Monte Carlo Analysis of Uncertainties in the Netherlands NIR for 1990-2004

Jeroen van der Sluijs (UU)
Andrea Ramirez Ramirez (UU)
Corry de Keitzer (UU)
Jos Olivier (MNP)
Laurens Brandes (MNP)

September 27-28, 2007

Copernicus Institute
Sustainable Development and Innovation
http://www.chem.uu.nl/nws/www/publica/publicaties2006/E2006-58.pdf

Contents

- Goals of the research
- Main methodological points
- Results and conclusions

GOALS

- Assess whether a Monte Carlo analysis of the uncertainties in the Dutch NIR would result in different levels of uncertainties compared to those provided by the Tier 1 analysis.
- Assess which parameters contribute the most to the total uncertainty in the emissions, in order to identify areas of high priority for the further improvement of the overall accuracy of the inventory.

METHOD

- Analysis performed for the Kyoto base year (1990/1995) and for 2004
- Basic data for the calculations obtained from NL NIR
- Same level of aggregation chosen as in NL Tier 1 analysis

For base case

- All known non-Gaussian distribution were taken into account
- Normal distribution assumed where standard deviation equal or below 30%
- Lognormal where standard deviation > 30%
- In some cases, normal distributions have been truncated (0,+inf)

- Software package used: @Risk
- PDFs for emission factors and activity data were based on uncertainty ranges used in TIER 1 and expert judgment from MNP.
- All known correlations were taken into account

CORRELATIONS

100% FOR

- ACTIVITY DATA: FOR THE SAME YEAR AND DIFFERENT EMISSION FACTORS
- SAME EMISSION FACTOR DIFFERENT SECTORS AND/OR DIFFERENT YEARS

GREENHOUSE GAS SOURCE AND SINK C	AGGREGATE ACTIVITY DATA			IMPLIED EMISSION FACTORS [2]						EMISSIONS		
	Consumption			CO_2		CH_4		N_2O		CO_2	CH_4	N_2O
	(TJ)	NCV/GCV [1]	RISK	(t/TJ)	RISK	(kg/TJ)	RISK	(kg/TJ)	RISK	Co2 equivalents		
1.A. Fuel Combustion	2604855.298	NCV								171683.61	624.79	724.89
Liquid Fuels	796056.4556	NCV		72.1096414		5.5812175		2.107079		57403.346	93.30224938	519.9798
Solid Fuels	281388.0379	NCV		112.02323		0.7992734		1.146397		31521.997	4.723025312	100.0006
Gaseous Fuels	1444005.831	NCV		56.1000208		13.877826		0.099456		81008.757	420.8328912	44.52047
Biomass	55145.53152	NCV		118.7936		76.101028		2.814937			88.12926391	48.12168
Other Fuels	28259.4421	NCV		61.908705		30		1.4		1749.5055	17.80344852	12.2646
1.A.1. Energy Industries	994842.4873	NCV								69,906.88	124.8449133	168.2168
Liquid Fuels	153765.0145	NCV	153,774.20	76.6510785		3.4700594	3.47	0.238345	0.24	11,786.96	11.20665196	11.31877
Solid Fuels	247854.816	NCV	247,854.82	108.950574		0.446393		1.27		27003.924	2.323508896	97.39041
Gaseous Fuels	523465.8892	NCV	523,465.89	56.1000573	56.10	6.13	6.13	0.1	0.10	29366.494	67.36823455	16.22744
Biomass	41497.325	NCV		123.45		30	30.00	2.43	2.43		26.14331506	31.25994
Other Fuels	28259.4421	NCV	28,259.44	61.908705	61.91	30	30.00	1.4	1.40	1749.5055	17.80387191	12.2646
a. Public Electricity and Heat Production	803566.7683	NCV								56,158.01	102.7550374	156.0949
Liquid Fuels	37218.1947	NCV	37,218.19	59.9278548	59.93	3.5430464	3.54	0.11	0.11	2,230.41	2.77	1.2691
Residual chemical gas	36222.1905			59.5						2155.2203		
Others	996.0042			56.33						56.104917		
HBO	384.98			74.3						28.604014		
Jet fuel petroleum basis												
LPG												
other petroleum products	107.6467			73.3						7.8905031		
Residual fuel oil	503.3775			77.4						38.961419		
Solid Fuels	247854.816	NCV	247,854.82	108.950572	108.95	0.45	0.45	1.27	1.27	27,003.92	2.32	97.39
Coke Oven and BF gas	25257.016		25,257.02	234.545218	234.55					5923.9123		
CO-gas	1574.556			41.2						64.871707		
BF/OX gas	23682.46			247.4						5859.0406		
Others (steenkool)	222597.8		222,597.80	94.7	94.70					21080.012		
Gaseous Fuels	448736.99	NCV	448,736.99	56.10		5.70	5.70	0.10		25,174.17	53.72	13.91
Biomass	41497.3255	NCV	41,497.33	123.45		30.00		2.43			26.14	31.26
Other Fuels	28259.4421	NCV	28,259.44	61.91		30.00		1.40		1,749.51	17.80	12.26
b. Petroleum Refining	156460.2234	NCV								11795.014	13.21	11.28
Liquid Fuels	116546.8198	NCV	116,546.82	81.991678	81.99	3.45	3.45	0.28	0.28	9,555.87	8.44	10.05
Refinery gas	83527.29			66.7						5571.2702		
Others	33019.5298			78.7166363						2599.1863		
HBO	8.0703			74.3						0.5996233		
LPG	252.9175			66.7						16.869597		
other petroleum products	25669.97			79.2						2033.0616		
Residual fuel oil	7088.572			77.4						548.65547		
Solid Fuels	NO	NCV	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Gaseous Fuels	39913.40	NCV	39,913.40		56.10	5.70		0.10		2,239.14	4.78	1.24
Biomass	NO	NCV	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
Other Fuels	NO	NCV	NO	NO	NO	NO	NO	NO	NO	NO	NO	NO
c. Manufacture of Solid Fuels and Other Energy Indus	34815.49569	NCV								1,953.86	8.88	0.84
Liquid Fuels		NCV	9.18	74.30	74.30	3.40	3.40	0.60	0.60	0.7	0.00066	0.00171

Universiteit Utrecht

PARTIAL CORRELATIONS

- FOR EMISSION FACTORS FROM SAME CATEGORY AMONG YEARS:

Universiteit Utrecht

CORR: 0.75

CORR: 0.5

2004

1990

GREENHOUSE GAS SOURCE AND SINK CATE	IMPLIED EMISSION FACTORS [2] (2004)						IMPLIED EMISSION FACTORS [2] (1990)					
	CO_2		CH_4		N_2O		CO_2		CH_4		N_2O	
	(t/TJ)	RISK	(kg/TJ)	RISK	(kg/TJ)	RISK	(t/TJ)	RISK	(kg/TJ)	RISK	(kg/TJ)	RISK
1.A.4 Other Sectors												
Liquid Fuels	73.6241046	73.62	4.42	4.42	0.55	0.55	73.71087805	73.71	4.07	4.07	0.57	0.57
Solid Fuels	96.6838116	96.68	1.65	1.65	1.40	1.40	95.57767502	95.58	0.99	0.99	1.40	
Gaseous Fuels	56.10		23.54	23.54	0.10		56.10		25.14	25.14	0.10	
Biomass	104.71		247.98	247.98	4.00	4.00	106.40		266.01	266.01	4.00	
Other Fuels		NO		NO		NO	NO			NO		NO
a. Commercial/Institutional												
Liquid Fuels	67.5059965	67.505997	0.453		0.18312367		72.51	72.5097	2.41		0.56	
Solid Fuels	97.0344306	97.034431	1.8622		1.4		96.05	96.0512	1.26		1.40	
Gaseous Fuels	56.10		5.70		0.10		56.10		5.68		0.11	
Biomass	84.20		30.00		3.99995072		84.20		30.00		4.00	
Other Fuels		NO		NO		NO		NO		NO		NO
b. Residential												
Liquid Fuels	71.93	71.927108	2.69		0.46791856		72.49	72.4941	2.85		0.50	
Solid Fuels	94.70	94.7	0.44		1.4		94.60	94.6	0.44		1.40	
Gaseous Fuels	56.10		40.73		0.10		56.10		40.73		0.10	
Biomass	109.60		[illegible]		4		109.60		[illegible]		4.00	
Other Fuels		NO		NO		NO		NO		NO		NO
c. Agriculture/Forestry/Fisheries												
Liquid Fuels	74.2388243	74.238824	4.8837		0.58615278		74.44	74.439	4.94		0.60	
Solid Fuels		NO		NO		NO		NO		NO		NO
Gaseous Fuels	56.10		5.70			0.10	56.10		5.70		0.10	
Biomass		NO		NO		NO		NO		NO		NO

PARTIAL CORRELATIONS

- For emission factors from same categories among years
- For some activity data across sectors (e.g., gas consumption in chemical industry in category 1A and chemical feedstock in category 2)
- Activity data among years considered independent (CORR=0), Exception: Emissions from Landfill waste

- Following the IPCC Tier 2 method, uncertainties in the trend emissions were calculated in absolute and in relative terms.
- A pedigree assessment was carried out for the most sensitive emissions factors and activity data to systematically assess strengths and weakness in the knowledge base (part of the NUSAP system).

