energy, not yet reflected in legislation but likely to be, is incorporated in the energy projections serving as input to GAINS.

2.2 Reduction scenarios

In general an emission reduction scenario shows how to reduce emissions or shows the effect of reduction measures. In the actual case the NEC related reduction scenario shows the best cost-efficient way of implementing reduction technologies in order to meet certain levels of emissions in 2020, defined by environmental objectives set by the TSAP.

A special type of reduction scenario is a scenario showing the maximal achievable reductions within the GAINS model (MRR). In other words it shows what emission level would then be reached if all reduction measures were activated no matter the costs. This serves well to understand the proportions of reduction measures in other scenarios.

2.2.1 Activity input data

IIASA has computed two parallel sets of baseline reduction scenarios. The one set - COH scenarios - takes activity projections computed by common European models like PRIMES (energy) and CAPRI (agriculture) as input, while the other set - NAT scenarios - partially are based upon activity projections as reported by national authorities. This especially applies for energy, but also for NMVOC sources, socioeconomics as well as agriculture, via the CAPRI model.

While national projections do reflect national plans and incorporate best available local information, they might not be in accordance with assumptions included in projections of the European countries leading to lack of balance in resources and production, e.g. import/export of electricity. Consistency is, however, assured in larger scale Europe-wide modelling activities such as PRIMES, CAPRI etc.

The COH-BL scenario also differs from the NAT-BL scenario in another way, since it in its energy input data set has included the effects of the EU Climate and Energy Package policies, not to be perceived as current legislation in 2006-2007 when the scenario was created. The effects are among others caused by targets for CO_2 emission reductions and renewable energy shares in 2020. This affects the levels of NEC pollutants directly and indirectly and as seen in the following chapters, it leads to less costly emission reductions as compared to the corresponding NAT scenario.

2.3 Differences between GAINS projections and NERI projections

The baseline emission projections computed by the GAINS model (NAT scenario) and by NERI are both based upon the same Danish data sources; however shows different results. The main reason for discrepancies is different energy data sets used for the projections. The GAINS-NAT-BL projection is based on the energy dataset that founds the Danish “Energy Strategy 2025” while the NERI projection as of October 2006 is based on the data founding the Danish “Visionary Energy Policy, 2025”. As seen in Chapter 9 the former totals in 962 PJ Primary Energy Supply while the latter totals in 899 PJ, which is 6.5 % lower.

Other reasons for differences are difficulties in transforming the energy data coming from the Danish categorization system to the GAINS categorizations system. Also, use of different emission factors affects the results. GAINS take use of various general guideline emission factors while NERI - especially for large point source emitters - relies on specific information from emitters about energy use and emission amounts now and in the future, resulting in Implied Emission Factors (IEF) often different to guidebook emission factors, however, perceived as more realistic.

2.4 Overview on emission projections and reduction potentials

2.4.1 Emission reductions

Table 2.1 gives an overview and shows the suggested emission ceilings for Denmark in 2020 as calculated by GAINS via the two sets of baseline and reduction scenarios for the five pollutant groups NO_X, SO_2, NH_3, NMVOC and $PM_{2,5}$. Also Danish inventory and projection data by NERI as of October 2006 is shown (Illerup et al., 2008).

Moreover, the NEC emission ceiling commitment for 2010 is shown, along with the EU proposal of June 2008 on emission ceilings for 2020 from the EC. These figures stems from a new reduction scenario computed by the GAINS model and published in the NEC-6 report (IIASA, 2008f). The “EU proposal scenario” is alike the COH scenario. It is based on common European activity projections by the models PRIMES, CAPRI and others, and the energy projection reflects the newly proposed EU Climate and Energy Package that implies a 20 % CO_2 reduction compared to 1990 and 20 % renewal energy, as of 2020.

The “2000” column in the table contains historical inventory data. The data from NERI and IIASA should be the same for each pollutant. However, due to varying sources and revision of data and inventory methods the figures differ slightly.

The “2010” column shows either the NEC-2010 commitment level or the modelled baseline projections of NERI and IIASA. The three “2020” columns shows figures from the BL scenarios, the TS reduction scenarios and the MRR, which indicates the maximal reduction potentials to be computed by the model.

Table 2.1 Emission data from GAINS and NERI for 2000 (historical) and for 2010 and 2020 (projections).

	2000 Historical	2010 BL	2020 BL	2020 TS	2020 MRR
NO_X emissions [kt]					
NEC ceiling		127		88*	
NERI**	205	136	115		
GAINS-NAT	213	168	126	89	85
GAINS-COH	217	155	104	87	80
SO_2 emissions [kt]					
NEC ceiling		55		16*	
NERI (historical/projection**)	29	20	21		
GAINS-NAT	28	19	21	15	13
GAINS-COH	29	18	19	16	13
NH_3 emissions [kt]					
NEC ceiling		69		52*	
NERI (historical/projection**)	90	65	55		
GAINS-NAT	91	58	53	48	47
GAINS-COH	91	59	53	50	47
NMVOC emissions [kt]					
NEC ceiling		85		73*	
NERI (historical/projection**)	127	87	74		
GAINS-NAT	141	92	71	62	46
GAINS-COH	126	81	62	59	36
$PM_{2,5}$ emissions [kt]					
NEC ceiling		-		17*	
NERI (historical/projection**)	22	19	16 (14***)		
GAINS-NAT	25	20	15 (14***)	12 (11***)	7
GAINS-COH	25	20	14 (12***)	13 (12***)	7

* EU proposal, June 2008.

**according to NERI acidification projection, October 2006 (Illerup et al., 2008).

*** excluded agricultural emissions reductions.

In the following the table shall be commented with respect to the year 2020 data from the BL and the TS scenarios.

NO_X

Looking at the 2020 data the GAINS-NAT and GAINS-COH reduction scenarios "TS" computes emission ceilings of 89 ktonnes and 87 ktonnes, respectively. The base for these reduction levels are the BL levels at 126 ktonnes and 104 ktonnes NO_X, respectively, meaning the NAT scenario demands a 37 ktonnes reduction and the COH scenario only demands a 17 ktonnes reduction.

NERI projects 115 ktonnes – right in the middle – and reduction efforts to reach about 87-89 ktonnes would be about 27 ktonnes NO_X.

SO_2

The NAT and COH projections almost agree on the TS emission level at 15 ktonnes and 16 ktonnes, respectively. The BL projection shows 21 and 19 ktonnes, respectively, and therefore the reduction demand would be 6 ktonnes and 3 ktonnes SO_2, respectively.

NERI projects a baseline level at 21 ktonnes similar to the NAT scenario.

NH_3
The NAT scenario projects 48 ktonnes while COH projects 50 ktonnes, and both have BL levels at 53 ktonnes NH_3, implying reductions demands at 5 and 3 ktonnes NH_3, respectively.

NERI projects 55 ktonnes NH_3 for 2020, 2 ktonnes above the two GAINS BL scenarios.

NMVOC
In the TS scenario GAINS projects a NMVOC emission level at 62 ktonnes for the NAT scenario and 59 ktonnes for the COH scenario. BL levels are 71 ktonnes and 62 ktonnes, respectively, implying reduction demands at 9 ktonnes and 3 ktonnes for the NAT and COH scenarios.

The NERI baseline projects 74 ktonnes, which is 3 ktonnes above the NAT scenario.

Agricultural NMVOC emission is not included in the figures as it is not included in the NEC directive reporting.

$PM_{2,5}$
The NAT and COH-TS emission levels are at 12 ktonnes and 13 ktonnes $PM_{2,5}$, respectively. BL levels are at 15 ktonnes and 14 ktonnes, respectively - taking a reduction demand at 3 ktonnes and 1 ktonnes, respectively.

The NERI baseline projects 16 ktonnes, which is 1 ktonnes more the NAT scenario.

Maximal reduction limits
As seen from Table 2.1 the TS reduction scenario levels for the three first pollutants NO_X, SO_2, and NH_3 are quite close to the maximal possible reduction levels. This is a common pattern for many North European countries.

2.4.2 Reduction costs

Table 2.2 shows the emission reductions costs that GAINS has computed for the BL, TS, and MRR scenarios 2020. The costs reflect the annual costs as of 2020 and onwards in annualized 2000 values.

Table 2.2 Cost associated emission control technology implementation, as of 2020, in the NAT and COH scenario groups regarding the BL, TS and MRR scenarios.

Costs M DKK pr year*	2020		
	BL	TS	MRR
NO_X emissions			
GAINS-NAT	3 131	3 578	4 115
GAINS-COH	3 414	3 615	4 062
GAINS-NAT additional to BL		*447*	*984*
GAINS-COH additional to BL		*201*	*648*
SO_2 emissions			
GAINS-NAT	1 804	1 938	2 311
GAINS-COH	1 401	1 401	1 699
GAINS-NAT additional to BL		*134*	*507*
GAINS-COH additional to BL		*0*	*298*
NH_3 emissions			
GAINS-NAT	3 369	3 712	3 913
GAINS-COH	3 228	3 384	3 757
GAINS-NAT additional to BL		*343*	*544*
GAINS-COH additional to BL		*157*	*529*
NMVOC emissions			
GAINS-NAT	125	164	2 363
GAINS-COH	91	72	2 552
GAINS-NAT additional to BL		*39*	*2 238*
GAINS-COH additional to BL		*-19*	*2 461*
$PM_{2,5}$ emissions**			
GAINS-NAT	894	693	2 564
GAINS-COH	842	596	2 191
GAINS-NAT additional to BL		*-201*	*1 871*
GAINS-COH additional to BL		*-246*	*1 595*

* Costs recalculated from EUR (2000) into DKK at the exchange rate DKK 7.45 pr EUR.

** Data excluded minimal very expensive reductions in the agricultural sector.

The first two entries for each pollutant shows the annual costs (factor prices) fulfilling the NAT and COH scenarios (annualised 2000 prices).

The next two entries calculate the *additional costs beyond* the BL scenario, fulfilling the TS scenarios and the MRR scenario.

The costs indicates the full costs implementing emission control technologies from no costs at all up until the present level as reflected in the BL scenario, the TS scenario or the MRR scenario, respectively. This explains why also the BL scenario is associated reduction costs since some emission control efforts are already implemented. Therefore, especially the additional costs moving from the BL scenarios to the TS scenario are of interest.

As seen from the table some reductions in the TS scenario are cheaper to achieve than in the BL case. One explanation is the implementation of more cost-efficient technologies than committed in the current legislation (BL) scenario. For example, GAINS allows for substitution of measures considering certain constraints that change over time, e.g. age of installation. Another explanation is the co-benefit of parallel reductions of other pollutants, e.g. measures in the residential sector reducing several pollutants at the same time. More detailed information is given in the coming sections.

3 Costs efficient reductions

In the following five chapters (Chapters 4-8), the specific suggestions of GAINS for control technologies implemented in various sectors and subsectors are assessed along with their emission reduction potentials. Associated costs are also listed in the tables but are, however, not assessed in this report.

The starting point is the baseline (BL) scenarios of the NAT and COH scenario groups (IIASA, 2007a). The NAT-BL scenario projects the future emission levels if only current legislation on emission control is carried out. This also applies for the COH-BL scenario. However, this scenario is driven by a constrained energy input data set reflecting the effects of the EU Climate and Energy Package (EC, 2008).

The BL scenarios are compared to the TS scenarios (IIASA, 2007b) that suggest implementation of various and more efficient emission control measures in order to reduce the emission level of the BL scenarios to appropriate level complying the environmental objectives of the TS on air pollution (EC, 2005b).

3.1 Emission calculations

Calculating emission amounts from a sector/activity combination with an emission control technology implemented follow the equation according to Klimont et al. (2002) though simplified:

$$E = Act * ef * (1 - eff) * X$$

Where

E	is resulting emission for the controlled part of the sector
Act	is activity level, e.g. energy use
ef	is uncontrolled emission factor
eff	is reduction efficiency factor (or removal efficiency)
X	implementation rate of the control (sectoral coverage)

In order to calculate the *total emission* from a sector, one has to add the emissions from the part of the sector under "no control" and of course also emissions from the sector under a different control measure:

$$\sum E = \sum (Act * ef * (1 - eff) * X)\ , \quad \sum X = 1$$

$\sum X = 1$ indicates that the sectoral coverage of different control measures should be 1 or 100 %, including the share under "no control".

3.1.1 Example

To calculate the resulting emission level after implementing de-NO_X equipment (removal efficiency at 80 %) at 70 % of all power and heating plants running on coal (58 PJ), with a uncontrolled emission factor at 0.15 ktonnes pr PJ, gives

$$E = [58 \text{ PJ} * 0.15 \text{ ktonnes pr PJ} * (100\ \% - 80\ \%) * 70\ \%] + [58\text{PJ} * 0.15 \text{ ktonnes pr PJ} * (100\ \% - 0\ \%) * 30\ \%]$$

$$\Rightarrow E = 3.8 \text{ ktonnes } NO_X$$

The first part of the equation calculates the emissions from the part of the sector under control, while the second part calculates the emissions from the part of the sector under „no control".

3.2 The cost calculation method

As mentioned previously, the core of GAINS is an optimisation procedure finding optimal cost-efficient solutions for emission reductions. For each pollutant cost curves are constructed that ranks emission reduction technologies to implement by increasing marginal costs. Then, in principle, the model by the optimisation procedure chooses the most cost-efficient technologies first and ads up until the desired emission levels have been reached.

The cost evaluation in GAINS attempts to quantify the values to society of the resources diverted to reduce emissions in Europe.

Quoting from the model documentation (Amman, 2004) "In practice, these values are approximated by estimating costs at the production level rather than prices to the consumers. Therefore, any mark-ups charged over production costs by manufacturers or dealers do not represent actual resource use and are ignored. Certainly, there will be transfers of money with impacts on the distribution of income or on the competitiveness of the market, but these should be removed from a consideration of the efficiency of a resource. Any taxes added to production costs are similarly ignored as transfers".

Moreover quoting IIASA, "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. The calculation routine takes into account several country specific parameters that characterise the situation in a given region. For instance, these parameters may include average operating hours, fuel prices, capacity/vehicles utilization rates and emission factors. The expenditures for emission controls are differentiated into:

- Investments.
- Fixed operating costs.
- Variable operating costs.
- Transaction costs.

From these elements RAINS/GAINS calculates the annual costs pr unit of activity level. Subsequently, these costs are expressed pr metric tonnes of pollutant abated. Some of the parameters are considered common to all countries. These include technology specific data such as removal efficiencies, unit investment costs, fixed operating and maintenance costs. Parameters used for calculating variable cost components such as the extra demand for labour, energy, and materials are also considered common to all countries. 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. In addition, the prices for labour, electricity, fuel and other materials as well as cost of waste disposal also belong to this category. Transaction costs are country specific since they describe costs of diverse activities such as training or even information distribution required for implementation of an abatement option. All costs in RAINS/GAINS are expressed in constant EUR (in prices of the year 2000)" (IIASA, 2005).

Danish evaluation of the accountancy method

According to the quote above, the cost calculation method of the single control technologies is the *financial economic cost* at production level, reflecting basic price of the technologies, excluding mark up, subsidies and taxes. According to the Danish evaluation of the NEC scenarios (Bach et al., 2006), the method that has become common in Denmark, is "a welfare economic cost analysis. The welfare economic analysis is carried out at consumer price level and is broader than the more narrow financial economic analysis as the derived welfare related effects such as derived environmental effects are included. IIASA does not include derived effects". Bach et al. (2006) shows that the country specific factors that influences the prices, used in GAINS, are different to Danish practice; this goes for wage level, energy prices and the discount rate. The discount rate used by IIASA, agreed upon by EU and UN as appropriate for the analysis of scenarios for Gothenburg Protocol and NEC directive, is a social long-term interest rate and not a business rate. The discount rate used in Danish evaluations in the case of NO_X reduction potential evaluations were at 6 % (EPA, 2006). In the GAINS online version it is possible to choose either a 4 % or 9 % discount rate.

The differences between the parameters used by IIASA and by the Danish administration are therefore sources for different economic evaluations of reduction costs.

Various relevant references for economic assessment and GAINS scenarios

Assessment of the options for Denmark to reduce NO_X emissions as of 2010. Analyse af Danmarks muligheder for at reducere emissionerne af NO_X i 2010 – Miljøstyrelsen (EPA, 2006), Copenhagen (in Danish).

Evaluation of the welfare economic consequences of the EC Thematic Strategy on Air Pollution (TSAP). Vurdering af de samfundsøkonomiske konsekvenser af Kommissionens temastrategi for luftforurening. NERI (Bach et al., 2006). Roskilde (in Danish).

RAINS REVIEW, 2004: The RAINS model. Documentation of the model approach prepared for the RAINS peer review 2004. IIASA (Amann et al., 2004).

NEC Scenario Analysis Report Nr. 4: Updated Baseline Projections for the Revision of the Emission Ceilings Directive of the European Union. (IIASA, 2007a).

NEC Scenario Analysis Report Nr. 5: Cost-effective Emission Reductions to Meet the Environmental Targets of the Thematic Strategy on Air Pollution Under Different Greenhouse Gas Constraints. (IIASA, 2007b).

NEC Scenario Analysis Report Nr. 6: National Emission Ceilings for 2020 based on the 2008 EU Climate and Energy Package. (IIASA, 2008f).

4 NO_X emission reduction and costs

In this and the following chapters the, by GAINS, suggested emission reductions and associated costs shall be assessed, for each NEC pollutant.

4.1 Overview

NO_X emissions are regulated by several EU directives covering both stationary and mobile sources. Also national regulations concerning stationary sources are in force. Offshore industry NEC emissions are not covered by any regulations. Large stationary sources are covered by the EC Large Combustion Plants (LCP) directive (EC, 2001) and moreover, a national quota system on NO_X and SO_2 emissions (Danish National Parliament, 1991; 1998) regulates the power and heating plants sector. Refer to EPA (2006) for a more detailed description (in Danish) of the various regulations.

Regulation of mobile sources follows the EURO standards implemented step by step over the years (EC, 2005a). The latest adopted ones EURO VI (heavy duty) and EURO 6 (light duty) are going to be implemented in 2013 and 2014, respectively, and covers both on-road and off-road vehicles and machines along with locomotives and inland vessels.

Table 4.1 NO_X emissions: NEC ceilings, NERI inventory and projection data, and GAINS model data for the two scenario groups NAT and COH.

NO_X-emissions [kt]	2000	2010	2020	2020	2020
	Historical*	BL	BL	TS	MRR
NEC ceiling		127		88**	
NERI inventory and projections***	205	136	115		
GAINS-NAT	213	168	126	89	85
GAINS-COH	213	155	104	87	80

* Historical inventory data varies between scenarios because of revision of inventory data.

** According to EU proposal, June 2008.

*** Projections of October 2006 (Illerup et al., 2008).

Table 4.1 shows the NO_X emission levels for 2000, 2010 and 2020 according to various inventories and scenario projections from NERI and the GAINS model.

First row shows the present NEC ceilings for Denmark in 2010 on NO_X emissions at 127 ktonnes. Also in the same row, the emission ceiling for 2020 at 88 ktonnes, as proposed by the EC is shown, though still to be negotiated.

Second row shows the Danish inventory figure for 2000 at 205 ktonnes and current legislation projection for 2010 and 2020 at 136 ktonnes and 115 ktonnes, respectively. The third and fourth row shows the GAINS model projections within the two alternate scenario groups NAT and COH.

The three GAINS scenarios in the 2020 columns are BL, TS and MRR. The latter refers to the maximum reduction obtainable within the GAINS model, no matter the costs. Refer to Chapter 2 for a description of these.

As seen from the table, the NERI emission projection for 2020 at 115 ktonnes is placed between the two GAINS scenarios BL levels at 126 ktonnes and 104 ktonnes.

For the two GAINS scenarios it is required to reduce emission levels to 87-89 ktonnes NO_X following the TS scenario.

What also appears from the table is that the suggested GAINS NO_X emission level, especially for the NAT scenario (89 ktonnes) is quite close to the maximal reduction limit at 85 ktonnes.

The EU proposal for NO_X emission ceiling of 88 ktonnes in 2020 reflects the two NAT and COH scenarios – to be analysed in a follow up study.

Table 4.2 NO_X emissions reduction costs as calculated by the GAINS model for the two scenario groups NAT and COH.

	2000	2010	2020	2020	2020
Costs M EUR pr year	Historical	BL	BL	TS	MRR
GAINS-NAT	98	243	420	480	552
GAINS-COH	98	264	458	485	545
Costs M DKK pr year*					
GAINS-NAT			3 131	3 578	4 115
GAINS-COH			3 414	3 615	4 062

* Costs recalculated from EUR (2000) into at the exchange rate DKK 7.45 pr EUR.

Table 4.2 shows the reduction costs as calculated by the GAINS model for the two scenarios NAT and COH, both in EUR and DKK. For the NAT scenario the costs meeting the TS target is DKK 447 M additional to the BL level at DKK 3 131 M, and DKK 201 M additional to DKK 3 414 M for the COH scenario.

4.2 Reasons for differences in the NERI and NAT-BL projections

Especially regarding NO_X emission projections, 2020, there is a pronounced difference between the NERI projection at 115 ktonnes (Illerup et al., 2008) and the GAINS-NAT projection at 126 ktonnes.

The main reason is that the primary energy projection dataset that Danish authorities have reported to IIASA is an older version then the energy projections used by NERI. The former has a total energy level about 7 % higher than the latter.

Raising the NERI projections with 7 %, results in 123 ktonnes, which then brings the two scenarios at level.

There are some differences not easy explainable at the sectoral levels. However, it seems to be a mixed result of the in general automatics mode of the GAINS model as compared to the semiautomatic projections of NERI, where specific sectoral conditions and circumstances are taken into consideration. The differences are to be elaborated during the rest of this chapter.

4.3 NO_X control technologies available in GAINS

According to the IIASA documentation on NO_X (Cofala & Syri, 1998), control technologies available in the GAINS model are described below.

4.3.1 Primary measures - combustion modification

All in furnace reduction technologies make use of the same two principles:

- Reduction of excess oxygen levels.
- Reduction of the peak flame temperature.

This is takes place by the following reduction technologies:

- *Low NO_X burners (LNB)* are advanced technologies that control the injection and composition of the fuel and air mixture in the very furnace process. Various techniques are: air staged low-NO_X burners; flue gas recirculation; fuel staged LNB - not to be explained in greater detail here.
- *Oxycombustion.* Pure oxygen is used in the combustion process instead of air.
- *Fluidized bed combustion (FBC).* Technique removes NO_X and SO_2 simultaneously. The bed material typically made of crushed sand, ashes and limestone is circulated in the combustion chamber by air jet and mixed with crushed solid fuel (e.g. coal) ensuring high fuel efficiency and a relatively low combustion temperature leading to low NO_X emissions. The SO_2 is adsorbed by the limestone forming gypsum.

4.3.2 Secondary measures – flue gas cleaning

Flue gas cleaning technologies are divided into two main groups:

- *Selective catalytic reduction (SCR).* By adding NH_3 to the NO_X flue gas, nitrogen (N_2) and water is formed. Titanium or other materials serve as catalyst for the process. The technology can either be placed directly after the boiler before any other flue gas treatment (High-dust system) or at the end of the flue gas path (Tail gas system).
- *Selective non-catalytic reduction (SNCR).* In principle the same process as SCR above but without presence of a catalyst. If using Urea (a nitrogen compound $CO(NH_2)_2$) as the reducing agent, additional to nitrogen and water, CO_2 will be formed, which of course is a greenhouse gas problem to be dealt with. This technology is especially applicable for small industrial boilers, according to Cofala & Syri (1998).

4.3.3 Combined NO_X control

When combined primary and secondary measures can unitedly reduce NO_X with 95 % or more and is applicable since the two types of measure targets two parts of the combustions system: the in furnace part and the flue gas part. The GAINS model takes a conservative and realistic approach and sets the removal efficiency to 80 %.

4.3.4 Stage 1-3 NO_X control:

Controlling emissions from industrial processes are process specific and depends on raw material in use, temperature and other parameters. This means that it is not possible to attach specific characteristics of the control technologies as is the case for fuel related emissions. Instead, IIASA has formed three groups, stage 1 – 3, with increasing removal efficiencies (40 %, 60 % and 80 %) and with increasing marginal cost of reduction based on various information from literature and experts (Cofala & Syri, 1998).

4.3.5 Other possible reduction techniques *not* available in the GAINS model

Boosting. By attaching e.g. a gas turbine to an existing coal fired boiler during peak hours, the capacity is enlarged and with higher energy efficiency. Moreover, the NO_X emissions are reduced since gas turbines emits less than boilers.

Fuel substitution. Fuel type plays a role for NO_X emission level. Though NO_X emissions mainly stems from the very combustion process where nitrogen from the air is oxidised, many coarse fuels - like coal and heavy fuel along with biomass and waste - contains nitrogen compounds originating from the protein in the plant or animal material that constitutes the fuel. However, the GAINS model cannot suggest a scenario substituting fuel types, which are exogenous to the model (this possibility is presently only implemented in GAINS regarding CO_2 reductions).

4.3.6 Control techniques relevant to Danish conditions

According to the publication "Analysis on Denmark's options to reduce NO_X emissions in 2010" (EPA, 2006) the options in Denmark to reduce NO_X are reductions either by technological measures or by fuel substitution. The latter is evident and relevant in its reduction effect. This goes both for shifting from coal to gas fuel or shifting to renewable energy sources like wind and solar.

In the power and heating plants sector the technologies in play are:

- SCR catalytic converter (80-95 % reductions).
- Boosting
- Advanced combustion, including low NO_X burning technologies and re-burning technologies.

In the offshore industry on single gas turbines:

- a low NO_X burning technology DLE (Dry Low Emission) is possible, which implies multi injection of gasses and advanced process control leading to a low combustion temperature and subsequently low NO_X emissions (80 % NO_X reductions).

In the mobile sector:

- SCR catalytic converter (80-95 % reductions).
- EGR (Exhaust Gas Recirculation) used on diesel engines. The technology is basically a flue gas recirculation technology (50 % reduction).

In general, all major power and heating plants are under NO_X emission control, at efficiency rates matching SCR technologies (80-90 %). Offshore turbines are - at present - only voluntarily controlled. However, upcoming NO_X emission taxes as of 2010, is expected to lead to reductions. Off-road vehicles and engines are not controlled. Emissions from on-road vehicles are regulated by common European norms, implemented in stages over years.

4.4 NAT-TS scenario: NO_X reductions and costs

Table 4.3 gives an overview on reductions and associated costs as suggested by the NAT-TS scenario. Note that the reduction amounts and costs are calculated as *beyond* the BL situation in 2020 and indicate the additional effort to reach the targets of the TS.

Furthermore, note that only sector/activity combinations that change from the BL case to the TS case are listed. Refer to Appendix 1 for thorough data on all sector/activity combinations, also showing activity, BL and TS scenario emission levels.

The table is divided into NO_X emitting subsectors and associated activities.

It appears from the table that the NAT-TS scenario suggests NO_X emission reductions widely spread over all sectors. Naturally, the three large energy consuming sectors: gas and oil industries, industrial combustion and power and heating plants sector (new and existing plants) take by far the most reductions and costs. However, no sector is ignored.

The most widespread measure that suggests reducing NO_X emissions is installation of combinations of combustion modification technologies and catalytic converters (SCR/SNCR), which implies quite substantial removal efficiencies of up to 80 %.

Also in the transport sector large reductions occur. However, these reductions are the results of implementation of EURO-VI standards for heavy duty on road vehicles fuelled by diesel oil - measures which are now adapted as law in the EU, and regarded as current legislation coming into force as of 2013. It is therefore included in the BL case in future scenarios calculations and not leading to additional measures in the TS scenario case.

The total reduction costs, when excluding the transport sector, amounts to DKK 390 M or DKK 11 400 pr tonnes NO_X reduced.

Table 4.3 NO_X emission reduction potentials within the NAT-TS scenario.

Sector	Activity (fuel/product)	BL emission level (tonnes)	Emission reductions beyond BL (tonnes)	Annual reduction costs beyond BL (thousand DKK pr year)
Gas and oil industry; combustion	Natural gas (incl. other gases)	11 145	-8 693	118 603
	Heavy fuel oil	84	- 54	1 008
	Liquified petroleum gas (LPG)	0	0	1
	Diesel oil and others	1	- 1	2
	SUBTOTAL	11 230	-8 748	119 616
Non-industrial combustion	Natural gas (incl. other gases)	2 115	- 465	10 850
	Gasoline and others incl. biofuels	64	- 7	330
	Heavy fuel oil	77	- 39	279
	Liquefied petroleum gas	52	- 6	266
	Diesel oil and others	997	- 120	5 104
	SUBTOTAL	3 305	- 637	16 829
Industrial combustion	Natural gas (incl. other gases)	2 402	-1 345	43 678
	Hard coal, grade 1	1 133	- 635	14 605
	Heavy fuel oil	3 170	-2 473	26 534
	Liquefied petroleum gas	157	- 78	460
	Diesel oil and others incl. biofuel	2 056	-1 028	5 263
	Biomass fuels	1 216	- 608	2 129
	Waste	97	- 68	677
	SUBTOTAL	10 231	-6 235	93 346
Power/heating plants: exist. other	Natural gas (incl. other gases)	17 048	-7 266	29 565
	Heavy fuel oil	685	- 270	1 468
	Diesel oil and others incl. biofuel	16	- 10	51
	Biomass fuels	187	- 52	241
	SUBTOTAL	17 936	-7 598	31 325
Power/heating plants: new	Hard coal, grade 1	3 814	-2 080	24 385
	Heavy fuel oil	908	- 584	20 300
	Waste	6 342	-5 074	52 176
	SUBTOTAL	11 064	-7 738	96 862
Ind. Process: cement production	No fuel use	2 868	-1 912	10 478
Ind. Process: lime production	No fuel use	141	- 94	527
Ind. Process: crude oil & other products*	No fuel use	1 849	-1 109	21 226
	SUBTOTAL	4 858	-3 115	32 231
Waste: agricultural waste burning	No fuel use	36	- 36	0
Waste: flaring in gas and oil industry	No fuel use	79	- 16	0
Waste: open burning of residential waste	No fuel use	26	- 26	0
	SUBTOTAL	141	- 78	0
Transport	Gasoline; diesel and others	56 595	-2 864	59 111
Other sector/fuel combinations with no changes (refer to Appendix 1)		10 761	0	0
	TOTAL	126 121	-37 013	449 319

* input to petroleum refineries.

4.5 NAT-TS scenario: NO_X control technologies and associated costs

In the following sections, divided into main NO_X emitting sectors, the specific control technologies that GAINS suggests implemented to meet the TS targets are analysed with respect to their feasibility and practicability. Only sector activity combinations with significant reductions or costs (above DKK 1 M) are to be assessed.

4.5.1 Gas and oil industries; combustion

Table 4.4 shows two sector activities (a and b) in the gas and oil industry with reduction costs above DKK 1 M. The first row(s) shows which control technologies are to be expected in the BL case, 2020, as consequence of the current legislation. The succeeding rows shows which control technologies the TS scenario suggests implemented to reduce emissions beyond BL in 2020.

Table 4.4 Gas and oil industries; combustion, as of 2020.

	Sectoral coverage (%)	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
a. Natural gas:				
NAT-BL	100	No control	11 145	0
Thematic Strategy	80	Combustion modification and SCR (rem. eff. 80 %)	1 783	105 664
	20	Combustion modification and SNCR (rem. eff. 70 %)	669	12 940
		Total removed emissions and related costs	-8 693	118 603
b. Heavy fuel oil:				
NAT-BL	80	Combustion modification	56	132
	20	No control	28	0
Thematic Strategy	80	Combustion modification and SCR (rem. eff. 80 %)	22	1 013
	20	Combustion modification and SNCR (rem. eff. 70 %)	8	127
		Total removed emissions and related costs	-54	1 008

Note: Sector/fuel combinations with reduction costs below DKK 1 thousand are not listed; refer to Appendix 1.

Gas and oil industries; combustion/natural gas

What appears from Table 4.4 is that in the gas and oil industry sector the largest reductions by far are suggested for natural gas combustion activities, which in the BL scenario case is uncontrolled. In the TS scenario combinations of combustion modification and both catalytic and non-catalytic selective reduction (SNCR/SCR) technologies are implemented. All together it leads to reductions of 8.7 ktonnes NO_X at the cost of DKK 118.6 M, or reduction costs of DKK 13 600 pr tonnes NO_X yearly.

A great deal of the gas combustion in this sector takes place at the gas and oil rigs in the North Sea and the emissions are not controlled. The Danish operators in the gas and oil extraction industry argues that implementing SCR on the gas turbines is infeasible because of high costs, lack of space, weight and working environment and security, according to EPA (2006). However, according to GAINS the emission reduction potential is about 20 % of the overall NO_X reduction potential in NAT-TS scenario and therefore important to consider.

Thirty-seven turbines in the North Sea are of the "single fuel" type while 25 are of the "dual fuel" type. The latter type is considered too costly to attach combustion modification technologies according to the NO_X analysis report from the EPA (2006). Same reference, however, finds it possible though expensive to install the DLE control technologies on the newer generation of single fuel gas turbines. This technology is to be categorised as Low-NO_X burners in the GAINS classification, though the DLE have much higher removal efficiency (78 %) than the general level of this group (50 %). Therefore this specific DLE technology is to be compared with the suggested SCR technologies in GAINS (removal efficiency at 80 %). However, the DEA report only finds potential for reducing 4 400 tonnes NO_X – or about half the GAINS model.

The biggest concessionaire in the Danish part of the North Sea, Maersk Oil, informs that new turbines to be installed in the future will have DLE technology incorporated, and thus from the start abate large amounts of NO_X (EPA, 2006). No information about the implementation rate to be expected is available.

Gas and oil industries; combustion/heavy fuel oil

As is the case above reductions in this sector occurs by implementation of combinations of combustion modification and selective catalytic and non-catalytic reduction technologies, leading to modest reductions of 54 tonnes NO_X at the cost of DKK 1.0 M, or reduction costs of DKK 18 700 pr tonnes NO_X yearly.

Heavy fuel consumption within this sector is taking place at oil refineries at land. The BL scenario case with 80 % combustion modification coverage seems like a realistic assumption and the reductions are therefore feasible.

4.5.2 Non-industrial combustion

Table 4.5 shows data for two fuel use activities in the non-industrial combustion sector leading to reduction costs exceeding DKK 1 M pr year each. The non-industrial sector includes subsectors like residential, commercial, agriculture, gardening and others.

Table 4.5 Non-industrial combustion, as of 2020.

	Sectoral coverage (%)	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
		a. Natural gas:		
NAT-BL	100	No control	2 115	
Thematic Strategy	100	Comb. modification on gas use in commercial sector (rem. eff. 22 %)	1 650	10 850
		Total removed emissions and related costs	-465	10 850
b. Diesel oil (and others incl. biofuels):				
NAT-BL	100	No control	997	0
Thematic Strategy	100	Combustion modification on gasoil use in commercial sector (rem. eff. 12 %)	877	5 104
		Total removed emissions and related costs	-120	5 104

Note: Sector/fuel combinations with reduction costs below DKK 1 thousand are not listed; refer to Appendix 1.

For both combinations (a and b) in Table 4.5 the pattern is the same. In the BL case there are no NO_X controls installed while in the TS scenario case combustion modification is implemented in the commercial subsector of the non-industrial sector. The reduction costs in the two combinations are respectively DKK 10.9 M and DKK 5.1 M or DKK 23 300 and DKK 42 800 pr tonnes NO_X yearly.

The BL cases where almost no sources are controlled seem correct and combustion modification technologies should be feasible to install. It is quite simple technologies to implement, however, since the commercial sector is made up of many small combustion units, leakage and non-optimal operations leading to more modest reductions is to be expected.

The Danish NO_X report (EPA, 2006) has not assessed possible NO_X controls in the non-industrial sector as an option. Moreover, it is explicitly mentioned that regarding gas boilers in the residential sector it is already enforced by law as of 2006 to install condensing boilers that lowers the NO_X emissions.

4.5.3 Industrial combustion

Table 4.6 shows the figures for five fuel use activities in the industrial combustion sector leading to reduction costs above DKK 1 M pr year each.

Table 4.6 Industrial combustion, as of 2020.

Fuel	Sectoral coverage (%)	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
a. Natural gas:				
NAT-BL	100	Combustion modification (rem. eff. 50 %)	2 402	7 454
Thematic Strategy	80	Combustion modification and SCR (rem. eff. 80 %)	769	45 554
	20	Combustion modification and SNCR (rem. eff. 70 %)	288	5 578
		Total removed emissions and related costs	-1 345	43 678
b. Hard coal:				
NAT-BL	100	Combustion modification (rem. eff. 50 %)	133	2 127
Thematic Strategy	80	Combustion modification and SCR (rem. eff. 80 %)	362	14 918
	20	Combustion modification and SNCR (rem. eff. 70 %)	136	1 814
		Total removed emissions and related costs	-635	14 605
c. Heavy fuel oil:				
NAT-BL	100	No control	3 170	0
Thematic Strategy	80	Combustion modification and SCR (rem. eff. 80 %)	507	23 124
	20	Combustion modification and SNCR (rem. eff. 70 %)	190	3410
		Total removed emissions and related costs	-2 473	26 534
d. Diesel oil:				
NAT-BL	100	No control	2 056	0
Thematic Strategy	100	Combustion modification (rem. eff. 50 %)	1 028	5 263
		Total removed emissions and related costs	-1 028	5 263
e. Biomass fuels:				
NAT-BL	100	No control	1 216	0
Thematic Strategy	100	Combustion modification (rem. eff. 50 %)	608	2 129
		Total removed emissions and related costs	-608	2 129

Note: Sector/fuel combinations with reduction costs below DKK 1 thousand is not listed; refer to Appendix 1.

From an overall assessment it appears from the table that the same control technology strategy is suggested for the industrial combustion sector as seen above for the gas and oil industry sector. The BL case with either no control or only combustion modification is replaced by the TS case by implementing more efficient technologies. These are combinations of combustion modification and selective catalytic or non-catalytic control technologies.

The annual reduction costs for the five combinations are:

Industrial combustion/Natural gas	DKK 32 500 pr tonnes NO_X
Industrial combustion/Hard coal	DKK 23 000 pr tonnes NO_X
Industrial combustion/Heavy fuel oil	DKK 10 700 pr tonnes NO_X
Industrial combustion/Diesel oil	DKK 5 100 pr tonnes NO_X
Industrial combustion/Biomass fuels	DKK 3 500 pr tonnes NO_X

The five different types of fuels can roughly be assigned to the following types of industries:

- Natural gas: small, medium and large scale units, e.g. paper industries, chemical industries and others.
- Hard coal: large scale industries: cement production, sugar refineries and others.
- Heavy fuel oil: mainly small and medium scale industries, but also some larger various food production industries.
- Diesel oil: mainly small scale units, emergency generators and others.
- Biomass: e.g. wood processing industries.

GAINS expects the industrial sector rather uncontrolled in the BL case regarding NO_X emissions, though larger units running on natural gas or hard coal have some combustion modifications implemented. However, it does not seem correct that heavy fuel activities are not controlled at all. Larger units will be under control to some extend due to the Danish Governmental order on air quality (Danish National Parliament, 2005). Since the regulation covers engines and turbines with a firing efficiency above 1 MW and in use more then 500 hours pr year, also medium sized units are expected to be under control as of 2020. Firing efficiency is defined as fuel consumption (kg pr hour) multiplied with net calorific value (kWh pr kg).

The suggested implementation of advanced SCR and SNCR technologies in the TS scenario regarding natural gas, hard coal and heavy fuel oil combustion is probably feasible. However, since many combustion units belong to small and medium sized industries, some leakage and non-optimal operations may be expected.

The Danish NO_X report (EPA, 2006) suggests replacing existing burners to low-NO_X burners as a possible measure within the industry. The report states 399 boilers running on natural gas and 273 boilers running on gasoil and estimates that 50 % of these are feasible to be renewed with low-NO_X burners - leading to reductions (by 2010) at 60 % or 664 tonnes NO_X for natural gas and 704 tonnes NO_X for gasoil and adding up to a total of 1 368 tonnes NO_X. The reason why the Danish NO_X report does not find it feasible implementing control technologies at more than 50 % coverage is mainly that small-sized boilers are left out of consideration. These reductions are about half of what GAINS suggests as of 2020 for natural gas and diesel oil (same category as gasoil) driven boilers, which is caused by an expectation of 100 % sectoral control coverage - and in the case of natural gas accomplished with the much more efficient control technologies SCR and SNCR.

All the five sector activity combinations are expected to be under total emission control as of 2020, with at least 50 % removal efficiency according to GAINS. As mentioned previously, it is to be questioned if it is practical to implement measures on small scale units. However, with increasing focus on NO_X reductions equipment designed especially for small and medium sized units may be developed - making the systems operational also for operators without the specific expertise in the field. The intensive innovation processes taking place in relation to diesel and gasoline fuelled vehicles may affect the industrial combustion sector.

4.5.4 Power and heating plants

The GAINS model discriminates between new and existing power and heating plants. Existing ones, commissioned before 1995, are subcategorised into wet bottom boilers types and others. All "existing" Danish power and heating plants are of the type "others". Though there exists a GAINS category "Integrated Gasification Combined Cycle" no separate category exists for combined heating and power plants (CHP), which is a shortcoming since 70 % of Denmark's electricity production and 80 % of the heating production stem from CHP's - with more efficient use of the energy and consequently lower emission factors than conventional plants.

Table 4.7 shows the suggested reductions within the power and heating plants sector going from the BL scenario to the TS scenario.

Table 4.7 Power and heating plants, as of 2020.

Plant type/fuel	Sectoral coverage %	Control technology	Emissions (tonnes)	Annual costs (thousand DKK)
a. Existing/natural gas:				
NAT-BL	40	No control	11 179	0
	60	Combustion modification (rem. eff. 65 %)	5 869	44 348
Thematic Strategy	100	Combustion modification (rem. eff. 65 %)	9 782	73 913
		Total removed emissions and related costs	-7 266	29 565
b. Existing/heavy fuel oil:				
NAT-BL	35	No control	415	0
	65	Combustion modification (rem. eff. 65 %)	270	2 727
Thematic Strategy	100	Combustion modification (rem. eff. 65 %)	415	4 195
		Total removed emissions and related costs	-270	1 468
c. New/heavy fuel oil:				
NAT-BL	45	No control	730	0
	55	SCR (rem. eff. 80 %)	178	24 812
Thematic Strategy	100	SCR (rem. eff. 80 %)	324	45 112
		Total removed emissions and related costs	-584	20 300
d. New/hard coal:				
NAT-BL	30	No control	2 600	0
	70	SCR (rem. eff. 80 %)	1 214	56 900
Thematic Strategy	100	SCR (rem. eff. 80 %)	1 734	81 285
		Total removed emissions and related costs	-2 080	24 385
e. New/waste:				
NAT-BL	100	No control	6 342	0
Thematic Strategy	100	SCR (rem. eff. 80 %)	1 268	52 176
		Total removed emissions and related costs	-5 074	52 176

Note: Sector/fuel combinations with reduction costs below DKK 1 thousand is not listed; refer to Appendix 1.

Quite strikingly, GAINS only assumes emission control technologies installed with sectoral coverage at 55-70 % as of 2020 depending on fuel type in the BL and none in the case of waste fuel. Those assumptions are very modest compared to the real world; in practice all power and heating plant units with thermal effect above 50 MW will have SCR technologies installed by 2010 in order to meet emission constraints set by EU directives and Danish regulations and quotas.

However, a report from the European Environmental Agency (EEA) (EEA, 2008) shows that as of 2004 Denmark has had some potentials reducing NO_X from hard coal and natural gas combustion. This is confirmed by NERI inventory data as of 2004 (unpublished). The average IEF for hard coal combustion was 150 g pr GJ while the best performing unit was at 28 g pr GJ. For natural gas the average emission factor was 88 g pr GJ while the best performing unit was 31 g pr GJ. Refer to Appendix 11 for an assessment of the EEA report.