Pedigree matrix

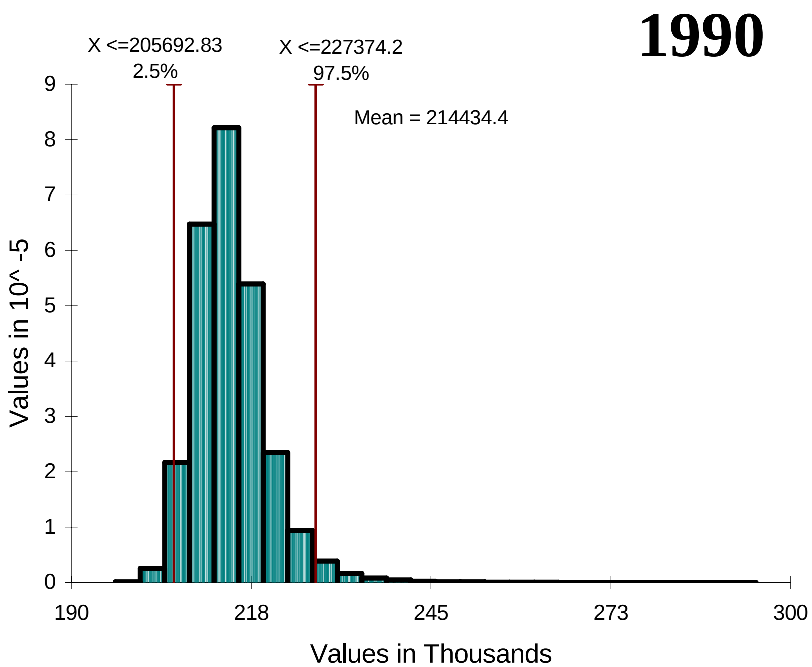
Scale value	Proxy	Empirical basis	Methodological rigour	Validation
4	Exact measure	Large sample of direct measurements	Best available practice	Compared with independent measurements of same variable
3	Good fit or measure	Small sample of direct measurements	Reliable method commonly accepted	Compared with independent measurements of closely related variable
2	Well correlated	Modelled/derived data	Acceptable method limited consensus on reliability	Compared with measurements not independent
1	Weak correlation	Educated guesses / rule of thumb estimates	Preliminary methods, unknown reliability	Weak / indirect validation
0	Not clearly related	Crude speculation	No discernable rigour	No validation

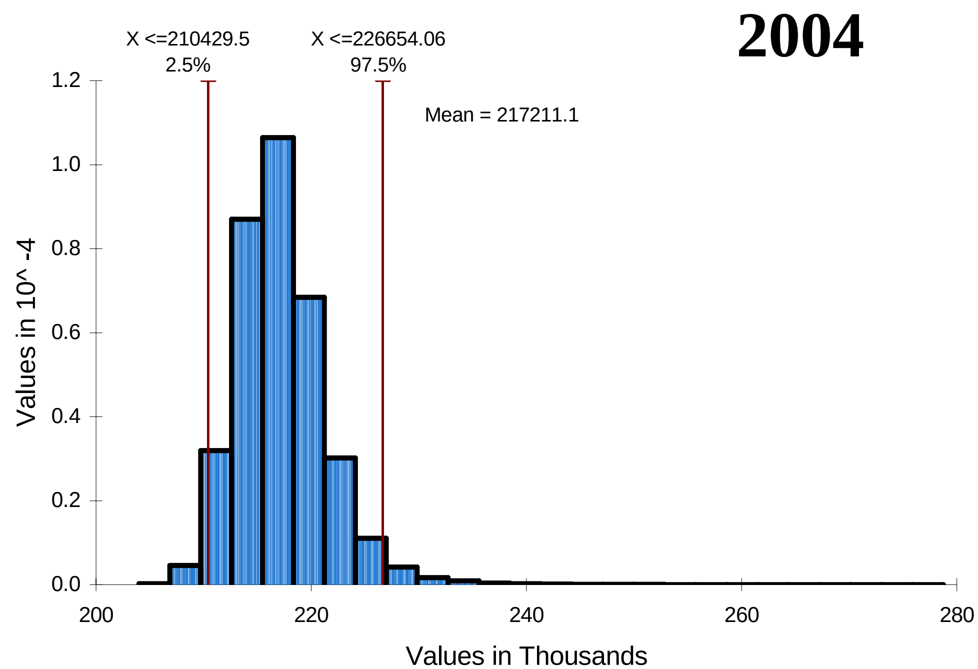
Source: Risbey et al., 2001

Universiteit Utrecht

Results

Total GHG emissions in the Netherlands Without LUCF





Tier 1:

1990: 213 Tg CO_{2eq}

2004: 217 Tg CO_{2eq}

std: 4.5% (6%)

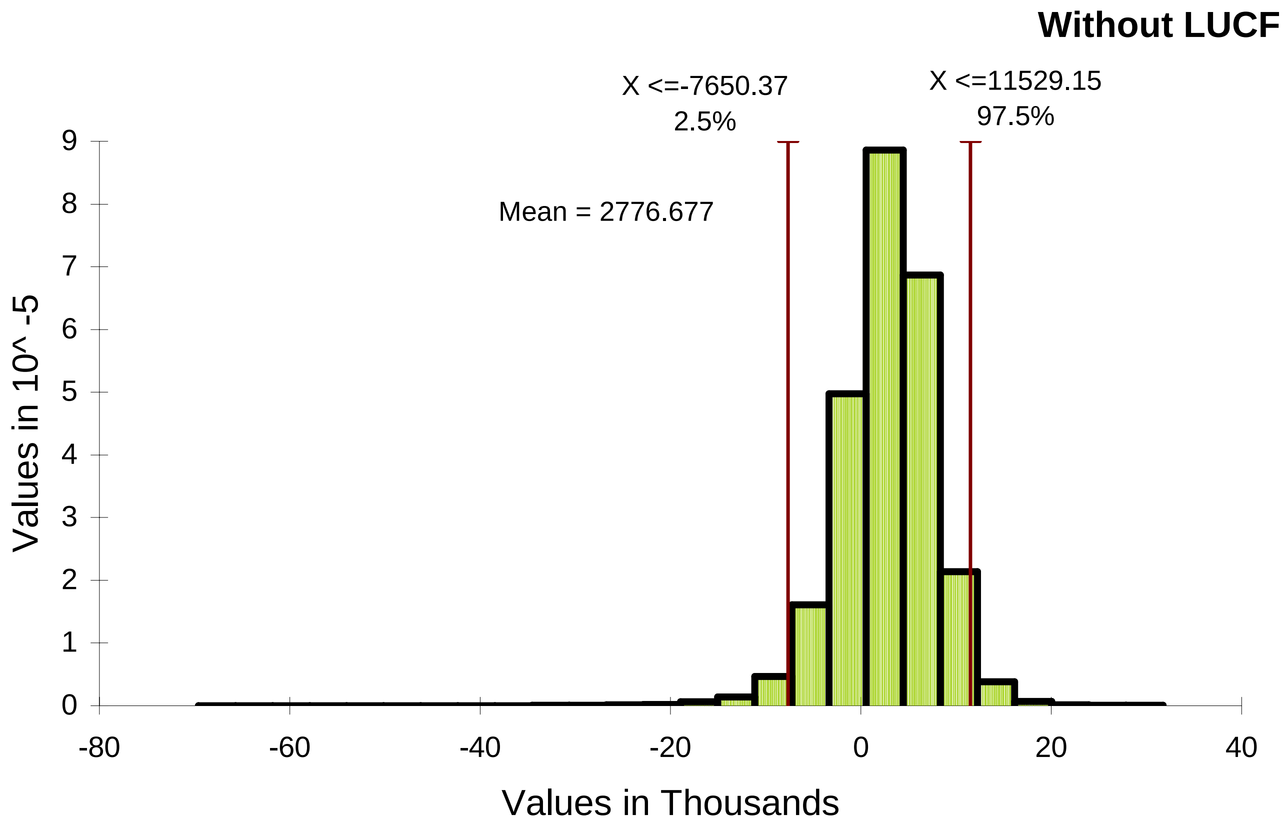
Monte Carlo analysis:

1990: 214 Tg CO_{2eq}

2004: 217 Tg CO_{2eq}

std: 5.3 % (1990); 3.9% (2004)

Trend in Total GHG emissions



Tier 1:
Relative change: 1.6%
std: 3.3%

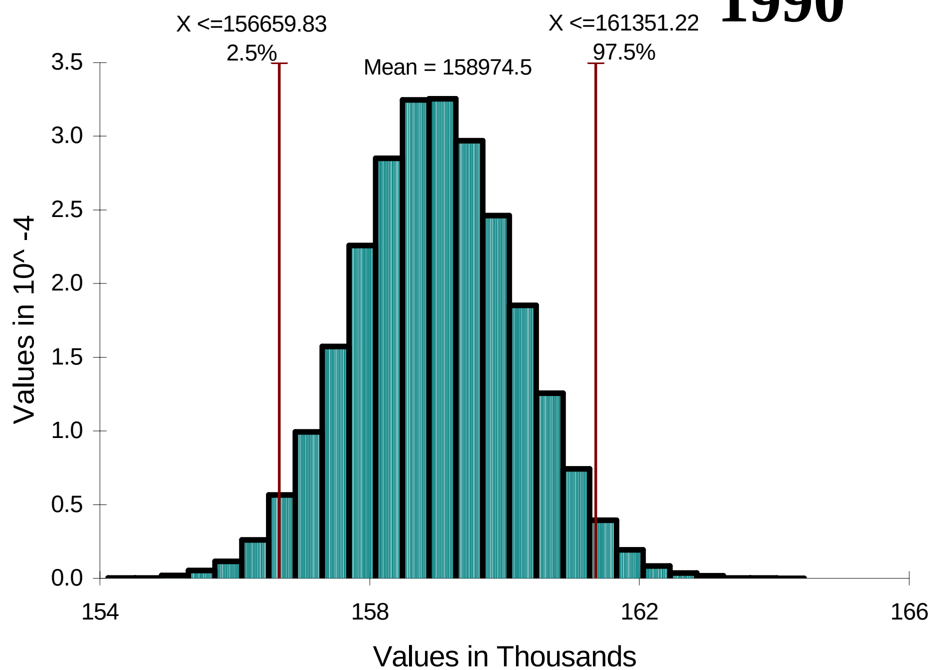
Monte Carlo analysis:
Relative change: 1.3%
std: 4.5%

http://www.chem.uu.nl/nws/www/publica/publicaties2006/E2006-58.pdf

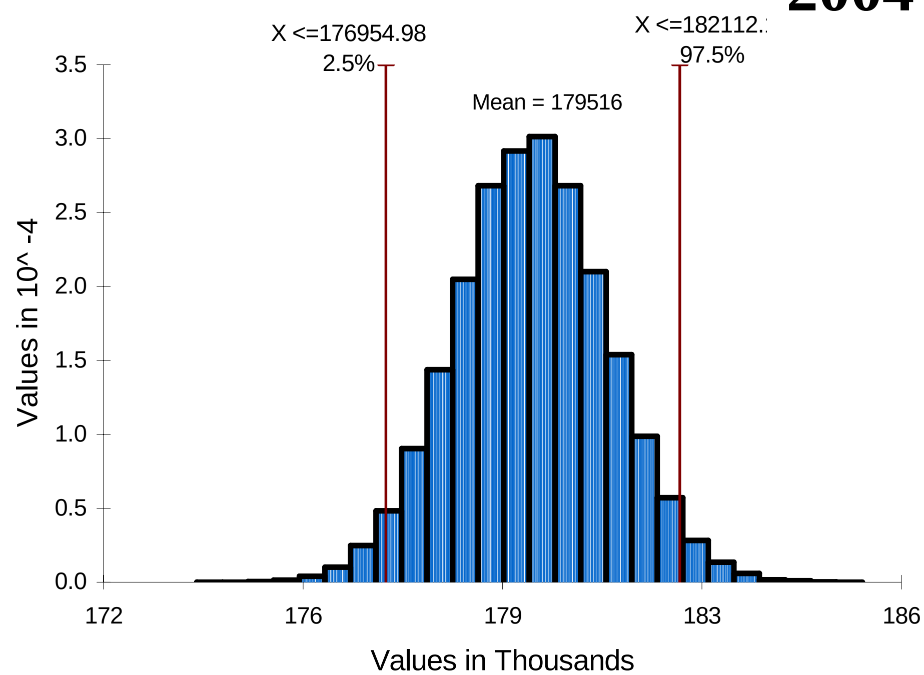
Total CO_2 emissions Without LUCF

Universiteit Utrecht

1990



2004



Tier 1:

1990: 159 Tg CO_{2eq}

2004: 179 Tg CO_{2eq}

std: 2.5% (5%)