Power and heating plants: existing/natural gas

Existing power and heating plants (commissioned before 1995) driven by natural gas are supposed to have a 60 % coverage combustion modification in the BL case, increasing to 100 % in the TS case and leading to

7 266 tonnes NO_X reduction at the cost of DKK 29.6 M - implying reduction costs of DKK 4 100 pr tonnes NO_X yearly, which is quite low.

Gas turbines are typically attached coal fired power and heating plants operating during peak hours (partial boosting). SCR technologies should not be a practical problem to implement.

A substantial part of the reductions in the NAT-TS scenario, about 20 % of the overall reductions needed, are assigned this sector activity combination. In case all gas turbine units - instead of CM (combustion modification) - are fully equipped with SCR, which have removal efficiency at 80 %, an additional 4 192 tonnes NO_X would be reduced - or in total 11 458 tonnes NO_X, which is about 30 % of the overall needed reductions in the NAT-TS scenario.

Power and heating plants: existing/heavy fuel oil

Following the same reduction strategy as mentioned above will - according to the TS scenario - lead to emission reductions at 270 tonnes NO_X at the cost of DKK 1.5 M, implying DKK 5 600 pr tonnes NO_X yearly.

A few large units are running entirely on heavy fuel oil ("Kyndbyværket" and "Østkraft") while heavy fuel oil in other cases serves as supporting fuel either in main boilers or supporting boilers.

Power and heating plants: New/heavy fuel oil

A total sectoral coverage with SCR going from 55 % coverage in the BL case would lead to NO_X reductions at 584 tonnes at the cost of DKK 20.3 M - or DKK 34 800 pr tonnes NO_X.

New power and heating plants running on heavy fuel oil (commissioned after 1995 according to the GAINS definition) count only few as compared to existing ones commissioned before 1995.

Power and heating plants: New/hard coal

By 2010 all coal fired power and heating plants in Denmark plans to be fully equipped with SCR enforced by regulation (Danish National Parliament, 2003a) according to EPA (EPA, 2006, p. 56). Therefore, the expected NO_X removal at 2 084 tonnes NO_X is not relevant in the TS scenario and has to be accounted for in the BL scenario instead of.

Power and heating plants: New/waste

According to GAINS the power and heating plant units fuelled with waste are not expected to be under any controls by 2020. However, according to the Danish government order on waste combustion (Government order, 2003) all facilities combusting waste and of noteworthy size are enforced to meet certain NO_X emission caps. The only exception is facilities solely disposing animal corpse by combustion.

The largest CHP using waste in Denmark is the facility "Vestforbraending". Other facilities are "Amager", "Aarhus Nord" and "KARA" and all facilities have NO_X emission controls implemented, either combustion modification or SCR.

Implementation of SCR controls should be practicable for all waste combusting facilities, though it may cause management problems for small power and heating plant units lacking skilled expertise.

Summing up on the power and heating plant sector

The control coverage assumed in the BL scenario case seems quite underestimated. Roughly spoken, all power and heating plants are and will be under some kind of emission control due to business as usual and current legislation.

It is striking that combustion fuelled by natural gas and heavy fuel oil in existing power and heating plants are only expected to be controlled by combustion modification technology in the TS scenario. Comparing to the industrial sector, which was analysed previously in Section 4.5.3, the natural gas and heavy fuel combustion activities are expected to be under SCR control. The opposite would preferably be the case that the power and heating sector have the most efficient technology implemented – since biggest emitters.

Because GAINS underestimates the emission control coverage in the BL scenario the realistic reduction potential is not as big as expected in the TS scenario.

4.5.5 Industrial processes

The method used by IIASA (Cofala & Syri, 1998) calculating process related emission from various industrial processes is subject to uncertainty. The method is to compare the total measured emission from a production activity (both combustion and process emissions) to the hypothetical emission from combustion calculated by standard emission factors. The difference is then considered as related the process emission. This method goes for the following sub-sectors: oil refineries, coke plants, sinter plants, pig iron/blast furnaces, non-ferrous metal smelters, sulphuric acid plants, nitric acid plants and pulp mills.

Emissions from cement and lime production is for each sector, aggregated to one factor for both fuel combustion and process related emissions. This is done to avoid negative SO_2 emission factors from the process, which is difficult for the model to handle. In the two cases estimated fuel consumption - reported in the industrial production sector - is subtracted the sector to avoid double counting.

Denmark does not assess emissions separately for the lime production sector, the paper mil sector and the non-ferrous metal production. Therefore, it is difficult to assess the GAINS data regarding those sectors.

Table 4.8 shows the figures for two fuel use activities in the industrial processes sector leading to reduction costs above DKK 1 M pr year each.

Table 4.8 Industrial processes, as of 2020.

	Sectoral coverage (%)	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
a. Cement production/No fuel use*:				
NAT-BL	100	Stage 1 NO_X control (rem. eff. 40 %)	2 868	3 493
Thematic Strategy	100	Stage 3 NO_X control (rem. eff. 80 %)	956	13 971
		Total removed emissions and related costs	-1 912	10 478
b. Crude oil and other products/No fuel use:				
NAT-BL	50	Stage 1 NO_X control (rem. eff. 40 %)	1 109	2 756
	50	Stage 2 NO_X control (rem. eff. 60 %)	740	9 096
Thematic Strategy	100	Stage 3 NO_X control (rem. eff. 80 %)	740	33 079
		Total removed emissions and related costs	-1 109	21 226

* This combination includes emission from both the cement production process (no fuel use) and fuel from related combustion, which is reflected in the emission factor that is used, based on tonnes cement produced.

Note: Sector/fuel combinations with reduction costs below DKK 1 thousand is not listed; refer to Appendix 1.

Cement production/No fuel use

By implementing more efficient NO_X control technologies the cement production industry is supposed to reduce emissions with 1 912 tonnes in the TS scenario at the cost of DKK 10.5 M or DKK 5 500 pr tonnes NO_X pr year.

The BL emission level at 2 868 tonnes for the year 2020 is very low. NERI expects emissions as of 2020 at about 6 700 tonnes NO_X in the sector. Therefore, emission reductions at 956 tonnes seem quite unrealistic.

Aalborg Portland, the only cement producer in Denmark, reports in their annual 2007 environmental report that they have installed SNCR technology in 2007 and expects full reduction benefit as of 2008 (Aalborg Portland, 2008) - going from about 8 ktonnes NO_X in 2006 to about 6.5 ktonnes NO_X in 2020. NERI projects a level at 6.5 ktonnes NO_X for the cement industry as of 2020.

The activity data that bases the GAINS-NAT computation is at 1.8 mtonnes cement produced in 2020, which seems like an error; the GAINS-COH scenarios, to be assessed later, have the correct figure: 2.9 mtonnes, which is a straight forward no-growth projection of the 2007 figure reported by Aalborg Portland (2008).

Aalborg Portland calculates a general IEF of 2.4 kg pr tonnes total cement equivalent (TCE) for 2007, which with 2.9 mtonnes cement produced reflects 7 070 ktonnes NO_X.

In 2003 Aalborg Portland had an IEF at 3.4 kg pr tonnes TCE. This factor reflected an average between "grey" and "white" cement production. "Grey cement" production had an IEF at 2.69 kg pr tonnes TCE and "white cement production" had an IEF at 4.66 kg pr tonnes TCE.

In 2007 the average IEF was as mentioned, 2.4 kg pr tonnes TCE, which reflects 1.97 kg pr tonnes TCE for "grey cement" and 3.36 kg pr tonnes TCE for "white cement".

GAINS uses an unabated emission factor of 2.55 ktonnes pr mtonnes cement (or 2.55 kg pr tonnes cement), which seems sizeable to "grey" cement production, but not to "white cement".

It seems like Aalborg Portland has a potential for further reductions. The NO_X control in the "grey cement" production with SNCR technology could be improved with SCR technologies. Moreover, the emissions from the "white cement" production currently only controlled by combustion modification, could probably be reduced substantially by implementation of SCR-technologies.

Crude oil and other products/no fuel use

In the refinery sector GAINS estimates reductions at 1 109 tonnes NO_X at the cost of DKK 21.2 M by going from the BL case to the TS scenario case. This implies a reduction cost of DKK 19 100 pr tonnes NO_X pr year.

The NO_X emissions from refineries come from combustion processes and it not related process emissions. The reason for categorising refineries under process related emissions is that other emissions than NO_X, e.g. SO_2 and NMVOC emits from the process.

In their environmental reports as of 2007, Shell (2007) reports NO_X emission in 2006 at 931 tonnes, and Statoil (2007) reports 542 tonnes, or in total 1 473 tonnes NO_X.

These two refineries are the only ones operating in Denmark. Both companies do not specifically mention which control technologies they have implemented at present. Reductions approaching the by GAINS suggested level at 740 tonnes as of 2020 may be achievable.

4.5.6 Transport

The NO_X emission reductions in the transport sector are mostly controlled by the common EU norms of which the EURO6 (targeting light duty) and EUROVI (targeting heavy duty) are to be implemented by 2013 and 2014. At the time the NAT-BL scenario was established the EURO VI norm on heavy duty vehicles was not finally adopted by the EU and therefore not accounted for as current legislations in the BL scenario. The effect of the EURO VI norm is consequently reflected in the TS scenario as reductions.

De-NO_X catalytic converters are possible to enforce by national laws in order to protect local health. The technology is not quite in place yet (2008) but for light duty vehicles (vans and passenger cars) it may, however, very well be a realistic option as of 2020, although such measures are not expected in the GAINS scenario.

4.6 COH-TS scenario: NO_X reductions and costs

Table 4.9 lists the emission reductions and associated costs that the COH scenario suggests in order to reduce emissions from the BL level to the TS level, as of 2020.

Table 4.9 NO_X emission reduction potentials within the COH-TS scenario.

Sector	Activity (fuel/product)		BL emission level (tonnes)	Emission reductions beyond BL (tonnes)	Annual reduction costs beyond BL (thousand DKK pr year)
Gas and oil industry; combustion	Natural gas (incl. other gases)		1 717	-859	2 663
	Heavy fuel oil		344	-172	408
		SUBTOTAL	2061	-1 031	3 071
Non-industrial combustion	Heavy fuel oil	SUBTOTAL	105	-52	382
Industrial combustion (boilers)	Heavy fuel oil		194	-97	375
	Biomass fuels		138	-69	389
		SUBTOTAL	331	-166	764
Industrial combustion (others)	Hard coal, grade 1		35	-14	216
	Heavy fuel oil		1 712	-856	2 028
	Liquefied petroleum gas		182	-91	533
	Diesel oil and others incl. biofuels		1 052	-526	2 693
		SUBTOTAL	2 981	-1 487	5 470
Power and heating plants: exist. other	Natural gas (incl. other gases)		7 918	-3 375	13 733
	Diesel oil and others incl. biofuels		2	-1	5
	Biomass fuels		2 940	-810	3 798
		SUBTOTAL	10 860	-4 186	17 536
Power and heating plants: new	Hard coal, grade 1	SUBTOTAL	3 670	-2 002	23 462
Industrial process: cement production	No fuel use		4 507	-3 005	16 467
Industrial process: lime production	No fuel use		176	-117	656
Industrial process: crude oil & other prod.	No fuel use		1 958	-1175	22 483
		SUBTOTAL	6 641	-4 297	39 606
Waste: agricultural waste burning	No fuel use		36	-36	0
Waste: open burning of residential waste	No fuel use		26	-26	0
		SUBTOTAL	62	-62	0
Transport sector	Gasoline, diesel and others		58 098	-4 161	118 686
Other sector/fuel combinations with no changes (refer to Appendix 2)			19 388		
		TOTAL	104 197	-17 444	208 978

Note that only sector/activity combinations that changes from the BL case to the TS case are listed. Refer to Appendix 2 for throughout data on all sector/activity combinations, which also shows activity and BL and TS scenario emission levels.

In total the COH-TS scenario only has to reduce 17.4 ktonnes NO_X as compared to the NAT-TS scenario that needed reductions at 37.0 ktonnes NO_X. However, as in the NAT-TS case, reductions take place in a broad variety of sectors. Largest reductions take place in the sectors: power and heating plants and industrial processes.

Also, the transport sector takes large reductions; however, these reductions are the results of implementation of EURO-VI standards for heavy duty on road vehicles fuelled by diesel oil, which are now adapted by the EU and regarded as current legislation coming into force as of 2013, and therefore included in the BL case - not leading to additional measures in the TS scenario case.

The overall cost, when excluding the transport sector, is DKK 90 M or DKK 6 800 pr tonnes NO_X reduced, which is about 60 % of the reduction cost pr tonnes NO_X in the NAT-TS scenario. The reason for this is mainly that the COH scenario has lower reduction needs and since the first reductions to implement are the cheapest, according to the optimisation procedure, unit cost becomes lower.

Process emissions

The method used by IIASA, at least in the RAINS model (Cofala & Syri, 1998), calculating process related emission from various industrial processes, is subject to uncertainty. The method is to compare the total measured emission from a production activity (both combustion and process emissions) to the hypothetical emission based upon combustion fuel use multiplied with standard emission factors. The difference is then considered as related the process emission. Refer to Section 4.4 for further discussion.

4.7 COH-TS scenario: NO_X Control technologies and associated costs

In the following sections the specific control technologies that the GAINS-COH scenarios suggest implemented to meet the TS targets are analysed with respect to their feasibility and practicability. Only sector activity combinations with significant reductions or costs (above DKK 1 M) are to be assessed.

4.7.1 Various industrial sectors

Table 4.10 lists emission reductions and associated costs that the COH scenario suggests within various industrial sectors in order to reduce emissions from the BL level to the TS level, as of 2020.

Table 4.10 Various industrial sectors, as of 2020.

	Sectoral coverage (%)	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
a. Gas and oil industry/natural gas:				
COH-BL	100	No control	1 717	0
COH-TS	100	Combustion modification (rem. eff. 50 %)	858	2 663
		Total removed emissions and related costs	-859	2 663
b. Industrial combustion (others)/heavy fuel oil:				
COH-BL	100	No control	1 712	0
COH-TS	100	Combustion modification (rem. eff. 50 %)	856	2 028
		Total removed emissions and related costs	-856	2 028
c. Industrial combustion (others)/diesel oil and others incl. biofuels:				
COH-BL	100	No control	1 052	0
COH-TS	100	Combustion modification (rem. eff. 50 %)	526	2 693
		Total removed emissions and related costs	-526	2 693
d. Industrial process: cement production:				
COH-BL	100	Stage 1 NO_X control (rem. eff. 40 %)	4 507	5 489
COH-TS	100	Stage 3 NO_X control (rem. eff. 80 %)	1 502	21 956
		Total removed emissions and related costs	-3 005	16 467
e. Industrial process: crude oil & other prod. – input to oil refineries				
COH-BL	50	Stage 1 NO_X control (rem. eff. 40 %)	1 175	2 920
	50	Stage 2 NO_X control (rem. eff. 60 %)	783	9 635
COH-TS	100	Stage 3 NO_X control (rem. eff. 80 %)	783	35 038
		Total removed emissions and related costs	-1 175	22 483

Note: Sector/fuel combinations with reduction costs below DKK 1 thousand is not listed; refer to Appendix 2.

Gas and oil industry/natural gas

Compared to the NAT scenario the reduction potential here is quite low, which is caused by much lower natural gas input to the COH scenario in this sector (13 PJ in contrast to 84 PJ for the NAT scenario). The implied reduction costs are DKK 3 100 pr tonnes NO_X reduced annually.

The reason for the low input level is not to be explained but seems an unattended result of the optimisation procedure that generates the PRIMES energy activity scenario.

As discussed in relation to the NAT-TS scenario - according to the Danish NO_X report (EPA, 2006) - it is not feasible to cover the whole sector (mostly gas and oil extraction sites in the North Sea) with control technologies and therefore the COH-TS scenario overshoots the reduction potential - however difficult to discuss with this seemingly defective low activity/emission levels.

Industrial combustion (others)

The sector, industrial combustion by other systems than boilers, shows reduction potential for diesel oil and heavy fuel having costs above DKK 1 M each. In the BL case both are uncontrolled and in the TS strategy both are 100 % covered with combustion modification technologies.

The reduction cost is DKK 2 400 pr tonnes NO_X for heavy fuel oil and DKK 5 100 pr tonnes NO_X for diesel oil.

These implementations may be feasible though not practicable for the entire sector, which also consists of small units where sufficient maintenance and operation skills may not be present and therefore causing leakage.

Industrial process: cement production

Reductions in the cement production have a cost of DKK 5 500 pr tonnes NO_X reduced annually. In this case the BL emission level is at 4 507 tonnes NO_X as of 2020.

As mentioned in Section 4.5.5 the COH scenario uses the correct activity data as reported by the sole cement producer in Denmark, Aalborg Portland. This results in higher BL emissions at 4 507 tonnes NO_X as compared to the 2 868 tonnes in the NAT scenario - however, still far from the NERI projection level at 6 700 tonnes NO_X for 2020. The reason is that the IEF reported by Aalborg Portland (2008) is much higher than the one used in GAINS; this, among others because the production of "white cement" seems to be associated with very high emissions factors. Refer to Section 4.5.5 for deepening.

Industrial process: crude oil and other products

Reductions in the crude oil and other products sector have cost DKK 19 100 pr tonnes NO_X reduced pr year.

For further discussion, please refer to the corresponding Section 4.5.5 under the NAT scenarios.

4.7.2 Power and heating plants

Table 4.11 lists emission reductions and associated costs that the COH scenario suggests within the power and heating plants sector in order to reduce emissions from the BL level to the TS level, as of 2020.

Table 4.11 Power and heating plants, as of 2020.

Type / fuel	Sectoral coverage (%)	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
a. Existing/natural gas:				
COH-BL	40	No control	5 192	
	60	Combustion modification (rem. eff. 65 %)	2 726	20 598
COH-TS	100	Combustion modification (rem. eff. 65 %)	4 543	34 331
		Total removed emissions and related costs	-3 375	13 733
b. Existing/biomass:				
COH-BL	38	No control	1 619	
	62	Combustion modification (rem. eff. 50 %)	1 321	6 197
COH-TS	100	Combustion modification (rem. eff. 50 %)	2 130	9 995
		Total removed emissions and related costs	- 810	3 798
c. New/hard coal:				
COH-BL	30	No control	2 502	
	70	SCR (rem. eff. 80 %)	1 168	54 746
COH-TS	100	SCR (rem. eff. 80 %)	1 668	78 208
		Total removed emissions and related costs	-2 002	23 462

Note: Sector/fuel combinations with reduction costs below DKK 1 thousand are not listed; see App. 2.

Power and heating plants: existing

For existing power and heating plants (commissioned before 1995) GAINS suggest a 100 % implementation of combustion modification technologies in the COH-TS scenario, leading to reduction costs additionally to the BL case of DKK 4 100 pr tonnes NO_X pr year for natural gas and DKK 4 700 pr tonnes NO_X pr year for biomass (straw and wood).

The largest CHP's running on biomass are primarily "Avedøreværket, blok 2". Minor CHP's are "Enstedværket", "Herningværket", "Assens fjernvarme", "AMV2" and "Køge kraftvarmeværk". Furthermore, there are many power and heating plants fuelled by biomass, like straw.

Power and heating plants: New

New power and heating plants (commissioned after 1995) running on hard coal are - to a 70 % coverage - expected to be equipped with SCR technology in the BL case, which increases to a 100 % coverage in the TS scenario. Reduction costs will be 11 700 pr tonnes NO_X pr year.

4.8 Summary on NO_X reductions suggested in the NAT-TS and COH-TS scenarios

In this chapter the suggested NO_X reductions of the GAINS TS scenario, presented in the NEC-5 report (IIASA, 2007), has been assessed, especially regarding reductions in sector/activity combinations with costs above DKK 1 M pr year.

A large part of the suggested NO_X emission reductions is to take place in the power and heating plants sector. As seen from the previous analyses some of the suggested reductions are questionable; first of all because the baseline assumptions on the level of implemented reduction technologies as of 2020 seem too modest. This leads to higher assumptions about reduction potentials in the TS scenarios, which again leads to higher additional costs.

NAT-reduction scenario

In detail - with reference to the NAT-reduction scenario - and based on activity input data reported from national Danish authorities, various combinations of sectors and activities have been analysed. Some of the suggested reductions are perceived as feasible. Others are strongly questioned regarding feasibility and practicability. This goes especially for the following:

- Gas and oil industry: Regarding natural gas the reduction potential at 8.7 ktonnes NO_X seem overstated. Probably only about half of the suggested reduction is feasible and practicable. This because much of the emission in this sector stems from the North Sea off shore oil and gas extractions sites where physical difficulties are a hindrance for implementations of optimal reductions technologies.
- Non-industrial combustion: Only reductions of 637 tonnes are suggested at the cost of about DKK 16.8 M annually. It is to be questioned if these minor reductions are feasible and practicable.
- Industrial combustion: Reductions are feasible. However, it does not seem practicable to expect 100 % control technology coverage in the sector because of many small and mediums scale units where implementations and daily management may cause problems and leakage. However, technological developments may in the near future lead to easy operational de-NO_X technologies thus solving that problem.
- Cement industry: Though incorrect activity data in the NAT scenario for the cement production, leading to undershot of emission levels, there seems to be reduction potential simply due to the fact that the only cement production site in Denmark has not implemented the most efficient de-NO_X technologies yet.
- Power and heating plants sector: the NAT-TS reductions scenario suggests about 50 % of all NO_X reductions to take place in the power and heating plants sector, especially regarding plants running on natural gas, waste and hard coal. However, the BL scenario expects too few control technologies installed only covering the sector with 55-70 % and causing the reduction potential to be too high. Especially regarding coal only 70 % of the sector activity is expected under control in the BL case, which by NERI is expected to be more - almost 100 % - since enforced by governmental order (Danish National Parliament, 2003a). However, it goes for all the sector/fuel combinations that an almost full coverage of control technologies are to be expected as of 2020, due to current legislation – though not including small power and heating plants.

Moreover, the TS scenario only suggests implementation of combustion modification controls with removal efficiencies at 65 % instead of SCR controls with removal efficiencies at 80 % for existing plants. As shown in the assessment of the subsector power and heating plants running on natural gas, full installation of SCR controls will increase the reduction potential substantially and is quite realistic. Also the assumption that power and heating plants running on waste fuel have no emission control implemented at all in the BL case is not correct - causing much higher reduction potential than realistic. In other words, the reduction potentials in the power and heating plants sector are more modest than expected by IIASA.

COH-reduction scenario

As it appears from the analysis the TS scenario under the COH group of scenarios needs fewer reductions as compared to the corresponding NAT-TS scenario. This is because the BL scenario projects emission levels in 2020 much lower than the corresponding NAT-BL scenario level. This again is caused by different energy input dataset, among others forcing the NO_X emissions down as a side effect of forcing CO_2 emissions down.

Since the internal parameters of the GAINS model are the same for both the NAT and COH scenarios the reservations about the suggested implementations are in principle the same.

Limitation of the GAINS optimization model

Due to the strict mathematical nature of the GAINS model the most cost-efficient measures are always chosen. However, this often leads to the choice of combustion modification control technologies with only moderate removal efficiencies. In the long term it is plausible that NO_X emissions shall be further curbed because of environmental perspectives - but also because of health perspectives where local concentrations in urban areas are threatening. Therefore, aiming for the most efficient reduction technologies may be the most feasible in the long run - though more expensive in initial investment costs. Especially the intense R&D in the field of SCR seems to improve the practicability and flexibility of the technology and reduce the costs.

4.9 Further detailed information

Detailed extract from the GAINS model on the BL and TS scenarios, listing all sector activity combinations along with activity level data are found in tables in Appendix 1 and 2.

5 SO_2 emission reduction and costs

5.1 Overview

Table 5.1 shows SO_2 emission levels for 2000, 2010 and 2020 according to various inventories and scenario projections from NERI and the IIASA GAINS model. The table is divided into three sections.

First row shows the present NEC ceilings for Denmark in 2010 on SO_2 emissions at 55 ktonnes. The same row shows the emission ceiling at 16 ktonnes proposed by the EC, June 2008, though still to be negotiated.

Second row gives the historical inventory figure by NERI for 2000 at 29 ktonnes and also the newest current legislation projection for 2010 and 2020 at 20 ktonnes and 21 ktonnes, respectively.

Third and fourth row gives the GAINS model's emission projections within the two alternate scenario groups NAT and COH. The NAT scenarios are based on national reported activity data while the COH scenarios are based on common European activity model data.

The three GAINS scenarios in the 2020 columns are BL, TS and MRR. The latter refers to the maximum reduction obtainable within the GAINS model no matter the costs. Refer to Chapter 2 for a description of these.

Table 5.1 SO_2 emissions: NEC ceilings, NERI inventory and projection data, and GAINS model data for the two scenario groups NAT and COH.

	2000	2010	2020	2020	2020
SO_2 emissions [kt]	Historical*	BL	BL	TS	MRR
NEC ceiling		55		16**	
NERI inventory and projections***	29	20	21		
GAINS-NAT	28	19	21	15	13
GAINS-COH	29	18	19	16	13

*Historical inventory data varies between scenarios because of revision of inventory data.

**EU proposal, June 2008.

***October 2006 (Illerup et al., 2008).

Table 5.2 shows the cost calculations of the GAINS model in both EUR and DKK. The figures may vary a little when compared to totals in the subsequent analysis because of rounding errors.

Table 5.2 SO_2 reduction costs as calculated by the GAINS model data for the two scenario groups NAT and COH.

	2000	2010	2020	2020	2020
Costs M EUR pr year	Historical	BL	BL	TS	MRR
GAINS-NAT		299	242	260	310
GAINS-COH		262	188	188	228
Costs M DKK pr year*					
GAINS-NAT			1 804	1 938	2 311
GAINS-COH			1 401	1 401	1 699

*exchange rate 7.45 from EUR (2000) to DKK.

Table 5.1 and Table 5.2 shows that according to the NAT scenarios Denmark can reduce SO_2 emissions with 6 ktonnes (from 21 to 15 ktonnes - from BL to TS level) which would cost DKK 134 M pr year additional to the BL cost at DKK 1 804 M. According to the COH scenarios a reduction of 3 ktonnes is sufficient (from 19 to 16 ktonnes) and this without additional costs, which will be explained later.

The EU proposal by June 2008 with an emission ceiling of 16 ktonnes SO_2 by 2020 is in accordance with the level of the two analysed reduction scenarios – refer to Chapter 10.

5.2 SO_2 control technologies available in GAINS

The GAINS BL projection for 2020 does not expect SO_2 reductions others than using low-sulphur fuels. In the model documentation on SO_2 control strategies (Cofala & Syri, 1998) IIASA writes that low-sulphur fuels do not cause investments on the actual facility site and either comes natural or is prepared by desulphurisation at refineries.

Low sulphur fuels

The low sulphur fuels taken into use are:

- *Low sulphur fuel (0.6 %)* – goes for both coal and fuel oil.
- *Low sulphur diesel oil – stage 1 (0.2 % S).* For diesel oil GAINS operates with three grades of sulphur content, stage 1 contains 0,2 % - equivalent to 2000 ppm.
- *Low sulphur diesel oil – stage 2 (0.045 % S).* For diesel oil GAINS operates with three grades of sulphur content, stage 2 contains 0.045 % - equivalent to 450 ppm.
- *Low sulphur diesel oil – stage 3 0.001 % S* For diesel oil GAINS operates with three grades of sulphur content, stage 3 contains 0.001 % - equivalent to 10 PPM. By current legislation maximal sulphur content for transport diesel is 50 ppm.
- *Low sulphur gasoline – 0.001 % S.* For Gasoline GAINS operates with a low sulphur variant containing 0.001 % - equivalent to 10 PPM. This is sold as sulphur free diesel.

The reason for the various sulphur contents is explained below.

Hard coal is not under any regulations regarding sulphur content. However, because of air quality regulations coal with as low sulphur content as possible is desirable. The GAINS model documentation (Cofala & Syri, 1998) on the SO_2 controls states that the 0.6 % content reflects a best estimate for what will also be available in the future, though hard coal with a natural lower sulphur content is available on the market.

Heavy fuel oil is by regulation forced below 1 % (EC, 2005c). GAINS operates with a control option of 0.6 % sulphur content achieved through demanding crude oil with natural low sulphur content or desulphurisation at the refinery. Though not a level enforced by law IIASA consider 0.6 % an economically competitive level (Cofala & Syri, 1998, p.23).

According to Statoil (2008) fuel oil comes in three qualities regarding sulphur: 0.05 %, 0.005 % and 0.001 %, respectively, 500 ppm, 50 ppm and 10 ppm. The two latter are added additives improving the combustion.

Diesel oil under control contains 0.2 % sulphur, 0.045 % sulphur or 0.001 % sulphur in GAINS, reflecting desulphurisation processes at various costs.

According to EPA all diesel (and gasoline) sold in Denmark whether for mobile or stationary combustion purposes only contains 0.005 % (50 ppm) sulphur.

As of 2005 all road transport has to be fuelled by low sulphur gasoline and diesel at maximum 50 ppm according to EURO-4 norms. And as of 2009 the maximum level must decrease to 10 ppm according to EURO-5.

Also most diesel oils used for stationary combustion contains only 50 ppm sulphur as a consequence of Danish duty tax policy on the different diesel oils.

Gasoline. As mentioned above, as of 2009 (EURO-5) the maximum sulphur content level is 10 ppm, according to EU legislations.

Desulphurisation add-on technologies

The TS scenarios suggest installation of two types of SO_2 control technologies depending on which fuel type is in use. In basic, both technologies make use of the chemical process that ties SO_2 into solid compounds when in reaction with calcium (Ca):

- *Wet flue gasses desulphurisation* is the designation for flue gas treatment where the SO_2 emission is absorbed in a spray of lime solution. The removal efficiency is set to 85 % in GAINS. However, advanced technologies may reach 95 %.
- *Limestone injection* is in its chemical principle the same as mentioned above. However, here the injection of pulverized lime takes place in the very combustion process. The removal efficiency is only about 60 %.

The add-on techniques may in theory be combined with desulphurised low-sulphur fuel - but it is often more cost-efficient removing all with the add-on techniques. However, legislation may demand a certain maximum level for sulphur content in fuel.

5.3 NAT-TS scenario: SO_2 reductions and costs

In the following specific control actions are analysed, which are proposed by the GAINS TS scenario in order to reduce SO_2 emission levels in 2020 - to meet the TS environment and health targets.

Table 5.3 shows emission reductions and associated costs beyond the BL scenario, as suggested by the GAINS-NAT-TS, in order to meet the TS targets on environmental and health exposure.

Note that only sector/activity combinations that changes from the BL case to the TS case are listed. Refer to Appendix 3 for throughout data on all sector/activity combinations, also showing activity and BL and TS scenario emission levels.

Table 5.3 SO_2 emission reductions and costs for the NAT-TS scenario beyond Baseline, 2020.

Sector	Activity (fuel/product)	BL emission level (tonnes)	Emission reduction beyond BL (tonnes)	Annual reduction costs beyond BL (thousand DKK)
Industrial combustion (other)	Hard coal, grade 1	2 955	-2 438	43 550
	Diesel oil and others incl. biofuel	1 210	-666	26 018
	Waste	47	-28	1 759
	Heavy fuel oil	5 595	-1 156	-11 904
	SUBTOTAL	9 807	-4 288	59 423
Power and heating plants (new)	Waste	1 057	-583	36 258
Power and heating plants (new)	Diesel oil and others incl. biofuel	55	-30	1 180
Power and heating plants (existing)	Diesel oil and others incl. biofuel	10	-6	206
	SUBTOTAL	1 122	-619	37 644
Ind. Process: cement production	No fuel use	534	-178	15 648
	SUBTOTAL	534	-178	15 648
Gas and oil industry; combustion	Heavy fuel oil	558	-244	766
	Medium distillates (diesel, light fuel oil; includes biofuels)	~0	~0	10
	SUBTOTAL	558	-244	776
Ind. Process: paper pulp mills	No fuel use	154	-52	578
Ind. Process: lime production	No fuel use	26	-8	571
Ind. Process: other non–ferrous metals prod.	No fuel use	10	-4	37
Non-industrial combustion	Heavy fuel oil	171	-32	141
Waste: agricultural waste burning	No fuel use	6	-6	0
Waste: open burning of residential waste	No fuel use	4	-4	0
Waste: flaring in gas and oil Industry	No fuel use	16	-3	0
	SUBTOTAL	387	-109	1 327
Transport (maritime activities)		1 670	-905	13 818
Transport (all others)		226	0	0
Other records without changes		6 638	0	-
	TOTAL	14 304	-6 343	128 635

The table shows relevant combinations of sectors and associated activity and gives data for emission reductions and costs beyond baseline. The sectors are grouped into subsectors.

In general GAINS seems to suggest that low-sulphur hard coal comes from natural sources with no associated removal costs, and therefore not figuring in the Table 5.3. – except from hard coal used for the industrial combustion. On the contrary, low sulphur diesel oil and fuel oil are regarded as desulphurised at refinery and thus associated controlling costs.

Process emissions

The method used by IIASA (Cofala & Syri, 1998) calculating process related emission from various industrial processes is subject to uncertainty. The method is to compare the total measured emission from a production activity (both combustion and process emissions) to the hypothetical emission based upon combustion fuel use multiplied with standard emission factors. The difference is then assigned process emissions.

This method is used in the following sub-sectors: oil refineries, coke plants, sinter plants, pig iron – blast furnaces, non-ferrous metal smelters, sulphuric acid plants, nitric acid plants, cement and lime plants and pulp mills.

Since Denmark does not assess emissions separately from the lime production sector, the paper mill sector and non-ferrous metal productions it is difficult to assess the GAINS data regarding those sectors.

However, SO_2 process emissions from the pulp mill sector seem wrong since Denmark has no virgin pulp production. All paper related production is based upon recycling and imported virgin pulp. SO_2 emission from pulp stems from the basic processes transforming wood and other into pulp.

5.4 NAT-TS scenario: SO_2 Control technologies and associated costs

In this section the specific control technologies that GAINS suggests implemented in order to reduce emissions are analysed. Only sector activity combinations at reduction costs above DKK 1 M are assessed.

5.4.1 Industrial combustion

For industrial combustion Table 5.4 shows four sector activity combinations (a-d) and the first row(s) shows which control technologies to be expected in the BL case 2020 as a consequence of the current legislation. The succeeding rows show which control technologies are suggested to be implemented to reduce emission levels to meet TS demands. For each sector/activity combination is shown the resulting emission levels when controlled (not the reduced amounts) and associated cost of implementing the control technology. In the row beneath the separation line is summed “total removed emissions and related costs”, which subtracts the TS levels from the BL levels.

Table 5.4 Industrial combustion sector, four different types of fuel activities (a-d), by 2020.

	Sector Coverage (%)	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
a. Hard coal:				
NAT-BL	100	Low sulphur coal (0.6 %) (rem. eff. 0 %)	2 955	0
NAT-TS	90	Wet flue gas desulphurisation (rem. eff. 85 %)	399	41 149
	10	In furnace control – limestone injection (rem. eff. 60 %)	118	2 401
		Total removed emissions and related costs	2 438	43 550
b. Diesel:				
NAT-BL	35.5	Low sulphur diesel oil – stage 1 (0.2 % S) (rem. eff. 50 %)	859	11 195
	64.5	Low sulphur diesel oil – stage 2 (0.045 % S) (rem. eff. 89 %)	351	67 611
NAT-TS	100	Low sulphur diesel oil – stage 2 (0.045 % S) (rem. eff. 89 %)	544	104 823
		Total removed emissions and related costs	666	26 018
c. Waste:				
NAT-BL	100	No control	47	0
NAT-TS	100	In furnace control – limestone injection (rem. eff. 60 %)	19	1 759
		Total removed emissions and related costs	28	1 759
d. Heavy fuel oil:				
NAT-BL	100	Low sulphur fuel (0.6%) (rem. eff. 81 %)	5 595	98 818
NAT-TS	5	Low sulphur fuel (0.6%) (rem. eff. 81 %)	280	4 941
	95	Wet flue gas desulphurisation (rem. eff. 85 %)	4 159	81 973
		Total removed emissions and related costs	1 156	-11 904

Industrial combustion - hard coal

The BL scenario expects 100 % use of coal with 0.6 % sulphur content. TS suggest 90 % sectoral coverage with wet flue gas desulphurisation (WFGD) and a remaining 10 % covered with limestone injection control technology. Reductions ads up to 2 438 tonnes SO_2 at a cost of DKK 43.6 M, which corresponds reduction cost at DKK 18 000 pr tonnes SO_2 yearly.

Main users of coal in this sector are energy intensive businesses like cement producers and sugar refineries. The suggested desulphurisation measures should be possible to implement at industries of a certain size.

Industrial combustion – diesel oil

The BL scenario expects the use of two stages of diesel oil. Stage 1 (0.2 %) covers 35.5 % while stage 2 (0.045 %) covers 64.5 % of the sector activity combination. According to the TS scenarios all 100 % is controlled by use of stage 2 diesel. This implies reductions at 666 tonnes SO_2 at the cost DKK 26 M - or DKK 39 000 pr tonnes SO_2 yearly.

Already diesel with sulphur content at 0.2 % is not in use as a consequence of Danish tax law. Therefore the suggested emission reduction measure is not realistic.

Industrial combustion - waste

The BL scenario is 100 % uncontrolled. This does change in the TS scenario. Here there is 100 % coverage in the sector with limestone injection desulphurisation technology. This leads to emission reductions at 28 tonnes SO_2 at the costs of DKK 1.8 M or DKK 63 000 pr tonnes yearly.

The assumption that there are no emission controls in the BL case is *not* correct. Governmental order (Danish National Parliament, 2003b) targeting plants combusting waste has set up limits for SO_2 emissions enforcing plants to reduce SO_2 emissions to some extent.

Industrial combustion - heavy fuel oil

In the BL scenario 100 % use of low sulphur oil (0.6 %) is expected. In the TS scenario the coverage is only 5 % while WFGD has taken over the 95 % coverage. This leads to reductions at 1 156 tonnes SO_2 at the *negative* cost of DKK -11.9 M. In other words, the cost of installing WFGD equipments is considered cheaper and more efficient than desulphurising fuel oil at refineries.

Current EU directive sets the maximum sulphur content in heavy fuel oil to 1 %. However, IIASA expects 0.6 % in the BL case as mentioned previously.

Industries using fuel oil shows a broad variety of sizes – small, medium and big. The installation of WFGD technologies may be feasible in some cases. However, it takes expert knowledge to operate and maintain such technologies, which could led to e.g. frequent leakages and non-optimal reductions.

Moreover, since heavy fuel oil is most often used in the industries as supporting fuel and only in units that are not in operation frequently, but e.g. only in case of breakdown in the main power system, it will - in these cases - not be feasible installing control technologies if fuel with low sulphur content is available.

5.4.2 Power and heating plants sector

In the power industry (power and heating plants) reduction costs are very high in comparison with a modest emission reduction. This is especially the case regarding facilities run on waste. The reason for few other reduction suggestions within the sector is that LCPs are strictly controlled as a result of legislation and emission quotas (Bach et al., 2006).

Table 5.5 shows the suggested SO_2 reductions within the power and heating plants sector at costs above DKK 1 M pr year - going from the BL scenario to the TS scenario.

Table 5.5 Power and heating plants (New), as of 2020.

	Sectoral coverage (%)	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
a. Waste:				
NAT-BL	100	In furnace control – limestone injection (rem. eff. 60 %)	1 057	54 397
NAT-TS	37	In furnace control – limestone injection (rem. eff. 60 %)	391	20 126
	63	Wet flue gas desulphurisation (rem. eff. 95 %)	83	70 528
		Total removed emissions and related costs	583	36 258
b. Diesel:				
NAT-BL	35.5	Low sulphur diesel oil – stage 1 (0.2 % S) (rem. eff. 50 %)	39	508
	64.5	Low sulphur diesel oil – stage 2 (0.045 % S) (rem. eff. 89 %)	16	3 066
NAT-TS	100	Low sulphur diesel oil – stage 2 (0.045 % S) (rem. eff. 89 %)	25	4 753
		Total removed emissions and related costs	30	1 180

As the case was with the industrial combustion sector the applicable SO_2 control technologies are either the use of low sulphur fuel, limestone injection or wet flue gas desulphurisation.

In the following the two sector activity combinations are assessed.

Power and heating plants (new)/waste

In the BL scenario 100 % in furnace control with limestone injection is expected. This - not very efficient technology - is in the TS scenario partly replaced by WFGD technology, covering 63 % of the sector. Removed emissions are 583 tonnes at the cost of DKK 36.3 M or DKK 62 000 pr tonnes SO_2 pr year.

In reality the major part of waste combusting plants are equipped with WFGD technologies. The rest have dry or semi-dry flue gas desulphurisation controls installed. Therefore the suggested emission reductions are not relevant.

Power and heating plants (new)/diesel

In the BL scenario the fuel is partly stage 1 (0.2 % S) and partly stage 2 (0.045 % S) low sulphur diesel oil. In the TS scenario all fuel becomes stage 2 (0.045 % S). This implies removal of 30 tonnes SO_2 at the cost DKK 1.2 M or DKK 39 000 pr tonnes SO_2 removed yearly.

As mentioned earlier Denmark only use diesel fuel with very low sulphur content (0.050 %) which implies that this suggestion of SO_2 reduction would have no effect.

5.4.3 Industrial processes – cement production

Table 5.6 shows the cement production. For cement production GAINS operates with emission controls in stage 2 and stage 3 assuming control efficiencies at 70 % and 80 %, respectively.

Table 5.6 Industrial process: cement production, as of 2020.

	Sectoral coverage (%)	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
Cement production/No fuel use*:				
NAT-BL	100	Process emissions – stage 2 SO_2 control (rem. eff. 70 %)	534	7 824
NAT-TS	100	Process emissions – stage 3 SO_2 control (rem. eff. 80 %)	356	23 472
		Total removed emissions and related costs	178	15 648

* This combination includes emission from both the cement production process (no fuel) and related fuel consumption, which is reflected in the emission factor that is used, based on tonnes cement produced.

For the cement production the emission figures covers both the process emissions and the related fuel combustion emissions. In the production process substantial amounts of SO_2 are absorbed in the cement leading to negative IEFs, which could lead to problems in the optimization procedure of the GAINS model. Therefore, according to IIASA (Cofala & Syri, 1998) the emissions from the process and the associated fuel combustion have been added in this "no fuel use" category.

Full implementation (100 %) of "Process emission stage 2 SO_2 control" is expected by 2020 in the BL case, which in the TS scenario is taken over by full implementation of stage 3 SO_2 controls. This leads to SO_2 reductions at 178 tonnes at the cost DKK 15.6 M pr year or reduction costs of DKK 88 000 pr tonnes SO_2.

The cement production sector in Denmark restricts to only one - Aalborg Portland - and according to their Environmental Report (Aalborg Portland, 2008) they had SO_2 emissions at 1 741 tonnes in 2006, which decreased a little in 2007 due to improved control technologies. With – presumably - the same production level up until 2020 at 2.95 mtonnes TCE the SO_2 emissions are expected to be about 1 620 tonnes using the emission factor 0.55 kg pr tonnes TCE, as reported by Aalborg Portland (2008).

This amount is much higher than the GAINS-NAT-BL projection at 534 tonnes SO_2, calculated from an activity level at 1.87 mtonnes cement and an emission factor at 0.285 kg pr tonnes (reflecting removal efficiencies at 70 %). However, the GAINS-NAT scenarios seem to use wrong cement production figures at 1.87 mtonnes TCE instead of 2.95 mtonnes as used in the GAINS-COH scenarios and in the NERI projection (based on energy consumption figures from the Danish Energy Agency). This causes a very low and not realistic SO_2 baseline emission projection.