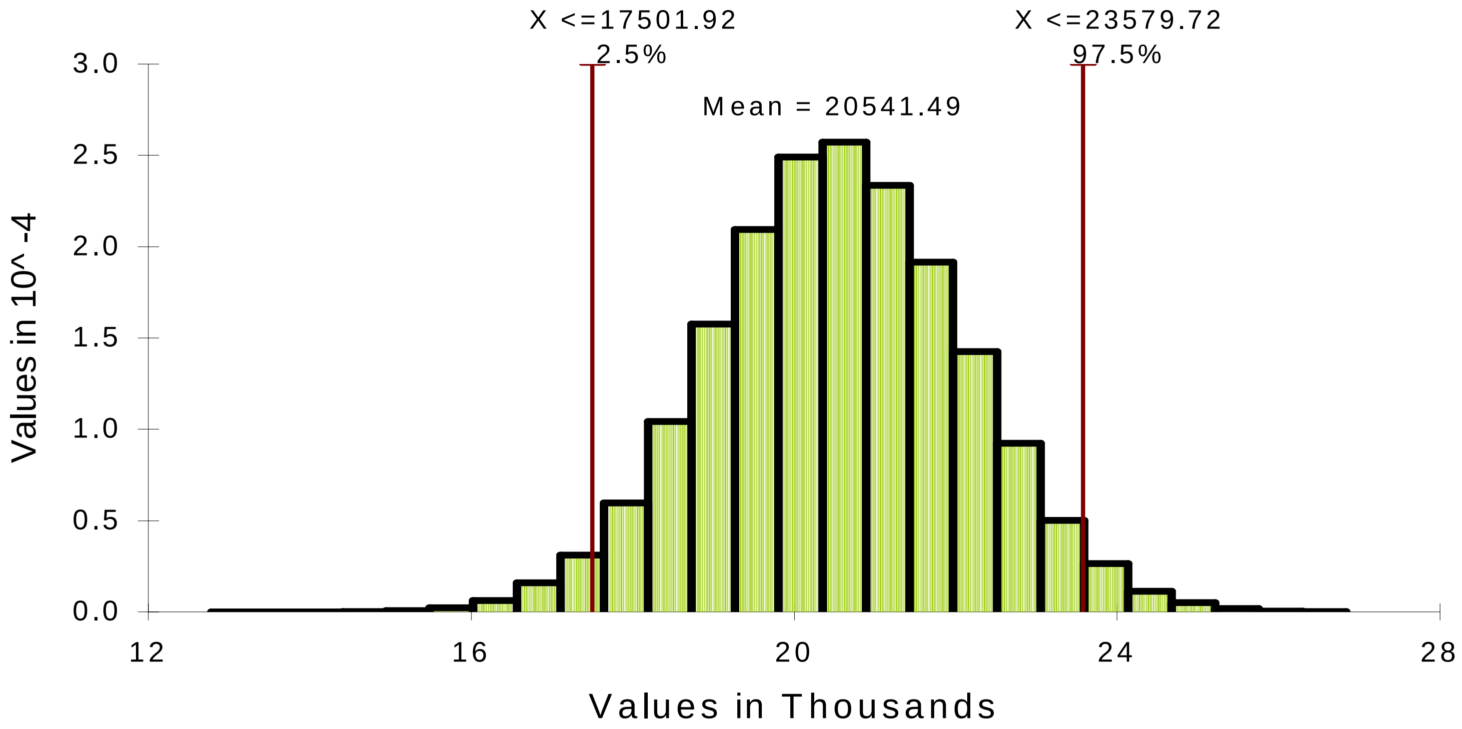
Monte Carlo analysis

1990: 159 Tg CO_{2eq}

2004: 180 Tg CO_{2eq}

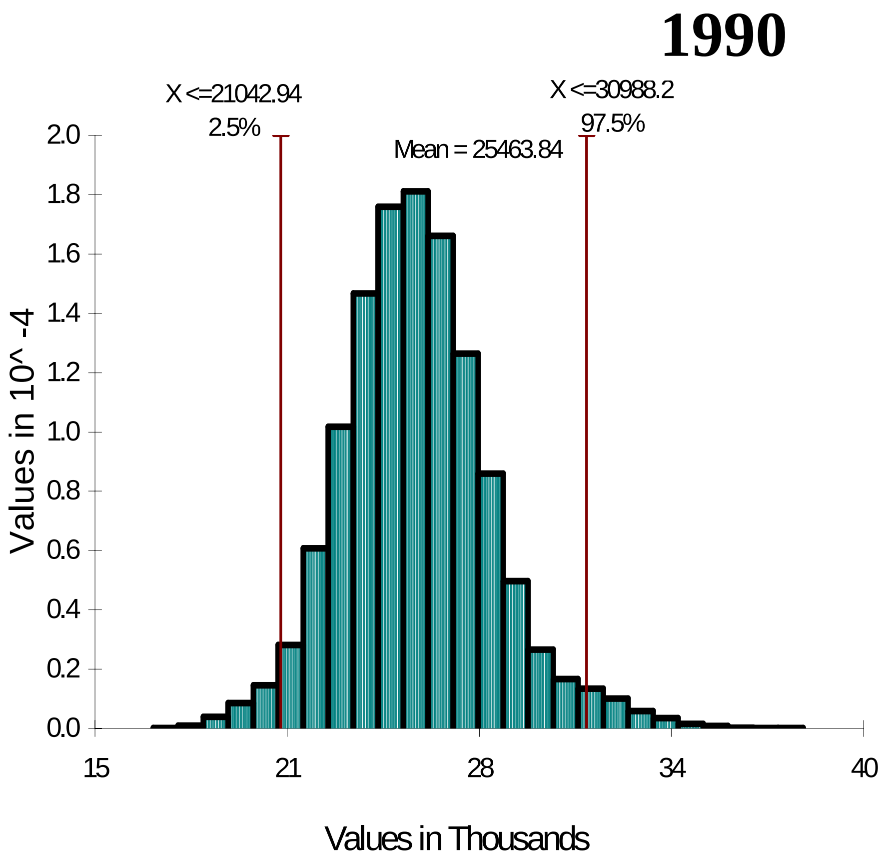
std: 1.5 % (1990 & 2004)

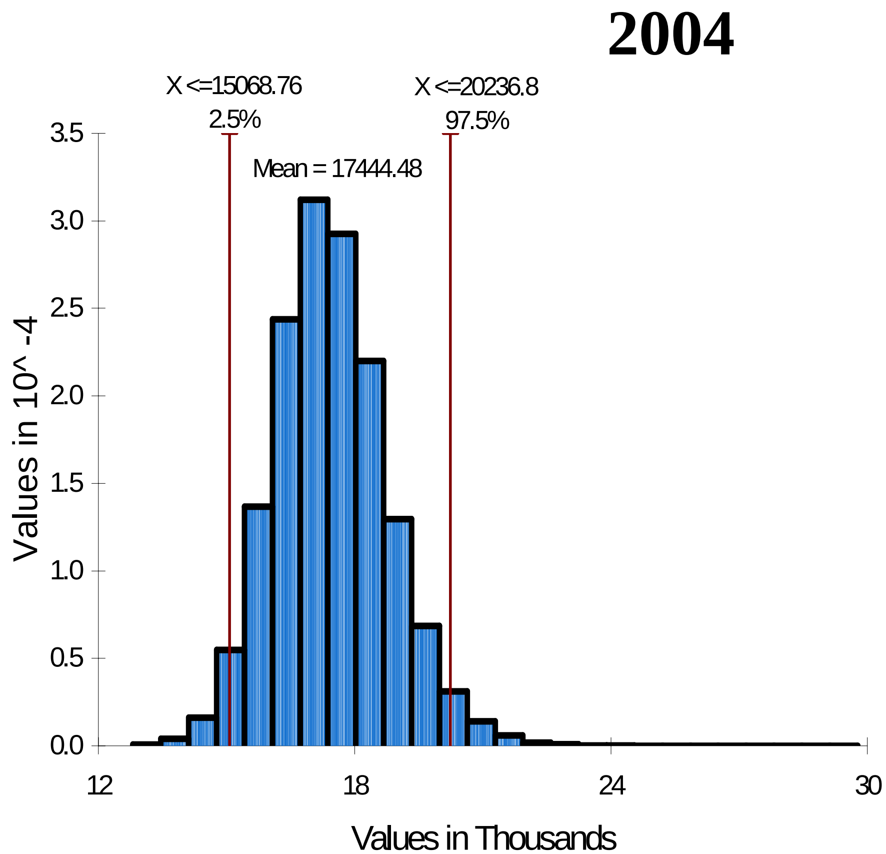
Trend in Total CO_2 emissions Without LUCF



Tier 1: **Relative change: 9.6%** **std: 2.1%**	**Monte Carlo analysis:** **Relative change: 9.6%** **std: 1.6%**

Total CH_4 emissions





Tier 1:

1990: 25.4 Tg CO_{2eq}

2004: 17.5 Tg CO_{2eq}

std: 18% (25%)

Monte Carlo analysis -:

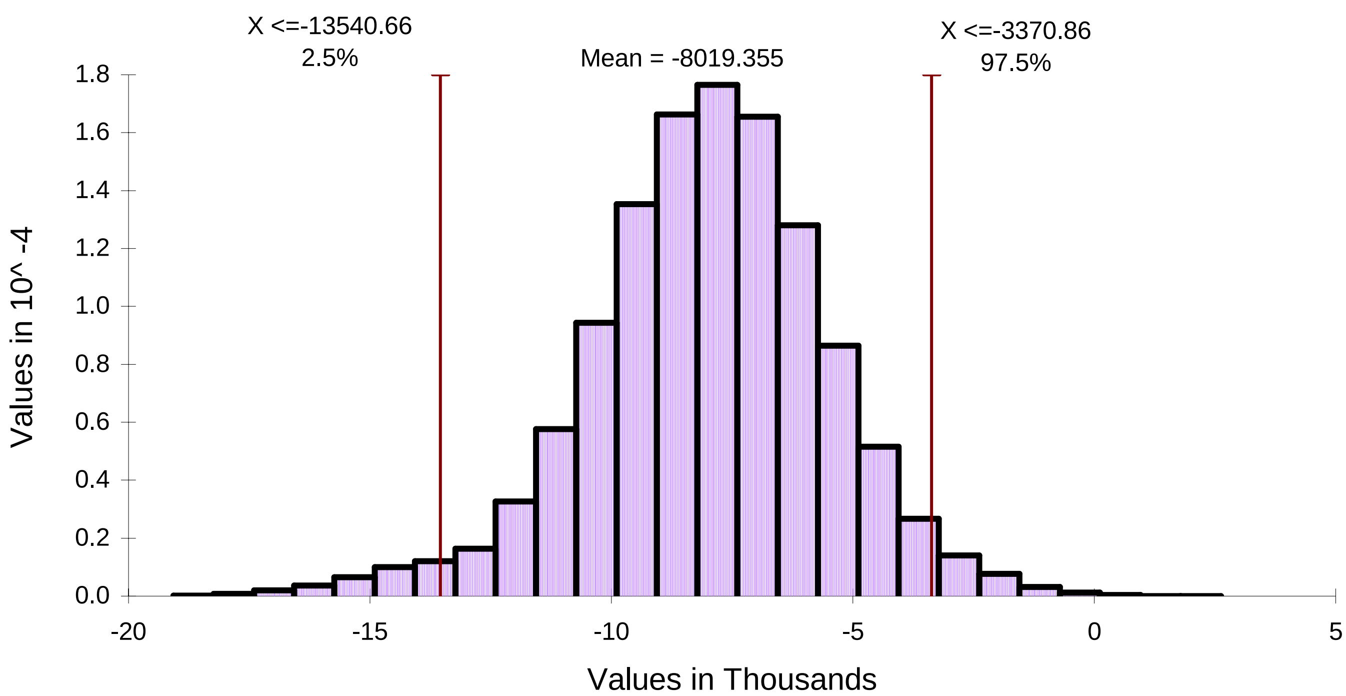
1990: 25.5 Tg CO_{2eq}

2004: 17.4 Tg CO_{2eq}

std: 18.7 % (1990); 15.1% (2004)

Universiteit Utrecht

Trend in Total CH_4 emissions



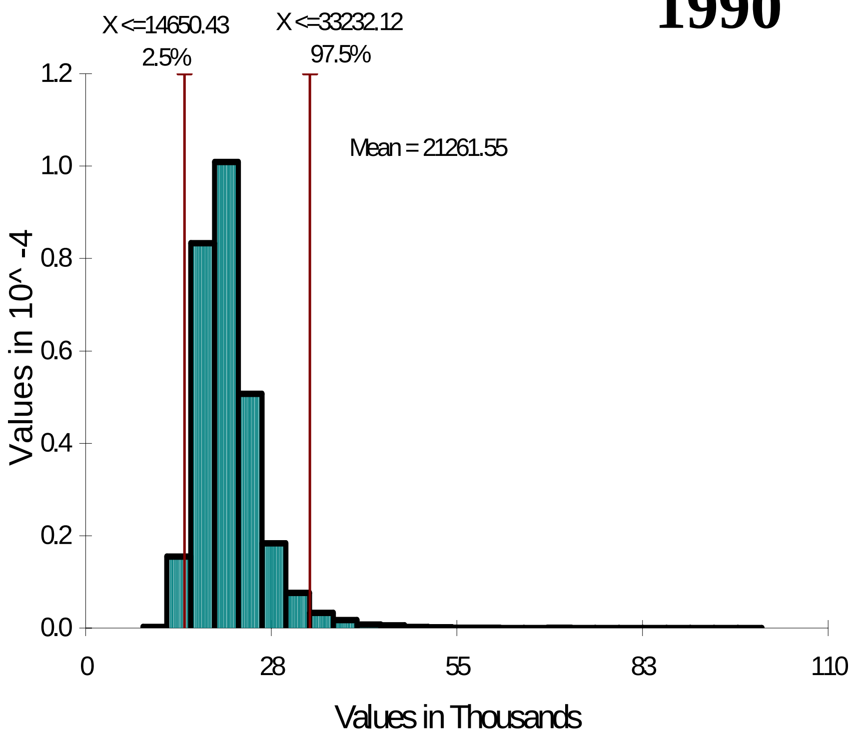
Tier 1:
Relative change: -3.7%
std: 1.4%

http://www.chem.uu.nl/nws/www/publica/publicaties

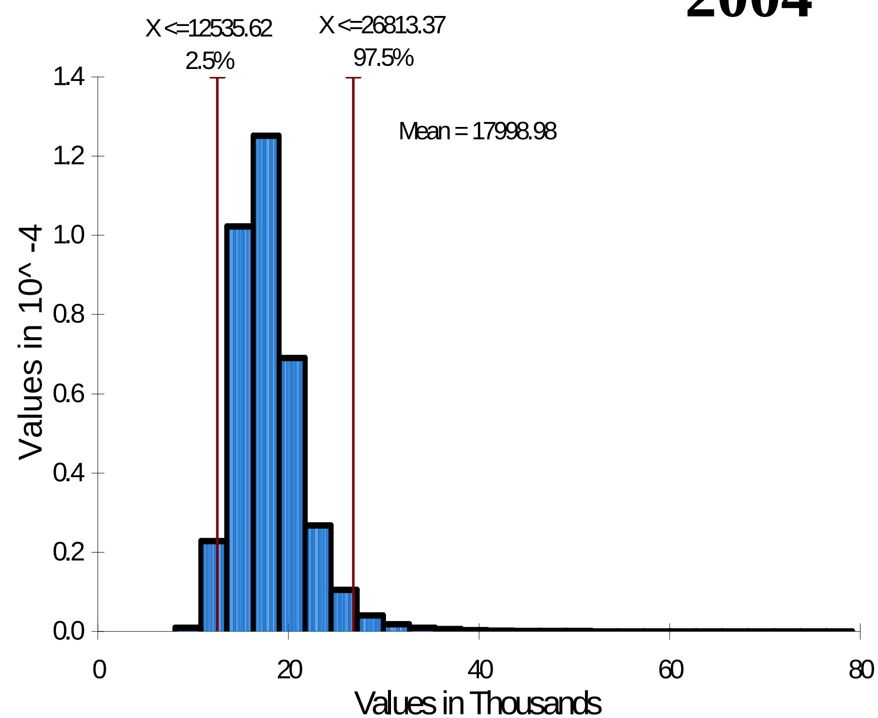
Monte Carlo analysis
Relative change: -3.7%
std: 2.2%

Total N_2O emissions Without LUCF

1990



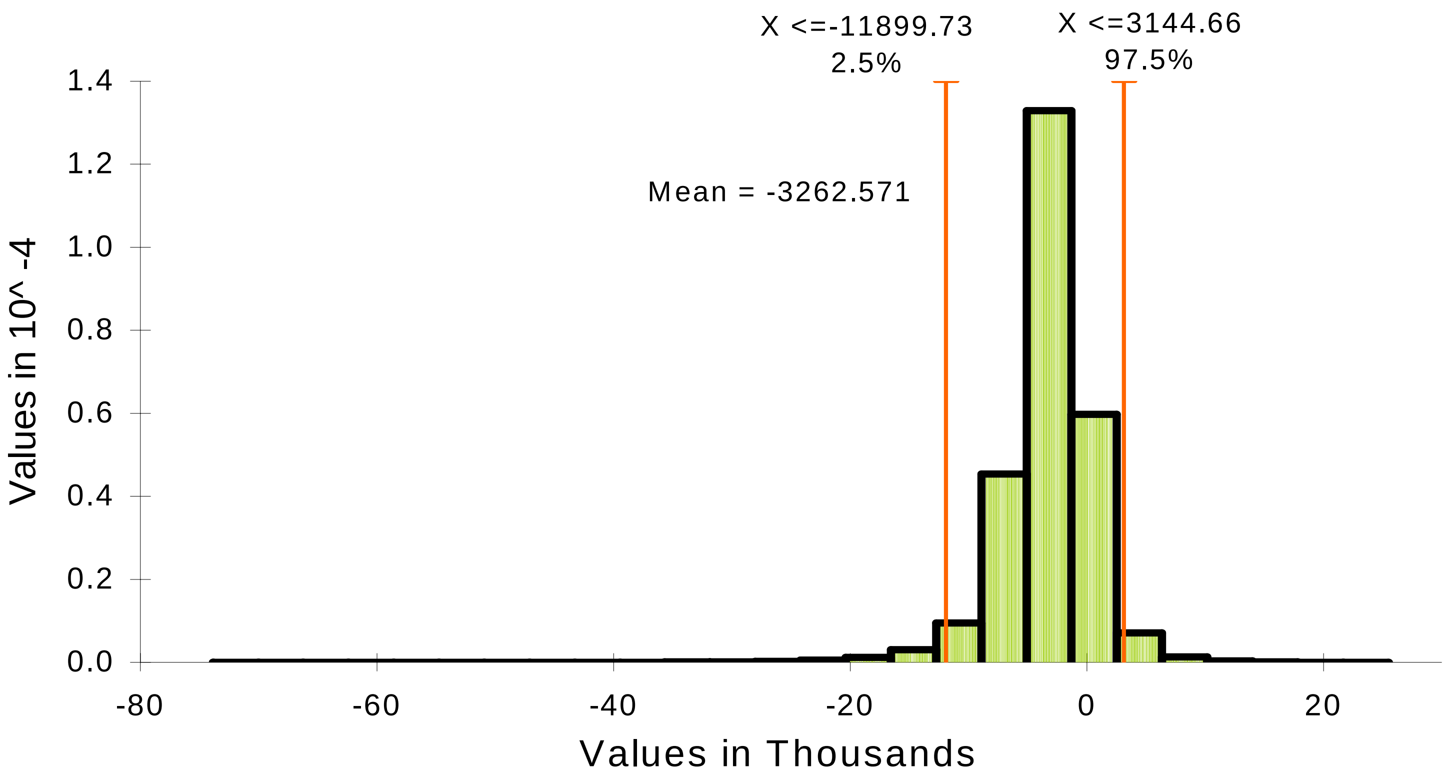
2004



Tier 1:
1990: 21.2 Tg CO_{2eq}
2004: 18.0 Tg CO_{2eq}
std: 45% (50%)

Monte Carlo analysis:
1990: 21.3 Tg CO_{2eq}
2004: 18.0 Tg CO_{2eq}
std: 46.2 % (1990); 42.0% (2004)