5.4.4 Maritime transport

Table 5.7 shows reduction suggestions for maritime transport, medium vessels <1000 GRT running on diesel oil and heavy fuel oil, respectively (a and b). The reductions are obtained by lowering the sulphur content of the fuels.

Table 5.7 Maritime transport (medium vessels <1000GRT), as of 2020.

	Sectoral coverage (%)	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
a. Diesel:				
NAT-BL	35.5	Low sulphur diesel – stage 1 (0.2 % S) (rem. eff.: n.a*)	367	4 785
	64.5	Low sulphur diesel – stage 2 (0.045 % S) (rem. eff.: n.a*)	150	28 896
NAT-TS	100	Low sulphur diesel – stage 2 (0.045 % S) (rem. eff.: n.a.*)	233	44 800
		Total removed emissions and related costs	284	11 120
b. Heavy fuel oil:				
NAT-BL	50	No control	887	
	50	Low sulphur oil (0.6 % S) (rem. eff. 70 %)	266	2 698
NAT-TS	100	Low sulphur oil (0.6 % S) (rem. eff. 70 %)	532	5 396
		Total removed emissions and related costs	621	2 698

* The removal efficiency depends on the initial sulphur content of the fuel to be replaced.

Maritime transport (medium vessels <1000GRT)/diesel

The BL scenario projects a combination of low sulphur diesel stage 1 (0.2 % S) and stage 2 (0.045 % S). In the TS scenario it changes solely to stage 2 diesel fuel leading to reductions of 284 tonnes SO_2 at the cost of DKK 11.1 M or reduction costs of DKK 39 000 pr tonnes SO_2 pr year.

The current legislation - as of 2008 - regarding gasoil (~diesel) according to EU directive 2005/33 for the SO_2 emission control area (SECA) region including the North Sea and Baltic Sea, sets limits at 0.1 % sulphur – 1000 ppm. No further legislation is planned, tightening this limit.

A blend of the stage 1 and stage 2 fuels in the BL scenario will lead to an average sulphur content of 0.1 % - fulfilling the SECA norm. The suggestion of a total use of stage 2 fuel with 0.045 % (450 ppm) seems feasible to implement taking into consideration that diesel for road transport is limited to 50 ppm sulphur and as of 2009 – by the EURO-5 – the norm is going to be limited to 10 ppm.

Maritime transport (medium vessels <1000GRT)/heavy fuel oil

In the BL case 50 % no control and 50 % control using low sulphur fuel (0.6 % S) is expected. This expands to 100 % coverage in the TS scenario. The reductions are 621 tonnes SO_2 at the costs DKK 2.7 M or reduction costs of DKK 4 000 pr tonnes SO_2 removed pr year.

MARPOL Annex VI amendments (DNV, 2005) is expected to be adapted ultimo 2008 by the International Maritime Organisation – and as a first step coming into action as of 2010. The amendment sets sulphur content limits at 1 % for heavy fuel oil use inside the SECA region. As of 2015 the percentage limit is lowered to 0.1 % sulphur for the same region. At present (2008) the current sulphur content limit is 1.5 %.

This implies that the suggested control measures - according to the TS scenario as of 2020 using heavy fuel oil in the entire sector with sulphur content at maximum 0.6 % - seems more than realistic since the limit in 2020 probably is going to be 0.1 %, i.e. much lower.

The reason for the choice of a 0.6 % limit in GAINS is because "The desulfurization of heavy fuel oil is considered to be economically competitive only down to a sulphur content of 0.6 percent. This sulphur content can be achieved either through refining North Sea crudes, or by desulfurization at the refinery" according to the RAINS documentation on SO_2 (Cofala & Syri, 1998) – an economic perspective that may be outdated by now, 10 years after.

Implementation of low sulphur heavy oil standards at 0.1 % implies a much higher reduction potential for 2020. Instead of reductions at 621 tonnes SO_2 in the TS scenario case the reductions by switching to 0.1 % sulphur fuel oil would amount 1 064 tonnes SO_2.

5.5 COH-TS scenario: SO_2 reductions and costs

In the previous sections the suggested SO_2 control options of the NAT scenarios have been assessed. In this section the SO_2 control options of the COH scenarios will be assessed.

Table 5.8 shows in which sectors the GAINS' COH-TS scenario suggests emission reductions beyond the BL scenario case. Also the associated costs are shown, which turn out to be almost zero in total (DKK 0.4 M pr year).

Note that only sector/activity combinations that changes from the BL case to the TS case are listed. Refer to Appendix 4 for throughout data on all sector/activity combinations also showing activity and BL and TS scenario emission levels.

Table 5.8 SO_2 emission reductions and costs for the COH-TS scenario beyond BL, 2020.

Sector	Activity (fuel)	BL level (tonnes)	Emission reduction beyond BL (tonnes)	Annual reduction costs beyond BL (thousand DKK)
Industrial combustion (other)	Heavy fuel oil	3 022	1	-9 046
Ind. Process: cement production	No fuel use	840	1	1
Gas and oil industry; combustion	Heavy fuel oil	5 673	3 014	9 456
Waste: agricultural waste burning	No fuel use	6	6	0
Waste: open burning of residential waste	No fuel use	4	4	0
Transport		1 869	0	0
Other records without changes		7 797	0	-
	TOTAL	19 211	3 026	409

As it appears from Table 5.8 the COH scenario suggests SO_2 emission reductions at about 3 ktonnes realised by measures in few sectors activity combinations. The reductions are obtained almost for free since expenses for implementing firm control technologies in the gas and oil industry sector is covered by shifting to more feasible technologies in the industrial combustion sector.

5.6 COH-TS scenario: SO_2 control technologies and associated costs

Table 5.9 shows the accountancy for the only two sector activity combinations that are affected by the COH-TS scenario.

Table 5.9 Gas and oil industry – combustion and industrial combustion, as of 2020.

	Sectoral coverage (%)	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
a. Gas and oil industry – combustion/heavy fuel oil:				
COH-BL	20	No control	3 546	
	80	Wet flue gas desulphurisation (rem. eff.: 85 %)	2 127	37 824
COH-TS	100	Wet flue gas desulphurisation (rem. eff.: 85 %)	2 659	47 279
		Total removed emissions and related costs	-3 014	9 456
b. Industrial combustion/heavy fuel oil:				
COH-BL	100	Low sulphur fuel (0.6 %) (rem. eff.: 81 %)	3 022	53 379
COH-TS	0.1	Low sulphur fuel (0.6 %) (rem. eff.: 81 %)	3	54
	4.9	No control	772	
	95	Wet flue gas desulphurisation (rem. eff.: 85 %)	2 246	44 280
		Total removed emissions and related costs	1	-9 046

Gas and oil industry; combustion/heavy fuel oil

In practice this is the only sector/activity combination that includes actual reductions in the COH-TS scenario. This is simply accomplished by going from 80 % WFGD control in the BL case to 100 % coverage in the TS case. This leads to reductions of 3 014 tonnes SO_2 at the cost of DKK 9.5 M or unit reduction costs of DKK 3 100 pr tonnes SO_2.

To the extent that the heavy fuel oil combustion takes place at land and not offshore the reductions should be feasible.

The suggested reduction potential at 3 014 tonnes is very high. In the NAT scenario only a reduction of 244 tonnes is suggested for this sector (Table 5.3). The reason for the differences is the underlying activity data that is very different for the COH and NAT scenarios, namely 10.1 PJ heavy fuel oil in the COH scenario in contrast to only 0.8 PJ in the NAT scenario.

Industrial combustion/heavy fuel oil

The BL case expects 100 % coverage using low sulphur fuel (0.6 % S). This control is almost eliminated in favour of 95 % coverage with WFGD implementation and about 5 % turning into a not controlled status. This result in about zero reductions, however, bringing *negative* costs of about DKK -9 M. In other words, the sector activity combination benefits from changing to a slightly more efficient and cheaper emission control technology.

This manoeuvre may seem dubious but it may also reflect a feasible option. However, in reality feasibility in implementing WFGD in small industrial businesses may turn out having technical problems in operation and maintenance issues, since it takes experts in the day-to-day management. Moreover, as mentioned in Section 5.4.1 heavy fuel oil is often used infrequently and as supporting fuel, which makes it economical infeasible to implement WFGD technologies when other options are available – in this case low sulphur oil.

5.7 Conclusion on SO_2 reductions suggested in the NAT-TS and COH-TS scenarios

The GAINS-NAT scenarios expect SO_2 emissions at 21 ktonnes by 2020 in BL and suggest reductions of 6 ktonnes to 15 ktonnes meeting the TS environmental and health related targets. Substantial parts of the reductions are to be achieved in the industrial combustion sector but also in the public power and heating plants sector as well as in the maritime transport sector.

The GAINS-COH-TS scenario expects 19 ktonnes SO_2 emissions in the BL case and reductions of 3 ktonnes to 16 ktonnes in the TS case. This more modest reduction is - according to the model - achievable by installing 100 % WFGD control technology in the gas and oil industry (instead of 80 % as is the BL case). From a welfare economic perspective the cost of this implementation can be outbalanced by changes in the industrial sector skipping low sulphur fuel use instead of installing WFGD technologies, which, according to the model, will save costs.

It is important to note that the underlying PRIMES energy scenario driving the COH scenarios seems very much unrealistic in its amount of heavy fuel oil combusted in the gas and oil industry; about 12 times higher than the energy scenario projected by the Danish Energy Agency and used in the NAT scenarios.

Reductions followed by implementation of control technologies - like WFGD on small and medium sized industries (instead of using coal or fuel oil with low sulphur content) seem dubious in their effect. The individual industries may lack expert knowledge to operate these optimally and economically it is not feasible because the fuel oil either serves as supporting fuel or the plants themselves are designated backup functions when primary power systems are down.

Changing diesel oil type from containing 0.2 % sulphur to containing 0,045 % sulphur (450 ppm) is not an option in Denmark as the most commonly used diesel oil already contains a maximum at 0.005 % (50 ppm). Though only enforced in the transport sector it has affected the stationary combustion sector, among others, because of lower taxation on the low sulphur diesel as compared to other diesels.

5.8 Further detailed information

In Appendix 3 and 4 present tables that show detailed extracts from the GAINS model on the BL and TS scenarios listing all sector activity combinations along with activity level data.

6 NH_3 emission reduction and costs

6.1 Overview – NH_3 - ammonia

Table 6.1 shows the NH_3 emission levels in 2000, 2010 and 2020 according to various inventories and scenario projections from NERI and the IIASA GAINS model. The table is divided into three sections.

The first row shows the present NEC ceilings for Denmark in 2010 on NH_3 emissions at 69 ktonnes. The same row shows the emission ceiling for 2020 at 52 ktonnes proposed by the EC, June 2008, though still to be negotiated.

Second row gives the historical inventory figure by NERI for 2000 at 90 ktonnes and the newest current legislation projection for 2010 and 2020 at 65 ktonnes and 55 ktonnes, respectively.

The third and fourth row shows the GAINS model's emission projections within the two alternate scenario groups NAT and COH. The NAT scenarios are based on national reported activity data while the COH scenarios are based on common European activity model data.

The three GAINS scenarios in the 2020 columns are BL, TS and MRR. The latter refers to the maximum reduction obtainable within the GAINS model no matter the costs. Refer to Chapter 2 for a description of these.

Table 6.1 NH_3 emissions: NEC ceilings, NERI inventory and projection data and GAINS model data for the two scenario groups NAT and COH.

	2000	2010	2020	2020	2020
NH_3 emissions [kt]	Historical *	BL	BL	TS	MRR
NEC ceiling		69		52**	
NERI inventory and projections ***	90	65	55		
GAINS-NAT	91	58	53	48	47
GAINS-COH	91	59	53	50	47

*Historical inventory data varies between scenarios because of revision of inventory data.
**EU proposal, June 2008.
***October 2006 (Illerup et al., 2008).

Table 6.2 shows the cost calculations of the GAINS model - both in EUR and DKK. The figures may vary a little when compared to totals in the subsequent analysis because of rounding errors.

Table 6.2 NH_3 reduction costs as calculated by the GAINS model data for the two scenario groups NAT and COH.

	2000	2010	2020	2020	2020
Costs M EUR pr year	Historical	BL	BL	TS	MRR
GAINS-NAT			452	480	552
GAINS-COH			433	485	545
Costs M DKK pr year *					
GAINS-NAT			3 369	3 712	3 913
GAINS-COH			3 228	3 384	3 757

*exchange rate 7.45 from EUR (2000) to DKK.

From Table 6.1 and 6.2 it appears that according to the NAT scenarios, Denmark can reduce NH_3 emissions with 5 ktonnes; from 53 to 48 ktonnes (from BL to TS level) in 2020, which would cost DKK 3 712 M pr year DKK - 343 M more than the BL case. According to the COH scenario a reduction at 3 ktonnes is sufficient, going from 53 to 50 ktonnes at the cost of DKK 3 384 M, which is DKK 157 M more than the BL scenario case.

In June 2008 the EC proposed an emission ceiling of 52 ktonnes NH_3 by 2020, which should be reachable both according to the NERI emission projection for 2020 and the two GAINS scenarios' baseline cases – refer to chapter 10.

6.2 NH_3 control technologies available in GAINS

In the agricultural sector it is possible to reduce NH_3 (ammonia) emissions from the animals with various control technologies. The technologies are listed in Table 6.3 that also shows removal efficiencies that varies for the single control technology depending on the stage of the manure lifecycle, going from animal house over storage to application, or alternatively, manure coming from grazing cows:

Table 6.3 NH_3 control technologies to implement in the agricultural sector.

		Removal efficiency [%]			
Abatement option	Application areas	Animal house	Storage	Application	Grazing
Low nitrogen feed (LNF)	Dairy cows	15	15	15	20
	Pigs	20	20	20	n.a.
	Laying hens	20	20	20	n.a.
	Other poultry	10	10	10	n.a.
Animal house adaptation (SA)	Dairy cows	25	80	n.a.	n.a.
	Other cattle	25	80	n.a.	n.a.
	Pigs	40	80	n.a.	n.a.
	Laying hens	65	80	n.a.	n.a.
	Other poultry	85	80	n.a.	n.a.
Covered storage (CS_low/high)	Dairy cows, other cattle, pigs, poultry [liquid manure]	n.a.	40/80	n.a.	n.a.
Low $_{NH3}$ application (LNA_low/high)	Dairy cows, other cattle, pigs, poultry, sheep [solid waste]	n.a.	n.a.	20/80	n.a.
	Dairy cows, other cattle, pigs [liquid manure]	n.a.	n.a.	40/80	n.a.
Bio filtration (BF)	Pigs, poultry	80	n.a.	n.a.	n.a.
Urea substitution (SUB)	Fertilizer use	80 – 93			
Stripping/adsorbtion	Industry	95			
Manure incineration	Other poultry	~60			

The four reduction technologies suggested in the present BL and TS scenarios are explained in the following - referring to the IIASA documentation on NH_3 emission reductions in RAINS (Klimont and Brink, 2004).

- LNF (low nitrogen feed): Lower nitrogen (N) content of fodder reduces N excretion by animals and consequently NH_3 emissions.
- SA (animal house adaptation): Design modifications of animal houses are possible to prevent or reduce emissions of NH_3 (Klaassen, 1991a; Monteny and Erisman, 1998; UNECE, 1999b). This is achieved if either the surface area of the slurry or manure exposed to the air is reduced or the waste is frequently removed (e.g., flushed with water or diluted with formaldehyde) and placed in covered storage (CS).
- CS-low/high (covered storage): Covered outdoor storage of manure [CS] (available for liquid slurry) distinguishing between:
  - low to medium efficiency [CS_low] options using floating foils or polystyrene, and
  - high efficiency options [CS_high] using tension caps, concrete, corrugated iron or polyester.
- LNA-low/high (low ammonia ($_{NH3}$) application): Several techniques are available to reduce the amount of NH_3 emissions during and after application of manure to arable land or grassland. The NH_3 reduction efficiency is different for solid and liquid manure. The RAINS model distinguishes between:
  - techniques with a high NH_3 removal efficiency, e.g. immediate incorporation, injection of manure, and
  - techniques with a low efficiency, e.g. slit injection, trailing shoe, band spreading. All techniques involve placement of manure in the soils as opposed to spreading it over the surface (broadcasting).
- Bio filtration (BF) – air purification: treatment of air ventilated from animal buildings by applying various techniques such as bio filtra-

tion, bio scrubbing and chemical scrubbers. These techniques can only be applied in animal houses equipped with mechanical ventilation, which is often the case for poultry and pigs. In bio filters and air scrubbers NH_3 in the air is absorbed in the process water then converted into nitrite and then into nitrate.

The single control techniques are often implemented in combinations, causing higher reduction efficiencies.

6.3 NAT-TS scenario: NH_3 reductions and costs

In the following it is to be assessed which specific actions is proposed by the TS scenario in order to reduce NH_3 emissions below BL projection levels in 2020.

Table 6.4 shows emission reductions and associated costs *additional* to the BL scenario, as suggested by the GAINS-NAT-TS, in order to meet the TS targets on environmental and health exposure. The table lists all sectors and associated activity type where changes take place between BL case and TS scenario case.

Note that only sector/activity combinations that changes from the BL case to the TS case are listed. Refer to Appendix 5 for throughout data on all sector/activity combinations, also showing activity and BL and TS scenario emission levels.

Table 6.4 NH_3 emission reductions and costs for the NAT-TS scenario beyond Baseline, 2020.

Sector	Activity (fuel/product)	BL emission level (tonnes)	Emission reductions beyond BL (tonnes)	Annual reduction costs beyond BL (thousand DKK pr year)
Agriculture: livestock – dairy cattle	Dairy cows – liquid (slurry) systems	6 441	-843	73 693
Agriculture: livestock – dairy cattle	Dairy cows – solid systems	496	-76	6 663
Milk yield over 3000 threshold	Dairy cows – liquid (slurry) systems	2 443	-320	-
Milk yield over 3000 threshold	Dairy cows – solid systems	492	-75	-
	SUBTOTAL	9 872	-1 314	0
Agriculture: livestock – pigs	Pigs – liquid (slurry) systems	15 097	-1 141	39 516
Agriculture: livestock – pigs	Pigs – solid systems	5 951	-2 493	217 766
	SUBTOTAL	21 048	-3 634	0
Agriculture: livestock – poultry	Laying hens	875	-35	1 049
Agriculture: livestock - other animals (sheep, horses)	Sheep and goats	231	-8	803
	SUBTOTAL	1 106	-43	803
Gas an oil industry: combustion	Natural gas (incl. other gases)	13	89	-
Gas & oil industry: combustion	Heavy fuel oil	~0	1	-
	SUBTOTAL	13	90	-
Industry: other combustion	Natural gas (incl. other gases)	4	40	-
Industry: other combustion	Hard coal, grade 1	~0	24	-
Industry: other combustion	Heavy fuel oil	12	22	-
Industry: other combustion	Medium distillates (diesel, light fuel oil; includes biofuels)	4	-1	-
Industry: other combustion	Biomass fuels	47	-19	-
	SUBTOTAL	67	66	-
Power/heating plants: exist. other	Natural gas (incl. other gases)	18	-3	-
Power/heating plants: exist. other	Biomass fuels	8	-2	-
Power/heating plants: new	Hard coal, grade 1	40	17	-
Power/heating plants: new	Heavy fuel oil	10	3	-
Power/heating plants: new	Other biomass and waste	27	-6	-
	SUBTOTAL	103	9	-
Transport	Gasoline, diesel and others	518	0	-
Other records without changes		20 459	0	-
	TOTAL	53 186	-4 828	339 489

As seen in the table most of the additional NH_3 reductions to realize - going from the BL case to the TS case - is within the agricultural sector.

A few reductions are suggested in the power and heating plants sector, the gas and oil industry and the industrial sector. However, they are all insignificant reductions, all at zero costs, as the reductions are side effects of control measures targeting the primarily pollutant NO_X from compositional activities. Much more pronounced is the increase of NH_3 emissions in these sectors, which is a result of NO_X reduction technologies that - as a negative side effect - increases NH_3 emissions, among others, from catalytic converters (SCR).

To avoid double counting the costs are therefore only assigned the primarily emission, NO_X (refer to footnote 1 in Section 7.3 for further explanations on the ranking system of pollutants).

6.4 NAT-TS scenario: NH_3 control technologies and associated costs

In the following sub sections the suggested reductions in the TS scenario shall be assessed for sector/activity combinations having additional costs to the BL scenario case above DKK 1 M.

6.4.1 Agricultural sector – cows

Table 6.5 shows suggested reductions in the agricultural sector for cows.

Table 6.5 NH_3 emitting sector/activities, as of 2020 (Cows).

	Sectoral coverage %	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
a. Agriculture: livestock – dairy cattle/dairy cows – liquid (slurry) systems				
NAT-BL	15	Combination of CS_LNA	938	38 409
	5	Low ammonia application (LNA); high efficiency	398	7982
	10	Low ammonia application (LNA); low efficiency	1 094	15 964
	15	Combination of LNF_LNA	1 031	36 636
	55	Combination of SA_LNA	2 980	246 493
NAT-TS	5	Low ammonia application (LNA); high efficiency	398	7 978
	10	Low ammonia application (LNA); low efficiency	1 094	15 956
	30	Combination of LNF_CS_LNA	1 587	102 231
	55	Combination of LNF_SA_LNA	2 519	293 011
		Total removed emissions and related costs	-843	73 693
b. Agriculture: livestock – dairy cattle/dairy cows – solid systems				
NAT-BL	85	Low ammonia application (LNA); high efficiency	395	3 096
	15	Low ammonia application (LNA); low efficiency	101	433
NAT-TS	85	Combination of LNF_LNA_high	334	8 766
	15	Combination of LNF_LNA_low	85	1 427
		Total removed emissions and related costs	-76	6 663
c. Milk yield over 3000 threshold/dairy cows – liquid (slurry) systems				
NAT-BL	15	Combination of CS_LNA	356	-
	5	Low ammonia application (LNA); high efficiency	151	-
	10	Low ammonia application (LNA); low efficiency	415	-
	15	Combination of LNF_LNA	391	-
	55	Combination of SA_LNA	1130	-
NAT-TS	5	Low ammonia application (LNA); high efficiency	151	-
	10	Low ammonia application (LNA); low efficiency	415	-
	30	Combination of LNF_CS_LNA	602	-
	55	Combination of LNF_SA_LNA	956	-
		Total removed emissions and related costs	-320	-
b. Milk yield over 3000 threshold/dairy cows – solid systems				
NAT-BL	85	Low ammonia application (LNA); high efficiency	392	-
	15	Low ammonia application (LNA); low efficiency	100	-
NAT-TS	85	Combination of LNF_LNA_high	332	-
	15	Combination of LNF_LNA_low	85	-
		Total removed emissions and related costs	-75	-

As explained in Section 6.2 the removal efficiencies of the individual control technology varies over the lifecycle of the manure - therefore no indication in the table – refer to Table 6.3 for specifications.

The NH_3 emission reductions in the sector/activity combinations "Milk cattle" are not associated any costs. The reason is that milk cattle is a subdivision of livestock cattle, thus reductions measures targeting the livestock cattle also targets the milk cattle share. Therefore to avoid double counting the costs are only associated to the livestock cattle. The reason for the subdivision is that NH_3 emissions are depending (among others) on the milk yield of the single cow, which is high in Denmark. High yield leads to less NH_3 emissions from manures.

Cows: Agriculture Livestock cattle and Milk cattle

The four sector/activity combinations in Table 6.5 (all involving diary cows) are here assessed together since the suggested control technologies are the same across the sector/activity combinations.

The two liquid systems (a and c) and the two solid systems (b and d) show in pairs the same control technologies implemented with the same sectoral coverage. Liquid and solid systems refers to either treating all manure as liquids or separating manure into liquid and solid fractions featuring maximal control on various emissions (NH_3, N_2O, CH_4).

For all four sector/activity combinations, the emission control efforts going from the BL scenarios case to the TS scenario case is about tightening existing BL scenario controls to more efficient controls in the future of the TS scenario (2020).

For the liquid systems (diary cattle) the reductions are 1 163 (843 + 320) tonnes NH_3 at the cost of DKK 73.7 M, or DKK 63 400 pr tonnes NH_3 pr year as of 2020.

For the solid systems (diary cattle) the reductions are 151 (76+75) tonnes NH_3 at the cost of DKK 6.7 M, or DKK 44 100 pr tonnes NH_3 pr year as of 2020.

6.4.2 Agricultural sector – pigs and laying hens

Table 6.6 shows suggested reductions in the agricultural sector for pigs and laying hens.

Agriculture: Livestock – pigs/pigs – liquid and solid systems

Manure from pigs resembles the case of cows managed in either liquid or solid systems.

For the liquid systems the reductions are 1,141 tonnes NH_3 at the cost of DKK 39.5 M, or DKK 34 600 pr tonnes NH_3 pr year as of 2020. For the solid systems the reductions are 2 493 ktonnes NH_3 at the cost of DKK 217.8 M or DKK 87 400 pr tonnes NH_3 pr year as of 2020.

The control technologies applied is low ammonia application (LNA) in combination with LNF, BF and animal house adaption or CS. LNF is to be questioned if practicable. As by now Denmark has the lowest consumption of nitrogen pr pig.

Table 6.6 NH_3 emitting sector/activities, as of 2020.

	Sectoral coverage (%)	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
a. Agriculture: Livestock – pigs/Pigs – liquid (slurry) systems				
NAT-BL	5	Low ammonia application (LNA); high efficiency	1 817	24 574
	5	Low ammonia application (LNA); low efficiency	2 287	26 134
	40	Combination of LNF_BF_CS_LNA	3 621	1 251 698
	30	Combination of LNF_BF_LNA	3 857	899 239
	20	Combination of LNF_SA_LNA	3 515	617 553
NAT-TS	5	Low ammonia application (LNA); high efficiency	1 817	24 576
	5	Low ammonia application (LNA); low efficiency	2 288	26 136
	70	Combination of LNF_BF_CS_LNA	6 336	2190 454
	20	Combination of LNF_SA_LNA	3 515	617 547
		Total removed emissions and related costs	-1 141	39 516
b. Agriculture: livestock – pigs/pigs – solid systems				
NAT-BL	85	Low ammonia application (LNA); high efficiency	4 803	45 326
	15	Low ammonia application (LNA); low efficiency	1 148	6 370
NAT-TS	65	Combination of BF_LNA_high	1 654	229 616
	20	Combination of LNF_LNA_high	884	23 472
	15	Combination of LNF_LNA_low	919	16 373
		Total removed emissions and related costs	-2 493	217 766
c. Agriculture: livestock – poultry/laying hens				
NAT-BL	57	Low ammonia application (LNA); low efficiency	701	2 001
	43	Combination of SA_LNA	174	5 040
NAT-TS	57	Low ammonia application (LNA); low efficiency	701	2 001
	43	Combination of LNF_SA_LNA	139	6 090
		Total removed emissions and related costs	-35	1 049

Agriculture: Livestock – poultry/laying hens

The reductions in this sector/activity combination are modest - only 35 tonnes NH_3 at the cost of DKK 1 M - or DKK 30 000 pr tonnes NH_3 removed. The reduction is caused by adding LNF to the control portfolio.

6.5 COH-TS scenario: NH_3 reductions and costs

In this section the NH_3 control options of the COH scenarios are assessed. Table 6.7 shows in which sectors (and with associated activities) the GAINS' COH-TS scenario suggests emission reductions beyond the BL scenario case. The associated costs are also shown.

Table 6.7 NH_3 emission reductions and costs for the COH-TS scenario beyond Baseline, 2020.

Sector	Activity	BL emission level (tonnes)	Emission reductions beyond BL (tonnes)	Annual reduction costs beyond BL (thousand DKK pr year)
Agriculture: Livestock – dairy cattle	Dairy cows – liquid (slurry) systems	7 194	-608	48 641
Agriculture: Livestock – dairy cattle	Dairy cows – solid systems	554	-85	7 442
Milk yield over 3000 threshold	Dairy cows – liquid (slurry) systems	2730	-231	-
Milk yield over 3000 threshold	Dairy cows – solid systems	550	-84	-
	SUBTOTAL	*11 028*	*-1 008*	*56 083*
Agriculture: Livestock – pigs	Pigs – liquid (slurry) systems	14 167	-1 071	37 085
Agriculture: Livestock – pigs	Pigs – solid systems	5 585	-1 115	62 591
	SUBTOTAL	*19 752*	*-2 186*	*99 676*
Agriculture: Livestock – poultry	Laying hens	809	-32	970
Agriculture: Livestock – other cattle	Other cattle –liquid/solid system	4 947	~0	-19
Agriculture: Livestock – other animals (sheep, horses)	Sheep and goats	220	0	1
	SUBTOTAL	*5 976*	*-32*	*952*
Gas and oil industry: combustion	Natural gas (incl. other gases)	2	-1	-
Gas and oil industry: combustion	Heavy fuel oil	4	0	-
	SUBTOTAL	*6*	*-1*	
Industry: combustion in boilers	Biomass fuels	5	-2	-
Industry: other combustion	Hard coal, grade 1	~0	1	-
Industry: other combustion	Heavy fuel oil	6	-2	-
Industry: other combustion	Medium distillates (diesel, light fuel oil; includes biofuels)	2	-1	-
	SUBTOTAL	*13*	*-4*	
Power/heating plants: exist. other	Natural gas (incl. other gases)	8	-1	-
Power/heating plants: exist. other	Biomass fuels	123	-25	-
Power/heating plants: new	Hard coal, grade 1	39	17	-
	SUBTOTAL	*170*	*-9*	
Transport		*327*	*0*	*0*
Other records without changes		*15 853*	*0*	-
	TOTAL	53 125	-3 241	156 710

Note that only sector/activity combinations that changes from the BL case to the TS case are listed. Refer to Appendix 6 for throughout data on all sector/activity combinations, also showing activity and BL and TS scenario emission levels.

From the table the same pattern as in the previous section regarding the NH_3 NAT scenarios is seen. Most of the reductions take place in the agricultural sector and a few reductions occur in sectors combusting fuels – appearing as 'side effect' of combustion modification control technologies targeting NO_X reductions.

The total emission reduction demand in the COH-TS scenario is lower than in the NAT-TS scenario and thus also the associated costs of reducing beyond the BL scenario as of 2020.

6.6 COH-TS scenario: NH_3 control technologies and associated costs

The following two tables list the suggested control technologies for sector/activity combinations having associated costs above DKK 1 M.

6.6.1 Agricultural sector – cows

Table 6.8 shows the control technologies suggested implemented in the agriculture reducing NH_3 emission from cows. The following is to be assessed:

Cows: Agriculture Livestock cattle and Milk cattle

For livestock cattle (cows) in liquid manure systems the reductions suggested by the COH-TS scenarios additional to the COH-BL scenario is 839 (608+231) tonnes NH_3 at the cost of DKK 48.6 M pr year or DKK 58 000 pr tonnes NH_3 reduced additional to the BL scenario, as of 2020.

For livestock cattle (cows) in solid systems the reductions suggested is at 169 (85+84) tonnes NH_3 at the cost of DKK 7.4 M pr year or DKK 44 000 pr tonnes NH_3 reduced as of 2020.

Refer to the previous section for a more detailed assessment.

Table 6.8 NH_3 emitting sector/activities, as of 2020.

	Sectoral coverage (%)	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
a. Agriculture: livestock – dairy cattle/dairy cows – liquid (slurry) systems				
COH-BL	15	Combination of CS_LNA	1 047	42 902
	5	Low ammonia application; high efficiency	445	8 915
	10	Low ammonia application; low efficiency	1 222	17 831
	15	Combination of LNF_LNA	1 151	40 921
	55	Combination of SA_LNA	3 329	275 328
COH-TS	5	Low ammonia application; high efficiency	444	8 898
	10	Low ammonia application; low efficiency	1 222	17 835
	30	Combination of LNF_CS_LNA	1 773	114 177
	19	Combination of LNF_SA_LNA	990	115 205
	36	Combination of SA_LNA	2 157	178 423
		Total removed emissions and related costs	-608	48 641
b. Milk yield over 3000 threshold/dairy cows – liquid (slurry) systems				
COH-BL	15	Combination of CS_LNA	397	-
	5	Low ammonia application; high efficiency	169	-
	10	Low ammonia application; low efficiency	464	-
	15	Combination of LNF_LNA	437	-
	55	Combination of SA_LNA	1 263	-
COH-TS	5	Low ammonia application; high efficiency	168	-
	10	Low ammonia application; low efficiency	464	-
	30	Combination of LNF_CS_LNA	672	-
	19	Combination of LNF_SA_LNA	376	-
	36	Combination of SA_LNA	818	
		Total removed emissions and related costs	-231	-
c. Agriculture: livestock – dairy cattle/dairy cows – solid systems				
COH-BL	85	Low ammonia application; high efficiency	441	3 459
	15	Low ammonia application; low efficiency	113	484
COH-TS	85	Combination of LNF_LNA_high	373	9 781
	15	Combination of LNF_LNA_low	96	1 603
		Total removed emissions and related costs	-85	7 442
d. Milk yield over 3000 threshold/dairy cows – solid systems				
COH-BL	85	Low ammonia application; high efficiency	438	-
	15	Low ammonia application; low efficiency	112	-
COH-TS	85	Combination of LNF_LNA_high	370	-
	15	Combination of LNF_LNA_low	95	-
		Total removed emissions and related costs	-84	-

6.6.2 Agricultural sector – pigs and laying hens

Table 6.9 shows control technologies suggested implemented according to the TS scenario in order to reduce NH_3 emissions from pigs and poultry/laying hens.

Table 6.9 NH_3 emitting sector/activities, as of 2020 (pigs and poultry/laying hens).

	Sectoral coverage (%)	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
	a. Agriculture: livestock – pigs/pigs – liquid (slurry) systems			
COH-BL	5	Low ammonia application; high efficiency	1 705	23 061
	5	Low ammonia application; low efficiency	2 147	24 525
	40	Combination of LNF_BF_CS_LNA	3 398	1174 625
	30	Combination of LNF_BF_LNA	3 619	843 869
	20	Combination of LNF_SA_LNA	3 298	579 527
COH-TS	5	Low ammonia application; high efficiency	1 705	23 062
	5	Low ammonia application; low efficiency	2 147	24 526
	70	Combination of LNF_BF_CS_LNA	5 946	2055 590
	20	Combination of LNF_SA_LNA	3 298	579 512
		Total removed emissions and related costs	-1 071	37 085
b. Agriculture: livestock – pigs/pigs – solid systems				
COH-BL	85	Low ammonia application; high efficiency	4 507	42 534
	15	Low ammonia application; low efficiency	1 078	5 978
COH-TS	85	Combination of LNF_LNA_high	3 607	95 736
	15	Combination of LNF_LNA_low	862	15 367
		Total removed emissions and related costs	-1 115	62 591
c. Agriculture: livestock – poultry/laying hens				
COH-BL	57	Low ammonia application; low efficiency	648	1 850
	43	Combination of SA_LNA	161	4 661
COH-TS	57	Low ammonia application; low efficiency	648	1 850
	43	Combination of LNF_SA_LNA	129	5 631
		Total removed emissions and related costs	-32	970

Agriculture: Livestock – pigs/pigs – liquid and solid systems

For pigs production and *liquid* systems the reductions are 1,071 tonnes NH_3 at the cost of DKK 37.1 M or DKK 34 600 pr tonnes NH_3 reduced pr year.

For pigs production and *solid* systems the reductions are 1,115 tonnes NH_3 at the cost of DKK 62.6 M or DKK 56 200 pr tonnes NH_3 reduced pr year.

Agriculture: Livestock – poultry/laying hens

For laying hens livestock production the reductions are 32 tonnes NH_3 at the cost of DKK 1.0 M or DKK 30 300 pr tonnes NH_3 reduced pr year.

6.7 Summing up on NH_3 reductions as suggested by the NAT-TS and COH-TS scenarios

Regarding NH_3 reductions GAINS primarily suggests reductions in the agricultural sector, which is the main emitter of NH_3.

In the baseline case, NERI projects NH_3 emissions at 55 ktonnes in 2020, while the two GAINS BL scenarios projects 53 ktonnes.

Denmark has and aims at advanced NH_3 controls in the agricultural sector. Never the less the GAINS TS scenarios find options for stricter controls. In the NAT-TS scenario it should be possible to achieve reductions at 4.8 ktonnes NH_3 in 2020 beyond the BL scenario. In the COH-TS scenario reductions at 3.2 ktonnes should be sufficient.

By far, the highest reduction potential is in the pig production sector. The reductions are achieved by even more efficient combinations of available measures. This goes for LNF, BF of fluids, LNA, CS and animal house adaptation.

The resulting emission limits, following the NAT-TS and COH-TS scenarios, are 48 ktonnes and 50 ktonnes NH_3, respectively. When compared to the minimum levels possible to obtain in the GAINS model - at 47 ktonnes NH_3 according to the MRR scenario (see Table 6.1) - it is obvious to question if Denmark can tighten the reductions more than already planned for in 2020.

NERI has estimated that some reductions below the 55 ktonnes level as projected by NERI for 2020 will be possible to achieve, however, much depending on the livestock size. The single factor that implies most uncertainty to the 2020 level of NH_3 emissions is the animal quantity. The development may show it feasible to expand the animal numbers regarding both cows and pigs. Regarding milk castles the milk quotas are set free - meaning that if farmers are competitive and can obtain expansion permits the emissions may consequently rise. Also the pig livestock may show feasible to expand. Right now the production decreases and thus the NH_3 related emissions. However, it is expected that the production will rise again because of an increasing demand over the years.

6.8 Further detailed information

Appendix 5 and 6 show detailed extracts from the GAINS model on the BL and TS scenarios listing all sector activity combinations along with activity level data.

7 NMVOC emission reductions and costs

7.1 Overview – NMVOC

Table 7.1 shows the NMVOC emission levels in 2000, 2010 and 2020, according to various inventories and scenario projections from NERI and the IIASA GAINS model.

The first row shows the present NEC ceilings for Denmark in 2010 on NMVOC emissions at 85 ktonnes. The same row shows the emission ceiling for 2020 at 73 ktonnes as proposed by the EC, June 2008, though still to be negotiated.

The second row gives the historical inventory figure by NERI for 2000 at 127 ktonnes and the newest current legislation projection for 2010 and 2020 at 87 ktonnes and 74 ktonnes, respectively.

The third and fourth row shows the GAINS model's emission projections within the two alternate scenario groups NAT and COH. The NAT scenarios are based on national reported activity data while the COH scenarios are based on common European activity model data.

The three GAINS scenarios in the 2020 columns are BL, TS and MRR. The latter refers to the maximum reduction obtainable within the GAINS model no matter the costs. Refer to Chapter 2 for a description of these.

Table 7.1 NMVOC emissions: NEC ceilings, NERI inventory and projection data, and GAINS model data for the two scenario groups NAT and COH.

	2000	2010	2020	2020	2020
NMVOC-emissions [kt]	Historical *	BL	BL	TS	MRR
NEC ceiling		85		73**	
NERI inventory and projections ***	127	87	74		
GAINS-NAT	141	92	71	62	46
GAINS-COH	126	81	62	59	36

*Historical inventory data varies between scenarios because of revision of inventory data.
**EU proposal, June 2008.
***October 2006 (Illerup et al., 2008).

Table 7.2 shows the cost calculations of the GAINS model - both in EUR and DKK. The figures may vary a little when compared to totals in the subsequent analysis because of rounding errors.

Table 7.2 NMVOC reduction costs as calculated by the GAINS model data for the two scenario groups NAT and COH.

	2000	2010	2020	2020	2020
Costs M EUR pr year	Historical	BL	BL	TS	MRR
GAINS-NAT			17	22	317
GAINS-COH			12	9	333
Costs M DKK pr year *					
GAINS-NAT			125	164	2363
GAINS-COH			91	72	2552

* exchange rate 7.45 from EUR (2000) to DKK.

From Table 7.1 and 7.2 it appears that according to the NAT scenarios Denmark can reduce the NMVOC emissions with 9 ktonnes from 71 to 62 ktonnes (from BL to TS level) in 2020, which would cost DKK 164 M pr year or DKK 39 M - additional to the BL case. According to the COH scenario a reduction of 3 ktonnes is sufficient (from 62 to 59 ktonnes and this with no additional costs) and with DKK 19 M gained as compared to the BL case, which will be explained later.

In June 2008 the EC proposed an emission ceiling of 73 ktonnes NMVOC by 2020, which should be reachable both according to the NERI emission projection for 2020 and the two GAINS scenarios' BL cases – this will be analysed in a follow up study.

All data is *exclusive agricultural* NMVOC emissions as the data is not included in the NEC reporting requirements.

7.2 NMVOC control technologies available in GAINS

The relevant control technologies to reduce NMVOC emission are very much dependent on the specific process and can not be categorised. However, there are three main approaches listed beneath along with some few examples:

- Input approach: change or reduce chemicals used as input to the process. E.g. water based dispersion paints (instead of paints containing solvents).
- Process approach: changing process so less pollutant is produced. E.g. process modification.
- Output approach: Emission capture/elimination. E.g. activated carbon adsorption or incineration.

7.3 NAT-TS scenario: NMVOC reductions and costs

The following will assess which specific actions are proposed by TS scenario in order to reduce NMVOC emissions below the baseline projection levels in 2020.

Table 7.3 shows emission reductions and associated costs beyond the BL scenario, as suggested by the GAINS-NAT-TS, in order to meet the TS targets on environmental and health exposure. The table lists all sectors and associated activity type where changes take place between the BL case and TS scenario case.

Note that only sector/activity combinations that change from the BL case to the TS case are listed. Refer to Appendix 7 for throughout data on all sector/activity combinations, also showing activity and BL and TS scenario emission levels.

Some reductions are not assigned any costs in the table. The reason is that NMVOC reductions in these particular sector/activity combinations occur along with other emission reductions with higher priority. For example, in the case of residential fireplaces run on fuelwood, also $PM_{2,5}$ is reduced, and to avoid double counting in the *output presentation* the associated reduction costs are all attributed the PM reductions. However, the reductions are not calculated as gratis as such[1] internally by the model. In this report, reduction measures covering more than one pollutant shall only be assessed with respect to the pollutant with the highest priority.

Another reason why no costs are assigned is when an activity is banned. This is exemplified in the combination "Waste: Agricultural waste burning – no fuel use". Here the model suggests the control technology "ban", which is legislative banning of waste burning and a measure considered without costs.

[1] Quoting IIASA: "For measures that influence more than one pollutant at the same time, the tables presented on this web site report their total costs under the main pollutant. In particular, if a measure reduces (inter alia) NO_X emissions, all costs of that measure are reported under NO_X. Second priority is given to PM, i.e., if a measure reduces PM and other pollutants (but not NO_X), all costs are reported under PM. However, these rules are only applied for the reporting of costs in the GAINS-online version. For the GAINS optimization, costs of multi-pollutant measures are not allocated to a single pollutant, but are associated with the particular measure, for which the simultaneous impacts on several pollutants are accounted (the "technology-based" approach of GAINS)." (IIASA, 2008: GAINS online > VOC > Costs)

Table 7.3 NMVOC emission reductions and costs for the NAT-TS scenario beyond Baseline, 2020.