Trend in Total N_2O emissions Without LUCF

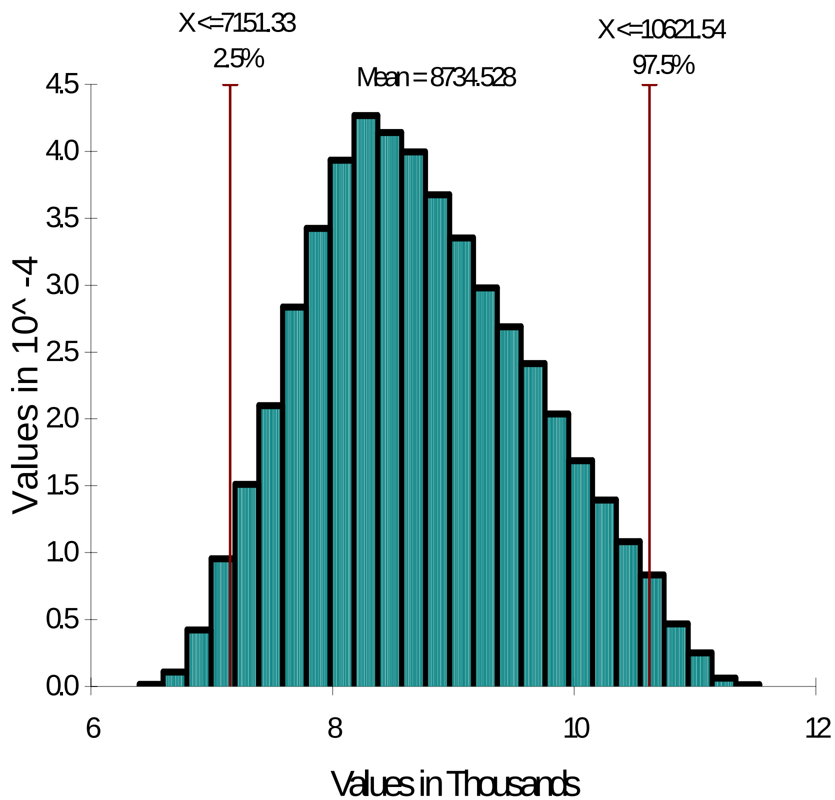


Tier 1:
Relative change: -1.5%
std: 2.0%

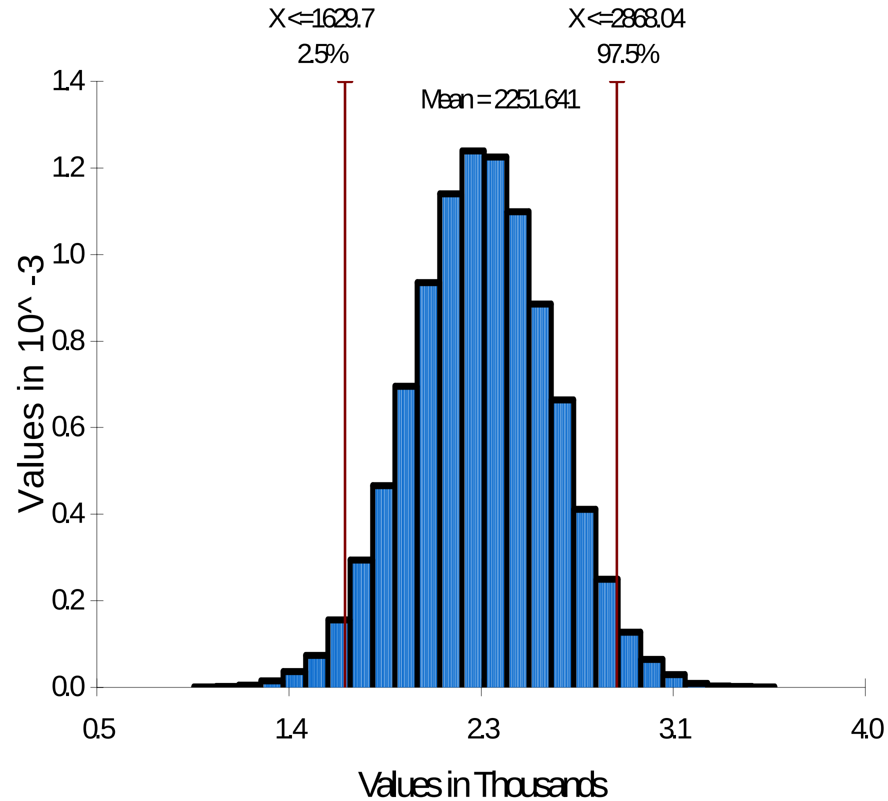
Monte Carlo analysis:
Relative change: -1.5%
std: 3.4%

Total F-emissions

1995



2004

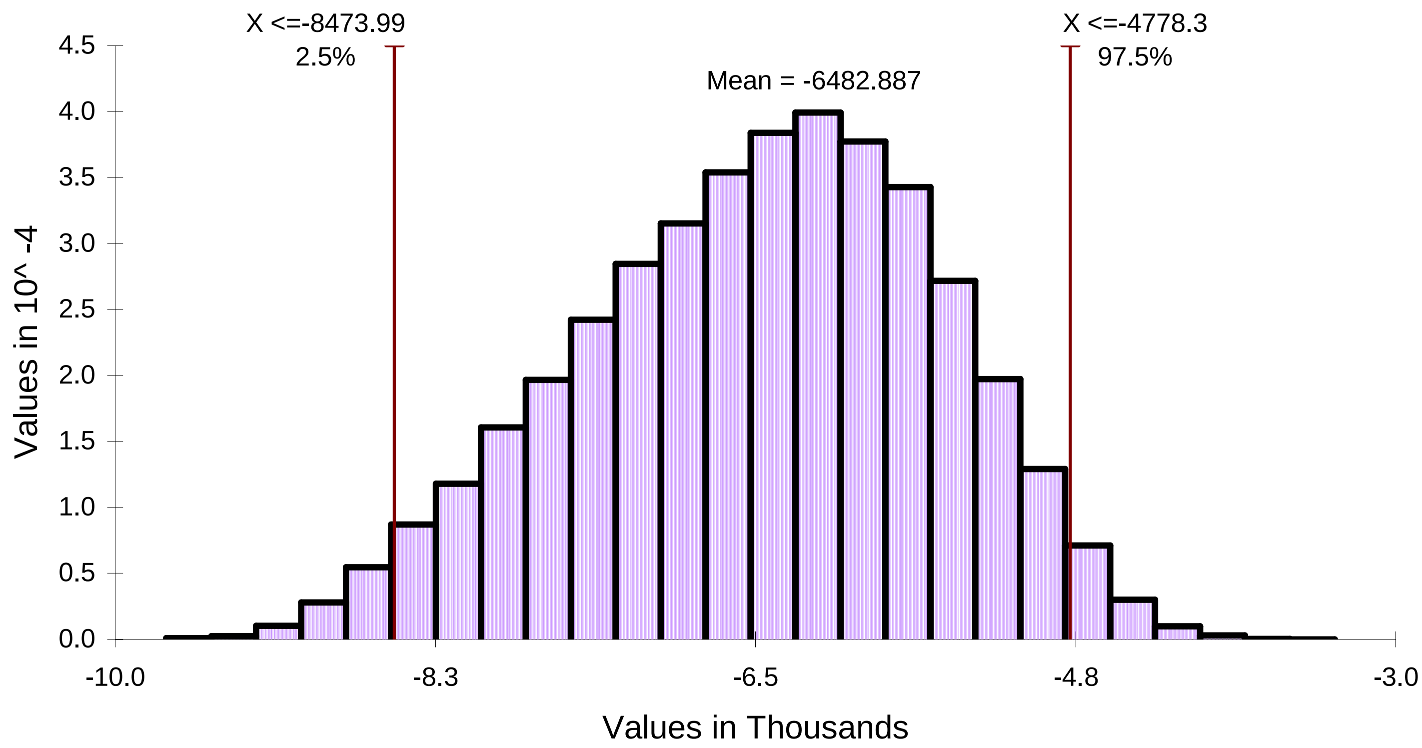


Tier 1:
1995: 8.25 Tg CO_{2eq}
2004: 2.24 Tg CO_{2eq}
std: 28% (50% Jos)

Monte Carlo analysis
1995: 8.7 Tg CO_{2eq}
2004: 2.25 Tg CO_{2eq}
std: 21.1 % (1990); 28.1% (2004)

Universiteit Utrecht

Trend in Total F-gas emissions



Tier 1:
Relative change: -2.8%
std: 0.4 %

Monte Carlo analysis:
Relative change: -3.0%
std: 0.9%

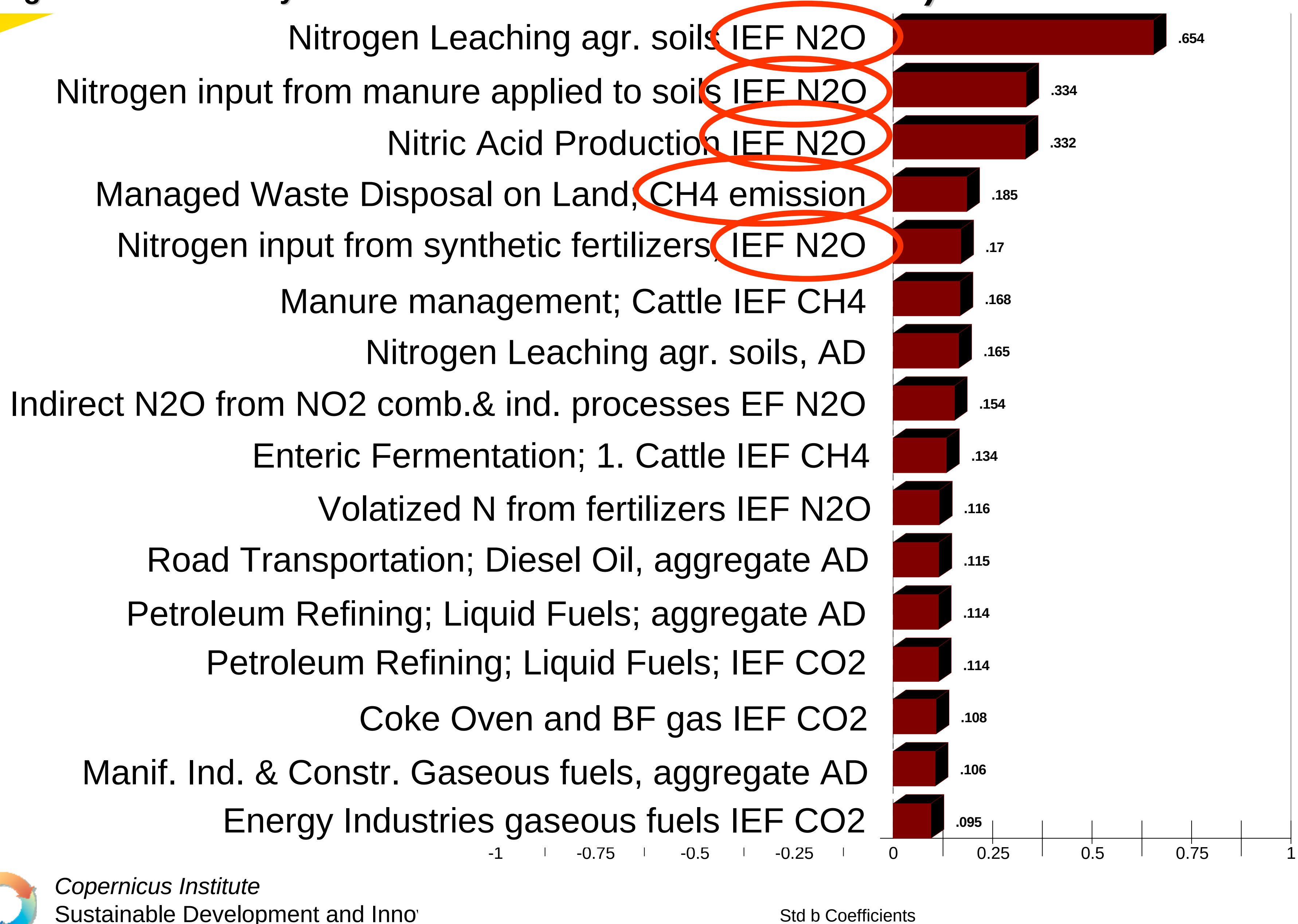
Sustainable Development and Innovation
http://www.chem.uu.nl/nws/www/publica/publicaties2006/E2006-58.pdf

- Resulting uncertainties are in the same order of magnitude as those obtained in the TIER-1
- For the NL inventory, accounting for correlations has a larger impact on the results for the trend than on the uncertainty in the total GHG emissions
- Accounting for correlations and asymmetrical distributions (in stead of using NL TIER 1 assumptions) did not lead to radically different uncertainty in total GHG emissions.

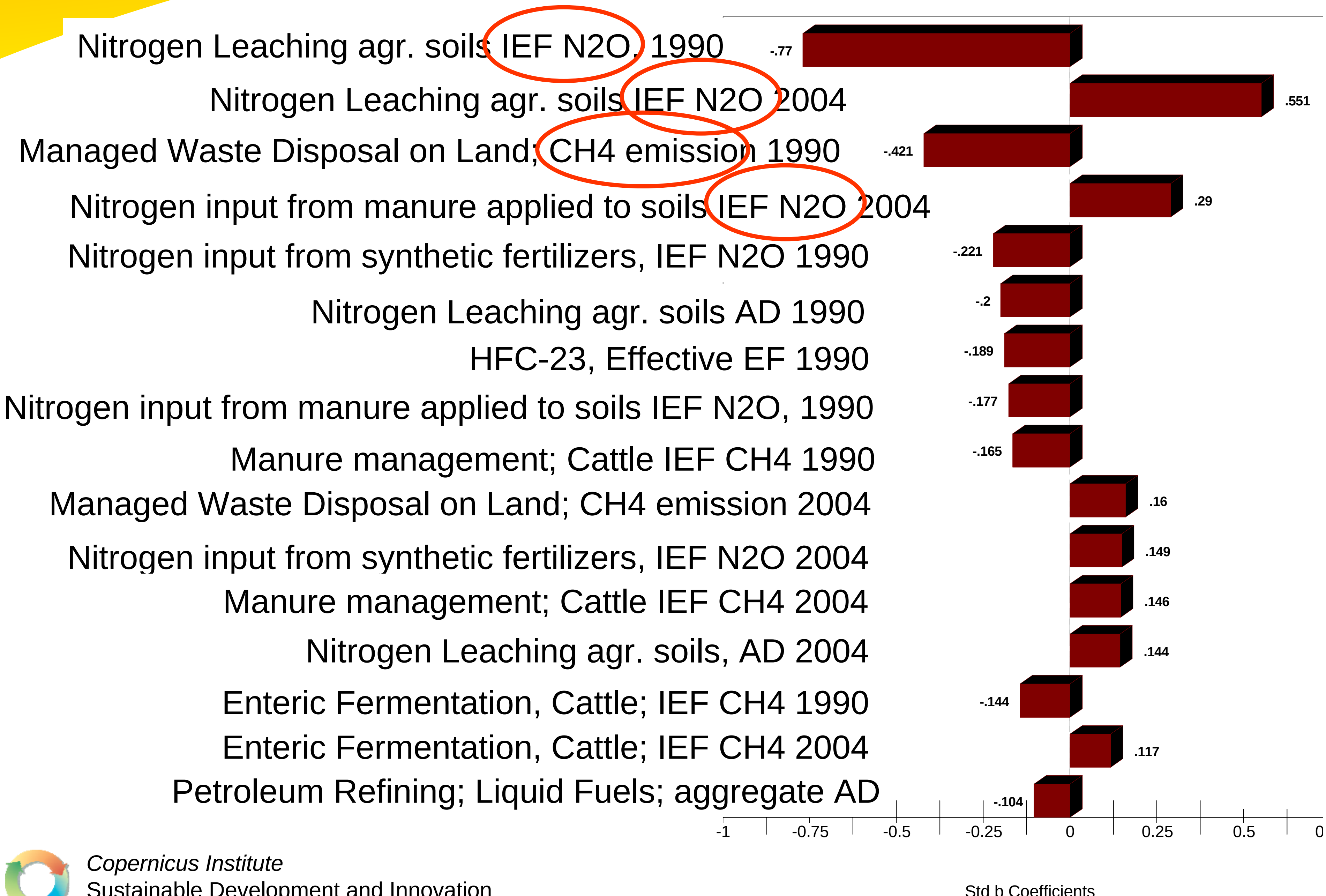
- Uncertainty assumptions in the NL are well in the range of European Studies
- Resulting uncertainty in the total Dutch GHG emissions is in the lower range →share of CO_2 emissions is higher → CO_2 emission factors are relatively well understood and monitored → lower uncertainties

Ranking of uncertain inputs according to their contribution in the variance

(Regression sensitivity base case no LUFC total 2004 GHG emission)