Sector	Activity	BL emission level (tonnes)	Emission reduction beyond BL (tonnes)	Reduction costs beyond BL (thousand DKK)
Coil coating (coating of aluminium and steel)	Coated surface	50	-39	538
Dry cleaning (new installations)	Textiles (clothing)	95	-38	-2 237
Industrial application of adhesives (use of traditional solvent based adhesives)	Adhesives	830	-585	3 916
Other industrial use of solvents	Emissions of NMVOC	2 643	-1 278	-1 005
Polystyrene processing	Expandable polystyrene beads consumption	377	-158	747
Ind. Process: crude oil & other products – input to petroleum refineries	Crude oil	1 812	-451	1 382
Flexography and rotogravure in packaging, new installed	Printing inks	2 538	-445	314
Rotogravure in publication, new installations	Printing inks	72	-10	28
Manufacturing of shoes	Shoes	361	-252	5 269
Synthetic rubber production	Synthetic rubber	380	-237	2 601
Tyre production	Tyres	506	-379	1 077
Waste treatment and disposal	Emissions of NMVOC	500	-30	89
Wood coating	Coated surface	2 296	-1 417	25 925
Residential/commercial: fireplaces	Fuelwood direct	907	-359	-
Residential/commercial: medium boilers (<50MW) - automatic	Fuelwood direct	342	-240	-
Residential/commercial: single house boilers (<50 kW) - manual	Fuelwood direct	1 504	-1 419	-
Residential/commercial: heating stoves	Fuelwood direct	4 682	-1 177	-
Waste: agricultural waste burning	No fuel use	653	-203	-
Transport sector (HD EURO-V>EURO-VI)		17 055	-440	-
Other records without changes		33 585	0	-
	Total	71 188	-9 157	38 646

As it appears from Table 7.3 high amounts of emissions are suggested to be reduced in the residential sector using fuelwood. Added up the reductions accounts for 3 195 tonnes NMVOC, which is 35 % of the total reductions.

One sector activity combination takes a great share of the costs. The industrial process, wood coating, accounts for 67 % of the costs but only reduces 15 % of the total reductions.

7.4 NAT-TS scenario: NMVOC control technologies and associated costs

In the following the most costly or beneficial sector activity reductions (above DKK 1 M) are assessed in detail.

7.4.1 Industrial production, 1

Table 7.4 shows five sector/activity combinations where the GAINS TS scenario suggests reduction measures implemented accounting for above DKK 1 M each. These reduction measures are assessed in the following.

Table 7.4 NMVOC emitting sector/activities, as of 2020.

	Sectoral coverage %	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
a. Dry cleaning (new installations)/textiles (clothing):				
NAT-BL	100	New generation closed circuit machine (rem. eff. 55 %)	95	6 406
NAT-TS	60	New generation closed circuit machine (rem. eff. 55 %)	57	3 844
	40	Water cleaning (rem. eff. 100 %)	0	326
		Total removed emissions and related costs	-38	- 2 237
b. Industrial application of adhesives (use of traditional solvent based adhesives)/adhesives:				
NAT-BL	5	Activated carbon adsorption (rem. eff. 76 %)	272	2 405
	53,5	Emulsions, water based dispersion paints (rem. eff. 98 %)	218	52 031
	40	Hot melts or UV cross-linking acrylates or electron beam curing systems (solids content 100 %) (rem. eff. 100 %)	0	-6 454
	1,5	No control	340	
NAT-TS	60	Emulsions, water based dispersion paints	244	58 353
	40	Hot melts or UV cross-linking acrylates or electron beam curing systems (solids content 100 %)	0	-6 454
		Total removed emissions and related costs	-585	3 916
c. Other industrial use of solvents/emissions of NMVOC:				
NAT-BL	50	No control	1 750	0
	50	Process modification (rem. eff. 49 %)	893	1 005
NAT-TS	100	Primary measures and new agrochemical products (rem. eff. 61 %)	1 365	0
		Total removed emissions and related costs	-1 278	-1 005
d. Manufacturing of shoes/shoes:				
NAT-BL	95	Good housekeeping and substitution (60 % solvent based and 40 % water based adhesives) (rem. eff. 48 %)	331	-259
	5	No control	33	
NAT-TS	5	Good housekeeping and substitution (60 % solvent based and 40 % water based adhesives) (rem. eff. 48 %)	17	-13
	95	Combination of the above options (rem. eff. 85 %)	95	5 023
		Total removed emissions and related costs	-252	5 269

Dry cleaning (new installations)/textiles (clothing)

It is suggested to partially go from closed circuit dry cleaning machines covering 100 % in the BL scenario to only 60 % coverage in the TS scenario. The closed circuit cleaning machines use solvents emitting NMVOCs. GAINS suggest that 40 % of the sector should shift to water based cleaning and thus reduce emissions with a modest 38 tonnes NMVOC at the *negative cost* of DKK -2.2 M pr year.

In the NMVOC documentation paper (Klimont et al., 2000) it is mentioned that the pattern of dry-cleaning varies with lifestyle from country to country in Europe and over time. Data stems either from CORe INventory AIR emissions (CORINAIR) 1990 inventory or assumptions about per capita demand.

Industrial application of adhesives (use of traditional solvent based adhesives)/ adhesives

GAINS suggest the sector to aim for an emission control below 100 % in the TS scenario and abandon the activated carbon adsorption control that covers 5 % in the BL scenario. The control technology "Hot melts or UV cross-linking acrylates or electron beam curing systems (solids content 100 %)" has 40 % coverage in both scenarios, while "Emulsions, water based dispersion paints" takes the remaining 60 % in the TS scenario.

The reductions are 585 tonnes at the cost of DKK 3,9 M or DKK 6 667 pr tonnes NMVOC pr year.

Other industrial use of solvents/emissions of NMVOC

In this sector/activity combination the TS scenarios suggests bringing the entire sector under emission control going from the process modification measures to the more efficient “Primary measures and new agricultural products”. There is potential for a reduction of 1 278 tonnes NMVOC at the *negative cost* of DKK -1 M.

The sector covers various activities. An example could be “Fat edible and non-edible oil extraction” where primary measures can be “improving the efficiency of the solvent extraction by adding abatement equipment like water scrubbers at the drying plant”. In the specific case GAINS also found the option for “Introduction of new agrochemical products with lower solvent content allowing lower application dosage rates”. (Klimont et al., 2000, p.31).

It is not quite obvious why the measure “Primary measures and new agrochemical products” is associated with any costs. Regarding “new agrochemical products” the costs are probably none because of a market perspective: the industries pay the same money for an improved product. Probably the same rationale goes for “primary measures” like good housekeeping that is assumed autonomously integrated into new installations.

Manufacturing of shoes/shoes

In the BL scenario NMVOC are reduced by good housekeeping and substitution (solvents>water) controlling 95 % of the sector. These controls are also in action in the TS scenario - however, only covering 5 % in identical form- while the remaining 95 % of the sector additionally is controlled by BF technologies. This leads to reductions of 252 tonnes NMVOC at the cost of DKK 5.3 M, which is DKK 20 900 pr tonnes NMVOC pr year.

7.4.2 Industrial production, 2

Table 7.5 shows suggested reductions within the industrial production.

Table 7.5 NMVOC emitting sector/activities, as of 2020.

	Sectoral coverage (%)	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
a. Synthetic rubber production/Synthetic rubber:				
NAT-BL	70	Incineration (rem. eff. 77 %)	133	7 255
	30	No control	247	
NAT-TS	30	Use of 30 % solvent based additives and 70 % low solvent additives (90 % vulcanized rubber and 10 % thermoplastic rubber produced) – (rem. eff. 63 %)	92	1 735
	70	Combination of the above options (rem. eff. 91 %)	50	8 120
		Total removed emissions and related costs	-237	2 601
b. Tyre production/Tyres:				
NAT-BL	100	No control	506	
NAT-TS	100	New process (rem. eff. 75 %)	126	1 077
		Total removed emissions and related costs	-379	1 077
c. Wood coating/Coated surface :				
NAT-BL	4.5	High solids coating systems (20 % solvent content), application process with an efficiency of 35 %	30	-2 970
	11	High solids coating systems (20 % solvent content), application process with an efficiency of 75 %	33	-16 307
	5	Low solids systems (80 % solvent content) and application process with an efficiency of 75 % (electrostatic, roller coating, curtain coating, dipping)	252	-5 731
	5	Medium solids systems (55 % solvent content), application process with an efficiency of 75 %	71	-7 998
	5	Very high solids systems (5 % solvent content), application process with an efficiency of 35 %	7	-5 369
	52	Very high solids systems (5 % solvent content), application process with an efficiency of 75 %	38	-82 423
	17.5	No control	1 865	
NAT-TS	5	High solids coating systems (20 % solvent content), application process with an efficiency of 35 %	30	-2 970
	11	High solids coating systems (20 % solvent content), application process with an efficiency of 75 %	33	-16 306
	5	Low solids systems (80 % solvent content) and application process with an efficiency of 75 % (electrostatic, roller coating, curtain coating, dipping)	252	-5 731
	5	Medium solids systems (55 % solvent content), application process with an efficiency of 75 %	71	-7 998
	5	Very high solids systems (5 % solvent content), application process with an efficiency of 35 %	7	-5 370
	52	Very high solids systems (5 % solvent content), application process with an efficiency of 75 %	38	-82 423
	18	Incineration	447	25 925
		Total removed emissions and related costs	-1 417	25 925
d. Industrial process: crude oil & other products – input to petroleum oil refineries/crude oil:				
NAT-BL	100	Leak detection and repair program, stage I (rem. eff. 34 %)	1 812	-266
NAT-TS	100	Combination of leak detection and other measures (rem. eff. 50 %)	1 361	1 116
		Total removed emissions and related costs	-451	1 382

Synthetic rubber production/synthetic rubber

According to the BL scenario NMVOC will be reduced by incineration of the emissions (thermal after treatment). This is the case for 70 % of the sector while 30 % remains uncontrolled. In the TS scenario 30 % of the sector will be covered by an advanced production technology using a high share of "low solvent additives". Another 70 % of the sector will be controlled by the above mentioned reduction technology and added incineration of emissions.

Reductions are 237 tonnes NMVOC at the cost of DKK 2.6 M or DKK 11 000 pr tonnes NMVOV pr year.

Tyre production/Tyres

Tyre production is not under any control in the BL scenario whilst under 100 % control in the TS scenario by "new process", which is not defined specifically in the GAINS model and documentation.

The reduction potential is 379 tonnes NMVOC at the cost of DKK 1.1 M amounting to DKK 2 800 pr year.

Wood coating/coated surface

This sector (industrial wood coating) includes all kinds of surface coating with paint (GAINS technical code: WOOD_P-SC).

A wide range of control technology variations are implemented in the sector according to the BL scenario and this remains unchanged in the TS scenario. The only change is that the 18 % uncontrolled share of the sector in the BL scenario is controlled in the TS scenario via the incineration technology, which is thermal after treatment of the NMVOC emissions.

This leads to reductions of 1 417 tonnes NMVOC at the cost of DKK 25.9 M or 1 DKK 8 300 pr tonnes NMVOC pr year.

The different solid coating systems reflect various percentages of solvents in use and various application efficiencies.

Industrial process: crude oil & other products – input to petroleum oil refineries/crude oil

The suggested control technology in this sector/activity combination is a combination of leak detection and "covers on oil/water separators" in the TS scenario whereas it is only "leak detected" in the BL scenario.

451 tonnes NMVOC is reduced at the cost of DKK 1.4 M or DKK 3 100 pr tonnes NMVOC yearly.

7.4.3 Residential/commercial sector

Table 7.6 shows NMVOC reductions in the residential sector.

Table 7.6 NMVOC controls for fuelwood combustion, as of 2020.

	Sectoral coverage (%)	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
a. Residential/commercial; single house boilers (<50 kW) -manual/fuelwood:				
NAT-BL	35	No control	1437	n.a.
	45	Biomass single house boiler new (rem. eff. 97 %)	55	n.a.
	20	Biomass single house boiler – pellets (rem. eff. 98.5 %)	12	n.a.
NAT-TS	40	Biomass single house boiler new (rem. eff. 97 %)	49	n.a.
	30	Biomass single house boiler – pellets (rem. eff. 98.5 %)	19	n.a.
	30	Biomass single house boiler - pellets and electrostatic precipitator (rem. eff. 98.5 %)	18	n.a.
		Total removed emissions and related costs	-1419	n.a.
b. Residential/commercial; heating stoves/fuelwood:				
NAT-BL	35	No control	3833	n.a.
	45	Biomass stove improved (rem. eff. 85 %)	739	n.a.
	20	Biomass stove new (rem. eff. 95 %)	110	n.a.
NAT-TS	20	No control	2190	n.a.
	80	Biomass stove improved (rem. eff. 85 %)	1314	n.a.
		Total removed emissions and related costs	-1177	n.a.

Residential/commercial; single house boilers (<50 kW) - manual/fuelwood

According to the TS strategy scenario it is possible to reduce a total of 1 419 tonnes NMVOC. This is done by bringing all fuelwood combustion under control either by new boiler installation or by shifting to fuelwood pellets or a combination of pellets and electrostatic precipitator.

Along with these reductions $PM_{2,5}$, which are considered as the main pollutant to reduce and assign all the technology implementation costs, are also reduced in order not to account the reductions cost double. Therefore the NMVOC reductions are presented as additional and gratis. However, in the mathematical optimisation procedure the sector/activity combination is optimised for all pollutants in one and the same procedure.

Thus the chosen control technologies reflect efforts to control both NMVOC and $PM_{2.5}$. As seen from the removal efficiencies indicated in the table it does not reduce additional NMVOC implementing electrostatic precipitator. The technology basically removes electrostatic charged particles from flue gas.

Never the less, the bottom line is that it is considered possible to reduce 1.4 ktonnes NMVOC - going from the BL case to the TS case.

Residential/commercial; heating stoves/fuelwood

By improving the biomass stoves and leaving only 20 % uncontrolled, as compared to the BL scenario, reductions of 1 177 tonnes NMVOC are possible.

This leaves out the implementation of "new boilers", which - in the somehow outdated NMVOC documentation - is defined as "new boilers with accumulator tank with an average efficiency of 80 %" (Klimont et al., 2000). The possibility of "improved stoves" is not mentioned in the documentation. However, improved stoves are typically existing stoves that have been improved to burn optimally, i.e. use the energy optimal and thus minimising the NMVOC emissions.

Apart from 'antique' stoves it may in many cases be more likely that owners will buy new stoves rather than spending money improving the existing. Therefore, the suggestion of the TS scenario to solely aim for "improved stoves" and not also "new stoves" as in the BL case does not seem quite realistic. However, from a cost minimising perspective it is logical since the costs of improving stoves are lower - according to the GAINS model.

However, as such, for both sector/activity combinations burning fuel-wood, the assumption that 35 % of the sectors will not be under control as of 2020(following the current legislation projection) seems realistic. Therefore the reduction potentials seem correct. The question is only which reduction measure to chose.

7.5 COH-TS scenario: NMVOC reductions and costs

In the previous sections the suggested NMVOC control options of the NAT scenarios - run by the GAINS model - have been assessed. In this section the NMVOC control options of the COH scenarios are assessed.

Table 7.7 shows the sectors, with associated activities, where the GAINS' COH-TS scenario suggests emission reductions beyond the BL scenario case. Also the associated costs are shown.

Note that only sector/activity combinations that changes from the BL case to the TS case are listed. Refer to Appendix 8 for throughout data on all sector/activity combinations, also showing activity and BL and TS scenario emission levels.

Many of the reductions are similar to the ones suggested in the NAT scenario. The reason for this is that some of the underlying activity data are the same for both scenario groups – reported by Danish authorities.

Table 7.7 NMVOC emission reductions and costs for the COH-TS scenario beyond Baseline, 2020.

Sector	Activity	BL emission level (tonnes)	Emission reduction beyond BL (tonnes)	Reduction costs beyond BL (thousand DKK)
Dry cleaning (new installations)	Textiles (clothing)	95	-95	-5 592
Industrial application of adhesives (use of traditional solvent based adhesives)	Adhesives	830	0.01	-3 251
Other industrial use of solvents	Emissions of NMVOC	2 643	-1 278	-1 005
Polystyrene processing	Expandable polystyrene beads consumption	377	-44	0
Ind. Process: crude oil & other products - input to petroleum refineries	Crude oil	1 920	-478	1 463
Flexography and rotogravure in packaging, new installations	Printing inks	2 538	-0.01	-10 287
Rotogravure in publication, new installations	Printing inks	72	-10	28
Synthetic rubber production	Synthetic rubber	380	0	-1 309
Tyre production	Tyres	506	-379	1 077
Waste treatment and disposal	Emissions of NMVOC	1 153	-233	89
Residential/commercial: heating stoves	Fuelwood direct	3 793	-230	-
Transport sector (HD EURO-V>EURO-VI)		10 449	-639	-
Other records without changes		37 440	0	-
	Total	62 196	-3 386	-18 785

Compared to the NAT-TS scenario that needs three times as many reductions beyond BL, the COH-TS scenario suggests reductions in some few sectors, e.g. coil coating, manufacturing of shoes and wood coating are omitted.

Quite strikingly the costs of reducing 3.4 ktonnes NMVOC implies the *negative cost* of DKK -18.8 M – as is the case with the SO_2 reductions (Section 5.5). The main reason for this is that various control measures are optimised resulting in lower costs as compared to the business-as-usual situation in the BL scenario. A typical way of saving money is shifting from use of expensive solvents to cheaper water based compounds.

7.6 NAT-TS scenario: NH_3 control technologies and associated costs

In the following the sector/activity combinations showing costs or savings at DKK 1 M or above are assessed.

7.6.1 Industrial production -1

Table 7.8 shows NMVOC reductions in the industrial sector.

Table 7.8 NMVOC emitting sector/activities, as of 2020.

	Sectoral coverage (%)	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
a. Dry cleaning (new installations)/textiles (clothing):				
COH-BL	100	New generation closed circuit machine (rem. eff. 55 %)	95	6 406
COH-TS	100	Water cleaning (rem. eff. 100 %)	0	814
		Total removed emissions and related costs	-95	-5 592
b. Industrial application of adhesives (use of traditional solvent based adhesives)/adhesives:				
COH-BL	5	Activated carbon adsorption (rem. eff. 76 %)	272	2 405
	54	Emulsions, water based dispersion paints (rem. eff. 98 %)	218	52 031
	40	Hot melts or UV cross-linking acrylates or electron beam curing systems (solids content 100 %) (rem. eff. 100 %)	0	-6 454
	2	No control	340	
COH-TS	5	Activated carbon adsorption (rem. eff. 76 %)	279	2 469
	48	Emulsions, water based dispersion paints (rem. eff. 98 %)	197	47 038
	40	Hot melts or UV cross-linking acrylates or electron beam curing systems (solids content 100%) (rem. eff. 100 %)	0	-6 454
	7	Incineration (rem. eff. 76 %)	353	1 679
		Total removed emissions and related costs	0	-3 251
c. Other industrial use of solvents/emissions of NMVOC:				
COH-BL	50	No control	1 750	0
	50	Process modification (rem. eff. 49 %)	893	1 005
COH-TS	100	Primary measures and new agrochemical products (rem. eff. 61 %)	1 365	0
		Total removed emissions and related costs	-1 278	-1 005

Dry cleaning (new installations)/textiles (clothing)

Contrary to the NAT-TS scenario the COH-TS scenario suggests 100 % water based cleaning in order to reduce NMVOC emissions beyond the BL scenario case with closed circuit machines. The reductions are 95 tonnes NMVOC at the *negative cost* of DKK -5.6 M pr year.

Industrial application of adhesives (use of traditional solvent based adhesives)/ adhesives

In this sector/activity combination no NMVOC emissions are reduced going from BL to TS scenario; however, by shifting the share of sectoral coverage by introducing the incineration technology the TS scenarios results in *negative costs* of DKK -3.3 M.

Other industrial use of solvents/emissions of NMVOC

This sector/activity combination shows a negative cost partly by bringing the entire sector under control and partly by taking use of cost free measures in the TS scenario. The reductions are 1 278 tonnes NMVOC at the *negative cost* of DKK -1 M pr year.

For all three sector/activity combinations please refer to the previous Section 7.3 "NAT-TS scenario: NMVOC reductions and costs" for extended elaborations.

7.6.2 Industrial production - 2

Table 7.9 below shows NMVOC reductions in the industrial sector – the reductions are being assessed in the following.

Synthetic rubber production/synthetic rubber

This sector/activity combination shows *negative costs* partly by bringing a higher share of the sector under control and partly by shifting to control technologies with lower costs. In total no emissions are reduced when going to the TS scenarios; however, the *negative cost* is DKK -1.3 M.

Tyre production/tyres

Quite identical to the NAT scenarios 379 tonnes NMVOC can be reduced at the cost of DKK 1.1 M pr year.

Industrial process: crude oil & other products – input to petroleum oil refineries/crude oil

With same measures and almost the same values as in the NAT scenario case, 478 tonnes NMVOC can be reduced at the cost of DKK 1.4 M pr year.

For all three sector/activity combinations above please refer to the previous Section 7.3 "NAT-TS scenario: NMVOC reductions and costs" for extended elaborations.

Flexography and rotogravure in packaging, new installations/printing inks

This sector/activity combination shows huge cost savings by toning down the very expensive emission control in the BL scenario case "Water based inks, enclosure and incineration – bio filtration" and focusing on the much cheaper "water based inks" control in the TS scenario. In total no emissions are reduced; however, the changing control technologies results in *negative* costs of DKK -10.3 M.

Table 7.9 NMVOC emitting sector/activities, as of 2020.

	Sectoral coverage (%)	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
a. Synthetic rubber production/synthetic rubber:				
COH-BL	70	Incineration (rem. eff. 77 %)	133	7 255
	30	No control	247	
COH-TS	45	Use of 10 % solvent based additives and 70 % low solvent additives (90 % vulcanized rubber and 10 % thermoplastic rubber produced) – (rem. eff. 78 %)	84	4 211
	30	Use of 30 % solvent based additives and 70 % low solvent additives (90 % vulcanized rubber and 10 % thermoplastic rubber produced) – (rem. eff. 63 %)	92	1 735
	25	No control	203	
		Total removed emissions and related costs	0	-1 309
b. Tyre production/tyres:				
COH-BL	100	No control	506	0
COH-TS	100	New process (rem. eff. 75 %)	126	1 077
		Total removed emissions and related costs	-379	1 077
c. Industrial process: crude oil & other products – input to petroleum oil refineries/crude oil:				
COH-BL	100	Leak detection and repair program, stage I (rem. eff. 34 %)	1 920	-282
COH-TS	100	Combination of leak detection and other measures (rem. eff. 50 %)	1 442	1 181
		Total removed emissions and related costs	-478	1 463
d. Flexography and rotogravure in packaging, new installations/printing inks				
COH-BL	60	No control	2 086	0
	40	Water based inks, enclosure and incineration – bio filtration (rem. eff.67 %)	452	22 371
COH-TS	19	No control	659	
	60	Water based inks (rem. eff. 21 %)	1 641	314
	21	Water based inks, enclosure and incineration – bio filtration (rem. eff.67 %)	238	11 770
		Total removed emissions and related costs	0	-10 287

7.7 Summing up on NMVOC reductions as suggested by the NAT-TS and COH-TS scenarios

The departure of the emission reduction efforts is described in the BL scenarios that projects the emission levels as by 2020 based on current legislation developments.

The results of the two reduction scenarios NAT-TS and COH-TS are that the NAT scenario suggests reductions from 71 ktonnes NMVOC to 62 ktonnes as by 2020 and the COH scenario suggest reductions from 62 ktonnes to 59 ktonnes. These emission levels are far above what GAINS shows as the levels obtained by maximal reduction effort at 46 ktonnes and 36 ktonnes, respectively.

It is noteworthy that the COH-TS scenario claims that 3.4 ktonnes NMVOC can be reduced not only free of costs but with economical benefits. However, it does make sense that a baseline scenario that projects current structure to 2020 does not reflect optimal solutions in individual firms and plants. Each company follows its own technological path, building on the past. Therefore - if not enforced by legislation - companies does not always chose what is economically optimal.

Some of the reductions that GAINS suggest are, however, not practicable or realistic. And here a mathematical model about “the real world” shows its limitations. Example given, when the model suggest stoves to be improved in order to reduce emissions instead of simply buying new stoves it follows the logics of cost-efficient optimisation but not the logics of human behaviour. Many people may prefer paying a little extra to get a new stove instead of getting the old one improved. It may even turn out to be more expensive improving and old stove when including the costs of skilled craftsmen.

Nevertheless, al things considered, is seems like the model is right in suggesting quite substantial reduction potentials especially in the sectors using solvents. Apparently the processes can often reduce NMVOC emissions by shifting to agents containing less solvents and more water.

7.8 Further detailed information

In Appendix 7 and 8 tables show detailed extract from the GAINS model on the BL and TS scenarios, listing all sector activity combinations along with activity level data.

8 $PM_{2.5}$ emission reductions and costs

8.1 Overview – $PM_{2.5}$

Table 8.1 shows the $PM_{2.5}$ emission levels in 2000, 2010 and 2020, according to various inventories and scenario projections from NERI and the IIASA GAINS model.

The first row shows the emission ceiling for 2020 at 17 ktonnes as proposed by the EC, June 2008, though still to be negotiated. For 2010 there is no ceiling under the NEC-2010 directive.

The second row gives the historical inventory figure by NERI for 2000 at 22 ktonnes and the newest current legislation projection for 2010 and 2020 at respectively 19 ktonnes and 16 ktonnes (14 ktonnes exclusive agriculture).

The third and fourth row gives the GAINS model's emission projections within the two alternate scenario groups NAT and COH. The NAT scenarios are based on national reported activity data while the COH scenarios are based on common European activity model data.

The three GAINS scenarios in the 2020 columns are BL, TS and MRR. The latter refers to the maximum reduction obtainable within the GAINS model no matter the costs. Refer to Chapter 2 for a description of these.

Table 8.1 $PM_{2.5}$ emissions: NEC ceilings, NERI inventory and projection data, and GAINS model data for the two scenario groups NAT and COH.

	2000	2010	2020	2020	2020
$PM_{2.5}$ emissions [kt]	Historical *	BL	BL	TS	MRR
NEC ceiling				17**	
NERI inventory and projections ***	22	19	16 (14)		
GAINS-NAT (incl. agric. emissions)	25	20	15 (14)	12 (11)	7
GAINS-COH (incl. agric. emissions)	25	20	14 (12)	13 (12)	7

Note: Figures in brackets for 2020 gives PM emissions exclusive the agricultural sector.

*Historical inventory data varies between scenarios because of revision of inventory data.

**EU proposal, June 2008.

***October 2006 (Illerup et al., 2008).

Table 8.2 shows the cost calculations of the GAINS model, both in EUR and DKK. The figures may vary a little when compared to totals in the subsequent analysis because of rounding errors.

Table 8.2 PM reduction costs as calculated by the GAINS model data for the two scenario groups NAT and COH.

	2000	2010	2020	2020	2020
Costs M EUR pr year	Historical *	BL	BL	TS	MRR
GAINS-NAT			120	93 **	344 **
GAINS-COH			113	80 **	294 **
Costs M DKK pr year *					
GAINS-NAT			894 **	693 **	2564 **
GAINS-COH			842 **	596 **	2191 **

*exchange rate 7.45 from EUR (2000) to DKK.

**excluded agricultural sector.

From Table 8.1 and 8.2 it appears that according to the NAT scenarios Denmark can reduce $PM_{2.5}$ emissions – exclusive agricultural sector - with 3 ktonnes from 14 to 11 ktonnes (from BL to TS level) in 2020, which would cost DKK 693 M pr year, which is DKK 201 M *less* than the BL case. According to the COH scenario no reduction is needed; however, changing production methods would result in costs at DKK 246 M *less* than the BL scenario case; this will be explained in the following assessments.

Regarding the agricultural sector - the reason why emission reductions costs are excluded in the totals is that the inferior reductions suggested by the GAINS model in this sector are associated with extremely high costs. Also, there are high uncertainties when estimating PM emissions from this sector. The reduction measures in the agricultural sector are likely to be left out of consideration when settling for the final NEC-2020 emission caps for $PM_{2.5}$.

In June 2008 the EC proposed an emission ceiling of 17 ktonnes NMVOC by 2020, which should be reachable both according to the NERI emission projection for 2020 and the two GAINS scenarios' BL cases – this will be analysed in a follow up study.

8.2 $PM_{2.5}$ control technologies available in GAINS

The relevant $PM_{2.5}$ control technologies to be implemented according to the GAINS model are listed in the following. Please refer to the documentation on PM reduction costs by Klimont et al. (2002) for thorough descriptions:

Stationary sources (power and heating plants, industrial combustion and industrial processes)

- Cyclones.
- Wet scrubbers.
- Electrostatic precipitators (three stages, i.e., one field, two fields, and more than two.
- Fields).
- Wet electrostatic precipitators.
- Fabric filters.
- Regular maintenance of oil fired industrial boilers.
- Two stages (low and high efficiency) of fugitive emissions control measures.

Residential/commercial sector

- Cyclones.
- Fabric filters.
- Regular maintenance of oil fired boilers.
- New type of boiler, e.g., pellets or wood chips.

Non-combustion PM sources/agriculture

- Feed modification (all livestock).
- Hay-silage for cattle.
- Free range poultry.
- Low-till farming, alternative cereal harvesting.
- Good practice (other animals) [generic option].

Other sources

- Good practice, storage and handling.
- Good practice in oil and gas industry, flaring.
- Ban on open burning of waste.
- Good practice in mining industry.
- Spraying water at construction sites.
- Filters in households (kitchen).
- Generic, e.g. street washing.

Mobile sources

- Changes in fuel quality, e.g. decreases in sulphur content. Changes in fuel specifications.
- May provide engine manufactures with greater flexibility to use new emission reduction technologies.
- Changes in engine design, which result in better control of the combustion processes in the engine.
- Flue gas post-combustion treatment, using various types of trap concepts and catalysts to convert or capture emissions before they leave the exhaust pipe.
- Better inspection and maintenance. Examples are: in-use compliance testing, in-service inspection and maintenance, on-board diagnostic systems.

Not all of the above listed control measures are dealt with in this report. The following will assess which specific control actions are proposed by the TS scenario in order to reduce $PM_{2.5}$ emissions below the BL projection levels in 2020.

8.3 NAT-TS scenario: $PM_{2.5}$ reductions and costs

Table 8.3 shows emission reductions and associated costs beyond the BL scenario, as suggested by the GAINS-NAT-TS, in order to meet the TS targets on environmental and health exposure. The table lists all sectors and associated activity types where changes take place between the BL case and the TS scenario case.

Note that only sector/activity combinations that changes from the BL case to the TS case are listed. Refer to Appendix 9 for detailed data on all sector/activity combinations, also showing activity level and BL and TS scenario emission levels.

What clearly appears from the table is that the vast majority of the reductions are suggested to take place in the residential sector. The reductions primarily targets fuelwood combustion in boilers, stoves and fire places and accounts for 72 % of the total reductions.

By optimizing the control technologies the reductions can be obtained by negative costs - in other words with economical savings - leaving out reductions in the agricultural sector.

Reductions in the agricultural sector is omitted

As mentioned above, the reductions suggested for the agricultural sector is left out of assessment in this report and is also excluded in the cost presentations in the NEC-4 and NEC-5 reports (IIASA, 2007a&b).

However, it is to be noted that fuel using combustion activities in the agricultural sector is included in the residential/commercial sector.

Table 8.3 PM2.5 emission reductions and costs for the NAT-TS scenario beyond Baseline, 2020.

Sector	Activity	BL emission level (tonnes)	Emission reduction beyond BL (tonnes)	Reduction costs beyond BL (t DKK)
Agriculture: ploughing, tilling, harvesting etc.	No fuel use	0	0	68 380
Agriculture: livestock - other cattle	No fuel use	38	-4	6 804
Agriculture: livestock - dairy cattle	No fuel use	35	-4	8 588
Agriculture: livestock - pigs	No fuel use	1 077	-108	420 729
Agriculture: livestock - poultry	No fuel use	191	-19	59 431
	Sub total	1 341	-134	563 932
Residential/commercial: fireplaces	Fuelwood direct	868	-167	10 601
Residential/commercial: medium boilers (<50MW) – automatic	Fuelwood direct	469	-427	10 933
Residential/commercial: medium boilers (<50MW) – automatic	Hard coal, grade 1	6	-4	20
Residential/commercial: medium boilers (<1MW) – manual	Hard coal, grade 1	1	0	5
Residential/commercial: single house boilers (<50 kW) – manual	Fuelwood direct	1 405	-1060	28 217
Residential/commercial: single house boilers (<50 kW) – manual	Hard coal, grade 1	~0	0	1
Residential/commercial: heating stoves	Fuelwood direct	4 817	-524	-228 650
Residential/commercial: heating stoves	Hard coal, grade 1	2	0	-54
	Sub total	7 568	-2 182	-178 927
Industry: other combustion, grate firing	Hard coal, grade 1	12	-9	326
Industry: other combustion, pulverized	Hard coal, grade 1	57	-37	511
Industry: other combustion	Biomass fuels	4	0	-154
Industry: other combustion	Other biomass and waste	1	0	-13
	Sub total	74	-46	670
Power/heating plants: exist. other, grate firing	Hard coal, grade 1	6	-3	74
Power/heating plants: exist. other, fluidized bed	Hard coal, grade 1	47	-25	514
Power/heating plants: exist. other, pulverized	Hard coal, grade 1	114	-26	434
Power/heating plants: exist. other	Other biomass and waste	3	0	-13
Power/heating plants: new, fluidized bed	Hard coal, grade 1	60	-33	508
Power/heating plants: new, pulverized	Hard coal, grade 1	257	-140	1 819
Power/heating plants: new	Other biomass and waste	36	0	-114
	Sub total	523	-228	3 222
Ind. Process: basic oxygen furnace	No fuel use	~0	0	-1
Ind. Process: cast iron (grey iron foundries)	No fuel use	231	-193	587
Ind. Process: electric arc furnace	No fuel use	137	-68	34
Ind. Process: crude oil & other products - input to petroleum refineries	No fuel use	44	-30	457
Ind. Process: small industrial and business facilities - fugitive	No fuel use	267	0	-34 724
	Sub total	679	-291	-33 648
Waste: agricultural waste burning	No fuel use	106	-106	65
Waste: flaring in gas and oil industry	No fuel use	101	-5	415
Waste: open burning of residential waste	No fuel use	116	-116	101
	Sub total	323	-227	581
Residential: meat frying, food preparation, BBQ	No fuel use	417	-42	342
Storage and handling: coal	No fuel use	121	0	-1
Transport		2 614	-35	0
Other records without changes		461	0	-
Total excluding agricultural activities		13 658	-3 050	-207 762
Total incl. agricultural activities		15 003	-3 185	356 171

8.4 NAT-TS scenario: $PM_{2,5}$ control technologies and associated costs

This chapter assesses in detail the most costly or beneficial sector/activity reductions (above DKK 1 M). However, as mentioned above excluding the agricultural sector.

8.4.1 Residential/commercial sector

Table 8.4 shows suggested $PM_{2.5}$ reductions in the residential/commercial sector.

Table 8.4 $PM_{2.5}$ emitting sector/activities, as of 2020.

	Sectoral coverage (%)	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
a. Residential/commercial: fireplaces/fuelwood direct:				
NAT-BL	55	No control	273	-
	45	Fireplace improved (rem. eff. 44 %)	595	13 630
NAT-TS	20	No control	216	
	80	Fireplace improved (rem. eff. 44 %)	485	24 230
		Total removed emissions and related costs	-167	10 601
b. Residential/commercial: medium boilers (<50MW) – automatic/fuelwood direct:				
NAT-BL	100	No control	469	-
NAT-TS	80	Medium boilers – pellets (rem. eff. 89 %)	41	7 208
	20	High efficiency deduster for medium boiler using fuelwood (rem. eff. 99 %)	1	3 725
		Total removed emissions and related costs	-247	10 933
c. Residential/commercial: single house boilers (<50MW) – manual/fuelwood direct:				
NAT-BL	35	No control	1 069	-
	45	Biomass single house boiler new (rem. eff. 80 %)	275	24 929
	20	Biomass single house boiler – pellets (rem. eff. 90 %)	61	13 935
NAT-TS	40	Biomass single house boiler new (rem. eff. 80 %)	244	22 159
	30	Biomass single house boiler – pellets (rem. eff. 90 %)	92	20 902
	30	Biomass single house boiler - pellets and electrostatic precipitator (rem. eff. 99 %)	9	24 019
		Total removed emissions and related costs	-1 060	28 217
d. Residential/commercial: heating stoves/fuelwood direct:				
NAT-BL	35	No control	3 030	-
	45	Biomass stove improved (rem. eff. 63 %)	1 441	86 427
	20	Biomass stove new (rem. eff. 80 %)	346	295 872
NAT-TS	20	No control	1 731	-
	80	Biomass stove improved (rem. eff. 63 %)	2 562	153 650
		Total removed emissions and related costs	-524	-228 650

Residential/commercial: fireplaces/fuelwood direct

Fireplaces in the residential sector fuelled directly by fuelwood are supposed to reduce 167 tonnes $PM_{2.5}$ emissions at the cost of DKK 10.6 M or DKK 63 500 pr tonnes $PM_{2.5}$ pr year. The reductions are accomplished by improved fireplaces measures.

The improvements are various measures that improve the burning and filtration - among others non-catalyst inserts.

Residential/commercial: medium boilers (<50MW) – automatic/fuelwood direct

The sector is uncontrolled in the BL scenario case and change to full control in the TS scenario by shifting to pellets fuel and high efficiency dedusters (cyclones fabric filters). $PM_{2.5}$ emissions are reduced by 247 tonnes at the cost of DKK 10.9 M or DKK 44 300 pr tonnes $PM_{2.5}$ emissions removed pr year.

The deduster technology is typically only feasible for larger boilers in the commercial sector. It is presumed that large boilers below 50 MW and above 50 kW are mostly found in the agricultural and horticultural sector, though far from 50MW in sized, more likely about 1-2 MW.

Residential/commercial: single house boilers (<50MW) – manual/fuelwood direct

Single house boilers fed manually by fuelwood is in the BL scenarios case expected to be partly under control by using pellets or changed into new boilers. In the TS scenario the entire sector is under control by the above mentioned controls and also by the advanced combination of pellet fuels and electrostatic precipitators that removes the emissions with 99 % efficiency.

1 060 tonnes $PM_{2.5}$ is removed at the cost of DKK 28.2 M pr year, which equals DKK 26 600 pr tonnes $PM_{2.5}$.

Residential/commercial: heating stoves/fuelwood direct

65 % of the sector/activity combination is expected to be under control in the BL scenarios by two control measures: either improved or new stoves. Still 20 % remains uncontrolled in the TS scenario while the rest, 80 %, have improved stoves.

The TS scenario marks a sort of step back abandoning new stoves and instead improving the existing ones. All in all, this leads to reductions of 524 tonnes $PM_{2.5}$ at the huge *negative cost* of DKK -228.7 M.

This is caused by the strict mathematical optimisation procedure that has chosen the less efficient but much cheaper solution.

It is not quite clear how to define "improved stoves" and "new stoves" besides different removal efficiencies. In the RAINS documentation on PM (Klimont et al., 2002) only two control technologies curbing the $PM_{2,5}$ emissions from stoves burning fuelwood are mentioned. These are non-catalytic and catalytic with removal efficiencies at 63 % and 65 %, respectively. Apparently an even better option "new stoves" has been implemented in the GIANS model leading to 80 % reductions. This option seems to be in line with state of the art in Denmark.

NERI estimates that there is only one way to reduce PM emissions from residential stoves in Denmark and that is to replace old stoves with new stoves. Modernising existing stoves do not seem to be a feasible option. By law (as of 2008) new installed stoves must be approved by authorities thus the new stoves have to be of the modern type having PM emission factors at about 125 g pr GJ, due to combustion modification technology, which reflects the reduction efficiency at about 90 % as compared to old stoves.

Denmark (NERI) operates with an unabated emission factor of 1200 g pr GJ according to the CORINAIR Guidebook (EEA, 2006). GAINS has chosen an unabated emission factor of 791 g pr GJ, which means that the emission level in this sector/activity combination is 66 % of the emission factor used in Danish projections.

In total for the residential/commercial sector NERI in 2006 (Illerup et al., 2008) projected an $PM_{2,5}$ emission level at 11.4 ktonnes for 2020. GAINS projects in the BL case 7.6 ktonnes $PM_{2,5}$ for 2020. If GAINS and the NERI had used the same unabated emission factor (1200 g pr GJ or 791 g pr GJ) the two projections would end at the same level.

8.4.2 Power and heating plants and industrial processes

Table 8.5 shows suggested $PM_{2.5}$ reductions in the power and heating plants sector and the industrial sector.

Table 8.5 $PM_{2.5}$ emitting sector activities, as of 2020.

	Sectoral coverage %	Control technology	Emission level (tonnes)	Annual costs (thousand DKK)
a. Power/heating plants: new, pulverized/hard coal, grade 1				
NAT-BL	40	Electrostatic precipitator: 2 fields (rem. eff. 96 %)	187	22 420
	60	High efficiency deduster (rem. eff. 99 %)	70	36 358
NAT-TS	100	High efficiency deduster (rem. eff. 99 %)	117	60 597
		Total removed emissions and related costs	-140	1 819
b. Ind. process: small industrial and business facilities fugitive/no fuel use				
NAT-BL	50	No control	167	-
	50	Good practice: industrial process - stage 1 (fugitive) (rem. eff. 40 %)	100	83 822
NAT-TS	75	No control	250	-
	25	Good practice: industrial process - stage 2 (fugitive) (rem. eff. 80 %)	17	49 098
		Total removed emissions and related costs	0	-34 382

Power and heating plants: new, pulverized/hard coal, grade 1

This sector/activity combination is controlled in the BL scenario by either electrostatic precipitator or high efficiency deduster technology (e.g. cyclones, fabric filters). The latter is a very efficient technology that covers the entire sector in the TS scenario.

Reductions are at 140 tonnes $PM_{2.5}$ at the cost of DKK 1.8 M or DKK 13 000 pr tonnes $PM_{2.5}$ pr year.

NERI estimates that the BL assumption that only 60 % of the power and heating plants running on coal are equipped with high efficiency deduster in 2020 is not correct, since already by now all plants have the technology implemented. This rule out the possibility of emission reductions in this sector/activity combination.

Industrial process: small industrial and business facilities fugitive/no fuel use

No emissions are reduced by going from the BL scenario to the TS scenario. This is because, thought shifting from good practice – stage 1 to stage 2 - which is double as efficient, the gains are lost by going back from 50 % of the sector under control to only 25 %. This leads to a total of *negative costs* at DKK -34.4 M pr year.

Good practice is simply about avoiding PM emissions by thoughtful management in the production process and naturally it differs from industry to industry. In the documentation (Klimont et al., 2002) it is not further specified what stage 1 and stage 2 implies, and why the costs are quite high.

As touched upon earlier, this is an example of the shortcoming of a mathematical optimisation model that strictly aims at minimising the costs and maximising the reductions. The shift from the BL scenario with 50 % uncontrolled to 75 % uncontrolled in the TS scenario does not seem realistic. However, it is all depending on with which legislative measures it is planned to bring the emissions under control. Decision makers can of course change policy aiming for the 25 % worst polluters in the TS scenario instead of the 50 % worst polluters under control in the BL scenario.

8.5 COH-TS scenario: $PM_{2.5}$ reductions and costs

In this section the $PM_{2.5}$ control options of the COH scenarios will be assessed. Table 8.6 shows in which sectors/activity combinations the GAINS-COH-TS suggests emission reductions beyond the BL scenario case. Also associated costs are shown.

Table 8.6 $PM_{2.5}$ emission reductions and costs for the COH-TS scenario beyond Baseline, 2020.

Sector	Activity	BL emission level (tonnes)	Emission reductions beyond BL (tonnes)	Annual reduction costs beyond BL (thousand DKK pr year)
Agriculture: ploughing, tilling, harvesting	No fuel use	0	0	68 380
Agriculture: livestock - other cattle	No fuel use	38	-4	6 647
Agriculture: livestock - dairy cattle	No fuel use	40	-4	9 593
Agriculture: livestock - pigs	No fuel use	1 010	-101	394 822
Agriculture: livestock - poultry	No fuel use	194	-19	60 398
	Sub total	1 282	-128	539 840
Residential/commercial: fireplaces	Fuelwood direct	703	0	-1
Residential/commercial: medium boilers (<50MW) auto	Hard coal, grade 1	62	-45	217
Residential/commercial: singl. house boilers (<50 kW) manual	Fuelwood direct	1 139	-83	-4 207
Residential/commercial: heating stoves	Fuelwood direct	3 904	0	-200 172
Residential/commercial: heating stoves	Hard coal, grade 1	18	0	-581
	Sub total	5 826	-129	-204 744
Industry: combustion in boilers, fluidized bed	Hard coal, grade 1	0	0	-1
Industry: combustion in boilers	Biomass fuels	70	-56	93
Industry: other combustion, grate firing	Hard coal, grade 1	0	0	-2
Industry: other combustion, pulverized	Hard coal, grade 1	2	0	-1
Industry: other combustion (used in emission tables)	Derived coal	0	0	-4
	Sub total	72	-56	84
Power/heating plants: exist. other, grate firing	Hard coal, grade 1	4	0	-10
Power/heating plants: exist. other, fluidized bed	Hard coal, grade 1	32	0	-39
Power/heating plants: exist. other, pulverized	Hard coal, grade 1	78	0	-16
Power/heating plants: new, fluidized bed	Hard coal, grade 1	58	0	-57
Power/heating plants: new, pulverized	Hard coal, grade 1	247	0	-124
	Sub total	419	0	-246
Ind. Process: aluminium production - secondary	No fuel use	22	0	-1
Ind. Process: cast iron (grey iron foundries) (fugitive)	No fuel use	27	0	-1
Ind. Process: cast iron (grey iron foundries)	No fuel use	189	-116	-443
Ind. Process: cement production	No fuel use	689	2	-1
Ind. Process: electric arc furnace	No fuel use	119	-59	29
Ind. Process: small industrial and business facilities - fugitive	No fuel use	265	0	-34 481
	Sub total	1 311	-173	-34 900
Waste: agricultural waste burning	No fuel use	106	-106	65
Waste: open burning of residential waste	No fuel use	116	-116	101
	Sub total	222	-222	165
Storage and handling: coal	No fuel use	121	0	-1
Transport		2 620	-51	0
Other records without changes		1 352	0	-
	Total excl. agriculture	12 292	-630	-239 641
	TOTAL incl. agriculture	13 573	-758	300 199

Note that only sector/activity combinations that changes from the BL case to the TS case are listed. Refer to Appendix 10 for throughout data on all sector/activity combinations, also showing activity and BL and TS scenario emission levels.

According to the COH-TS scenario reductions at 630 tonnes $PM_{2.5}$ will be possible at the *negative cost* of DKK -239.6 M obtained by shifting to more efficient and cheaper control technologies as compared to the technologies expected in the BL scenario case.

The reduction demand going from the BL scenario to the TS scenario is very modest and no sector/activity combinations show addition reduction costs above DKK 1 M. On the contrary, three combinations show high negative costs. These are Residential sector, single house boilers, and Residential sector, heating stoves, both fuelled directly by fuelwood. The third one is Industrial process: small industrial and business facilities – fugitives based on no fuel use.

8.6 COH-TS scenario: $PM_{2,5}$ control technologies and associated costs

All the relevant three sector/activity combinations are assessed in the previous Section 8.4 "COH-TS scenario: $PM_{2,5}$ control technologies and associated costs". Therefore, refer to this section for further details.

The bottom line of the reduction efforts reflected in the COH-TS scenario is that by changing to more efficient and cheaper control technologies it is possible to optimize the emitter's reductions efforts leading to economic benefits in some sectors.

8.7 Summing up on $PM_{2.5}$ reductions as suggested by the NAT-TS and COH-TS scenarios

It is crucial whether the agricultural sector is with or within the NEC-2020 reduction commitments when it comes to determine if the reduction efforts are associated with costs or savings. As already stated the agricultural sector is omitted assessment in this report because it is expected that the sector will not be included in the NEC-2020 commitments regarding $PM_{2.5}$.

The necessary reductions changing from the COH-BL scenario to the COH-TS scenario are quite few, only accounting for 630 tonnes $PM_{2.5}$, and these reductions can be achieved at *negative* costs at DKK -240 M yearly as of 2020.

The reductions in the NAT-TS scenario at 3.1 ktonnes are according to GAINS achievable by optimising the control technologies implementation. Here the vast majority of the reductions have to take place in the residential sector combusting fuelwood in boilers, fireplaces and stoves. This is in line with the emerging realisation that these sources are very problematic emitters of $PM_{2.5}$ and NMVOC.

Because of the consistent chimney control system in Denmark any legislation enforcing improvement or renewal of fuelwood combusting stoves, ovens and fireplaces, would be practicable and quite efficient.

8.8 Further detailed information

Appendix 9 and 10 present tables with detailed extracts from the GAINS model on the BL and TS scenarios, listing all sector/activity combinations along with activity level data.

9 Scenario drivers: Energy projections

9.1 The two GAINS energy scenarios

The various energy scenarios in play in Denmark serving as input to the GAINS model are assessed in this chapter.

It is important to note that energy scenarios are different to the emission scenarios. When first established, the energy scenarios projecting energy use up until 2020 where fixed and served as static input to the GAINS model that ran the emission scenarios. In addition it reduced the emission output by implementing various control technologies. However, since the energy input data is the most determinant factor for the resulting emission level the emission scenarios are often characterised by the features of the energy projections.

9.1.1 The National reporting Energy scenario (NAT)

In 2006 the Danish authorities, DEA, EPA and NERI reported the Danish energy inventory and projection data to the GAINS activity database. The energy projections reported by individual countries served as input drivers for the GAINS scenario group "NAT" containing among others the NAT-BL and NAT-TS scenarios, which are assessed in this present report.

The energy projection data reported to IIASA were similar to the official energy strategy projection as of April 2005. However, since the categorisation system in GAINS and in the Danish Energy projections by DEA is different it has caused some difficulties trying to place the energy data in the right sectors.

9.1.2 The PRIMES Energy scenario (COH)

Previously, when generating scenarios, IIASA had entered activity projection data based on inventory data from Eurostat and other European statistical sources and common European projections performed by the PRIMES model. The advantage of establishing a common European dataset on energy activities is to secure consistency – consistency in the projection method and consistency in import-export balances.

For the GAINS emission scenarios group named "Coherent" (COH in this report) the PRIMES model established a normative energy scenario not only projecting current legislation but also including current policy on CO_2 emission reductions and a minimum share of renewable energy.

The norms set up in the energy scenario driving the COH emission scenarios were not quite the same as the ones set up in the upcoming EU Climate and Energy Package, however, similar.

The EU Climate and Energy Package has two main goals for the EU in general: 20 % CO_2 emission reduction by 2020 as compared to the 1990 level and 20 % renewable energy in the energy portfolio, including 10 % share of biofuels. For sectors not covered by the European Emission Trading system (ETS) (transport, building, agriculture, waste etc.) a burden share has been implemented; here Denmark has to reduce CO_2 with 20 % in 2020 as compared to 2005 and increase its share of renewable energy to 30 %.

The COH energy scenario was developed before the adaptation of the EU Climate and Energy Package and is perceived as an explorative assessment of the implications of the upcoming package. Here the individual countries have CO_2 emission reduction targets at 20 % while a 17 % share of renewable energy in 2020 as compared to 1990 levels (IIASA, 2007a).

9.2 Comparison between energy projections

Figure 9.1 shows various Danish energy projections along with the energy projections used as drivers for the GAINS emission scenarios. The energy use is accounted as total primary energy supply, which reflects the all over energy supply (adjusted for net trade and stock changes) before conversion and reefing processes.

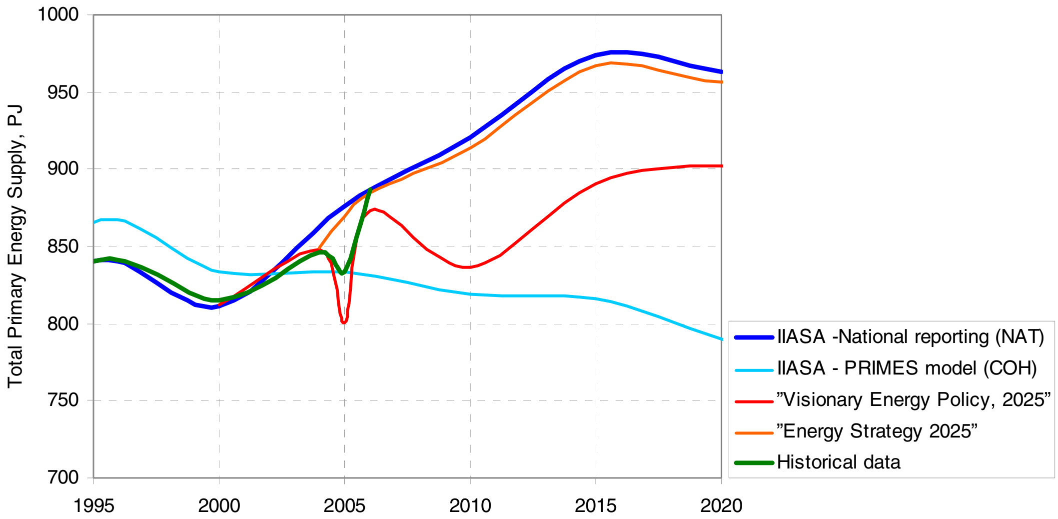

Figure 9.1 Various Danish energy projections compared to energy projections used in GAINS.

The orange curve illustrates the Danish energy projection "Energy Strategy, 2025" from April 2005 while the red curve illustrates the newer Danish energy projection "Visionary Energy Policy, 2025" from October 2006.

The dark blue curve shows the energy activity data used as driver in the GAINS-NAT scenarios. This data is reported by Danish authorities and is identical to the Danish "Energy Strategy 2025" projection mentioned above (orange curve). The green curve shows the development in actual historical energy data up until 2006. Finally the light blue curve shows the course of the PRIMES COH energy scenario.

The PRIMES energy projection is reflecting the situation after including the EU Climate and Energy Package in current legislation and marks quite substantial reductions in energy consumption as compared to the two Danish projections.

Projections as of 2008

Figure 9.2 includes energy projections published in 2008. There is a new projection from PRIMES, named PRIMES 2007 and it is used in the NEC-6 projections. Furthermore, a revised basis projection from DEA from April 2008 (ENS, 2008) and an "Energy Agreement Projection" from September 2008 (ENS, 2008) exist. The latter builds upon the norms of the EU Climate and Energy Package while the former is designated a basic projection (before the effects of the EU Climate and Energy Package).

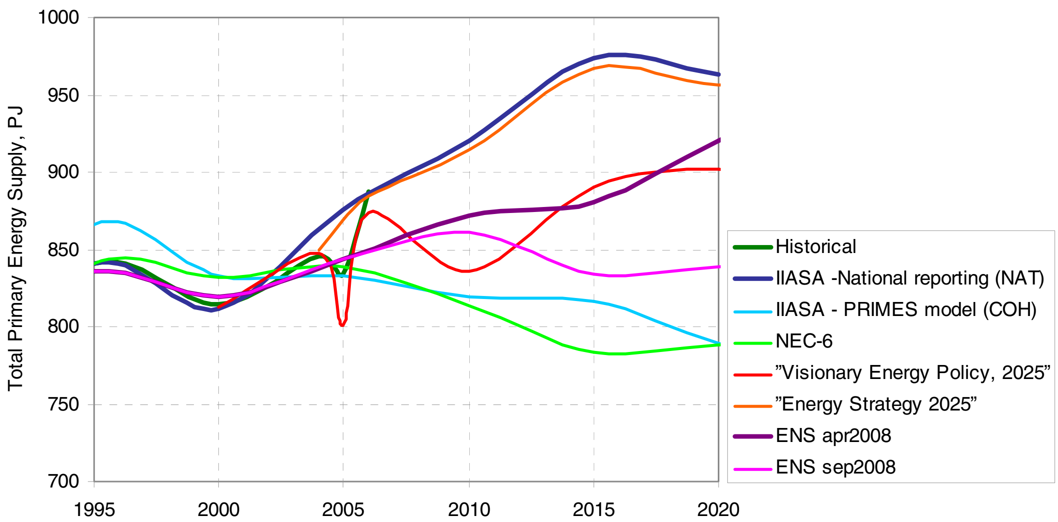

Figure 9.2 Various Danish energy projections compared to energy projections used in GAINS, included newer projections.

From the table it is seen that the "ENS apr 2008" projection (purple) ends at the same level as the previous projection "Visionary Energy Policy" (red) however, showing a more stable development over the years. The newest projection "ENS sep2008" runs quite stable and ends in 2020 at the same level as in 2005.

The NEC-6 energy projection "PRIMES 2007" ends at the same level in 2020 as the COH projection, however, it reaches the level already in 2015.

Projections divided on energy sectors

Table 9.1 beneath lists the data from the various projections divided into energy sectors.

Table 9.1 Various energy projections dived into energy sectors.

	IIASA						Danish Energy Agency					
Origin	Danish reporting (“Energy Strategy 2025”)		PRIMES projections				Danish projection (as of 2007)		Danish projections (as of 2008)			
Name	NAT		COH		PRIMES 2007		”Visionary Energy Policy, 2025”		April 2008		September 2008	
Peta Joule	2000	2020	2000	2020	2000	2020	2000	2020	2000	2020	2000	2020
Biomass, waste	70	122	72	113	73	203	72	143	73	150	73	190
Coal	165	114	167	89	166	133	165	129	171	188	171	119
Diesel	152	174	161	168	158	168	146	153	146	147	146	131
Electr. import	2	-8	2	-12	2	10	2	-8	0	-1	0	-1
Gasoline, LPG	125	146	125	117	126	128	131	141	131	145	131	140
Heavy fuel oil	72	54	89	43	92	33	72	48	75	43	75	33
Natural gas	205	315	201	221	199	65	202	247	202	216	202	181
Nuclear	0	0	0	0	0	0	0	0	0	0	0	0
Other renewable	19	45	16	52	16	49	19	46	19	29	19	43
Sum	810	962	833	791	832	788	810	899	817	918	817	837

Based on the table data Figure 9.3 shows primarily the energy supply for 2020 as projected by DEA and the PRIMES model – divided into main fuel categories. In the greater lines the patterns of each projection are the same. However, especially regarding natural gas the “NEC-6” projection falls very low.

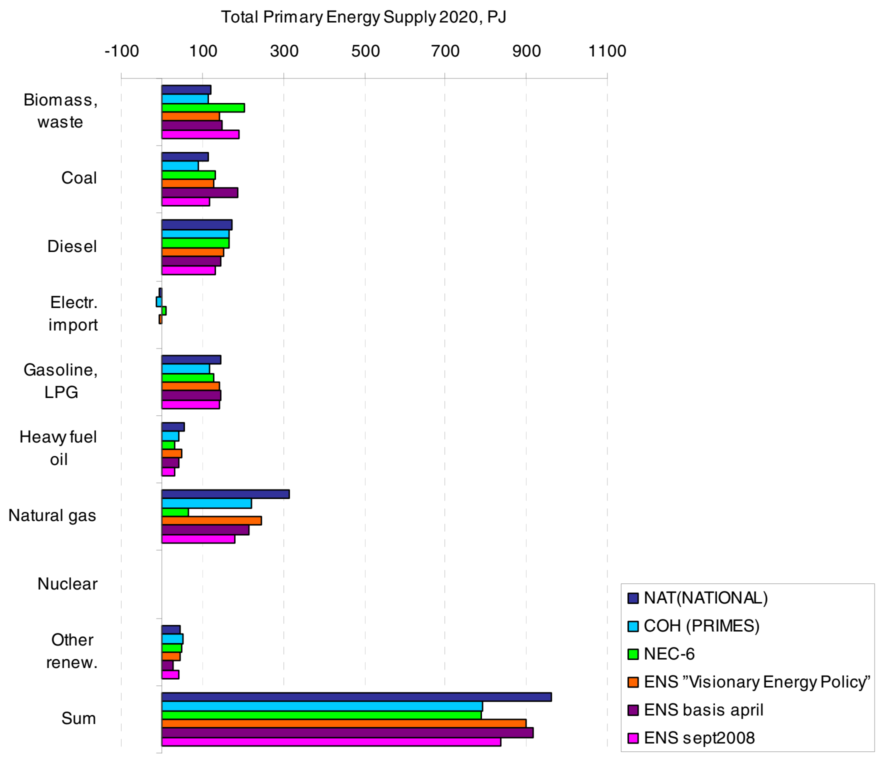

Figure 9.3 Energy projections for 2020, divided into main fuel categories.

10 EU proposal, June 2008

This chapter briefly assesses the new emission reduction scenario from IIASA (published in the NEC-6 report by IIASA, 2008f), which led to the EU proposal of June 2008 on NEC-2020 emission ceilings.

IIASA writes in the NEC-6 report (IIASA, 2008f) that the new scenario is an "examination of cost-effective emission ceilings for an energy projection that reflects the recent EU Climate and Energy Package of the EC. This scenario assumes that the national targets on greenhouse gas emissions for the non-ETS sources are met in each member state and that there is full trade of renewable energy within the EU-27. It is further assumed that Clean Development Mechanism/Joint Implementation (CDM/JI) is implemented so that carbon prices in both the ETS and non-ETS sectors do not exceed EUR 30 pr tonnes CO_2."

In short, the EC has proposed the EU Climate and Energy Package, which sets up targets for 2020. The CO_2 emissions shall be reduced by 20 % as compared to 1990 (and 30 % if comprehensive international climate change agreement succeeds). The general share of renewable energy shall be at 20 %. The share of biofuels in the transport sector shall be at 10 %. Moreover, it is the intention that the energy level should be reduced with 20 % as of 1990 by increased energy efficiency (EC, 2008). For stationary combustion sectors the ETS is in action, meaning that the member states can buy and sell deficit or surplus emission permits. For sectors not subject to ETS, which goes for sectors like transport, waste, buildings agriculture etc., a burden sharing agreement has been established. Here, Denmark is committed to CO_2 emission reduction targets at 20 % as compared to 2005 and a share of renewable energy at 30 %.

10.1 EU proposal energy projection "PRIMES 2007"

The energy projection that serves as input to the EU proposal scenario is named PRIMES 2007. IIASA writes in the NEC-6 report (IIASA, 2008f) "the PRIMES model projects the EU-27 total primary energy consumption to increase by 10 % between 2000 and 2020 (compared to 17 % for the case without the EU Climate and Energy Package). Most markedly, biomass and other forms of renewable energy will increase by 235 % and 65 %, respectively, and coal consumption will decline by 10 %. Transport fuels would grow by only 8 % (compared to 16 %), and natural gas would see lower growth rates too. As a consequence, this projection sees CO_2 emissions of the EU-27 declining by 11 % between 2000 and 2020. Part (six % points of the 20 % in GHG reduction in 2020 compared to 1990) would come from reductions outside the EU through CDM/JI limiting the reduction in the EU's GHG emissions to around 15 % below 1990 level. Since mitigation measures for non-CO_2 GHG emissions are more cost-effective than those for CO_2, the cut in total CO_2 emissions (compared to 1990) amounts to around 11 %. Energy related CO_2 emissions are reduced by about 12 % in 2020 compared to 1990".

Table 10.1 shows basic projection assumptions for the PRIMES 2007 energy scenario for Denmark (IIASA, 2008f).

Table 10.1 Assumptions on population development and economic growth of the PRIMES 2007 baseline projection.

	Population (M people)		GDP pr capita (EUR pr person)		Increase in GDP
	2000	2020	2000	2020	2000 to 2020
EU proposal	5.3	5.5	36 553	50 873	44 %

10.2 Comparison between two PRIMES energy related emission scenarios

Table 10.2 lists the emissions levels and associated reduction costs for the two reduction scenarios COH and EU proposal. The emissions and costs are divided into the selected nomenclature for air pollution (SNAP) categories. As shown in Chapter 9 the energy input to the two scenarios is at the same level and the COH scenarios have been assessed throughout this report's Chapter 4 to Chapter 8.

Note that the reduction *costs* for PM are not in the same magnitude as in previous tables throughout the report. In previous tables the figures reflects the cost of reducing only the $PM_{2,5}$ fraction of total suspended particulate matter (TSP) while the figures in this chapter reflect the costs of reducing all TSP. No other figures were available. The reason is probably that it is associated with high uncertainty dividing PM reduction costs into the TSP and 2,5 fractions.

Emission differences

Regarding NO_X, SO_2 and NH_3 the total emissions for 2020 are about the same in both scenarios. Also in detail, when comparing the SNAP sectors, the emission levels are about the same.

Regarding NMVOC and $PM_{2.5}$ there are bigger differences. For NMVOC the emission levels have gone up in most of the SNAP sectors. For $PM_{2.5}$ especially the SNAP 2 sector "Non-industrial combustion" is the cause of higher emission levels in the EU proposal scenario.

Cost differences

In total, the annual reduction costs as of 2020, obtaining the EU proposal scenario's emission levels, are slightly lower than in the COH scenario – about 3 %. This is especially caused by lower reduction costs for the NO_X emissions - especially in the transport sector and also for PM in the agricultural sector. The latter saving is balanced out by the highest increase in costs, which occurs for PM in the non-industrial combustion sector.

Table 10.2 Comparison between COH scenario and EU proposal scenario, for 2020.

	SNAP category	COH (ktonnes)	EU proposal (ktonnes)	COH (M DKK pr year)	EU proposal (M DKK pr year)
NO_X	01: Combustion in energy and transformation industries	20	20	201	235
	02: Non-industrial combustion plants	7	7	1	1
	03: Combustion in manufacturing industry	6	4	39	29
	04: Production processes	1	2	35	12
	07: Road transport	20	22	2 314	1 875
	08: Other mobile sources and machinery	34	33	1 029	961
	09: Waste treatment and disposal	0	0		
	10: Agriculture	0	0		
	NO_X Sum	87	88	3 618	3 111
SO_2	01: Combustion in energy and transformation industries	7	7	453	549
	02: Non-industrial combustion plants	2	2	139	119
	03: Combustion in manufacturing industry	5	5	104	75
	04: Production processes	0	0	1	1
	07: Road transport	0	0	486	594
	08: Other mobile sources and machinery	2	1	216	207
	09: Waste treatment and disposal	0	0		
	10: Agriculture	0	0		
	SO_2 Sum	16	16	1 398	1 545
NH_3	01: Combustion in energy and transformation industries	0	0		
	02: Non-industrial combustion plants	0	0		
	03: Combustion in manufacturing industry	0	0		
	07: Road transport	0	0		
	08: Other mobile sources and machinery	0	0		
	09: Waste treatment and disposal	1	1		
	10: Agriculture	48	50	3 385	3 431
	NH_3 Sum	50	52	3 385	3 431
NMVOC	01: Combustion in energy and transformation industries	3	4		
	02: Non-industrial combustion plants	6	10		
	03: Combustion in manufacturing industry	0	0		
	04: Production processes	2	2	1	
	05: Extraction and distribution of fossil fuels and geothermal energy	12	12	106	103
	06: Solvent and other product use	24	26	-35	-19
	07: Road transport	6	9		
	08: Other mobile sources and machinery	4	8		
	09: Waste treatment and disposal	0	1		
	10: Agriculture	0	0		
	NMVOC Sum	59	73	72	84
$PM_{2.5}$ *	01: Combustion in energy and transformation industries	1	1	224	347
	02: Non-industrial combustion plants	6	10	190	602
	03: Combustion in manufacturing industry	1	1	44	51
	04: Production processes	0	0	66	97
	05: Extraction and distribution of fossil fuels and geothermal energy	0	0	51	51
	07: Road transport	1	1		
	08: Other mobile sources and machinery	1	1		
	09: Waste treatment and disposal	1	1		1
	10: Agriculture	1	1	566	25
*emissions: $PM_{2,5}$; costs: PM_{TSP}	$PM_{2,5}$ Sum	13	17	1 142	1 175
	TOTAL all five pollutants			9 615	9 347

Taking the above mentioned differences into account the assessment in this report of the COH scenario founds a fine basis for assessing the emission reduction suggestions of the EU proposal scenario.

Feasibility of reaching proposed emission ceilings

Table 10.3 compares emission levels of various GAINS emission reduction scenarios with Danish emission projections as of 2006 (Illerup et al., 2008).

Table 10.3 Thematic Strategy scenario emission reductions of the GAINS model.

Unit: ktonnes	NO_X	SO_2	NH_3	NMVOC	$PM_{2.5}$
GAINS-NAT	89	15	48	62	12
GAINS -COH	87	16	50	59	13
GAINS-EU proposal	88	16	52	73	17
NERI (2006)	115	21	55	74	16

The proposed emission ceilings for NMVOC and $PM_{2,5}$ - according to the EU proposal - at respectively 73 ktonnes and 17 ktonnes seem feasible when compared to the projections of NERI (Illerup et al., 2008) at 74 ktonnes and 16 ktonnes (refer to Table 2.1).

Moreover, the proposed NH_3 ceiling at 52 ktonnes as compared to 55 ktonnes projected by NERI does not seem infeasible to reach.

The proposed SO_2 emission ceiling at 16 ktonnes seems difficult to reach, when compared to the NERI projection at 21 ktonnes. However, taking into account the effect of the EU Climate and Energy Package it may be possible to reach the level.

Finally, the proposed NO_X emission level at 88 ktonnes is 23 % below the latest NERI projection at 115 ktonnes. It is evident that there are reduction potentials in Denmark - both in the LCP sector and others and as in the case with SO_2 the effects of the EU Climate and Energy Package may ease the reductions. However, still both the SO_2 and NO_X emission levels are hugely dependent and sensitive to the total energy consumption level, which is 6.2 % higher in the latest Danish energy projection as compared to the PRIMES 2007 energy projection.

11 Conclusion

Introduction

The execution of emission scenarios, which are based on the NEC-2020 negotiations, is an ongoing process. The newest available scenarios from 2007 when the study forming this report began is described in the reports NEC-4 and NEC-5 (IIASA, 2007 a; b). Therefore, this report focuses on emission reduction scenarios from these two reports.

A new report, NEC-6, was published in June 2008, basing the proposal of the EC for emission reduction targets as of 2020. The scenarios computed for this proposal was based on a coherent PRIMES energy scenario covering all European countries. As a further step a new scenario based on national reporting on projected activity levels (energy, agriculture, processes etc.) is expected by the end of 2009.

In other words, the main part of this report reflects an intermediate step in the ongoing NEC-2020 negotiation process and in the related scenario executions by IIASA with the GAINS model. However, in order to be up to date the previous Chapter 10 briefly assesses the new data of the NEC-6 scenario, which is also concluded on at the end of this chapter.

The basic aim of this report is to describe and discuss various emission control measures suggested by the GAINS model with respect to actual feasibility in Denmark. This knowledge is applicable when analysing subsequent scenarios, as the internal factors and parameters of the model in principle are static.

Main results

Based on emission scenarios of the GAINS model - as presented in the two reports NEC-4 and NEC-5 (IIASA, 2007 a; b) - measures to reduce NEC pollutants have been assessed. Two pairs of baseline scenarios, NAT-BL and COH-BL, and two pairs of reductions scenarios, NAT-TS and COH-TS, have been assessed. The NAT scenarios takes activity input (energy and other) as reported by national authorities while COH scenarios takes activity input modelled by the common European PRIMES model.

The reduction scenarios are named TS (Thematic Strategy) referring to the EU Thematic Strategy, which sets targets for environmental and health exposure of pollutants, and which the reduction scenarios are developed to meet.

The emission output of the GAINS scenarios is compared to the output of Danish emission projections conducted by NERI and based on similar energy projection data as used in the NAT scenarios.

In general, the current legislation emission projections of NERI and the GAINS-NAT-BL scenario for 2020 are in accordance regarding the totals (Table 11.1). However, in the case of NO_X the results differ.

Table 11.1 Baseline projections of the NERI and GAINS model; emissions 2020.

ktonnes	NO_X	SO_2	NH_3	NMVOC	$PM_{2.5}$
NERI	115	21	55	74	16
GAINS-NAT	126	21	53	71	15
GAINS-COH	104	19	53	62	14

The emissions of the COH-BL projection are not comparable to the Danish NERI projections as the energy input data for the two projections are different. In the COH scenario case the energy projection reflects current legislation and current policy illustrating the effects of the upcoming EU Climate and Energy Package. Therefore, the level of energy consumption is lower and the share of renewable energy is higher than in the energy projection data used for the Danish emission projections in 2006.

Table 11.2 shows the resulting emission levels of the two reduction scenarios, NAT-TS and COH-TS, named TS scenarios.

Table 11.2 Thematic Strategy scenario emission reductions of the GAINS model, 2020.

Ktonnes	NO_X	SO_2	NH_3	NMVOC	$PM_{2.5}$
GAINS-NAT	89	15	48	62	12
GAINS-COH	87	16	50	59	13

Obviously, the results for the two scenarios are quite similar as both scenarios aims at meeting the same TS targets.

Table 11.3 shows the additional costs going from the BL scenario to the TS scenario. Again it is obvious that the COH scenario is less expensive to meet because the BL level – the set-off level - is stricter.

Table 11.3 Thematic Strategy scenario reductions costs of the GAINS model, 2020.

M DKK (2000)	NO_X	SO_2	NH_3	NMVOC	$PM_{2.5}$
GAINS-NAT	447	134	343	39	-201
GAINS-COH	201	0	157	-19	-246

Some of the costs reducing $PM_{2,5}$ and NMVOC are negative; in other words, one saves production costs from the $PM_{2,5}$ and NMVOC emission reduction efforts. The general reason is that some reductions are secondary (e.g. $PM_{2.5}$) following a primary reduction (e.g. NO_X) taking all the costs, and therefore are free of costs. Another reason is shifting from expensive production processes to cheaper processes (e.g. using water instead of solvents). A third reason could simply be changing from expensive to more cost-efficient reduction technologies (e.g. shifting from expensive processes lowering sulphur content in fuels to add-on techniques, e.g. WFGD).

In the following is concluded on the emission reduction suggestions of the two scenarios NAT and COH.

The NAT scenarios are interesting because the results are directly comparable to the Danish emissions projections by NERI, which are based on the same activity input (energy, agriculture, processes etc). The COH scenarios are interesting because it investigates the consequences of tightening the energy activity and composition to a quantity and quality level matching the EU Climate and Energy Package (which is not reflected in the Danish energy projection of 2005 serving as input for the NAT scenarios).

NO_X emission reductions

The GAINS-NAT-TS scenario suggests substantial reductions in 2020 from a BL level at 126 ktonnes to 89 ktonnes at the annualised cost of DKK 447 M pr year as of 2020 (constant year 2000-basis).

The COH-TS scenario suggests reductions from 104 ktonnes in the BL case to 87 ktonnes at the additional cost of DKK 201 M (2000) annually as of 2020.

Though substantial NO_X emission reduction efforts have been carried out in the power and heating plants sector in Denmark, there seems to be NO_X reduction potentials. The presently measured NO_X emission factor (as of 2004) on average for this sector is about 150 g pr GJ coal and 88 g pr GJ natural gas. With the best available technology the factor can be reduced to about 28 g pr GJ for coal and 43 g pr GJ for gas – and theoretically even lower (refer to Appendix 11).

Also, in other sectors there seems to be quite substantial reduction potentials though difficulties may appear in implementing control technologies in small and medium scale industries because of lacking expert knowledge for daily management and maintenance. In the oil and gas extraction sites in the North Sea there is quite a big potential for reductions, however, technical implementation difficulties are caused by lack of space according to the industry itself.

The suggested emission reductions follows the cost-efficiency principle (in line with the optimisation nature of the GAINS model) which often results in suggesting combustion modification solely, instead of the more expensive combinations of combustion modification and SCR technologies. Because of still tightening quotas for the big NO_X emitters, stricter EURO norms in the mobile sector and future introduction of NO_X duty the combination of reduction technologies - leading to 90 % or higher reductions - may possible be the most feasible choice, even though the costs will be higher. Managing advanced SCR technologies may not be practicable for individual and small businesses. However, de-NO_X technologies are still developing - among others due to the efforts in the transport sector and it is thinkable that easy operational technologies will be at the market as of 2020.

At a more detailed level when analysing the reasons for differences between the GAINS-NAT-BL scenario and the Danish emission projections some sectors draws special attention.

- **Gas and oil industry/natural gas.** The reduction potential at 8.7 ktonnes NO_X seem overstated. Probably only half the amount is feasible and practicable. This is because much of the emission in this sector stems from the North Sea off shore oil and gas extractions sites where physical difficulties are a hindrance for implementations of optimal reductions technologies.
- **Non-industrial combustion**. Reductions of only 637 tonnes are suggested at the cost of about DKK 16.8 M annually. It is to be questioned if these minor reductions are feasible and practicable.

- **Industrial combustion.** Reductions are feasible. However, it does not seem practicable to expect 100 % control technology coverage in the sector because of many small and mediums scale units where implementations and daily management may cause problems and leakage.
- **Power and heating plants**. The NAT-TS reductions scenario suggest about 50 % of all NO_X reductions to take place in the power and heating plants sector, especially regarding plants running on natural gas, waste and hard coal. However, the BL scenario expects too few control technologies installed - only covering the sector with 55-70 %, and causing the reduction potential to be too high. Especially regarding coal only 70 % of the sector activity is expected to be under control in the BL case, which by NERI is expected to be more - almost 100 % - since enforced by governmental order (Danish National Parliament, 2003a). However, it applies for all the sector/fuel combinations that almost full coverage of control technologies are to be expected as of 2020 due to current legislation – though not including small power and heating plants. Moreover, the TS scenario only suggests implementation of combustion modification controls with removal efficiencies at 65 % instead of SCR controls with efficiency at 80 % for existing plants. As shown in the assessment of the subsector power and heating plants running on natural gas full installation of SCR controls will increase the reduction potential substantially - this being quite a realistic assessment. Also, the assumption that power and heating plants running on waste have no emission control implemented at all in the BL case is not correct, causing much higher reduction potential than realistic.

In other words, the reduction potentials in this sector are more modest than expected by IIASA.

Turning to the COH reduction scenario the suggested control technologies to implement are fewer than in the NAT scenario case. This is because the take-off emission level is lower. However, though lower reduction demand the pattern is the same and so are the above mentioned hesitations.

SO_2 emission reductions in the NAT scenario

The BL scenario of NERI and GAINS-NAT are in accordance, expecting 21 ktonnes SO_2 emissions as of 2020, while the COH-BL scenarios lies at 19 ktonnes.

The NAT-TS reduction scenario suggests a reduction of 6 ktonnes to 15 ktonnes. The reductions are mainly to take place in the industrial sector. However, also the maritime sector takes a great deal. The costs additional to the BL case are DKK 134 M (2000-basis) annually as of 2020.

The COH-TS scenario suggests a reduction in the SO_2 level from 19 ktonnes to 16 ktonnes at the additional cost of zero DKK. The reduction at 3 ktonnes is to be realised by choosing more cost-efficient control technologies and measures than assumed in the BL scenario.

Minor reductions in the power and heating plants sector and the cement production sector are associated with very high costs and seem very unfeasible.

The suggested reductions in the industrial sector are to be achieved by installing desulphurisation technologies. However, for small and medium sized companies there may be practical problems in the day-by-day operation of the technologies making the option less feasible and possibly causing leakages.

At a more detailed level - when analysing the GAINS-NAT-BL scenario with respect to the real world - some fuel related reductions draw special attention.

- **Diesel fuel combustion**. In both the industrial sector and the power and heating plants sector the GAINS model assumes - in the NAT-BL scenario - diesel fuel with a sulphur content at 0.2 %, which is much above the current legislation at maximum 0.05 %. This means that the suggested reductions shifting to low sulphur at 0.045 % has no effect.
- **Waste combustion**. In both the industrial sector and the power and heating plants sector in the NAT-BL case no control is expected. However, by governmental order limits for SO_2 emissions has been set up, which means that the suggested emission reductions by implementing in furnace control is not realistic.
- **Heavy fuel oil combustion**. The industrial sector expects an almost 100 % coverage of WFGD technology in the TS scenario. This may not be realistic because of the high number of small and medium sized businesses where optimal day-by-day management is not to be expected. Furthermore, since heavy fuel combustion often takes place occasionally or as support for primary machinery WFGD may not be feasible to install.

NH_3 emission reduction suggestions

The GAINS-NAT-BL scenario projects 53 ktonnes NH_3 emission level in 2020 while NERI projects 55 ktonnes. The GAINS-COH-BL scenario also projects 53 ktonnes.

Though the GAINS input data on agricultural activity comes from the European CAPRI model the input to this model is coming from Danish authorities.

The GAINS-COH-TS scenario reduces from 53 ktonnes to 50 ktonnes and the GAINS-NAT-TS scenario suggests reductions from 53 ktonnes to 48 ktonnes. This level, 48 ktonnes, is only 1 ktonnes from the maximal possible reduction level reachable within the GAINS model (refer to Table 2.1), which indicates that the suggested reduction effort will be hard to achieve – and costly as well. Moreover, accepting such a tight reduction scheme makes the sector very sensitive and inflexible with respect to possible growth in the animal stock.

It is mainly in the pig meat producing agricultural sector the suggested reductions should take place. This, by efficient combination of available measures, e.g. LNF, BF of fluids, LNA, CS and animal house adaptation.

The reduction costs additional to the BL case are high at DKK 343 M (2000) pr year as of 2020 for the NAT-TS scenario while cheaper at DKK 157 M (2000) for the COH-TS scenario.

NMVOC emission reduction suggestions

While NERI projects baseline emissions at 74 ktonnes as of 2020, GAINS-NAT-BL projects 71 ktonnes and GAINS-COH-BL projects only 62 ktonnes.

The NAT-TS reduction scenario suggests substantial reductions at 9 ktonnes from 71 ktonnes to 62 ktonnes NVVOC at the annual cost of DKK 39 M (2000) as of 2020.

The COH-TS scenario suggests reductions from the BL level at 62 ktonnes to 59 ktonnes implying the *negative cost* DKK -19 M (2000) annually as of 2020. In other words - by implementing more cost-efficient technologies and measures than in the BL projection - about 3 ktonnes NMVOC reductions should be achievable and implying economic savings.

The potential for reductions suggested by the TS scenarios seems quite realistic both regarding the industrial sector and for the fuelwood combusting in the household sector. The industrial sector has substantial reduction potential shifting from use of solvent based products and processes to water based products and processes. The residential sector has reduction potential in getting the fuel combusting activities under total control and improving the existing stoves and boilers.

$PM_{2.5}$ emission reduction suggestions

The GAINS-NAT BL scenario projects 15 ktonnes $PM_{2,5}$ emission level in 2020 while NERI projects 16 ktonnes. The GAINS-COH-BL scenario projects 14 ktonnes.

The NAT-TS reduction scenario goes from 15 ktonnes to 12 ktonnes, while the COH-TS scenario goes from 14 ktonnes to 13 ktonnes.

The reductions for the COH-TS scenario are few and can be achieved at *negative* costs at DKK -240 M (2000) annually as of 2020 because of more cost-efficient control measures.

The reductions in the NAT-TS scenario at 3 ktonnes should also be achievable by optimising the control technologies implementation. Here the vast majority of the reductions have to take place in the residential sector combusting fuelwood in boilers, fireplaces and stoves. The associated additional costs are DKK 208 M (2000) annually.

11.1 EU proposal on emission ceilings from June 2008

In June 2008 the EC presented its proposal for new NEC-2020 emission ceilings. The underlying emission scenario, named EU proposal in this report, has not been assessed in details.

Table 11.4 compares the emissions of the two scenarios assessed in this report with the new EU proposal presented in the NEC-6 report (IIASA, 2008f).

Table 11.4 Thematic Strategy scenario emission reductions of the GAINS model.

Unit: ktonnes	NO_X	SO_2	NH_3	NMVOC	$PM_{2.5}$
GAINS-NAT	89	15	48	62	12
GAINS-COH	87	16	50	59	13
GAINS-EU proposal	88	16	52	73	17
NERI (2006)	115	21	55	74	16

As seen from Table 11.4 the suggested emission levels from the EU proposal reduction scenario are in line with the NAT-TS and COH-TS scenario levels for NO_X, SO_2 and NH_3 while higher for NMVOC and $PM_{2,5}$.

When comparing to the latest Danish emission projections from NERI from 2006 (Illerup et al., 2008) it is seen that NERI expects about the same NMVOC and $PM_{2,5}$ emissions (74 ktonnes and 16 ktonnes) as the EU proposal (73 ktonnes and 17 ktonnes).

NERI projects 55 ktonnes of NH_3 while the EU proposal says 52 ktonnes – still quite close.

In the case of SO_2 the differences are bigger. NERI projects 21 ktonnes while the EU proposal reduces to 16 ktonnes. For NO_X the difference becomes even bigger: 115 ktonnes (NERI) vs. 88 ktonnes (EU proposal). However, because of the effects of the implementation of the EU Climate and Energy Package, which is not included in the NERI projection, it may be possible to reduce the NO_X and SO_2 emission quite substantially, though, all depending on the total energy consumption in 2020, which by Danish authorities are projected at a higher level as compared to the PRIMES energy projections used in the GAINS model.

12 References

Aalborg Portland, 2008: Miljøredegørelse og grønt regnskab, 2007. http://www.aalborg-portland.dk

Amann, M., Cofala, J., Heyes, C., Klimont, Z,. Mechler, R., Posch, M. & Schöpp, W. 2004: RAINS REVIEW 2004. The RAINS model. Documentation of the model approach prepared for the RAINS peer review 2004. IIASA.

Bach, H., Andersen, M.S., Illerup, J.B., Møller, F., Birr-Pedersen, K., Brandt, J., Ellermann, T. Frohn, L.M., Hansen, K.M., Palmgren, F., Nielsen, J.S. & Winther, M. 2006: Vurdering af de samfundsøkonomiske konsekvenser af Komissionens temastrategi for luftforurening. Faglig rapport fra DMU, nr. 586, 2006. DMU. http://www2.dmu.dk/1_viden/2_Publikationer/3_fagrapporter/rapporter/FR586.pdf

Cofala J. & Syri, S. 1998: Sulphur emissions, abatement technologies and related costs for Europe in the RAINS model database. IR-98-035. IIASA, Laxenburg.

EPA (Danish Environmental Protection Agency), 2006: Analyse af Danmarks muligheder for at reducere emissionerne af NO_X i 2010 - Hovedrapport. Miljøprojekt Nr. 1104. Copenhagen, Miljøstyrelsen (in Danish).

EPA (Danish Environmental Protection Agency), 2008: On national energy projections. Note. http://glwww.mst.dk/transport/word/Bil5a_EnerFrem18mar04.doc

EPA (Danish Environmental Protection Agency), 2001: Luftvejledningen. Begrænsning af luftforurening fra virksomheder Vejledning fra miljøstyrelsen Nr. 2, 2001. Copenhagen, Miljøstyrelsen. http://www2.mst.dk

Danish National Parliament, 1991: Bekendtgørelse 885 af 18. december 1991.

Danish National Parliament, 1998. BEK nr. 321 af 04/06/1998.

Danish National Parliament, 2003a. Bekendtgørelse om begrænsning af visse luftforurenende emissioner fra store fyringsanlæg. BEK nr. 808 af 25/09/2003.

Danish National Parliament, 2003b. Bekendtgørelse om anlæg, der forbrænder affald. BEK nr. 162 af 11/03/03.

Danish National Parliament, 2005. Luftvejledningen. BEK nr. 621 af 23/06/2005.

EC, 2001: Directive 2001/80/EC of the European Parliament and of the Council of 23 October 2001 on the limitation of emissions of certain pollutants into the air from large combustion plants. OJ L 309, 27.11.2001, p. 1–21.

EC, 2005a: Directive 2005/55/EC of the European Parliament and of the Council of 28 September 2005 on the approximation of the laws of the member states relating to the measures to be taken against the emission of gaseous and particulate pollutants from compression-ignition engines for use in vehicles, and the emission of gaseous pollutants from positive-ignition engines fuelled with natural gas or liquefied petroleum gas for use in vehicles. OJ L 275, 20.10.2005, p. 1–163.

EC, 2005b: Communication from the Commission to the Council and the European Parliament on a Thematic Strategy on Air Pollution. SEC(2005) 1132, Commission of the European Communities, Brussels, Belgium.

EC, 2005c: Directive 2005/33/EC of the European Parliament and of the Council, of 6 July 2005 - amending Directive 1999/32/EC, on reduction in the sulphur content of certain liquid fuels. OJ L 191, 22.7.2005.

EC, 2006: Integrated Pollution Prevention and Control. Reference Document on Best Available Techniques for Large Combustion Plants (LCP BREF). European Commission. http://ec.europa.eu/environment/ippc/brefs/lcp_bref_0706.pdf

EC, 2008: 20 20 by 2020. Europe's climate change opportunity. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. COM(2008) 30 final. Commission of the European Communities. Brussels, Belgium.

European Environmental Agency (EEA), 2006: EMEP/CORINAIR Emission Inventory Guidebook – 2006. Technical report No 11/2006. EEA, Copenhagen.

European Environmental Agency (EEA), 2008: Air pollution from electricity-generating large combustion plants. -An assessment of the theoretical emission reduction of SO_2 and NO_X through implementation of BAT as set in the BREFs. EEA Technical report No 4/2008. EEA, Copenhagen.

Klimont, Z., Amann, M. & Cofala, J. 2000: Estimating Costs for Controlling Emissions of Volatile Organic Compounds (VOC) from Stationary Sources in Europe. IR-00-51. IIASA, Laxenburg.

Det Norske Veritas (DNV), 2005: Marpol 73/78 Annex VI: Regulations for the prevention of air pollution from ships, technical and operational implications, DNV, 21 February 2005. Available at: http://www.dnv.com/binaries/marpol_annex_vi_tcm4-125462.pdf

Klimont, Z., Cofala, J., Bertok, I., Amann, M., Heyes, C. & Gyarfas, F., 2002: Modelling Particulate Emissions in Europe. IR-02-076. IIASA, Laxenburg.

Klimont, Z. & Brink, C., 2004: Modelling of Emissions of Air Pollutants and Greenhouse Gases from Agricultural Sources in Europe. Interim Report IR-04-048. IIASA, Laxenburg, Austria.

IIASA, 2005: Winiwarter W. The GAINS Model for Greenhouse Gases - Version 1.0: Nitrous Oxide (N2O) IIASA Interim Report IR-05-55.

IIASA, 2007a: NEC Scenario Analysis Report No. 4. Updated Baseline Projections for the Revision of the Emission Ceilings Directive of the European Union.
http://www.iiasa.ac.at/rains/CAFE_files/NEC4-v1.pdf

IIASA, 2007b: NEC Scenario Analysis Report No. 5. Cost-effective Emission Reductions to Meet the Environmental Targets of the Thematic Strategy on Air Pollution Under Different Greenhouse Gas Constraints.
http://www.iiasa.ac.at/rains/CAFE_files/NEC5-v1.pdf

IIASA, 2008a: Interim Reports to the European Commission for the Directive on National Emission Ceilings and the EU Ozone Strategy. IIASA homepage. http://www.iiasa.ac.at/~rains/interim_reports.html

IIASA, 2008b: The Clean Air for Europe (CAFE) programme of the EU. IIASA homepage. http://www.iiasa.ac.at/rains/cafe.html?sb=21

IIASA, 2008c: The revision of the EU directive on National Emission Ceilings. IIASA homepage.
http://www.iiasa.ac.at/rains/nec2007.html?sb=20

IIASA, 2008d: GAINS online. http://gains.iiasa.ac.at/gains

IIASA, 2008e: Documentation of model methodology: various reports on the RAINS/GAINS model.
http://www.iiasa.ac.at/rains/gains-methodology.html

IIASA, 2008f: (Amann, M., Bertok, I., Cofala, J., Heyes, C., Klimont, Z., Rafaj, P., Schöpp, W. & Wagner, F.). National Emission Ceilings for 2020 based on the 2008 Climate & Energy Package. NEC Scenario Analysis Report Nr. 6. IIASA.
http://www.iiasa.ac.at/rains/reports/NEC6-final110708.pdf

Illerup, J.B., Nielsen, O.-K., Winther, M., Mikkelsen, M.H., Fauser, P. & Gyldenkærne, S. 2008: Projection of SO_2 , NO_X , NMVOC, NH_3 and particle emissions - 2005 to 2030, National Environmental Research Institute, University of Aarhus - Denmark (NERI Technical Report; no 655).
http://www2.dmu.dk/Pub/FR655.pdf

Shell – Denmark, 2007: Miljøredegørelse 2006.

Statoil, 2007: Grønt regnskab 2006. http://www.statoil.dk.

Statoil, 2008: Lavsvovlet fyringsolie.
http://www.statoil.dk/FrontServlet?ds=OmStatoil&state=OmStatoil_dynamic&viewid=1881653

Vattenfall, 2006: Etablering af de-NO_X-anlæg på Vattenfall Fynsværket. PJV 11. October 2006. PowerPoint file. http://www.vattenfall.dk

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Zbigniew Klimont, 2008 - 2009. IIASA, Laxenburg, Austria.

Januz Kofala, 2008 -2009. IIASA, Laxenburg, Austria.

Jytte Boll Illerup, 2009. Technical University of Denmark, Kgs. Lyngby, Denmark.

Appendices

Appendix 1	NO_x – GAINS-NAT detailed data
Appendix 2	NO_x – GAINS-COH detailed data
Appendix 3	SO_2 – GAINS-NAT detailed data
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Appendix 11	Evaluation of EEA report "Air pollution from electricity-generating large combustion plants"

Appendix 1- 11

In the following 11 appendices detailed data on the emission reductions suggested by the GAINS model is presented.

From the tables it is possible to derive exactly which control options GAINS consider to implement as of 2020 according to the Baseline scenario and which additional measures GAINS suggests implemented in order to reduce the emissions, meeting the environmental objectives of the Thematic Strategy from EU.

Each appendix covers a scenarios (either NAT or COH) for five pollutants (NO_X, SO_2, NH_3, NMVOC, $PM_{2,5}$). All sector/activity combinations where there are changes between the Baseline (BL) scenarios case and the TS (Thematic strategy) scenario case are listed. Each sector/activity combination occupies 1, 2 or more rows. To ease the reading every second sector/activity combinations is shaded gray.

The bottom of the tables presents subtotals, transport totals and totals for non-controlled sector/activities.

Explanations to the column labels:	
Sector	The sector the activity takes place in
Activity	The activity that takes place in the sector
Control technology	Technology or measure to reduce emissions
Sectoral Activity (unit)	The activity level, e.g. fuel consumption, within a sector. Units as in next column
Unit	Units for the activity level
Removal_efficiency (%)	The efficiency of the control technology to reduce emissions
BL_Cap. contr (%)	Capacity controlled in the sector, i.e. sectoral coverage in BL-scenario
TS_Cap. contr (%)	Capacity controlled in the sector, i.e. sectoral coverage in TS-scenario
BL_Emiss (tonne)	Resulting emission level after reduction in BL-scenario
TS_Emiss (tonne)	Resulting emission level after reduction in TS-scenario
BL_costs (t DKK pr year)	The total annual costs as of 2020 in thousand DKK (2000 annualised) implementing control technologies in the BL-scenario(converted from EURO to DKK by the exchange rate 745,5)
TS_costs (t DKK pr year)	The total annual costs as of 2020 in thousand DKK(2000 annualised) implementing control technologies in the TS-scenario (converted from EURO to DKK by the exchange rate 745,5)

Appendix 1 NO_x reductions; NAT-scenario.

Sector	Activity	Control technology	Sectoral_activity (unit)	Unit	Re-moval_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Gas & Oil industry: combustion	Natural gas (incl. other gases)	Combustion modification and selective catalytic reduction on oil and gas industrial boilers and furnaces	84.43	PJ	80		80		1783		105664
Gas & Oil industry: combustion	Natural gas (incl. other gases)	Combustion modification and selective non-catalytic reduction on oil and gas industrial boilers and furnaces	84.43	PJ	70		20		669		12940
Gas & Oil industry: combustion	Natural gas (incl. other gases)	No control	84.43	PJ		100		11145			
Gas & Oil industry: combustion	Heavy fuel oil	Combustion modification on oil and gas industrial boilers and furnaces	0.82	PJ	50	80		56		132	
Gas & Oil industry: combustion	Heavy fuel oil	Combustion modification and selective catalytic reduction on oil and gas industrial boilers and furnaces	0.82	PJ	80		80		22		1013
Gas & Oil industry: combustion	Heavy fuel oil	Combustion modification and selective non-catalytic reduction on oil and gas industrial boilers and furnaces	0.82	PJ	70		20		8		127
Gas & Oil industry: combustion	Heavy fuel oil	No control	0.82	PJ		20		28			
Gas & Oil industry: combustion	Liquefied petroleum gas	Combustion modification on oil and gas industrial boilers and furnaces	0.01	PJ	50		100				1
Gas & Oil industry: combustion	Liquefied petroleum gas	No control	0.01	PJ		100					
Gas & Oil industry: combustion	Diesel oil and others incl. biofuel	Combustion modification on oil and gas industrial boilers and furnaces	0.01	PJ	50		100				2
Gas & Oil industry: combustion	Diesel oil and others incl. biofuel	No control	0.01	PJ		100		1			
Non-industrial combustion	Natural gas (incl. other gases)	Comb. modification on gas use in commercial sector	42.31	PJ	22		100		1650		10850
Non-industrial combustion	Natural gas (incl. other gases)	No control	42.31	PJ		100		2115			
Non-industrial combustion	Gasoline and others incl. biofuel	Combustion modification on gasoil use in commercial sector	1.07	PJ	12		100		57		330
Non-industrial combustion	Gasoline and others incl. biofuel	No control	1.07	PJ		100		64			
Non-industrial combustion	Heavy fuel oil	Combustion modification on heavy fuel oil use in commercial sector	0.48	PJ	50		100		38		279
Non-industrial combustion	Heavy fuel oil	No control	0.48	PJ		100		77			
Non-industrial combustion	Liquefied petroleum gas	Combustion modification on gasoil use in commercial sector	0.87	PJ	12		100		46		266
Non-industrial combustion	Liquefied petroleum gas	No control	0.87	PJ		100		52			
Non-industrial combustion	Diesel oil and others incl. biofuel	Combustion modification on gasoil use in commercial sector	16.61	PJ	12		100		877		5104

Sector	Activity	Control technology	Sectoral_activity (unit)	Unit	Re-moval_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Non-industrial combustion	Diesel oil and others incl. biofuel	No control	16.61	PJ		100		997			
Industrial combustion	Natural gas (incl. other gases)	Combustion modification on oil and gas industrial boilers and furnaces	36.40	PJ	50	100		2402		7454	
Industrial combustion	Natural gas (incl. other gases)	Combustion modification and selective catalytic reduction on oil and gas indus-trial boilers and furnaces	36.40	PJ	80		80		769		45554
Industrial combustion	Natural gas (incl. other gases)	Combustion modification and selective non-catalytic reduction on oil and gas industrial boilers and furnaces	36.40	PJ	70		20		288		5578
Industrial combustion	Gasoline and others incl. biofuel	Combustion modification on oil and gas industrial boilers and furnaces	0.12	PJ	50	100	100	4	4	25	25
Industrial combustion	Hard coal. grade 1	Combustion modification on solid fuels fired industrial boilers and furnaces	9.85	PJ	50	100		1133		2127	
Industrial combustion	Hard coal. grade 1	Combustion modification and selective catalytic reduction on solid fuels fired industrial boilers and furnaces	9.85	PJ	80		80		362		14918
Industrial combustion	Hard coal. grade 1	Combustion modification and selective non-catalytic reduction on solid fuels fired industrial boilers and furnaces	9.85	PJ	70		20		136		1814
Industrial combustion	Heavy fuel oil	Combustion modification and selective catalytic reduction on oil and gas indus-trial boilers and furnaces	18.65	PJ	80		80		507		23124
Industrial combustion	Heavy fuel oil	Combustion modification and selective non-catalytic reduction on solid fuels fired industrial boilers and furnaces	18.65	PJ	70		20		190		3410
Industrial combustion	Heavy fuel oil	No control	18.65	PJ		100		3170			
Industrial combustion	Liquefied petroleum gas	Combustion modification on oil and gas industrial boilers and furnaces	2.25	PJ	50		100		79		460
Industrial combustion	Liquefied petroleum gas	No control	2.25	PJ		100		157			
Industrial combustion	Diesel oil and others incl. biofuel	Combustion modification on oil and gas industrial boilers and furnaces	25.70	PJ	50		100		1028		5263
Industrial combustion	Diesel oil and others incl. biofuel	No control	25.70	PJ		100		2056			
Industrial combustion	Biomass fuels	Combustion modification on solid fuels fired industrial boilers and furnaces	9.35	PJ	50		100		608		2129
Industrial combustion	Biomass fuels	No control	9.35	PJ		100		1216			
Industrial combustion	Other biomass and waste fuels	Combustion modification and selective non-catalytic reduction on solid fuels fired industrial boilers and furnaces	0.75	PJ	70		100		29		677
Industrial combustion	Other biomass and waste fuels	No control	0.75	PJ		100		97			
Power heat plants: Exist. other	Natural gas (incl. other gases)	No control	147.09	PJ		40		11179			

Sector	Activity	Control technology	Sectoral_activity (unit)	Unit	Re-moval_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Power heat plants: Exist. other	Natural gas (incl. other gases)	Combustion modification on existing oil and gas power plants	147.09	PJ	65	60	100	5869	9782	44348	73913
Power heat plants: Exist. other	Hard coal. grade 1	Combustion modification and selective catalytic reduction on existing hard coal power plants	44.67	PJ	80	100	100	2680	2680	98776	98776
Power heat plants: Exist. other	Heavy fuel oil	No control	5.93	PJ		35		415			
Power heat plants: Exist. other	Heavy fuel oil	Combustion modification on existing oil and gas power plants	5.93	PJ	65	65	100	270	415	2727	4195
Power heat plants: Exist. other	Diesel oil and others incl. biofuel	No control	0.21	PJ		100		16			
Power heat plants: Exist. other	Diesel oil and others incl. biofuel	Combustion modification on existing oil and gas power plants	0.21	PJ	65		100		6		51
Power heat plants: Exist. other	Biomass fuels	No control	2.08	PJ		38		103			
Power heat plants: Exist. other	Biomass fuels	Combustion modification on existing hard coal power plants	2.08	PJ	50	62	100	84	135	393	634
Power heat plants: Exist. other	Other biomass and waste fuels	Combustion modification on existing hard coal power plants	3.55	PJ	50	100	100	392	392	540	540
Power heat plants: New	Hard coal. grade 1	No control	57.79	PJ		30		2600			
Power heat plants: New	Hard coal. grade 1	Selective catalytic reduction on new hard coal power plants	57.79	PJ	80	70	100	1214	1734	56900	81285
Power heat plants: New	Heavy fuel oil	No control	16.22	PJ		45		730			
Power heat plants: New	Heavy fuel oil	Selective catalytic reduction on new oil and gas power plants	16.22	PJ	80	55	100	178	324	24812	45112
Power heat plants: New	Other biomass and waste fuels	No control	42.28	PJ		100		6342			
Power heat plants: New	Other biomass and waste fuels	Selective catalytic reduction on new hard coal power plants	42.28	PJ	80		100		1268		52176
Ind. Process: Cement production	No fuel use	Process emissions - stage 1 NO_X control	1.87	Mt	40	100		2868		3493	
Ind. Process: Cement production	No fuel use	Process emissions - stage 3 NO_X control	1.87	Mt	80		100		956		13971
Ind. Process: Lime production	No fuel use	Process emissions - stage 1 NO_X control	0.09	Mt	40	100		141		175	
Ind. Process: Lime production	No fuel use	Process emissions - stage 3 NO_X control	0.09	Mt	80		100		47		702
Ind. Process: Other non -ferrous metals prod. - primary and sec-ondary	No fuel use	Process emissions - stage 1 NO_X control	0.00	Mt	40	100	100				
Ind. Process: Paper pulp mills	No fuel use	Process emissions - stage 1 NO_X control	0.06	Mt	40	100	100				
Ind. Process: Crude oil & other products - input to Petroleum refineries	No fuel use	Process emissions - stage 1 NO_X control	7.40	Mt	40	50		1109		2756	
Ind. Process: Crude oil & other products - input to Petroleum refineries	No fuel use	Process emissions - stage 2 NO_X control	7.40	Mt	60	50		740		9096	

Sector	Activity	Control technology	Sectoral_activity (unit)	Unit	Re-moval_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Ind. Process: Crude oil & other products - input to Petroleum refineries	No fuel use	Process emissions - stage 3 NO_X control	7.40	Mt	80		100		740		33079
Waste: Agricultural waste burning	No fuel use	Ban on open burning of agricultural or residentail waste	0.53	Mt	100	95	100				
Waste: Agricultural waste burning	No fuel use	No control	0.53	Mt		5		36			
Waste: Flaring in gas and oil industry	No fuel use	Good practice in oil and gas industry - flaring	1.58	PJ	20		100		63		
Waste: Flaring in gas and oil industry	No fuel use	No control	1.58	PJ		100		79			
Waste: Open burning of residential waste	No fuel use	Ban on open burning of agricultural or residentail waste	0.02	Mt	100		100				
Waste: Open burning of residential waste	No fuel use	No control	0.02	Mt		100		26			
Sub total								61841	27692	253753	643961
Transport								*56595*	*53731*	*2876711*	*2935822*
No control								*7685*	*7685*	-	-
Total								**126121**	**89108**	**3130464**	**3579783**

Appendix 2 NO_X reductions; COH-scenario.

Sector	Activity	Control technology	Sectoral_activity (unit)	Unit	Removal_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Gas & Oil industry: combustion	Natural gas (incl. other gases)	Combustion modification on oil and gas industrial boilers and furnaces	13.01	PJ	50		100		858		2663
Gas & Oil industry: combustion	Natural gas (incl. other gases)	No control	13.01	PJ		100		1717			
Gas & Oil industry: combustion	Heavy fuel oil	Combustion modification on oil and gas industrial boilers and furnaces	10.13	PJ	50	80	100	689	861	1632	2039
Gas & Oil industry: combustion	Heavy fuel oil	No control	10.13	PJ		20		344			
Non-industrial combustion	Heavy fuel oil	Combustion modification on heavy fuel oil use in commercial sector	0.66	PJ	50		100		53		382
Non-industrial combustion	Heavy fuel oil	No control	0.66	PJ		100		105			
Industry: Combustion in boilers	Natural gas (incl. other gases)	Combustion modification on oil and gas industrial boilers and furnaces	12.63	PJ	50	100	100	833	833	5278	5278
Industry: Combustion in boilers	Hard coal. grade 1	Combustion modification and selective non-catalytic reduction on solid fuels fired industrial boilers and furnaces	0.01	PJ	70	100	100	1	1	17	17
Industry: Combustion in boilers	Heavy fuel oil	Combustion modification on oil and gas industrial boilers and furnaces	1.14	PJ	50		100		97		375
Industry: Combustion in boilers	Heavy fuel oil	No control	1.14	PJ		100		194			
Industry: Combustion in boilers	Biomass fuels	Combustion modification on solid fuels fired industrial boilers and furnaces	1.06	PJ	50		100		69		389
Industry: Combustion in boilers	Biomass fuels	No control	1.06	PJ		100		138			
Industrial combustion	Natural gas (incl. other gases)	Combustion modification on oil and gas industrial boilers and furnaces	22.73	PJ	50	100	100	1500	1500	4655	4655
Industrial combustion	Gasoline and others incl. biofuel	Combustion modification on oil and gas industrial boilers and furnaces	0.06	PJ	50	100	100	2	2	13	13
Industrial combustion	Hard coal. grade 1	Combustion modification on solid fuels fired industrial boilers and furnaces	0.31	PJ	50	100		35		66	
Industrial combustion	Hard coal. grade 1	Combustion modification and selective non-catalytic reduction on solid fuels fired industrial boilers and furnaces	0.31	PJ	70		100		21		282
Industrial combustion	Heavy fuel oil	Combustion modification on oil and gas industrial boilers and furnaces	10.07	PJ	50		100		856		2028
Industrial combustion	Heavy fuel oil	No control	10.07	PJ		100		1712			
Industrial combustion	Liquefied petroleum gas	Combustion modification on oil and gas industrial boilers and furnaces	2.60	PJ	50		100		91		533
Industrial combustion	Liquefied petroleum gas	No control	2.60	PJ		100		182			

Sector	Activity	Control technology	Sectoral_activity (unit)	Unit	Removal_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Industrial combustion	Diesel oil and others incl. biofuel	Combustion modification on oil and gas industrial boilers and furnaces	13.15	PJ	50		100		526		2693
Industrial combustion	Diesel oil and others incl. biofuel	No control	13.15	PJ		100		1052			
Power heat plants: Exist. other	Natural gas (incl. other gases)	No control	68.32	PJ		40		5192			
Power heat plants: Exist. other	Natural gas (incl. other gases)	Combustion modification on existing oil and gas power plants	68.32	PJ	65	60	100	2726	4543	20598	34331
Power heat plants: Exist. other	Hard coal. grade 1	Combustion modification and selective catalytic reduction on existing hard coal power plants	30.63	PJ	80	100	100	1838	1838	67734	67734
Power heat plants: Exist. other	Diesel oil and others incl. biofuel	No control	0.02	PJ		100		2			
Power heat plants: Exist. other	Diesel oil and others incl. biofuel	Combustion modification on existing oil and gas power plants	0.02	PJ	65		100		1		5
Power heat plants: Exist. other	Biomass fuels	No control	32.77	PJ		38		1619			
Power heat plants: Exist. other	Biomass fuels	Combustion modification on existing hard coal power plants	32.77	PJ	50	62	100	1321	2130	6197	9995
Power heat plants: New	Hard coal. grade 1	No control	55.60	PJ		30		2502			
Power heat plants: New	Hard coal. grade 1	Selective catalytic reduction on new hard coal power plants	55.60	PJ	80	70	100	1168	1668	54746	78208
Power heat plants: New	Heavy fuel oil	No control	3.49	PJ		45	45	157	157		
Power heat plants: New	Heavy fuel oil	Selective catalytic reduction on new oil and gas power plants	3.49	PJ	80	55	55	38	38	5340	5340
Ind. Process: Cement production	No fuel use	Process emissions - stage 1 NO_X control	2.95	Mt	40	100		4507		5489	
Ind. Process: Cement production	No fuel use	Process emissions - stage 3 NO_X control	2.95	Mt	80		100		1502		21956
Ind. Process: Lime production	No fuel use	Process emissions - stage 1 NO_X control	0.12	Mt	40	100		176		219	
Ind. Process: Lime production	No fuel use	Process emissions - stage 3 NO_X control	0.12	Mt	80		100		59		875
Ind. Process: Other non -ferrous metals prod. - primary and secon-dary	No fuel use	Process emissions - stage 1 NO_X control	0.00	Mt	40	100	100				
Ind. Process: Paper pulp mills	No fuel use	Process emissions - stage 1 NO_X control	0.07	Mt	40	100	100				
Ind. Process: Crude oil & other products - input to Petroleum refineries	No fuel use	Process emissions - stage 1 NO_X control	7.84	Mt	40	50		1175		2920	
Ind. Process: Crude oil & other products - input to Petroleum refineries	No fuel use	Process emissions - stage 2 NO_X control	7.84	Mt	60	50		783		9635	
Ind. Process: Crude oil & other products - input to Petroleum refineries	No fuel use	Process emissions - stage 3 NO_X control	7.84	Mt	80		100		783		35038

Sector	Activity	Control technology	Sectoral_activity (unit)	Unit	Removal_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Waste: Agricultural waste burning	No fuel use	Ban on open burning of agricultural or residentail waste	0.53	Mt	100	95	100				
Waste: Agricultural waste burning	No fuel use	No control	0.53	Mt		5		36			
Waste: Open burning of residential waste	No fuel use	Ban on open burning of agricultural or residentail waste	0.02	Mt	100		100				
Waste: Open burning of residential waste	No fuel use	No control	0.02	Mt		100		26			
Sub total								31770	18487	184539	274831
Transport								58098	53937	3224766	3343452
No control								14329	14329	-	-
Total								104197	86753	3409304	3618283

Appendix 3 SO_2 reductions; NAT-scenario.

Sector	Activity	Control technology	Sectoral activity	Unit	Remo-val_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Gas & Oil industry: combustion	Heavy fuel oil	Industry - wet flue gases desulphurisation	0.82	PJ	85	80	99.902	172	214	3051	3810
Gas & Oil industry: combustion	Heavy fuel oil	No control	0.82	PJ		20		286			
Gas & Oil industry: combustion	Heavy fuel oil	High efficiency flue gases desulphurisation	0.82	PJ	98		.098				7
Gas & Oil industry: combustion	Diesel oil and others incl. biofuel	Low sulphur diesel oil - stage 1 (.2 % S)	0.01	PJ	50	35.5				4	
Gas & Oil industry: combustion	Diesel oil and others incl. biofuel	Low sulphur diesel oil - stage 2 (.045 % S)	0.01	PJ	89	64.5	100			25	40
Non-industrial combustion	Heavy fuel oil	Low sulphur fuel oil (.6 %S)	0.48	PJ	70	90	100	125	139	1266	1407
Non-industrial combustion	Heavy fuel oil	No control	0.48	PJ		10		46			
Non-industrial combustion	Diesel oil and others incl. biofuel	Low sulphur diesel oil - stage 2 (.045 % S)	16.61	PJ	89	100	100	352	352	67739	67739
Industrial combustion	Hard coal. grade 1	Industry - wet flue gases desulphurisation	9.85	PJ	85		90		399		41149
Industrial combustion	Hard coal. grade 1	In-furnace control - limestone injection	9.85	PJ	60		10		118		2401
Industrial combustion	Hard coal. grade 1	Low sulphur coal (.6 %S)	9.85	PJ		100		2955			
Industrial combustion	Heavy fuel oil	Industry - wet flue gases desulphurisation	18.65	PJ	85		95		4159		81973
Industrial combustion	Heavy fuel oil	Low sulphur fuel oil (.6 %S)	18.65	PJ	81	100	5	5595	280	98818	4941
Industrial combustion	Heavy fuel oil	No control	18.65	PJ							
Industrial combustion	Diesel oil and others incl. biofuel	Low sulphur diesel oil - stage 1 (.2 % S)	25.70	PJ	50	35.5		859		11195	
Industrial combustion	Diesel oil and others incl. biofuel	Low sulphur diesel oil - stage 2 (.045 % S)	25.70	PJ	89	64.5	100	351	544	67611	104823
Industrial combustion	Other biomass and waste fuels	In-furnace control - limestone injection	0.75	PJ	60		100		19		1759
Industrial combustion	Other biomass and waste fuels	No control	0.75	PJ		100		47			
Power heat plants: Exist. other	Hard coal. grade 1	Power plant - wet flue gases desulphurisation	44.67	PJ	95	100	100	670	670	260549	260549
Power heat plants: Exist. other	Heavy fuel oil	Power plant - wet flue gases desulphurisation	5.93	PJ	95	100	100	518	518	119765	119765
Power heat plants: Exist. other	Diesel oil and others incl. biofuel	Low sulphur diesel oil - stage 1 (.2 % S)	0.21	PJ	50	35.5		7		89	
Power heat plants: Exist. other	Diesel oil and others incl. biofuel	Low sulphur diesel oil - stage 2 (.045 % S)	0.21	PJ	89	64.5	100	3	4	539	835
Power heat plants: Exist. other	Other biomass and waste fuels	In-furnace control – limestone injection	3.55	PJ	60	100	100	89	89	7194	7194
Power heat plants: New	Hard coal. grade 1	Power plant - wet flue gases desulphurisation	57.79	PJ	95	100	100	867	867	201200	201200
Power heat plants: New	Heavy fuel oil	Power plant - wet flue gases desulphurisation	16.22	PJ	95	100	100	1419	1419	140068	140068

Sector	Activity	Control technology	Sectoral activity	Unit	Remo-val_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Power heat plants: New	Diesel oil and others incl. biofuel	Low sulphur diesel oil - stage 1 (.2 % S)	1.17	PJ	50	35.5		39		508	
Power heat plants: New	Diesel oil and others incl. biofuel	Low sulphur diesel oil - stage 2 (.045 % S)	1.17	PJ	89	64.5	100	16	25	3066	4753
Power heat plants: New	Other biomass and waste fuels	In-furnace control - limestone injection	42.28	PJ	60	100	37	1057	391	54397	20126
Power heat plants: New	Other biomass and waste fuels	Power plant - wet flue gases desulphurisation	42.28	PJ	95		63		83		70528
Ind. Process: Cement production	No fuel use	Process emissions - stage 2 SO_2 control	1.87	Mt	70	100		534		7824	
Ind. Process: Cement production	No fuel use	Process emissions - stage 3 SO_2 control	1.87	Mt	80		100		356		23472
Ind. Process: Lime production	No fuel use	Process emissions - stage 2 SO_2 control	0.09	Mt	70	100		26		289	
Ind. Process: Lime production	No fuel use	Process emissions - stage 3 SO_2 control	0.09	Mt	80		100		18		860
Ind. Process: Other non -ferrous metals prod. - primary and sec-ondary	No fuel use	Process emissions - stage 2 SO_2 control	0.00	Mt	70	100		10		82	
Ind. Process: Other non -ferrous metals prod. - primary and sec-ondary	No fuel use	Process emissions - stage 3 SO_2 control	0.00	Mt	80		100		6		119
Ind. Process: Paper pulp mills	No fuel use	Process emissions - stage 2 SO_2 control	0.06	Mt	70	100		154		1316	
Ind. Process: Paper pulp mills	No fuel use	Process emissions - stage 3 SO_2 control	0.06	Mt	80		100		102		1894
Non-industrial combustion	Hard coal. grade 1	Low sulphur coal (.6 %S)	0.03	PJ			100		7		
Non-industrial combustion	Hard coal. grade 1	No control	0.03	PJ		100		7			
Ind. Process: Crude oil & other products - input to Petroleum refineries	No fuel use	Process emissions - stage 1 SO_2 control	7.40	Mt	50		100				
Ind. Process: Crude oil & other products - input to Petroleum refineries	No fuel use	Process emissions - stage 2 SO_2 control	7.40	Mt	70	100					
Waste: Agricultural waste burning	No fuel use	Ban on open burning of agricultural or residen-tail waste	0.53	Mt	100	95	100				
Waste: Agricultural waste burning	No fuel use	No control	0.53	Mt		5		6			
Waste: Flaring in gas and oil industry	No fuel use	Good practice in oil and gas industry - flaring	1.58	PJ	20		100		13		

Sector	Activity	Control technology	Sectoral activity	Unit	Remo-val_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Waste: Flaring in gas and oil industry	No fuel use	No control	1.58	PJ		100		16			
Waste: Open burning of residen-tial waste	No fuel use	Ban on open burning of agricultural or residen-tail waste	0.02	Mt	100		100				
Waste: Open burning of residen-tial waste	No fuel use	No control	0.02	Mt		100		4			
Sub total								16230	10792	1046595	1161412
Transport (maritime activities)								1670	765	36378	50197
Transport (all others)								226	226	723380	723380
No control								2816	2816	-	-
Total								20942	14599	1806354	1934989

Appendix 4 SO_2 reductions; COH-scenario.

Sector	Activity	Control technology	Sectoral activity	Unit	Remo-val_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Gas & Oil industry: combustion	Heavy fuel oil	Industry - wet flue gases desulphurisation	10.13	PJ	85	80	100	2127	2659	37824	47279
Gas & Oil industry: combustion	Heavy fuel oil	No control	10.13	PJ		20		3546			
Non-industrial combustion	Heavy fuel oil	Low sulphur fuel oil (.6 %S)	0.66	PJ	70	90	90	171	171	1737	1737
Non-industrial combustion	Heavy fuel oil	No control	0.66	PJ		10	10	63	63		
Non-industrial combustion	Diesel oil and others incl. biofuel	Low sulphur diesel oil - stage 2 (.045 % S)	33.59	PJ	89	100	100	711	711	136999	136999
Industry: Combustion in boilers	Heavy fuel oil	Low sulphur fuel oil (.6 %S)	1.14	PJ	81	100	100	342	342	6035	6035
Industrial combustion	Heavy fuel oil	Industry - wet flue gases desulphurisation	10.07	PJ	85		95		2246		44280
Industrial combustion	Heavy fuel oil	Low sulphur fuel oil (.6 %S)	10.07	PJ	81	100	0.1	3022	3	53379	54
Industrial combustion	Heavy fuel oil	No control	10.07	PJ			4.9		772		
Industrial combustion	Diesel oil and others incl. biofuel	Low sulphur diesel oil - stage 1 (.2 % S)	13.15	PJ	50	35.5	35.5	439	439	5727	5727
Industrial combustion	Diesel oil and others incl. biofuel	Low sulphur diesel oil - stage 2 (.045 % S)	13.15	PJ	89	64.5	64.5	180	180	34590	34590
Power heat plants: Exist. other	Hard coal. grade 1	Power plant - wet flue gases desulphuri-sation	30.63	PJ	95	100	100	459	459	178669	178669
Power heat plants: Exist. other	Diesel oil and others incl. biofuel	Low sulphur diesel oil - stage 1 (.2 % S)	0.02	PJ	50	35.5	35.5	1	1	9	9
Power heat plants: Exist. other	Diesel oil and others incl. biofuel	Low sulphur diesel oil - stage 2 (.045 % S)	0.02	PJ	89	64.5	64.5			53	53
Power heat plants: New	Hard coal. grade 1	Power plant - wet flue gases desulphuri-sation	55.60	PJ	95	100	100	834	834	193582	193582
Power heat plants: New	Heavy fuel oil	Power plant - wet flue gases desulphuri-sation	3.49	PJ	95	100	100	305	305	30143	30143
Power heat plants: New	Diesel oil and others incl. biofuel	Low sulphur diesel oil - stage 1 (.2 % S)	1.03	PJ	50	35.5	35.5	34	34	449	449
Power heat plants: New	Diesel oil and others incl. biofuel	Low sulphur diesel oil - stage 2 (.045 % S)	1.03	PJ	89	64.5	64.5	14	14	2709	2709
Ind. Process: Cement production	No fuel use	No control	2.95	Mt			0				
Ind. Process: Cement production	No fuel use	Process emissions - stage 2 SO_2 control	2.95	Mt	70	100	100	840	839	12296	12295
Ind. Process: Lime production	No fuel use	Process emissions - stage 2 SO_2 control	0.12	Mt	70	100	100	33	33	361	361
Ind. Process: Other non -ferrous metals prod. - primary and sec-ondary	No fuel use	Process emissions - stage 2 SO_2 control	0.00	Mt	70	100	100	2	2	14	14
Ind. Process: Paper pulp mills	No fuel use	Process emissions - stage 2 SO_2 control	0.07	Mt	70	100	100	178	178	1527	1527

Sector	Activity	Control technology	Sectoral activity	Unit	Remo-val_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Non-industrial combustion	Hard coal. grade 1	Low sulphur coal (.6 %S)	0.28	PJ			100		78		
Non-industrial combustion	Hard coal. grade 1	No control	0.28	PJ		100		78			
Industry: Combustion in boilers	Hard coal. grade 1	Low sulphur coal (.6 %S)	0.01	PJ		100	100	4	4		
Industrial combustion	Hard coal. grade 1	Low sulphur coal (.6 %S)	0.31	PJ		100	100	92	92		
Ind. Process: Crude oil & other products - input to Petroleum refineries	No fuel use	Process emissions - stage 1 SO_2 control	7.84	Mt	50		100				
Ind. Process: Crude oil & other products - input to Petroleum refineries	No fuel use	Process emissions - stage 2 SO_2 control	7.84	Mt	70	100					
Waste: Agricultural waste burning	No fuel use	Ban on open burning of agricultural or residentail waste	0.53	Mt	100	95	100				
Waste: Agricultural waste burning	No fuel use	No control	0.53	Mt		5		6			
Waste: Open burning of residential waste	No fuel use	Ban on open burning of agricultural or residentail waste	0.02	Mt	100		100				
Waste: Open burning of residential waste	No fuel use	No control	0.02	Mt		100		4			
Sub total								13485	10459	696104	696513
Transport								1869	1869	701527	701527
No control								3857	3857	-	-
Total								19211	16185	1397631	1398040

Appendix 5 NH_3 reductions; NAT-scenario.

Sector	Activity	Control technology	Sectoral_activity_(unit)	Unit	Removal_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonme)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Agriculture: Livestock - other cattle	Other cattle - liquid (slurry) systems	Combination of CS_LNA	0.21	M animals	n.a.	70	70	702	702	45067	45067
Agriculture: Livestock - other cattle	Other cattle - liquid (slurry) systems	Low ammonia application; low efficiency	0.21	M animals	n.a.	10	10	164	164	3517	3517
Agriculture: Livestock - other cattle	Other cattle - liquid (slurry) systems	Combination of SA_LNA	0.21	M animals	n.a.	20	20	178	178	36117	36117
Agriculture: Livestock - other cattle	Other cattle - solid systems	Low ammonia application; high efficiency	0.65	M animals	n.a.	80	80	2983	2983	19832	19832
Agriculture: Livestock - other cattle	Other cattle - solid systems	Low ammonia application; low efficiency	0.65	M animals	n.a.	20	20	1037	1037	3928	3928
Agriculture: Livestock - dairy cattle	Dairy cows - liquid (slurry) systems	Combination of CS_LNA	0.42	M animals	n.a.	15		938		38409	
Agriculture: Livestock - dairy cattle	Dairy cows - liquid (slurry) systems	Low ammonia application; high efficiency	0.42	M animals	n.a.	5	5	398	398	7982	7978
Agriculture: Livestock - dairy cattle	Dairy cows - liquid (slurry) systems	Low ammonia application; low efficiency	0.42	M animals	n.a.	10	10	1094	1094	15964	15956
Agriculture: Livestock - dairy cattle	Dairy cows - liquid (slurry) systems	Combination of LNF_CS_LNA	0.42	M animals	n.a.		30		1587		102231
Agriculture: Livestock - dairy cattle	Dairy cows - liquid (slurry) systems	Combination of LNF_LNA	0.42	M animals	n.a.	15		1031		36636	
Agriculture: Livestock - dairy cattle	Dairy cows - liquid (slurry) systems	Combination of LNF_SA_LNA	0.42	M animals	n.a.		55		2519		293011
Agriculture: Livestock - dairy cattle	Dairy cows - liquid (slurry) systems	No control	0.42	M animals	n.a.						
Agriculture: Livestock - dairy cattle	Dairy cows - liquid (slurry) systems	Combination of SA_LNA	0.42	M animals	n.a.	55		2980		246493	
Agriculture: Livestock - dairy cattle	Dairy cows - solid systems	Low ammonia application; high efficiency	0.03	M animals	n.a.	85		395		3096	
Agriculture: Livestock - dairy cattle	Dairy cows - solid systems	Low ammonia application; low efficiency	0.03	M animals	n.a.	15		101		433	
Agriculture: Livestock - dairy cattle	Dairy cows - solid systems	Combination of LNF_LNA_high	0.03	M animals	n.a.		85		334		8766
Agriculture: Livestock - dairy cattle	Dairy cows - solid systems	Combination of LNF_LNA_low	0.03	M animals	n.a.		15		85		1427
Agriculture: Livestock - other animals (sheep. horses)	Sheep and goats	Low ammonia application; high efficiency	0.10	M animals	n.a.	15	50	32	107	344	1146

Agriculture: Livestock - other animals (sheep. horses)	Sheep and goats	Low ammonia application; low efficiency	0.10	M animals	n.a.	50	50	116	116	962	962
Agriculture: Livestock - other animals (sheep. horses)	Sheep and goats	No control	0.10	M animals	n.a.	35		83			
Agriculture: Livestock - pigs	Pigs - liquid (slurry) systems	Low ammonia application; high efficiency	12.86	M animals	n.a.	5	5	1817	1817	24574	24576
Agriculture: Livestock - pigs	Pigs - liquid (slurry) systems	Low ammonia application; low efficiency	12.86	M animals	n.a.	5	5	2287	2288	26134	26136
Agriculture: Livestock - pigs	Pigs - liquid (slurry) systems	Combination of LNF_BF_CS_LNA	12.86	M animals	n.a.	40	70	3621	6336	1251698	2190454
Agriculture: Livestock - pigs	Pigs - liquid (slurry) systems	Combination of LNF_BF_LNA	12.86	M animals	n.a.	30		3857		899239	
Agriculture: Livestock - pigs	Pigs - liquid (slurry) systems	Combination of LNF_SA_LNA	12.86	M animals	n.a.	20	20	3515	3515	617553	617547
Agriculture: Livestock - pigs	Pigs - solid systems	Combination of BF_LNA_high	1.87	M animals	n.a.		65		1654		229616
Agriculture: Livestock - pigs	Pigs - solid systems	Low ammonia application; high efficiency	1.87	M animals	n.a.	85		4803		45326	
Agriculture: Livestock - pigs	Pigs - solid systems	Low ammonia application; low efficiency	1.87	M animals	n.a.	15		1148		6370	
Agriculture: Livestock - pigs	Pigs - solid systems	Combination of LNF_LNA_high	1.87	M animals	n.a.		20		884		23472
Agriculture: Livestock - pigs	Pigs - solid systems	Combination of LNF_LNA_low	1.87	M animals	n.a.		15		919		16373
Agriculture: Livestock - poultry	Laying hens	Low ammonia application; low efficiency	3.64	M animals	n.a.	57	57	701	701	2001	2001
Agriculture: Livestock - poultry	Laying hens	Combination of LNF_SA_LNA	3.64	M animals	n.a.		43		139		6090
Agriculture: Livestock - poultry	Laying hens	Combination of SA_LNA	3.64	M animals	n.a.	43		174		5040	
Agriculture: Livestock - poultry	Other poultry	Low ammonia application; low efficiency	14.50	M animals	n.a.	56	56	1953	1953	6510	6510
Agriculture: Livestock - poultry	Other poultry	Combination of SA_LNA	14.50	M animals	n.a.	45	45	341	341	22654	22654
Gas & Oil industry: combustion	Natural gas (incl. other gases)	Combustion modification and selective catalytic reduction on oil and gas industrial boilers and furnaces	84.43	PJ	n.a.		80		68		
Gas & Oil industry: combustion	Natural gas (incl. other gases)	Combustion modification and selective non-catalytic reduction on oil and gas industrial boilers and furnaces	84.43	PJ	n.a.		20		34		
Gas & Oil industry: combustion	Natural gas (incl. other gases)	No control	84.43	PJ	n.a.	100		13			
Gas & Oil industry: combustion	Heavy fuel oil	Combustion modification on oil and gas industrial boilers and furnaces	0.82	PJ	n.a.	80					
Gas & Oil industry: combustion	Heavy fuel oil	Combustion modification and selective catalytic reduction on oil and gas industrial boilers and furnaces	0.82	PJ	n.a.		80		1		
Gas & Oil industry: combustion	Heavy fuel oil	Combustion modification and selective non-catalytic reduction on oil and gas industrial boilers and furnaces	0.82	PJ	n.a.		20				
Gas & Oil industry: combustion	Heavy fuel oil	No control	0.82	PJ	n.a.	20					

Gas & Oil industry: combustion	Liquefied petroleum gas	Combustion modification on oil and gas industrial boilers and furnaces	0.01	PJ	n.a.		100		
Gas & Oil industry: combustion	Liquefied petroleum gas	No control	0.01	PJ	n.a.	100			
Gas & Oil industry: combustion	Diesel oil and others incl. biofuel	Combustion modification on oil and gas industrial boilers and furnaces	0.01	PJ	n.a.		100		
Gas & Oil industry: combustion	Diesel oil and others incl. biofuel	No control	0.01	PJ	n.a.	100			
Milk yield over 3000 treshold	Dairy cows - liquid (slurry) systems	Combination of CS_LNA	3163.30	Mt above threshold	n.a.	15		356	
Milk yield over 3000 treshold	Dairy cows - liquid (slurry) systems	Low ammonia application; high efficiency	3163.30	Mt above threshold	n.a.	5	5	151	151
Milk yield over 3000 treshold	Dairy cows - liquid (slurry) systems	Low ammonia application; low efficiency	3163.30	Mt above threshold	n.a.	10	10	415	415
Milk yield over 3000 treshold	Dairy cows - liquid (slurry) systems	Combination of LNF_CS_LNA	3163.30	Mt above threshold	n.a.		30		602
Milk yield over 3000 treshold	Dairy cows - liquid (slurry) systems	Combination of LNF_LNA	3163.30	Mt above threshold	n.a.	15		391	
Milk yield over 3000 treshold	Dairy cows - liquid (slurry) systems	Combination of LNF_SA_LNA	3163.30	Mt above threshold	n.a.		55		956
Milk yield over 3000 treshold	Dairy cows - liquid (slurry) systems	No control	3163.30	Mt above threshold	n.a.				
Milk yield over 3000 treshold	Dairy cows - liquid (slurry) systems	Combination of SA_LNA	3163.30	Mt above threshold	n.a.	55		1130	
Milk yield over 3000 treshold	Dairy cows - solid systems	Low ammonia application; high efficiency	249.11	Mt above threshold	n.a.	85		392	
Milk yield over 3000 treshold	Dairy cows - solid systems	Low ammonia application; low efficiency	249.11	Mt above threshold	n.a.	15		100	
Milk yield over 3000 treshold	Dairy cows - solid systems	Combination of LNF_LNA_high	249.11	Mt above threshold	n.a.		85		332
Milk yield over 3000 treshold	Dairy cows - solid systems	Combination of LNF_LNA_low	249.11	Mt above threshold	n.a.		15		85
Non-industrial combustion	Natural gas (incl. other gases)	Comb. modification on gas use in commercial sector	42.31	PJ	n.a.		100		10
Non-industrial combustion	Natural gas (incl. other gases)	No control	42.31	PJ	n.a.	100		10	
Non-industrial combustion	Gasoline and others incl. biofuel	Combustion modification on gasoil use in commercial sector	1.07	PJ	n.a.		100		
Non-industrial combustion	Gasoline and others incl. biofuel	No control	1.07	PJ	n.a.	100			
Non-industrial combustion	Heavy fuel oil	Combustion modification on heavy fuel oil use in commercial sector	0.48	PJ	n.a.		100		
Non-industrial combustion	Heavy fuel oil	No control	0.48	PJ	n.a.	100			
Non-industrial combustion	Liquefied petroleum gas	Combustion modification on gasoil use in commercial sector	0.87	PJ	n.a.		100		
Non-industrial combustion	Liquefied petroleum gas	No control	0.87	PJ	n.a.	100			
Non-industrial combustion	Diesel oil and others incl. biofuel	Combustion modification on gasoil use in commercial sector	16.61	PJ	n.a.		100		16
Non-industrial combustion	Diesel oil and others incl. biofuel	No control	16.61	PJ	n.a.	100		16	
Industrial combustion	Natural gas (incl. other gases)	Combustion modification on oil and gas industrial boilers and furnaces	36.40	PJ	n.a.	100		4	

Industrial combustion	Natural gas (incl. other gases)	Combustion modification and selective catalytic reduction on oil and gas industrial boilers and furnaces	36.40	PJ	n.a.		80		29
Industrial combustion	Natural gas (incl. other gases)	Combustion modification and selective non-catalytic reduction on oil and gas industrial boilers and furnaces	36.40	PJ	n.a.		20		15
Industrial combustion	Gasoline and others incl. biofuel	Combustion modification on oil and gas industrial boilers and furnaces	0.12	PJ	n.a.	100	100		
Industrial combustion	Hard coal. grade 1	Combustion modification on solid fuels fired industrial boilers and furnaces	9.85	PJ	n.a.	100			
Industrial combustion	Hard coal. grade 1	Combustion modification and selective catalytic reduction on solid fuels fired industrial boilers and furnaces	9.85	PJ	n.a.		80		16
Industrial combustion	Hard coal. grade 1	Combustion modification and selective non-catalytic reduction on solid fuels fired industrial boilers and furnaces	9.85	PJ	n.a.		20		8
Industrial combustion	Heavy fuel oil	Combustion modification and selective catalytic reduction on oil and gas industrial boilers and furnaces	18.65	PJ	n.a.		80		22
Industrial combustion	Heavy fuel oil	Combustion modification and selective non-catalytic reduction on solid fuels fired industrial boilers and furnaces	18.65	PJ	n.a.		20		11
Industrial combustion	Heavy fuel oil	No control	18.65	PJ	n.a.	100		12	
Industrial combustion	Liquefied petroleum gas	Combustion modification on oil and gas industrial boilers and furnaces	2.25	PJ	n.a.		100		
Industrial combustion	Liquefied petroleum gas	No control	2.25	PJ	n.a.	100			
Industrial combustion	Diesel oil and others incl. biofuel	Combustion modification on oil and gas industrial boilers and furnaces	25.70	PJ	n.a.		100		3
Industrial combustion	Diesel oil and others incl. biofuel	No control	25.70	PJ	n.a.	100		4	
Industrial combustion	Biomass fuels	Combustion modification on solid fuels fired industrial boilers and furnaces	9.35	PJ	n.a.		100		28
Industrial combustion	Biomass fuels	No control	9.35	PJ	n.a.	100		47	
Industrial combustion	Other biomass and waste fuels	Combustion modification and selective non-catalytic reduction on solid fuels fired industrial boilers and furnaces	0.75	PJ	n.a.		100		1
Industrial combustion	Other biomass and waste fuels	No control	0.75	PJ	n.a.	100		1	
Power heat plants: Exist. other	Natural gas (incl. other gases)	No control	147.09	PJ	n.a.	40		9	
Power heat plants: Exist. other	Natural gas (incl. other gases)	Combustion modification on existing oil and gas power plants	147.09	PJ	n.a.	60	100	9	15
Power heat plants: Exist. other	Hard coal. grade 1	Combustion modification and selective catalytic reduction on existing hard coal power plants	44.67	PJ	n.a.	100	100	54	54
Power heat plants: Exist. other	Heavy fuel oil	No control	5.93	PJ	n.a.	35		1	

Power heat plants: Exist. other	Heavy fuel oil	Combustion modification on existing oil and gas power plants	5.93	PJ	n.a.	65	100	2	2		
Power heat plants: Exist. other	Diesel oil and others incl. biofuel	No control	0.21	PJ	n.a.	100					
Power heat plants: Exist. other	Diesel oil and others incl. biofuel	Combustion modification on existing oil and gas power plants	0.21	PJ	n.a.		100				
Power heat plants: Exist. other	Biomass fuels	No control	2.08	PJ	n.a.	38		4			
Power heat plants: Exist. other	Biomass fuels	Combustion modification on existing hard coal power plants	2.08	PJ	n.a.	62	100	4	6		
Power heat plants: Exist. other	Other biomass and waste fuels	Combustion modification on existing hard coal power plants	3.55	PJ	n.a.	100	100	4	4		
Power heat plants: New	Hard coal. grade 1	No control	57.79	PJ	n.a.	30					
Power heat plants: New	Hard coal. grade 1	Selective catalytic reduction on new hard coal power plants	57.79	PJ	n.a.	70	100	40	58		
Power heat plants: New	Heavy fuel oil	No control	16.22	PJ	n.a.	45		3			
Power heat plants: New	Heavy fuel oil	Selective catalytic reduction on new oil and gas power plants	16.22	PJ	n.a.	55	100	7	13		
Power heat plants: New	Other biomass and waste fuels	No control	42.28	PJ	n.a.	100		27			
Power heat plants: New	Other biomass and waste fuels	Selective catalytic reduction on new hard coal power plants	42.28	PJ	n.a.		100		21		
Waste: Flaring in gas and oil industry	No fuel use	Good practice in oil and gas industry - flaring	1.58	PJ	n.a.		100				
Waste: Flaring in gas and oil industry	No fuel use	No control	1.58	PJ	n.a.	100					
Sub total								39655	34826	3365875	3705364
Transport								518	518	-	-
No control								13013	13013	-	-
TOTAL								53186	48358	3365875	3705364

Appendix 6 NH_3 reductions; COH-scenario.

Sector	Activity	Control technology	Sec-toral_activity_(unit)	Unit	Removal_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Agriculture: Livestock - other cattle	Other cattle - liquid (slurry) systems	Combination of CS_LNA	0.20	M animals	n.a.	70	70	686	686	44027	44045
Agriculture: Livestock - other cattle	Other cattle - liquid (slurry) systems	Low ammonia application; low efficiency	0.20	M animals	n.a.	10	10	160	160	3435	3432
Agriculture: Livestock - other cattle	Other cattle - liquid (slurry) systems	Combination of SA_LNA	0.20	M animals	n.a.	20	20	174	174	35283	35248
Agriculture: Livestock - other cattle	Other cattle - solid systems	Low ammonia application; high efficiency	0.64	M animals	n.a.	80	80	2914	2914	19374	19373
Agriculture: Livestock - other cattle	Other cattle - solid systems	Low ammonia application; low efficiency	0.64	M animals	n.a.	20	20	1013	1014	3838	3839
Agriculture: Livestock - dairy cattle	Dairy cows - liquid (slurry) systems	Combination of CS_LNA	0.47	M animals	n.a.	15		1047		42902	
Agriculture: Livestock - dairy cattle	Dairy cows - liquid (slurry) systems	Low ammonia application; high efficiency	0.47	M animals	n.a.	5	5	445	444	8915	8898
Agriculture: Livestock - dairy cattle	Dairy cows - liquid (slurry) systems	Low ammonia application; low efficiency	0.47	M animals	n.a.	10	10	1222	1222	17831	17835
Agriculture: Livestock - dairy cattle	Dairy cows - liquid (slurry) systems	Combination of LNF_CS_LNA	0.47	M animals	n.a.		30		1773		114177
Agriculture: Livestock - dairy cattle	Dairy cows - liquid (slurry) systems	Combination of LNF_LNA	0.47	M animals	n.a.	15		1151		40921	
Agriculture: Livestock - dairy cattle	Dairy cows - liquid (slurry) systems	Combination of LNF_SA_LNA	0.47	M animals	n.a.		19		990		115205
Agriculture: Livestock - dairy cattle	Dairy cows - liquid (slurry) systems	No control	0.47	M animals	n.a.						
Agriculture: Livestock - dairy cattle	Dairy cows - liquid (slurry) systems	Combination of SA_LNA	0.47	M animals	n.a.	55	36	3329	2157	275328	178423
Agriculture: Livestock - dairy cattle	Dairy cows - solid systems	Low ammonia application; high efficiency	0.04	M animals	n.a.	85		441		3459	
Agriculture: Livestock - dairy cattle	Dairy cows - solid systems	Low ammonia application; low efficiency	0.04	M animals	n.a.	15		113		484	
Agriculture: Livestock - dairy cattle	Dairy cows - solid systems	Combination of LNF_LNA_high	0.04	M animals	n.a.		85		373		9781
Agriculture: Livestock - dairy cattle	Dairy cows - solid systems	Combination of LNF_LNA_low	0.04	M animals	n.a.		15		96		1603
Agriculture: Livestock - other animals (sheep. horses)	Sheep and goats	Low ammonia application; high efficiency	0.09	M animals	n.a.	15	15	31	30	329	328
Agriculture: Livestock - other animals (sheep. horses)	Sheep and goats	Low ammonia application; low efficiency	0.09	M animals	n.a.	50	50	110	110	918	919

Sector	Activity	Control technology	Sec-toral_activity_(unit)	Unit	Removal_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Agriculture: Livestock - other animals (sheep. horses)	Sheep and goats	No control	0.09	M animals	n.a.	35	35	79	79		
Agriculture: Livestock - pigs	Pigs - liquid (slurry) systems	Low ammonia application; high efficiency	12.07	M animals	n.a.	5	5	1705	1705	23061	23062
Agriculture: Livestock - pigs	Pigs - liquid (slurry) systems	Low ammonia application; low efficiency	12.07	M animals	n.a.	5	5	2147	2147	24525	24526
Agriculture: Livestock - pigs	Pigs - liquid (slurry) systems	Combination of LNF_BF_CS_LNA	12.07	M animals	n.a.	40	70	3398	5946	1174625	2055590
Agriculture: Livestock - pigs	Pigs - liquid (slurry) systems	Combination of LNF_BF_LNA	12.07	M animals	n.a.	30		3619		843869	
Agriculture: Livestock - pigs	Pigs - liquid (slurry) systems	Combination of LNF_SA_LNA	12.07	M animals	n.a.	20	20	3298	3298	579527	579512
Agriculture: Livestock - pigs	Pigs - solid systems	Low ammonia application; high efficiency	1.75	M animals	n.a.	85		4507		42534	
Agriculture: Livestock - pigs	Pigs - solid systems	Low ammonia application; low efficiency	1.75	M animals	n.a.	15		1078		5978	
Agriculture: Livestock - pigs	Pigs - solid systems	Combination of LNF_LNA_high	1.75	M animals	n.a.		85		3607		95736
Agriculture: Livestock - pigs	Pigs - solid systems	Combination of LNF_LNA_low	1.75	M animals	n.a.		15		862		15367
Agriculture: Livestock - poultry	Laying hens	Low ammonia application; low efficiency	3.37	M animals	n.a.	57	57	648	648	1850	1850
Agriculture: Livestock - poultry	Laying hens	Combination of LNF_SA_LNA	3.37	M animals	n.a.		43		129		5631
Agriculture: Livestock - poultry	Laying hens	Combination of SA_LNA	3.37	M animals	n.a.	43		161		4661	
Agriculture: Livestock - poultry	Other poultry	Low ammonia application; low efficiency	15.07	M animals	n.a.	55.5	56	2029	2029	6766	6766
Agriculture: Livestock - poultry	Other poultry	Combination of SA_LNA	15.07	M animals	n.a.	44.5	45	354	354	23544	23544
Gas & Oil industry: combustion	Natural gas (incl. other gases)	Combustion modification on oil and gas industrial boilers and furnaces	13.01	PJ	n.a.		100		1		
Gas & Oil industry: combustion	Natural gas (incl. other gases)	No control	13.01	PJ	n.a.	100		2			
Gas & Oil industry: combustion	Heavy fuel oil	Combustion modification on oil and gas industrial boilers and furnaces	10.13	PJ	n.a.	80	100	3	4		
Gas & Oil industry: combustion	Heavy fuel oil	No control	10.13	PJ	n.a.	20		1			
Milk yield over 3000 treshold	Dairy cows - liquid (slurry) systems	Combination of CS_LNA	3533.35	Mt above threshold	n.a.	15		397			
Milk yield over 3000 treshold	Dairy cows - liquid (slurry) systems	Low ammonia application; high efficiency	3533.35	Mt above threshold	n.a.	5	5	169	168		
Milk yield over 3000 treshold	Dairy cows - liquid (slurry) systems	Low ammonia application; low	3533.35	Mt above	n.a.	10	10	464	464		

Sector	Activity	Control technology	Sec-toral_activity_(unit)	Unit	Removal_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
		efficiency		threshold							
Milk yield over 3000 treshold	Dairy cows - liquid (slurry) systems	Combination of LNF_CS_LNA	3533.35	Mt above threshold	n.a.		30		672		
Milk yield over 3000 treshold	Dairy cows - liquid (slurry) systems	Combination of LNF_LNA	3533.35	Mt above threshold	n.a.	15		437			
Milk yield over 3000 treshold	Dairy cows - liquid (slurry) systems	Combination of LNF_SA_LNA	3533.35	Mt above threshold	n.a.		19		376		
Milk yield over 3000 treshold	Dairy cows - liquid (slurry) systems	No control	3533.35	Mt above threshold	n.a.						
Milk yield over 3000 treshold	Dairy cows - liquid (slurry) systems	Combination of SA_LNA	3533.35	Mt above threshold	n.a.	55	36	1263	818		
Milk yield over 3000 treshold	Dairy cows - solid systems	Low ammonia application; high efficiency	278.25	Mt above threshold	n.a.	85		438			
Milk yield over 3000 treshold	Dairy cows - solid systems	Low ammonia application; low efficiency	278.25	Mt above threshold	n.a.	15		112			
Milk yield over 3000 treshold	Dairy cows - solid systems	Combination of LNF_LNA_high	278.25	Mt above threshold	n.a.		85		370		
Milk yield over 3000 treshold	Dairy cows - solid systems	Combination of LNF_LNA_low	278.25	Mt above threshold	n.a.		15		95		
Non-industrial combustion	Heavy fuel oil	Combustion modification on heavy fuel oil use in commercial sector	0.66	PJ	n.a.		100		1		
Non-industrial combustion	Heavy fuel oil	No control	0.66	PJ	n.a.	100		1			
Industry: Combustion in boilers	Natural gas (incl. other gases)	Combustion modification on oil and gas industrial boilers and furnaces	12.63	PJ	n.a.	100	100	1	1		
Industry: Combustion in boilers	Hard coal. grade 1	Combustion modification and selec-tive non-catalytic reduction on solid fuels fired industrial boilers and furnaces	0.01	PJ	n.a.	100	100				
Industry: Combustion in boilers	Heavy fuel oil	Combustion modification on oil and gas industrial boilers and furnaces	1.14	PJ	n.a.		100				
Industry: Combustion in boilers	Heavy fuel oil	No control	1.14	PJ	n.a.	100		1			
Industry: Combustion in boilers	Biomass fuels	Combustion modification on solid fuels fired industrial boilers and furnaces	1.06	PJ	n.a.		100		3		
Industry: Combustion in boilers	Biomass fuels	No control	1.06	PJ	n.a.	100		5			
Industrial combustion	Natural gas (incl. other gases)	Combustion modification on oil and gas industrial boilers and furnaces	22.73	PJ	n.a.	100	100	2	2		
Industrial combustion	Gasoline and others incl. biofuel	Combustion modification on oil and gas industrial boilers and furnaces	0.06	PJ	n.a.	100	100				
Industrial combustion	Hard coal. grade 1	Combustion modification on solid	0.31	PJ	n.a.	100					

Sector	Activity	Control technology	Sec-toral_activity_(unit)	Unit	Removal_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
		fuels fired industrial boilers and furnaces									
Industrial combustion	Hard coal. grade 1	Combustion modification and selective non-catalytic reduction on solid fuels fired industrial boilers and furnaces	0.31	PJ	n.a.		100		1		
Industrial combustion	Heavy fuel oil	Combustion modification on oil and gas industrial boilers and furnaces	10.07	PJ	n.a.		100		4		
Industrial combustion	Heavy fuel oil	No control	10.07	PJ	n.a.	100		6			
Industrial combustion	Liquefied petroleum gas	Combustion modification on oil and gas industrial boilers and furnaces	2.60	PJ	n.a.		100				
Industrial combustion	Liquefied petroleum gas	No control	2.60	PJ	n.a.	100					
Industrial combustion	Diesel oil and others incl. biofuel	Combustion modification on oil and gas industrial boilers and furnaces	13.15	PJ	n.a.		100		1		
Industrial combustion	Diesel oil and others incl. biofuel	No control	13.15	PJ	n.a.	100		2			
Power heat plants: Exist. other	Natural gas (incl. other gases)	No control	68.32	PJ	n.a.	40		4			
Power heat plants: Exist. other	Natural gas (incl. other gases)	Combustion modification on existing oil and gas power plants	68.32	PJ	n.a.	60	100	4	7		
Power heat plants: Exist. other	Hard coal. grade 1	Combustion modification and selective catalytic reduction on existing hard coal power plants	30.63	PJ	n.a.	100	100	37	37		
Power heat plants: Exist. other	Diesel oil and others incl. biofuel	No control	0.02	PJ	n.a.	100					
Power heat plants: Exist. other	Diesel oil and others incl. biofuel	Combustion modification on existing oil and gas power plants	0.02	PJ	n.a.		100				
Power heat plants: Exist. other	Biomass fuels	No control	32.77	PJ	n.a.	38		62			
Power heat plants: Exist. other	Biomass fuels	Combustion modification on existing hard coal power plants	32.77	PJ	n.a.	62	100	61	98		
Power heat plants: New	Hard coal. grade 1	No control	55.60	PJ	n.a.	30					
Power heat plants: New	Hard coal. grade 1	Selective catalytic reduction on new hard coal power plants	55.60	PJ	n.a.	70	100	39	56		
Power heat plants: New	Heavy fuel oil	No control	3.49	PJ	n.a.	45	45	1	1		
Power heat plants: New	Heavy fuel oil	Selective catalytic reduction on new oil and gas power plants	3.49	PJ	n.a.	55	55	2	2		
Sub total								*39396*	*36155*	*3227981*	*3384691*
Transport/mobile								*327*	*327*	*-*	*-*
No control								*13401*	*13401*	*-*	*-*
Total								**53125**	**49884**	**3227981**	**3384691**

Appendix 7 NMVOC reductions; NAT-scenario.

Sector	Activity	Control technology	Sectoral activity	Unit	Removal eff %	BL_cap. contr	TS_cap. contr	BL_emiss. (tonne)	TS_emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Coil coating (coating of aluminum and steel)	Coated surface	Incineration	11.8	mln m2	90	100		50		608	
Coil coating (coating of aluminum and steel)	Coated surface	Modernized plant (lower fugitives) and improved thermal oxidation	11.8	mln m2	98		100		10		1146
Dry cleaning (new installations)	Textiles (clothing)	New generation closed circuit machine	10.7	kt TEX	55	100	60	95	57	6406	3844
Dry cleaning (new installations)	Textiles (clothing)	Water cleaning	10.7	kt TEX	100		40				326
Extraction.proc..distr.of lq.fuels (incl. new (Un)Load	Emissions of NMVOC	No control	10.7	kt VOC		100		10740			
Extraction.proc..distr.of lq.fuels (incl. new (Un)Load	Emissions of NMVOC	Vapour balancing on tankers and loading facilities	10.7	kt VOC			100		10740		
Industrial application of adhesives (use of traditional solvent based adhesives)	Adhesives	Activated carbon adsorption	29	kt	76	5		272		2405	
Industrial application of adhesives (use of traditional solvent based adhesives)	Adhesives	Emulsions. water-based dispersion paints	29	kt	98	53.5	60	218	244	52031	58353
Industrial application of adhesives (use of traditional solvent based adhesives)	Adhesives	Hot melts or UV cross-linking acrylates or electron beam curing systems (solids content 100 %)	29	kt	100	40	40			-6454	-6454
Industrial application of adhesives (use of traditional solvent based adhesives)	Adhesives	No control	29	kt		1.5		340			
Other industrial use of solvents	Emissions of NMVOC	No control	3.5	kt VOC		50		1750			
Other industrial use of solvents	Emissions of NMVOC	Process modification	3.5	kt VOC	49	50		893		1005	
Other industrial use of solvents	Emissions of NMVOC	Primary and new agrochemical products	3.5	kt VOC	61		100		1365		
Polystyrene processing	Expandable polystyrene beads consumption	No control	6.5	kt		75		294			
Polystyrene processing	Expandable polystyrene beads consumption	6 % Pentane expandable beads (85 %) and recycled EPS waste (15 %)	6.5	kt	15	25		83			
Polystyrene processing	Expandable polystyrene beads consumption	Combination of the above options	6.5	kt	44		100		218		747
Ind. Process: Crude oil & other products - input to Petroleum refineries	Crude oil	Leak detection and repair program. stage I	7.4	Mt Crude oil	34	100		1812		-266	

Sector	Activity	Control technology	Sectoral activity	Unit	Removal eff %	BL_cap. contr	TS_cap. contr	BL_emiss. (tonne)	TS_emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Ind. Process: Crude oil & other products - input to Petroleum refineries	Crude oil	Combination of the above options	7.4	Mt Crude oil	50		100		1361		1116
Flexography and rotogravure in packaging. new installat	Printing inks	No control	4.9	kt INK		60		2086			
Flexography and rotogravure in packaging. new installat	Printing inks	Water based inks	4.9	kt INK	21		60		1641		314
Flexography and rotogravure in packaging. new installat	Printing inks	Water bsaed inks. incineration (for new inst. with enclosure)	4.9	kt INK	67	40	40	452	452	22371	22371
Rotogravure in publication. new installations	Printing inks	No control	0.4	kt INK		100		72			
Rotogravure in publication. new installations	Printing inks	Water based inks	0.4	kt INK	14		100		62		28
Screen printing. new installations	Printing inks	Water based inks. enclosure and incineration-Bioflitration	10.9	kt INK	83	100	100	659	659	42404	42404
Manufacturing of shoes	Shoes	No control	11.2	mln pairs		5		33			
Manufacturing of shoes	Shoes	Good housekeeping and substitution (60 % solvent based and 40 % water based adhesives)	11.2	mln pairs	48	95	5	331	17	-259	-13
Manufacturing of shoes	Shoes	Combination of the above options	11.2	mln pairs	85		95		95		5023
Synthetic rubber production	Synthetic rubber	Incineration	39.1	kt	77	70		133		7255	
Synthetic rubber production	Synthetic rubber	No control	39.1	kt		30		247			
Synthetic rubber production	Synthetic rubber	Use of 30 % solvent based additives and 70 % low solvent additives (90 % vulcanized rubber and 10 % thermoplastic rubber produced)	39.1	kt	63		30		92		1735
Synthetic rubber production	Synthetic rubber	Combination of the above options	39.1	kt	91		70		50		8120
Tyre production	Tyres	No control	50.6	kt		100		506			
Tyre production	Tyres	New process	50.6	kt	75		100		126		1077
Vehicle refinishing (new installations)	Paint use	Primary measures and 25 % of high solids and water based paints	1.7	kt paint	61	100	100	477	477	20144	20144
Waste treatment and disposal	Emissions of NMVOC	Improved Landfills	0.5	kt VOC	6		100		470		89
Waste treatment and disposal	Emissions of NMVOC	No control	0.5	kt VOC		100		500			

Sector	Activity	Control technology	Sectoral activity	Unit	Removal eff %	BL_cap. contr	TS_cap. contr	BL_emiss. (tonne)	TS_emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Wood coating	Coated surface	High solids coating systems (20 % solvent content). application process with an efficiency of 35 %	30.8	mln m2	94	4.5	5	30	30	-2970	-2970
Wood coating	Coated surface	High solids coating systems (20 % solvent content). application process with an efficiency of 75 %	30.8	mln m2	97	11	11	33	33	-16307	-16306
Wood coating	Coated surface	Incineration	30.8	mln m2	76		18		447		25925
Wood coating	Coated surface	Low solids systems (80 % solvent content) and application process with an efficiency of 75 % (electrostatic. roller coating. curtain coating. dipping)	30.8	mln m2	53	5	5	252	252	-5731	-5731
Wood coating	Coated surface	Medium solids systems (55 % solvent content). application process with an efficiency of 75 %	30.8	mln m2	87	5	5	71	71	-7998	-7998
Wood coating	Coated surface	No control	30.8	mln m2		17.5		1865			
Wood coating	Coated surface	Very high solids systems (5 % solvent content). application process with an efficiency of 35 %	30.8	mln m2	99	5	5	7	7	-5369	-5370
Wood coating	Coated surface	Very high solids systems (5 % solvent content). application process with an efficiency of 75 %	30.8	mln m2	99	52	52	38	38	-82423	-82423
Residential/Commercial: Fireplaces	Fuelwood direct	Fireplace improved	1.4	PJ	75	45	80	154	274		
Residential/Commercial: Fireplaces	Fuelwood direct	No control	1.4	PJ		55	20	753	274		
Residential/Commercial: Medium boilers (<50MW) - automatic	Fuelwood direct	High efficiency deduster for medium boiler using fuelwood	6.8	PJ	70		20		20		
Residential/Commercial: Medium boilers (<50MW) - automatic	Fuelwood direct	Medium boiler - pellets	6.8	PJ	70		80		82		
Residential/Commercial: Medium boilers (<50MW) - automatic	Fuelwood direct	No control	6.8	PJ		100		342			
Residential/Commercial: Medium boilers (<50MW) - automatic	Hard coal. grade 1	Cyclone for medium boiler	0	PJ		60	30				
Residential/Commercial: Medium boilers (<50MW) - automatic	Hard coal. grade 1	High efficiency deduster for medium boiler	0	PJ			70				
Residential/Commercial: Medium boilers (<50MW) - automatic	Hard coal. grade 1	No control	0	PJ		40					
Residential/Commercial: Medium boilers (<1MW) - manual	Hard coal. grade 1	Cyclone for medium boiler	0	PJ			100				

Sector	Activity	Control technology	Sectoral activity	Unit	Removal eff %	BL_cap. contr	TS_cap. contr	BL_emiss. (tonne)	TS_emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Residential/Commercial: Medium boilers (<1MW) - manual	Hard coal. grade 1	No control	0	PJ		100					
Residential/Commercial: Single house boilers (<50 kW) - manual	Fuelwood direct	No control	4.1	PJ		35		1437			
Residential/Commercial: Single house boilers (<50 kW) - manual	Fuelwood direct	Biomass single house boiler new	4.1	PJ	97	45	40	55	49		
Residential/Commercial: Single house boilers (<50 kW) - manual	Fuelwood direct	Biomass single house boiler - pellets	4.1	PJ	98	20	30	12	19		
Residential/Commercial: Single house boilers (<50 kW) - manual	Fuelwood direct	Biomass single house boiler - pellets and electrostatic precipitator	4.1	PJ	99		30		18		
Residential/Commercial: Single house boilers (<50 kW) - manual	Hard coal. grade 1	No control	0	PJ		100	79				
Residential/Commercial: Single house boilers (<50 kW) - manual	Hard coal. grade 1	Coal single house boiler new	0	PJ	75		21				
Residential/Commercial: Heating stoves	Fuelwood direct	No control	11	PJ		35	20	3833	2190		
Residential/Commercial: Heating stoves	Fuelwood direct	Biomass stove improved	11	PJ	85	45	80	739	1314		
Residential/Commercial: Heating stoves	Fuelwood direct	Biomass stove new	11	PJ	95	20		110			
Residential/Commercial: Heating stoves	Hard coal. grade 1	No control	0	PJ		40	34				
Residential/Commercial: Heating stoves	Hard coal. grade 1	Coal stove improved	0	PJ	70	50	66				
Residential/Commercial: Heating stoves	Hard coal. grade 1	Coal stove new	0	PJ	80	10					
Waste: Agricultural waste burning	No fuel use	Ban on open burning of agricultural or residentail waste	0.5	Mt	90	95	100	428	450		
Waste: Agricultural waste burning	No fuel use	No control	0.5	Mt		5		225			
Sub total								32425	23708	26852	65497
No changes from BL to TS								16483	16483	98400	98400
Transport	Diesel oil and others incl. biofuel	Going from HD EUROV to EUROVI for Heavy Duty						17055	16616		
No control								5225	5225	-	-
Total								71188	62032	125252	163898

Appendix 8 NMVOC reductions; COH-scenario.

Sector	Activity	Control technology	Sectoral activity	Unit	Removal eff %	BL_cap. contr	TS_cap. contr	BL_emiss. (tonne)	TS_emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Coil coating (coating of aluminum and steel)	Coated surface	Incineration	11.8	mln m2	90	100	100	50	50	608	608
Gas & Oil industry: combustion	Natural gas (incl. other gases)	No control	13	PJ		100	100	33	33		
Gas & Oil industry: combustion	Heavy fuel oil	No control	10.1	PJ		100	100	51	51		
Gasoline distribution - service stations	Gasoline and others incl. biofuel	Stage II and IB at service station	74.8	PJ	73	100	100	1036	1036	80722	80722
Gasoline distribution - transport and depots (used in stationary sources)	Gasoline and others incl. biofuel	IFC and Stage IA (single stage) controls	0.2	PJ	90	100	100	1	1		
Gasoline distribution - transport and depots (used in mobile sources)	Gasoline and others incl. biofuel	IFC and Stage IA (single stage) controls	74.8	PJ	90	100	100	310	310	25423	25423
Decorative paints	Paint use	Simulation of changes in paint formulation and application patterns in order to comply with the EU Product Directive	41.6	kt	50	100	100	3066	3066	24178	24178
Domestic use of solvents (other than paint)	Total population (in emissions modules)	No control	5.8	M people		25	25	1707	1707		
Domestic use of solvents (other than paint)	Total population (in emissions modules)	Reformulation of products (stage 1 - see BIPRO. 2002 study; researched options)	5.8	M people	10	75	75	4609	4609	16281	16281
Dry cleaning (new installations)	Textiles (clothing)	New generation closed circuit machine	10.7	kt TEX	55	100		95		6406	
Dry cleaning (new installations)	Textiles (clothing)	Water cleaning	10.7	kt TEX	100		100				814
Extraction.proc..distr.of lq.fuels (incl. new (Un)Load	Emissions of NMVOC	No control	10.7	kt VOC		100		10740			
Extraction.proc..distr.of lq.fuels (incl. new (Un)Load	Emissions of NMVOC	Vapour balancing on tankers and loading facilities	10.7	kt VOC			100		10740		
Fat. edible and non	edible oil extraction	Seeds-Activated carbon adsorption	226.5	kt	73	8	8	20	20	-285	-285
Fat. edible and non	edible oil extraction	Seeds-Schumacher type desolventiser-toaster-dryer-cooler plus a new hexane recovery section and process optimization	226.5	kt	83	93	93	157	157	-4085	-4085
Industrial application of adhesives (use of traditional solvent based adhesives)	Adhesives	Activated carbon adsorption	29	kt	76	5	5	272	279	2405	2469
Industrial application of adhesives (use of traditional solvent based adhesives)	Adhesives	Emulsions. water-based dispersion paints	29	kt	98	54	48	218	197	52031	47038
Industrial application of adhesives	Adhesives	Hot melts or UV cross-linking acry-	29	kt	100	40	40			-6454	-6454

Sector	Activity	Control technology	Sectoral activity	Unit	Removal eff %	BL_cap. contr	TS_cap. contr	BL_emiss. (tonne)	TS_emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
(use of traditional solvent based adhesives)		lates or electron beam curing systems (solids content 100 %)									
Industrial application of adhesives (use of traditional solvent based adhesives)	Adhesives	Incineration	29	kt	76		7		353		1679
Industrial application of adhesives (use of traditional solvent based adhesives)	Adhesives	No control	29	kt		2		340			
Other industrial use of solvents	Emissions of NMVOC	No control	3.5	kt VOC		50		1750			
Other industrial use of solvents	Emissions of NMVOC	Process modification	3.5	kt VOC	49	50		893		1005	
Other industrial use of solvents	Emissions of NMVOC	Primary and new agrochemical products	3.5	kt VOC	61		100		1365		
Industrial paint applications - General industry (continuous processes)	Paint use	Use of improved solvent based paints (55 %). application efficiency as above	4.7	kt	37	4	4	81	81	-56	-56
Industrial paint applications - General industry (continuous processes)	Paint use	Combination of the above options	4.7	kt	85	48	48	232	232	188356	188357
Industrial paint applications - General industry (continuous processes)	Paint use	No control	4.7	kt		15	15	483	483		
Industrial paint applications - General industry (continuous processes)	Paint use	Powder coating system (solvent free)	4.7	kt	100	30	30			-15573	-15572
Industrial paint applications - General industry (continuous processes)	Paint use	Use of water based paints (5 %): application efficiency as above	4.7	kt	95	3	3	5	5	447	448
Industrial paint applications - General industry	Paint use	Use of current standard solvent based paints (60 % solvent content) and application efficiency 65 %	15.8	kt	51	18	18	1048	1048	-19873	-19873
Industrial paint applications - General industry	Paint use	Use of improved solvent based paints (55 %). application efficiency as above	15.8	kt	75	22	22	660	660	-48810	-48810
Industrial paint applications - General industry	Paint use	No control	15.8	kt		7	7	824	824		
Industrial paint applications - General industry	Paint use	Powder coating system (solvent free)	15.8	kt	100	41	41			-176486	-176488
Industrial paint applications - General industry	Paint use	Use of water based paints (5 %): application efficiency as above	15.8	kt	96	12	12	58	58	-11843	-11842
Industrial paint applications - General industry (plastic parts)	Paint use	Use of current standard solvent based paints (60 % solvent content) and application efficiency 65 %	0.6	kt	59	29	29	51	51	-2619	-2619
Industrial paint applications - General industry (plastic parts)	Paint use	No control	0.6	kt		32	32	139	139		

Sector	Activity	Control technology	Sectoral activity	Unit	Removal eff %	BL_cap. contr	TS_cap. contr	BL_emiss. (tonne)	TS_emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Industrial paint applications - General industry (plastic parts)	Paint use	Use of water based paints (5 %): application efficiency as above	0.6	kt	96	40	40	6	6	-2535	-2535
Leather coating	Coating	Use of water based coating	1.4	kt	65	100	100	511	511	70	70
Products incorporating solvents	Paint and glue produced	Basic emissions management techniques	152.3	kt PG	27	80	80	633	633	779	779
Products incorporating solvents	Paint and glue produced	Upgrade of the condensation units or carbon adsorption and solvent recovery	152.3	kt PG	50	20	20	109	109	1918	1918
Polystyrene processing	Expandable polystyrene beads consumption	No control	6.5	kt		75		294			
Polystyrene processing	Expandable polystyrene beads consumption	6 % Pentane expandable beads (85 %) and recycled EPS waste (15 %)	6.5	kt	15	25	100	83	333		
Ind. Process: Crude oil & other products - input to Petroleum refineries	Crude oil	Leak detection and repair program. stage I	7.8	Mt Crude oil	34	100		1920		-282	
Ind. Process: Crude oil & other products - input to Petroleum refineries	Crude oil	Combination of the above options	7.8	Mt Crude oil	50		100		1442		1181
Printing. offset. new installations	Printing inks	Incineration	1.9	kt INK	66	100	100	294	294	7788	7788
Flexography and rotogravure in packaging. new installat	Printing inks	No control	4.9	kt INK		60	19	2086	659		
Flexography and rotogravure in packaging. new installat	Printing inks	Water based inks	4.9	kt INK	21		60		1641		314
Flexography and rotogravure in packaging. new installat	Printing inks	Water bsaed inks. incineration (for new inst. with enclosure)	4.9	kt INK	67	40	21	452	238	22371	11770
Rotogravure in publication. new installations	Printing inks	No control	0.4	kt INK		100		72			
Rotogravure in publication. new installations	Printing inks	Water based inks	0.4	kt INK	14		100		62		28
Screen printing. new installations	Printing inks	Water based inks. enclosure and incineration-Bioflitration	10.9	kt INK	83	100	100	659	659	42404	42404
Manufacturing of shoes	Shoes	No control	11.2	mln pairs		5	5	33	33		
Manufacturing of shoes	Shoes	Good housekeeping and substitution (60 % solvent based and 40 % water based adhesives)	11.2	mln pairs	48	95	95	331	331	-259	-259
Synthetic rubber production	Synthetic rubber	Incineration	39.1	kt	77	70		133		7255	
Synthetic rubber production	Synthetic rubber	No control	39.1	kt		30	25	247	203		
Synthetic rubber production	Synthetic rubber	Use of 30 % solvent based additives and 70 % low solvent additives (90 % vulcanized rubber and 10 % thermoplastic rubber produced)	39.1	kt	63		30		92		1735
Synthetic rubber production	Synthetic rubber	Use of 10 % solvent based additives and 90 % low solvent additives (90 %	39.1	kt	78		45		84		4211

Sector	Activity	Control technology	Sectoral activity	Unit	Removal eff %	BL_cap. contr	TS_cap. contr	BL_emiss. (tonne)	TS_emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
		vulcanized rubber and 10 % thermo-plastic rubber produced)									
Tyre production	Tyres	No control	50.6	kt		100		506			
Tyre production	Tyres	New process	50.6	kt	75		100		126		1077
Vehicle refinishing (new installati-ons)	Paint use	Primary measures and 25 % of high solids and water based paints	1.7	kt paint	61	100	100	477	477	20144	20144
Waste: Agricultural waste burning	No fuel use	Ban on open burning of agricultural or residentail waste	0.5	Mt	90	95	100	428	450		
Waste: Agricultural waste burning	No fuel use	No control	0.5	Mt		5		225			
Waste treatment and disposal	Emissions of NMVOC	Improved Landfills	0.5	kt VOC	6		100		470		89
Waste treatment and disposal	Emissions of NMVOC	No control	0.5	kt VOC		100		500			
Wood coating	Coated surface	High solids coating systems (20 % solvent content). application process with an efficiency of 35 %	30.8	mln m2	94	5	5	30	30	-2970	-2970
Wood coating	Coated surface	High solids coating systems (20 % solvent content). application process with an efficiency of 75 %	30.8	mln m2	97	11	11	33	33	-16307	-16306
Wood coating	Coated surface	Low solids systems (80 % solvent content) and application process with an efficiency of 75 % (electrostatic. roller coating. curtain coating. dipping)	30.8	mln m2	53	5	5	252	252	-5731	-5731
Wood coating	Coated surface	Medium solids systems (55 % solvent content). application process with an efficiency of 75 %	30.8	mln m2	87	5	5	71	71	-7998	-7998
Wood coating	Coated surface	No control	30.8	mln m2		18	18	1865	1865		
Wood coating	Coated surface	Very high solids systems (5 % solvent content). application process with an efficiency of 35 %	30.8	mln m2	99	5	5	7	7	-5369	-5370
Wood coating	Coated surface	Very high solids systems (5 % solvent content). application process with an efficiency of 75 %	30.8	mln m2	99	52	52	38	38	-82423	-82423
Residential. Commercial: Firepla-ces	Fuelwood direct	Fireplace improved	1.1	PJ	75	45	45	125	125		
Residential. Commercial: Firepla-ces	Fuelwood direct	No control	1.1	PJ		55	55	610	610		
Residential. Commercial: Medium boilers (<50MW) - automatic	Hard coal. grade 1	Cyclone for medium boiler	0.2	PJ		60	30	2	1		
Residential. Commercial: Medium boilers (<50MW) - automatic	Hard coal. grade 1	High efficiency deduster for medium boiler	0.2	PJ			70		3		
Residential. Commercial: Medium boilers (<50MW) - automatic	Hard coal. grade 1	No control	0.2	PJ		40		1			

Sector	Activity	Control technology	Sectoral activity	Unit	Removal eff %	BL_cap. contr	TS_cap. contr	BL_emiss. (tonne)	TS_emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Residential. Commercial: Single house boilers (<50 kW) - manual	Fuelwood direct	No control	3.3	PJ		35	8	1164	276		
Residential. Commercial: Single house boilers (<50 kW) - manual	Fuelwood direct	Biomass single house boiler improved	3.3	PJ	65		80		932		
Residential. Commercial: Single house boilers (<50 kW) - manual	Fuelwood direct	Biomass single house boiler new	3.3	PJ	97	45	12	45	12		
Residential. Commercial: Single house boilers (<50 kW) - manual	Fuelwood direct	Biomass single house boiler - pellets	3.3	PJ	98.49	20		10			
Residential. Commercial: Heating stoves	Fuelwood direct	No control	8.9	PJ		35	30	3105	2626		
Residential. Commercial: Heating stoves	Fuelwood direct	Biomass stove improved	8.9	PJ	85	45	70	599	937		
Residential. Commercial: Heating stoves	Fuelwood direct	Biomass stove new	8.9	PJ	95	20		89			
Residential. Commercial: Heating stoves	Hard coal. grade 1	No control	0.1	PJ		40	33	4	4		
Residential. Commercial: Heating stoves	Hard coal. grade 1	Coal stove improved	0.1	PJ	70	50	67	2	2		
Residential. Commercial: Heating stoves	Hard coal. grade 1	Coal stove new	0.1	PJ	80	10					
Sub total								46980	44232	90633	71849
Transport	Diesel oil and others incl. biofuel	Going from HD EUROV to EUROVI for Heavy Duty						10449	9810	-	-
No control								4772	4772	-	-
Total								62196	58810	90634	71849

Appendix 9 $PM_{2.5}$ reductions; NAT-scenario.

Sector	Activity	Control technology	Sectoral_activity_(unit)	Unit	Removal_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Agriculture: Ploughing. tilling. harvesting. Arable agricultural land in temporal and subboreal climate	No fuel use	Low-till farming. alternative cereal harvesting	2.30	M ha			100				68380
Agriculture: Livestock - other cattle	No fuel use	Feed modification (all livestock)	0.86	M animals	10		100		35		6804
Agriculture: Livestock - other cattle	No fuel use	No control	0.86	M animals		100		38			
Agriculture: Livestock - dairy cattle	No fuel use	Feed modification (all livestock)	0.45	M animals	10		100		32		8588
Agriculture: Livestock - dairy cattle	No fuel use	No control	0.45	M animals		100		35			
Agriculture: Livestock - pigs	No fuel use	Feed modification (all livestock)	14.73	M animals	10		100		969		420729
Agriculture: Livestock - pigs	No fuel use	No control	14.73	M animals		100		1077			
Agriculture: Livestock - poultry	No fuel use	Feed modification (all livestock)	18.15	M animals	10		100		172		59431
Agriculture: Livestock - poultry	No fuel use	No control	18.15	M animals		100		191			
Gas & Oil industry: combustion	Heavy fuel oil	Good housekeeping: industrial oil boilers	0.82	PJ	30	100	100	7	7	84	84
Gas & Oil industry: combustion	Diesel oil and others incl. biofuel	Good housekeeping: industrial oil boilers	0.01	PJ	30	100	100			1	1
Residential -Commercial: Fireplaces	Fuelwood direct	Fireplace improved	1.37	PJ	44	45	80	273	485	13630	24230
Residential -Commercial: Fireplaces	Fuelwood direct	No control	1.37	PJ		55	20	595	216		
Residential -Commercial: Medium boilers (<50MW) - automatic	Fuelwood direct	High efficiency deduster for medium boiler using fuelwood	6.85	PJ	99		20		1		3725
Residential -Commercial: Medium boilers (<50MW) - automatic	Fuelwood direct	Medium boiler - pellets	6.85	PJ	89		80		41		7208
Residential -Commercial: Medium boilers (<50MW) - automatic	Fuelwood direct	No control	6.85	PJ		100		469			
Residential -Commercial: Medium boilers (<50MW) - automatic	Hard coal. grade 1	Cyclone for medium boiler	0.02	PJ	30	60	30	3	1	8	4
Residential -Commercial: Medium boilers (<50MW) - automatic	Hard coal. grade 1	High efficiency deduster for medium boiler	0.02	PJ	99		70				24
Residential -Commercial: Medium boilers (<50MW) - automatic	Hard coal. grade 1	No control	0.02	PJ		40		3			
Residential -Commercial: Medium boilers (<1MW) - manual	Hard coal. grade 1	Cyclone for medium boiler	0.00	PJ	30		100		1		5

Sector	Activity	Control technology	Sectoral_activity_(unit)	Unit	Removal_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Residential -Commercial: Medium boilers (<1MW) - manual	Hard coal. grade 1	No control	0.00	PJ		100		1			
Residential -Commercial: Single house boilers (<50 kW) - manual	Fuelwood direct	No control	4.11	PJ		35		1069			
Residential -Commercial: Single house boilers (<50 kW) - manual	Fuelwood direct	Biomass single house boiler new	4.11	PJ	80	45	40	275	244	24929	22159
Residential -Commercial: Single house boilers (<50 kW) - manual	Fuelwood direct	Biomass single house boiler - pellets	4.11	PJ	90	20	30	61	92	13935	20902
Residential -Commercial: Single house boilers (<50 kW) - manual	Fuelwood direct	Biomass single house boiler - pellets and electrostatic precipitator	4.11	PJ	99		30		9		24019
Residential -Commercial: Single house boilers (<50 kW) - manual	Hard coal. grade 1	No control	0.00	PJ		100	79				
Residential -Commercial: Single house boilers (<50 kW) - manual	Hard coal. grade 1	Coal single house boiler new	0.00	PJ	40		21				1
Residential -Commercial: Heating stoves	Fuelwood direct	No control	10.95	PJ		35	20	3030	1731		
Residential -Commercial: Heating stoves	Fuelwood direct	Biomass stove improved	10.95	PJ	63	45	80	1441	2562	86427	153650
Residential -Commercial: Heating stoves	Fuelwood direct	Biomass stove new	10.95	PJ	80	20		346		295872	
Residential -Commercial: Heating stoves	Hard coal. grade 1	No control	0.01	PJ		40	34	1	1		
Residential -Commercial: Heating stoves	Hard coal. grade 1	Coal stove improved	0.01	PJ	30	50	66	1	1	44	58
Residential -Commercial: Heating stoves	Hard coal. grade 1	Coal stove new	0.01	PJ	50	10				68	
Non-industrial combustion	Heavy fuel oil	Good housekeeping: domestic oil boilers	0.48	PJ	30	100	100	3	3	581	581
Non-industrial combustion	Diesel oil and others incl. biofuel	Good housekeeping: domestic oil boilers	16.61	PJ	30	100	100	9	9	20109	20109
Industry: Other combustion. grate firing	Hard coal. grade 1	Electrostatic precipitator: 2 fields - industrial combustion	1.97	PJ	96	100		12		2981	
Industry: Other combustion. grate firing	Hard coal. grade 1	High efficiency deduster - industrial combustion	1.97	PJ	99		100		3		3307
Industry: Other combustion. fluidized bed	Hard coal. grade 1	High efficiency deduster - industrial combustion	2.96	PJ	99	100	100	7	7	4648	4648
Industry: Other combustion. pulveri-zed	Hard coal. grade 1	Electrostatic precipitator: 2 fields - industrial combustion	4.93	PJ	96	100		50		6166	
Industry: Other combustion. pulveri-zed	Hard coal. grade 1	High efficiency deduster - industrial combustion	4.93	PJ	99		100		12		6677
Industrial combustion	Heavy fuel oil	Good housekeeping: industrial oil boilers	18.65	PJ	30	100	100	135	135	1930	1930
Industrial combustion	Diesel oil and others incl. biofuel	Good housekeeping: industrial oil boilers	25.70	PJ	30	100	100	5	5	2659	2659

Sector	Activity	Control technology	Secto-ral_activity_(unit)	Unit	Remo-val_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Industrial combustion	Biomass fuels	Electrostatic precipitator: 1 field - industrial combustion	9.35	PJ	93		50		4		3674
Industrial combustion	Biomass fuels	Electrostatic precipitator: 2 fields - industrial combustion	9.35	PJ	96	100		4		9007	
Industrial combustion	Biomass fuels	High efficiency deduster - industrial combustion	9.35	PJ	99		50		1		5179
Industrial combustion	Other biomass and waste fuels	Electrostatic precipitator: 1 field - industrial combustion	0.75	PJ	93		50		1		288
Industrial combustion	Other biomass and waste fuels	Electrostatic precipitator: 2 fields - industrial combustion	0.75	PJ	96	100		1		708	
Industrial combustion	Other biomass and waste fuels	High efficiency deduster - industrial combustion	0.75	PJ	99		50				408
Power heat plants: Exist. other. grate firing	Hard coal. grade 1	Electrostatic precipitator: 2 fields - power plants	0.89	PJ	96	40		4		640	
Power heat plants: Exist. other. grate firing	Hard coal. grade 1	High efficiency deduster - power plants	0.89	PJ	99	60	100	2	3	1071	1785
Power heat plants: Exist. other. fluidized bed	Hard coal. grade 1	Electrostatic precipitator: 2 fields - power plants	8.93	PJ	96	40		34		5746	
Power heat plants: Exist. other. fluidized bed	Hard coal. grade 1	High efficiency deduster - power plants	8.93	PJ	99	60	100	13	21	9390	15650
Power heat plants: Exist. other. pulverized	Hard coal. grade 1	Electrostatic precipitator: 2 fields - power plants	34.84	PJ	96	10		35		4691	
Power heat plants: Exist. other. pulverized	Hard coal. grade 1	High efficiency deduster - power plants	34.84	PJ	99	90	100	79	88	46117	51242
Power heat plants: Exist. other	Heavy fuel oil	Good housekeeping: industrial oil boilers	5.93	PJ	30	100	100	39	39	3659	3659
Power heat plants: Exist. other	Diesel oil and others incl. biofuel	Good housekeeping: industrial oil boilers	0.21	PJ	30	100	100			38	38
Power heat plants: Exist. other	Biomass fuels	High efficiency deduster - power plants	2.08	PJ	99	100	100			4641	4641
Power heat plants: Exist. other	Other biomass and waste fuels	Electrostatic precipitator: 1 field - power plants	3.55	PJ	93		20		2		358
Power heat plants: Exist. other	Other biomass and waste fuels	Electrostatic precipitator: 2 fields - power plants	3.55	PJ	96	40		2		876	
Power heat plants: Exist. other	Other biomass and waste fuels	High efficiency deduster - power plants	3.55	PJ	99	60	80	1	1	1516	2021
Power heat plants: Exist. other	Other biomass and waste fuels	No control	3.55	PJ			0				
Power heat plants: New. fluidized bed	Hard coal. grade 1	Electrostatic precipitator: 2 fields - power plants	11.56	PJ	96	40		44		6487	
Power heat plants: New. fluidized bed	Hard coal. grade 1	High efficiency deduster - power plants	11.56	PJ	99	60	100	16	27	10493	17488
Power heat plants: New. pulverized	Hard coal. grade 1	Electrostatic precipitator: 2 fields - power plants	46.23	PJ	96	40		187		22420	

Sector	Activity	Control technology	Secto-ral_activity_(unit)	Unit	Remo-val_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Power heat plants: New. pulverized	Hard coal. grade 1	High efficiency deduster - power plants	46.23	PJ	99	60	100	70	117	36358	60597
Power heat plants: New	Heavy fuel oil	Good housekeeping: industrial oil boilers	16.22	PJ	30	100	100	106	106	5631	5631
Power heat plants: New	Diesel oil and others incl. biofuel	Good housekeeping: industrial oil boilers	1.17	PJ	30	100	100			99	99
Power heat plants: New	Biomass fuels	High efficiency deduster - power plants	36.12	PJ	99	100	100	4	4	23748	23748
Power heat plants: New	Other biomass and waste fuels	Electrostatic precipitator: 1 field - power plants	42.28	PJ	93		20		22		3289
Power heat plants: New	Other biomass and waste fuels	Electrostatic precipitator: 2 fields - power plants	42.28	PJ	96	40		25		8020	
Power heat plants: New	Other biomass and waste fuels	High efficiency deduster - power plants	42.28	PJ	99	60	80	9	12	13851	18468
Ind. Process: Aluminum production - primary	No fuel use	No control	0.00	Mt		2.8	100				
Ind. Process: Aluminum production - primary	No fuel use	Electrostatic precipitator: 1 field - industrial processes	0.00	Mt	93	42.2					
Ind. Process: Aluminum production - primary	No fuel use	High efficiency deduster - industrial processes	0.00	Mt	99	55					
Ind. Process: Aluminum production - secondary	No fuel use	No control	0.09	Mt		7.5	7.5	35	35		
Ind. Process: Aluminum production - secondary	No fuel use	High efficiency deduster - industrial processes	0.09	Mt	99	92.5	92.5	4	4	1986	1986
Ind. Process: Basic oxygen furnace	No fuel use	No control	0.00	Mt		.5	100				
Ind. Process: Basic oxygen furnace	No fuel use	High efficiency deduster - industrial processes	0.00	Mt	99	99.5				1	
Ind. Process: Cast iron (grey iron foundries) (fugitive)	No fuel use	No control	0.10	Mt		1		1			
Ind. Process: Cast iron (grey iron foundries) (fugitive)	No fuel use	Good practice: ind.process - stage 2 (fugitive)	0.10	Mt	80	99	100	28	29	3632	3669
Ind. Process: Cast iron (grey iron foundries)	No fuel use	Cyclone - - industrial process	0.10	Mt	30	25		194		301	
Ind. Process: Cast iron (grey iron foundries)	No fuel use	High efficiency deduster - industrial processes	0.10	Mt	99	75	100	8	11	2555	3406
Ind. Process: Cement production	No fuel use	High efficiency deduster - industrial processes	1.87	Mt	99	100	100	439	439	20657	20657
Ind. Process: Electric arc furnace	No fuel use	No control	0.92	Mt		1		69			
Ind. Process: Electric arc furnace	No fuel use	High efficiency deduster - industrial processes	0.92	Mt	99	99	100	68	69	3319	3353
Ind. Process: Glass production (flat. blown. container glass)	No fuel use	High efficiency deduster - industrial processes	0.64	Mt	99	100	100	19	19	2862	2862
Ind. Process: Lime production	No fuel use	High efficiency deduster - industrial	0.09	Mt	99	100	100	1	1	1438	1438

Sector	Activity	Control technology	Secto-ral_activity_(unit)	Unit	Remo-val_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
		processes									
Ind. Process: Other non -ferrous metals prod. - primary and secondary	No fuel use	No control	0.00	Mt		1					
Ind. Process: Other non -ferrous metals prod. - primary and secondary	No fuel use	High efficiency deduster - industrial processes	0.00	Mt	99	99	100			7	7
Ind. Process: Production of glass fiber. gypsum. PVC. other	No fuel use	High efficiency deduster - industrial processes	0.00	Mt	99	100	100			1	1
Ind. Process: Paper pulp mills	No fuel use	Cyclone - - industrial process	0.06	Mt			100				
Ind. Process: Crude oil & other prod-ucts - input to Petroleum refineries	No fuel use	No control	7.40	Mt		1	1	7	7		
Ind. Process: Crude oil & other prod-ucts - input to Petroleum refineries	No fuel use	Electrostatic precipitator: 1 field - industrial processes	7.40	Mt	93	40		20		648	
Ind. Process: Crude oil & other prod-ucts - input to Petroleum refineries	No fuel use	Electrostatic precipitator: 2 fields - industrial processes	7.40	Mt	96	59		17		1124	
Ind. Process: Crude oil & other prod-ucts - input to Petroleum refineries	No fuel use	High efficiency deduster - industrial processes	7.40	Mt	99		99		7		2229
Ind. Process: Small industrial and business facilities - fugitive	No fuel use	No control	5.57	M people		50	75	167	250		
Ind. Process: Small industrial and business facilities - fugitive	No fuel use	Good practice: ind.process - stage 1 (fugitive)	5.57	M people	40	50		100		83822	
Ind. Process: Small industrial and business facilities - fugitive	No fuel use	Good practice: ind.process - stage 2 (fugitive)	5.57	M people	80		25		17		49098
Residential: Meat frying. food prepa-ration. BBQ	No fuel use	Filters in households (kitchen)	5.57	M people	10		100		376		342
Residential: Meat frying. food prepa-ration. BBQ	No fuel use	No control	5.57	M people		100		417			
Storage and handling: Agricultural products (crops)	No fuel use	No control	14.10	Mt			0				
Storage and handling: Agricultural products (crops)	No fuel use	Good practice: storage and handling	14.10	Mt	10	100	100	51	51	24341	24341
Storage and handling: Coal	No fuel use	No control	22.39	Mt			0				
Storage and handling: Coal	No fuel use	Good practice: storage and handling	22.39	Mt	10	100	100	121	121	51766	51766
Storage and handling: N.P.K fertiliz-ers	No fuel use	Good practice: storage and handling	3.14	Mt	10	100	100	11	11	5153	5153
Storage and handling: Other indus-trial products (cement. bauxite. coke)	No fuel use	No control	6.47	Mt			0				
Storage and handling: Other indus-trial products (cement. bauxite. coke)	No fuel use	Good practice: storage and handling	6.47	Mt	10	100	100	12	12	3737	3737
Waste: Agricultural waste burning	No fuel use	Ban on open burning of agricultural or residentail waste	0.53	Mt	100	95	100			1240	1304
Waste: Agricultural waste burning	No fuel use	No control	0.53	Mt		5		106			
Waste: Flaring in gas and oil industry	No fuel use	Good practice in oil and gas industry	1.58	PJ	5		100		96		415

Sector	Activity	Control technology	Secto-ral_activity_(unit)	Unit	Remo-val_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
		- flaring									
Waste: Flaring in gas and oil industry	No fuel use	No control	1.58	PJ		100		101			
Waste: Open burning of residential waste	No fuel use	Ban on open burning of agricultural or residentail waste	0.02	Mt	100		100				101
Waste: Open burning of residential waste	No fuel use	No control	0.02	Mt		100		116			
Sub total								11928	8778	897874	1254045
Transport								2614	2579		
No control								461	461		
Total								15003	11818	897874	1254045

Appendix 10 $PM_{2.5}$ reductions; COH-scenario.

Sector	Activity	Control technology	Sectoral_activity_(unit)	Unit	Removal_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss (tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Agriculture: Ploughing. tilling. harvesting. Arable agricultural land in temporal and subboreal climate	No fuel use	Low-till farming. alternative cereal harvesting	2,30	M ha			100				68380
Agriculture: Livestock - other cattle	No fuel use	Feed modification (all livestock)	0,84	M animals	10		100		34		6647
Agriculture: Livestock - other cattle	No fuel use	No control	0,84	M animals		100		38			
Agriculture: Livestock - dairy cattle	No fuel use	Feed modification (all livestock)	0,50	M animals	10		100		36		9593
Agriculture: Livestock - dairy cattle	No fuel use	No control	0,50	M animals		100		40			
Agriculture: Livestock - pigs	No fuel use	Feed modification (all livestock)	13,82	M animals	10		100		909		394822
Agriculture: Livestock - pigs	No fuel use	No control	13,82	M animals		100		1010			
Agriculture: Livestock - poultry	No fuel use	Feed modification (all livestock)	18,44	M animals	10		100		174		60398
Agriculture: Livestock - poultry	No fuel use	No control	18,44	M animals		100		194			
Gas & Oil industry: combustion	Heavy fuel oil	Good housekeeping: industrial oil boilers	10,13	PJ	30	100	100	83	83	1048	1048
Residential -Commercial: Fireplaces	Fuelwood direct	Fireplace improved	1,11	PJ	44	45	45	221	221	11042	11041
Residential -Commercial: Fireplaces	Fuelwood direct	No control	1,11	PJ		55	55	482	482		
Residential -Commercial: Medium boilers (<50MW) - automatic	Hard coal. grade 1	Cyclone for medium boiler	0,18	PJ	30	60	30	32	16	92	46
Residential -Commercial: Medium boilers (<50MW) - automatic	Hard coal. grade 1	High efficiency deduster for medium boiler	0,18	PJ	99		70		1		263
Residential -Commercial: Medium boilers (<50MW) - automatic	Hard coal. grade 1	No control	0,18	PJ		40		30			
Residential -Commercial: Single house boilers (<50 kW) - manual	Fuelwood direct	No control	3,33	PJ		35	8	866	205		
Residential -Commercial: Single house boilers (<50 kW) - manual	Fuelwood direct	Biomass single house boiler improved	3,33	PJ	60		80		792		22026
Residential -Commercial: Single house boilers (<50 kW) - manual	Fuelwood direct	Biomass single house boiler new	3,33	PJ	80	45	12	223	58	20195	5250
Residential -Commercial: Single house boilers (<50 kW) - manual	Fuelwood direct	Biomass single house boiler - pellets	3,33	PJ	90	20		50		11288	
Residential -Commercial: Heating stoves	Fuelwood direct	No control	8,87	PJ		35	30	2455	2076		

Sector	Activity	Control technology	Sectoral_activity_(unit)	Unit	Removal_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Residential -Commercial: Heating stoves	Fuelwood direct	Biomass stove improved	8,87	PJ	63	45	70	1168	1827	70015	109530
Residential -Commercial: Heating stoves	Fuelwood direct	Biomass stove new	8,87	PJ	80	20		281		239687	
Residential -Commercial: Heating stoves	Hard coal. grade 1	No control	0,06	PJ		40	33	9	7		
Residential -Commercial: Heating stoves	Hard coal. grade 1	Coal stove improved	0,06	PJ	30	50	67	8	10	482	644
Residential -Commercial: Heating stoves	Hard coal. grade 1	Coal stove new	0,06	PJ	50	10		1		743	
Non-industrial combustion	Heavy fuel oil	Good housekeeping: domestic oil boilers	0,66	PJ	30	100	100	4	4	797	797
Non-industrial combustion	Diesel oil and others incl. biofuel	Good housekeeping: domestic oil boilers	33,59	PJ	30	100	100	17	17	40670	40670
Non-industrial combustion	Diesel oil and others incl. biofuel	No control	33,59	PJ							
Industry: Combustion in boilers. grate firing	Hard coal. grade 1	High efficiency deduster - industrial combustion	0,00	PJ	99	100	100			7	7
Industry: Combustion in boilers. fluidized bed	Hard coal. grade 1	Electrostatic precipitator: 1 field - industrial combustion	0,00	PJ	93		51				3
Industry: Combustion in boilers. fluidized bed	Hard coal. grade 1	Electrostatic precipitator: 2 fields - industrial combustion	0,00	PJ	96	100				7	
Industry: Combustion in boilers. fluidized bed	Hard coal. grade 1	High efficiency deduster - industrial combustion	0,00	PJ	99		49				4
Industry: Combustion in boilers. pulverized	Hard coal. grade 1	Electrostatic precipitator: 1 field - industrial combustion	0,01	PJ	93		51				4
Industry: Combustion in boilers. pulverized	Hard coal. grade 1	Electrostatic precipitator: 2 fields - industrial combustion	0,01	PJ	96	100				10	
Industry: Combustion in boilers. pulverized	Hard coal. grade 1	High efficiency deduster - industrial combustion	0,01	PJ	99		49				5
Industry: Combustion in boilers	Heavy fuel oil	Good housekeeping: industrial oil boilers	1,14	PJ	30	100	100	8	8	189	189
Industry: Combustion in boilers	Biomass fuels	Cyclone - industrial combustion	1,06	PJ	30	50		69		282	
Industry: Combustion in boilers	Biomass fuels	Electrostatic precipitator: 1 field - industrial combustion	1,06	PJ	93		100		14		1292
Industry: Combustion in boilers	Biomass fuels	High efficiency deduster - industrial combustion	1,06	PJ	99	50		1		916	
Industry: Other combustion. grate firing	Hard coal. grade 1	Electrostatic precipitator: 1 field - industrial combustion	0,06	PJ	93		50				40
Industry: Other combustion. grate firing	Hard coal. grade 1	Electrostatic precipitator: 2 fields - industrial combustion	0,06	PJ	96	100				93	
Industry: Other combustion. grate firing	Hard coal. grade 1	High efficiency deduster - industrial combustion	0,06	PJ	99		50				51
Industry: Other combustion. fluidized bed	Hard coal. grade 1	High efficiency deduster - industrial combustion	0,09	PJ	99	100	100			145	145
Industry: Other combustion. pulverized	Hard coal. grade 1	Electrostatic precipitator: 1 field - industrial combustion	0,15	PJ	93		50		1		86

Sector	Activity	Control technology	Secto-ral_activity_(unit)	Unit	Remo-val_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
Industry: Other combustion. pulverized	Hard coal. grade 1	Electrostatic precipitator: 2 fields - industrial combustion	0,15	PJ	96	100		2		192	
Industry: Other combustion. pulverized	Hard coal. grade 1	High efficiency deduster - industrial combus-tion	0,15	PJ	99		50				104
Industrial combustion	Derived coal (coke. briquettes)	Electrostatic precipitator: 1 field - industrial combustion	0,25	PJ	93		50				93
Industrial combustion	Derived coal (coke. briquettes)	Electrostatic precipitator: 2 fields - industrial combustion	0,25	PJ	96	100				230	
Industrial combustion	Derived coal (coke. briquettes)	High efficiency deduster - industrial combus-tion	0,25	PJ	99		50				133
Industrial combustion	Heavy fuel oil	Good housekeeping: industrial oil boilers	10,07	PJ	30	100	100	73	73	1042	1042
Industrial combustion	Diesel oil and others incl. biofuel	Good housekeeping: industrial oil boilers	13,15	PJ	30	100	100	2	2	1361	1361
Power heat plants: Exist. other. grate firing	Hard coal. grade 1	Electrostatic precipitator: 1 field - power plants	0,61	PJ	93		20		3		184
Power heat plants: Exist. other. grate firing	Hard coal. grade 1	Electrostatic precipitator: 2 fields - power plants	0,61	PJ	96	40		3		439	
Power heat plants: Exist. other. grate firing	Hard coal. grade 1	High efficiency deduster - power plants	0,61	PJ	99	60	80	1	1	734	979
Power heat plants: Exist. other. fluidized bed	Hard coal. grade 1	Electrostatic precipitator: 1 field - power plants	6,13	PJ	93		20		20		1755
Power heat plants: Exist. other. fluidized bed	Hard coal. grade 1	Electrostatic precipitator: 2 fields - power plants	6,13	PJ	96	40		23		3940	
Power heat plants: Exist. other. fluidized bed	Hard coal. grade 1	High efficiency deduster - power plants	6,13	PJ	99	60	80	9	12	6439	8586
Power heat plants: Exist. other. pulver-ized	Hard coal. grade 1	Electrostatic precipitator: 1 field - power plants	23,89	PJ	93		5		21		1443
Power heat plants: Exist. other. pulver-ized	Hard coal. grade 1	Electrostatic precipitator: 2 fields - power plants	23,89	PJ	96	10		24		3216	
Power heat plants: Exist. other. pulver-ized	Hard coal. grade 1	High efficiency deduster - power plants	23,89	PJ	99	90	95	54	57	31624	33381
Power heat plants: Exist. other. pulver-ized	Hard coal. grade 1	No control	23,89	PJ							
Power heat plants: Exist. other	Diesel oil and others incl. biofuel	Good housekeeping: industrial oil boilers	0,02	PJ	30	100	100			4	4
Power heat plants: Exist. other	Biomass fuels	High efficiency deduster - power plants	32,77	PJ	99	100	100	4	4	73220	73220
Power heat plants: New. fluidized bed	Hard coal. grade 1	Electrostatic precipitator: 1 field - power plants	11,12	PJ	93		20		37		2819
Power heat plants: New. fluidized bed	Hard coal. grade 1	Electrostatic precipitator: 2 fields - power plants	11,12	PJ	96	40		42		6241	
Power heat plants: New. fluidized bed	Hard coal. grade 1	High efficiency deduster - power plants	11,12	PJ	99	60	80	16	21	10095	13461
Power heat plants: New. pulverized	Hard coal. grade 1	Electrostatic precipitator: 1 field - power	44,48	PJ	93		20		157		9787

Sector	Activity	Control technology	Sectoral_activity_(unit)	Unit	Removal_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
		plants									
Power heat plants: New. pulverized	Hard coal. grade 1	Electrostatic precipitator: 2 fields - power plants	44,48	PJ	96	40		180		21572	
Power heat plants: New. pulverized	Hard coal. grade 1	High efficiency deduster - power plants	44,48	PJ	99	60	80	67	90	34982	46642
Power heat plants: New	Heavy fuel oil	Good housekeeping: industrial oil boilers	3,49	PJ	30	100	100	23	23	1212	1212
Power heat plants: New	Diesel oil and others incl. biofuel	Good housekeeping: industrial oil boilers	1,03	PJ	30	100	100			88	88
Power heat plants: New	Biomass fuels	High efficiency deduster - power plants	45,25	PJ	99	100	100	5	5	29750	29750
Ind. Process: Aluminum production - secondary	No fuel use	No control	0,03	Mt		7.5	8	11	11		
Ind. Process: Aluminum production - secondary	No fuel use	High efficiency deduster - industrial processes	0,03	Mt	99	92.5	92	1	1	602	600
Ind. Process: Basic oxygen furnace	No fuel use	No control	0,00	Mt		.5	100				
Ind. Process: Basic oxygen furnace	No fuel use	High efficiency deduster - industrial processes	0,00	Mt	99	99.5					
Ind. Process: Cast iron (grey iron foundries) (fugitive)	No fuel use	No control	0,10	Mt		1	1	1	1		
Ind. Process: Cast iron (grey iron foundries) (fugitive)	No fuel use	Good practice: ind.process - stage 2 (fugitive)	0,10	Mt	80	99	99	26	26	3382	3380
Ind. Process: Cast iron (grey iron foundries)	No fuel use	Cyclone - - industrial process	0,10	Mt	30	25		181		280	
Ind. Process: Cast iron (grey iron foundries)	No fuel use	Electrostatic precipitator: 1 field - industrial processes	0,10	Mt	93		100		72		2216
Ind. Process: Cast iron (grey iron foundries)	No fuel use	High efficiency deduster - industrial processes	0,10	Mt	99	75		8		2378	
Ind. Process: Cement production	No fuel use	No control	2,95	Mt			0		2		
Ind. Process: Cement production	No fuel use	High efficiency deduster - industrial processes	2,95	Mt	99	100	100	689	689	32462	32461
Ind. Process: Electric arc furnace	No fuel use	No control	0,79	Mt		1		60			
Ind. Process: Electric arc furnace	No fuel use	High efficiency deduster - industrial processes	0,79	Mt	99	99	100	59	60	2862	2891
Ind. Process: Glass production (flat. blown. container glass)	No fuel use	High efficiency deduster - industrial processes	0,57	Mt	99	100	100	17	17	2566	2566
Ind. Process: Lime production	No fuel use	High efficiency deduster - industrial processes	0,12	Mt	99	100	100	2	2	1793	1793
Ind. Process: Other non -ferrous metals prod. - primary and secondary	No fuel use	No control	0,00	Mt		1					
Ind. Process: Other non -ferrous metals prod. - primary and secondary	No fuel use	High efficiency deduster - industrial processes	0,00	Mt	99	99	100			1	1
Ind. Process: Production of glass fiber.	No fuel use	High efficiency deduster - industrial proc-	0,00	Mt	99	100	100			1	1

Sector	Activity	Control technology	Secto-ral_activity_(unit)	Unit	Remo-val_efficiency (%)	BL_Cap. contr (%)	TS_Cap. contr (%)	BL_Emiss (tonne)	TS_Emiss tonne)	BL_costs (t DKK pr year)	TS_costs (t DKK pr year)
gypsum. PVC. other		esses									
Ind. Process: Paper pulp mills	No fuel use	Cyclone - - industrial process	0,07	Mt			100				
Ind. Process: Crude oil & other products - input to Petroleum refineries	No fuel use	No control	7,84	Mt		1	1	8	8		
Ind. Process: Crude oil & other products - input to Petroleum refineries	No fuel use	Electrostatic precipitator: 1 field - industrial processes	7,84	Mt	93	40	40	21	21	686	686
Ind. Process: Crude oil & other products - input to Petroleum refineries	No fuel use	Electrostatic precipitator: 2 fields - industrial processes	7,84	Mt	96	59	59	18	18	1191	1191
Ind. Process: Small industrial and business facilities - fugitive		No control	5,53	M people		50	75	166	249		
Ind. Process: Small industrial and business facilities - fugitive	No fuel use	Good practice: ind.process - stage 1 (fugitive)	5,53	M people	40	50		99		83237	
Ind. Process: Small industrial and business facilities - fugitive	No fuel use	Good practice: ind.process - stage 2 (fugitive)	5,53	M people	80		25		17		48756
Storage and handling: Agricultural products (crops)	No fuel use	No control	14,10	Mt			0				
Storage and handling: Agricultural products (crops)	No fuel use	Good practice: storage and handling	14,10	Mt	10	100	100	51	51	24341	24341
Storage and handling: Coal	No fuel use	No control	22,39	Mt			0				
Storage and handling: Coal	No fuel use	Good practice: storage and handling	22,39	Mt	10	100	100	121	121	51766	51766
Storage and handling: N.P.K fertilizers	No fuel use	Good practice: storage and handling	3,14	Mt	10	100	100	11	11	5153	5153
Storage and handling: Other industrial products (cement. bauxite. coke)	No fuel use	No control	6,47	Mt			0				
Storage and handling: Other industrial products (cement. bauxite. coke)	No fuel use	Good practice: storage and handling	6,47	Mt	10	100	100	12	12	3737	3737
Waste: Agricultural waste burning	No fuel use	Ban on open burning of agricultural or residentail waste	0,53	Mt	100	95	100			1240	1304
Waste: Agricultural waste burning	No fuel use	No control	0,53	Mt		5		106			
Waste: Open burning of residential waste	No fuel use	Ban on open burning of agricultural or residentail waste	0,02	Mt	100		100				101
Waste: Open burning of residential waste	No fuel use	No control	0,02	Mt		100		116			
Sub total								9601	8894	841770	1141969
No control								1352	1352	-	-
Transport								2620	2569	-	-
Total								13573	12815	841770	1141969

Appendix 11 Evaluation of EEA report “Air pollution from electricity-generating large combustion plants”.

Background

The EU Commission has argued that implementation of Best Available Technologies (BAT) in the stationary combustion sector would lead to substantial NO_x and SO_2 reductions and contribute considerably to meet the proposed 2020 emission ceilings. The arguments are based on the EEA report “Air pollution from electricity-generating large combustion plants. -An assessment of the theoretical emission reduction of SO_2 and NO_x through implementation of BAT as set in the BREFs” (EEA. 2008) - in the following referred to “the EEA report”.

Scope

In this paper the conclusions of the EEA report and the calculated reduction potentials are evaluated with respect to Danish circumstances.

Method and results of the EEA report

The EEA report (2008) on LCP (Large Combustion Plant) emission reduction potentials estimates the reduction potentials in the European (EU25) power sector for facilities with production capacity above 50 MW.

Relevant data about power plant emissions, energy consumption and installed emission abatement technologies are not easily accessible and are derived from two sources. The EPER database (EPER. 2006) is open to the public while the Platts WEPP database (Platts. 2006) is only commercially available. The EPER database contains data on emissions from 1 268 facilities with main activity 1.1 within Annex 1 of the IPPC directive (EC. 1996), which implies electricity production as main activity. The Platts WEPP database provides information on fuel type, installed abatement technologies and electrical capacity.

When joining data from the two databases it is possible to derive fuel type and quantity consumption and emission factors for each facility and also implement control technologies. After the joining process 450 facilities remain.

In order to find reduction potentials for each facility (and subsidiary units) emission levels “as is” for 2004 was either derived from the EPER database or estimated. The “as is” reflects the present 2004 level of emissions of the individual units and therefore includes the effect of various emission reduction measures installed.

The “as is” emissions are compared to emission levels associated implementation of Best Available Technologies (BAT) to reduce emissions as described in the LCP BREF document [1] (EC. 2006).

[1] LCP BREF is: Large Combustion Plants Best available technology REFerence document.

Knowing the BAT Associated Emission Levels (AEL) and the "as-is" emission level it is possible to calculate potentials for further emission reductions.

The BAT Upper and Lower emissions levels are calculated by multiplying the BAT emission factors with energy consumption of the individual units. Data on energy consumption is not stemming from national inventories directly but is calculated from the CO_2 emission inventory in the PLATT database - there is a quite unambiguous relationship between the amounts of fuel consumed and emitted CO_2 depending on the fuel type.

The aggregated result of the calculations is reflected in Table A11.1, which indicates the reduction potentials for EU in general in the case when power plants in 2004 were fully equipped BATs either at Upper end or Lower end of the range. Upper end and Lower end refers to the range framed by least stringent and most stringent control efforts.

Table A11.1 Over all NO_x and SO_2 reduction potentials.

Pollutant	2004 EPER emissions "as is"	Estimated emissions reduction potential (kt pr year)			
		'Upper end of BAT'		'Lower end of BAT'	
	Kt	kt	% of "as is"	kt	% of "as is"
NO_X	1 506	884	– 59 %	1 308	– 87 %
SO_2	2 853	2 287	– 80 %	2 754	– 97 %

As seen from the table there are quite substantial reduction potentials both regarding NO_x emissions and SO_2 emissions in Europe in general.

Table A11.2 shows the emission factors as calculated in the EEA report for facilities equipped with either Lower end or Upper end BAT. The facilities are split into three capacity groups (50-100 MW. 100-300 MW and >300 MW). The report gives data for all fuel types, however, in the Danish context for the two most relevant fuels: hard coal and natural gas.

In the table is also given ranges of implied emission factors of Danish power plant units as calculated by NERI and based on confidential inventory data on fuel consumption and emissions, directly from emitters. Average values are placed in brackets.

Table A11.2 AEL emission factors compared to Dansih real world values.

Pollutant Emission factor	Capacity (MW)	EEA Emission factor (g pr GJ) Hard coal	EEA Emission factor (g pr GJ) Gas	NERI Emission factor (g pr GJ) average in brackets Hard coal	NERI Emission factor (g pr GJ) average in brackets Gas
NO_X					
'Lower end of BAT' AEL	50–100	72	5		
	100–300	32	5		
	> 300	18	5		
'Upper end of BAT' AEL	50–100	108	27		
	100–300	72	27		
	> 300	54	27		
NERI 2004 inventory				28-240 (150)	31-243 (88)
SO_2					
'Lower end of BAT' AEL	50–100	54	3		
	100–300	36	3		
	> 300	7	3		
'Upper end of BAT' AEL	50–100	144	3		
	100–300	90	3		
	> 300	72	3		
NERI 2004 inventory				9-342 (33)	< 1

Source: EEA, 2008 and NERI, 2008: non published data.

The BAT emission factors in the report are calculated from values given in the IPCC BREF document for large combustion plants (EC, 2006). This has implied an simplification process among others joining new and existing power plants, which means the BAT emission factors levels are to be perceived as rough approximations of possible achievable emission factors.

Assessment of the results

Where the final EEA report only shows EU_{25} average figures, the draft version of the report (not published) lists the calculated reduction potentials for the individual countries and shows emission levels in graphs. Denmark is appointed to have quite substantial reduction potentials both regarding NO_x and SO_2 measured in percentage as of current 2004 emission levels. By this country specific data it has been possible to roughly verify the calculation methods and that data are in accordance with Danish inventory data.

In the following the theoretical BAT Emission Factors (EF) are assessed in comparison with real world IEF (Implied Emission Factor) of large combustion plants in Denmark fuelled either by coal or natural gas.

Practically all power plants in Denmark are of the type CHP – Combined Heating and Power Plants. Most of the large coal fired plants have thermal capacities above 300 MW_{th}. The thermal capacity of gas fired plants is most often below 100 MW, however, above for two single units (~ 180 MWth) producing 38 % of the total energy from gas turbines.

NO_x - Coal

As seen from Table A11.2 the BAT emission factors for units above $300MW_{th}$ are at 18 and 54 g pr GJ for the Lower and Upper end of the BAT range, respectively. This represents control technologies with reduction potential between 80 % and 95 % (EC, 2006).

In principle all coal fired CHPs have de-NO_x controls installed. Non-published calculations by NERI (2008) show that the IEF (Implied Emission Factor) in 2004 ranges between 28 and 240 g pr GJ NO_x for the 17 largest coal fired units in Denmark with an average on 150 g pr GJ. This average NO_x implied emission factor is quite high. Five coal fired CHP plants accounting for 44 % of the coal energy use have emission factors ranging from 28 to 65 g pr GJ, which shows that reductions down to about 54 g pr GJ as indicated by the BAT Upper end level would be feasible for all power plants running full time.

Reducing down to 18 g pr GJ – the lower level of BAT is to be questioned if practically obtainable when considering possible occasional breakdowns of the control technologies and also use of hard coal with higher unabated emission factors than standard average.

NO_x – Natural gas

The EEA-report finds potential emission levels at 27 g pr GJ and 5 g pr GJ after respectively "Upper end" and "Lower end" BAT reduction efforts for all sizes of plants.

The 12 largest power plants combusting natural gas in Denmark have IEF (Implied Emission Factors) ranging from 31 g pr GJ to 243 g pr GJ, or on average 88 g pr GJ. Four gas fired units in Denmark shows IEF below 43 g pr GJ. Therefore, there may be potential for further NO_x reductions.

SO_2 – Coal

The EEA report finds potential for SO_2 emission levels down to 72 g pr GJ and 7 g pr GJ after respectively "Upper end" and "Lower end" reduction efforts.

The 17 largest power plant units in Denmark emitted SO_2 between 9 g pr GJ and 342 g pr GJ or on average 33 g pr GJ in 2004.

Excluding the five units with highest EFs at 190 g pr GJor above the others have EFs between 9 g pr GJ and 36 g pr GJ or on average 16 g pr GJ. This place the units quite close to the lower end of the BAT emission factors.

SO_2 - Natural gas

The EEA report has en BAT AEL at 3 g pr GJ for both Upper and Lower level and all sizes.

NERI (2008) found SO_2 emissions below 1 g pr GJ for plants running solely on natural gas in the central power sector.

Plants running on mixed fuels - typically residual oil and natural gas - show emission factors between 11 g pr GJ and 378 g pr GJ. But since natural gas in use is almost free of sulphur the SO_2 emissions stems from the residual oil combustion.

Conclusion

The EEA report shows quite substantial reduction potential in the LCP sector. The title of the report explicitly mentions that is it about theoretical emission reductions. In practice the actual reductions will be somewhat more modest.

For hard coal combustion there seems to be some NO_x emission reduction potentials in the LCP sector at least at 70 % down from the average level in 2004. However, units showing emission factors at the level of 50 g pr GJ may have reached the in practice obtainable minimal level.

Regarding SO_2 emissions from hard coal combustion most of the power plants have achieved sufficient reductions as an effect of the tight quota system in Denmark and no further reductions seem practicable except from some outliers.

For natural gas combustion there seem to be potential for NO_x reductions. Only the best performing unit in Denmark could match the BAT Upper level EF at 27 g pr GJ with 31 g pr GJ. However, as mentioned above units showing emission factors at the level 50 g pr GJ may have reached the in practice obtainable minimal level.

Finally, SO_2 emissions from natural gas seem quite well under control in Denmark and are to be perceived as zero for plants running solely on natural gas because of almost no sulphur in the natural gas.

Perspectives

In further analyses it is important to keep in mind that although some units may show quite huge emission factors it is the actual quantity of emission that counts. In other words, implementation of advanced control technologies may not be feasible at units with small productions e.g. units applied for only peak hours running or emergency services.

The most advanced hard coal combustion plants in Denmark are equipped with advanced de-NO_x control technologies including SCRs. The implied emission factors from these plants indicate that at present the level of emission factors ranging from 28 to 65 g pr GJ seems to be the best obtainable in practice.

However technologies may improve over the next 12 years until 2020, leading to more efficient reduction technologies. This to be paced by more and more tightened NO_x emission quotas and tarifs for the power plant sector over the coming years.

References

EC, 1996: Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control. OJ L 257. 10.10.1996. pp 26–40. 1996. http://eur-lex.europa.eu/.../

EC, 2006: Integrated pollution prevention and control reference document on best available techniques for large combustion plants (LCP BREF). European Commission. July 2006.

EEA, 2008: Air pollution from electricity-generating large combustion plants. -An assessment of the theoretical emission reduction of SO_2 and NO_x through implementation of BAT as set in the BREFs. EEA Technical report No 4/2008. EEA. Copenhagen.

EPER, 2006: EPER dataset for reporting year 2004. European Pollutant Emission Register. http://eper.ec.europa.eu/eper

Platts, 2006: UDI world electric power plants database (WEPP Database). version September 2006; http://www.Platts.com

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