Regression sensitivity base case no LUFC, trend

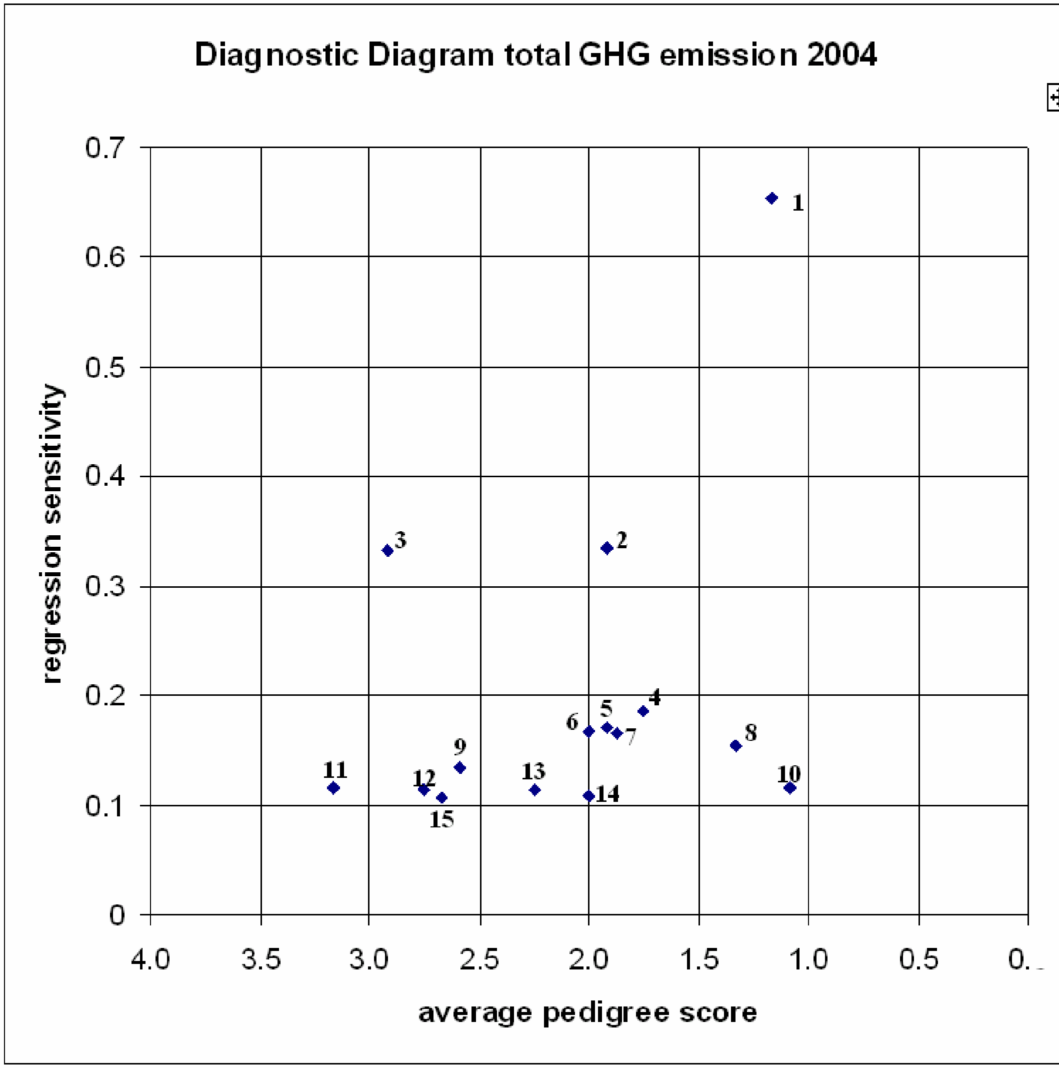


Copernicus Institute
Sustainable Development and Innovation
http://www.chem.uu.nl/nws/www/publica/publicaties2006/I

Regression sensitivity (Std. b coefficient), average pedigree scores (scale 0-4, see table 4.3) and standard deviation in pedigree scores for the 15 inputs that contribute most to uncertainty in total 2004 greenhouse gas emission.

Rank	IPCC Cat	Description	Std b coeffi.	avg. proxy	avg. emp.	avg. meth.	avg. val.	stdv. proxy	stdv. emp.	stdv. meth.	stdv. val.	avg. pedigree
#1	4D3	Agricultural Soils; 3. indirect emissions; 2. Nitrogen Leaching and Run-off; N from fertilizers, animal manures and other that is lost through leaching and run-off; implied emission factor 2004	0.654	1.3	1.3	1.7	0.3	0.6	0.6	0.6	0.6	1.2
#2	4D1	Agricultural Soils; 1. Direct soil emissions; 2. Animal Manure Applied to Soils; Nitrogen input from manure applied to soils; implied emission factor N2O, 2004	0.334	1.7	2	2.3	1.7	0.6	0	0.6	1.5	1.9
#3	2B2	B. Chemical industry; 2. Nitric Acid Production; implied emission factor N2O 2004	0.332	3	3.3	3	2.3	1.0	0.6	0	1.2	2.9
#4	6A1	Solid waste disposal; 1 Managed Waste Disposal on Land; CH4 emission aggregate 2004	0.185	1.5	2	2.5	1	0.7	0	0.7	0	1.8
#5	4D1	Agricultural Soils; 1. Direct soil emissions; 1. Synthetic Fertilizers; Nitrogen input from application of synthetic fertilizers; implied emission factor N2O, 2004	0.17	1.7	2	2.3	1.7	1.2	0	0.6	1.5	1.9
#6	4B1	Manure management; 1. Cattle implied emission factor CH4, 2004	0.168	2	2	2	2	0	1	0	1	2
#7	4D3	Agricultural soils; 3. Indirect emissions: 2. Nitrogen Leaching and Run-off; N from fertilizers, animal manures and other that is lost through leaching and run-off; Activity data, 2004	0.165	1.5	2	2.5	1.5	0.7	0	0.7	0.7	1.9
#8	2G	G. Other; Indirect N2O from NO2 from combustion and industrial processes, Gg NO2, emission factor N2O, 2004	0.154	1.7	1.3	1.7	0.7	0.6	0.6	0.6	1.2	1.3
#9	4A1	Enteric Fermentation; 1. Cattle; implied emission factor CH4 2004	0.134	2	2.7	3	2.7	0	0.6	0	0.6	2.6
#10	4D3	agricultural soils; 3. Indirect Emissions; 1. Atmospheric Deposition; Volatized N from fertilizers, animal manures and other; Implied emission factor N2O, 2004	0.116	1	1.3	1.7	0.3	0	0.6	0.6	0.6	1.1
#11	1A3b	1.A.3 Transport; b. Road Transportation; Diesel Oil, aggregate activity data, 2004	0.115	2.7	3.3	3.3	3.3	0.6	1.2	0.6	0.6	3.2
#12	1A1b	1.A.1. Energy Industries; b. Petroleum Refining; Liquid Fuels; aggregate activity data ,2004	0.114	3	3	3	2	0	1	0	1.7	2.8
#13	1A1b	1.A.1. Energy Industries; b. Petroleum Refining; Liquid Fuels; implied emission factor CO2, 2004	0.114	2	2.3	2.7	2	1	1.5	0.6	1.7	2.3
#14	2B8	Manure management; 8. Swine, implied emission factor CH4, 2004	0.108	2	2	2	2	0	1	0	1	2
#15	1A1a	1.A.1. Energy Industries; a. Public Electricity and Heat Production; Coke Oven and BF gas Coke Oven and BF gas	0.106	2.3	2.7	2.7	3	0.6	0.6	0.6	0	2.7

* Pedigree scores between 0 and 1.3 are marked red, 1.4-2.6 amber and 2.7-4 green. High standard deviations are printed in red and very high (>1) in bold



Regression sensitivity (Std. b coefficient), average pedigree scores (scale 0-4, see tab
the 15 inputs that contribute most to uncertainty in total 2004 greenhouse gas emis

Rank	IPCC Cat	Description
#1	4D3	Agricultural Soils; 3. indirect emissions; 2. Nitrogen Leaching and Run-off; N from fertilizers, animal manures and other that is lost through leaching and run-off; implied emission factor 2004
#2	4D1	Agricultural Soils; 1. Direct soil emissions; 2. Animal Manure Applied to Soils; Nitrogen input from manure applied to soils; implied emission factor N2O, 2004
#3	2B2	B. Chemical industry; 2. Nitric Acid Production; implied emission factor N2O 2004
#4	6A1	Solid waste disposal; 1 Managed Waste Disposal on Land; CH4 emission aggregate 2004
#5	4D1	Agricultural Soils; 1. Direct soil emissions; 1. Synthetic Fertilizers; Nitrogen input from application of synthetic fertilizers; implied emission factor N2O, 2004
#6	4B1	Manure management; 1. Cattle implied emission factor CH4, 2004
#7	4D3	Agricultural soils; 3. Indirect emissions: 2. Nitrogen Leaching and Run-off; N from fertilizers, animal manures and other that is lost through leaching and run-off; Activity data, 2004
#8	2G	G. Other; Indirect N2O from NO2 from combustion and industrial processes, Gg NO2, emission factor N2O, 2004
#9	4A1	Enteric Fermentation; 1. Cattle; implied emission factor CH4 2004
#10	4D3	agricultural soils; 3. Indirect Emissions; 1. Atmospheric Deposition; Volatized N from fertilizers, animal manures and other; Implied emission factor N2O, 2004
#11	1A3b	1.A.3. Transport; b. Road Transportation; Diesel Oil, aggregate activity data, 2004
#12	1A1b	1.A.1. Energy Industries; b. Petroleum Refining; Liquid Fuels; aggregate activity data ,2004
#13	1A1b	1.A.1. Energy Industries; b. Petroleum Refining; Liquid Fuels; implied emission factor CO2, 2004
#14	2B8	Manure management; 8. Swine, implied emission factor CH4, 2004
#15	1A1a	1.A.1. Energy Industries; a. Public Electricity and Heat Production; Coke Oven and BF gas Coke Oven and BF gas

* Pedigree scores between 0 and 1.3 are marked red, 1.4-2.6 amber and 2.7-4 green. High standard deviati

- From the diagnostic diagram: for the uncertainty in total GHG emission improvements in our knowledge of the emission factors for categories indirect N_2O emissions from agricultural soils, direct N_2O emissions from agricultural soils, indirect N_2O from combustion and industrial processes and emissions from manure management might be given the highest priority.
- Inspection of the pedigree table reveals that the main problem in the knowledge base is in validation and empirical basis.

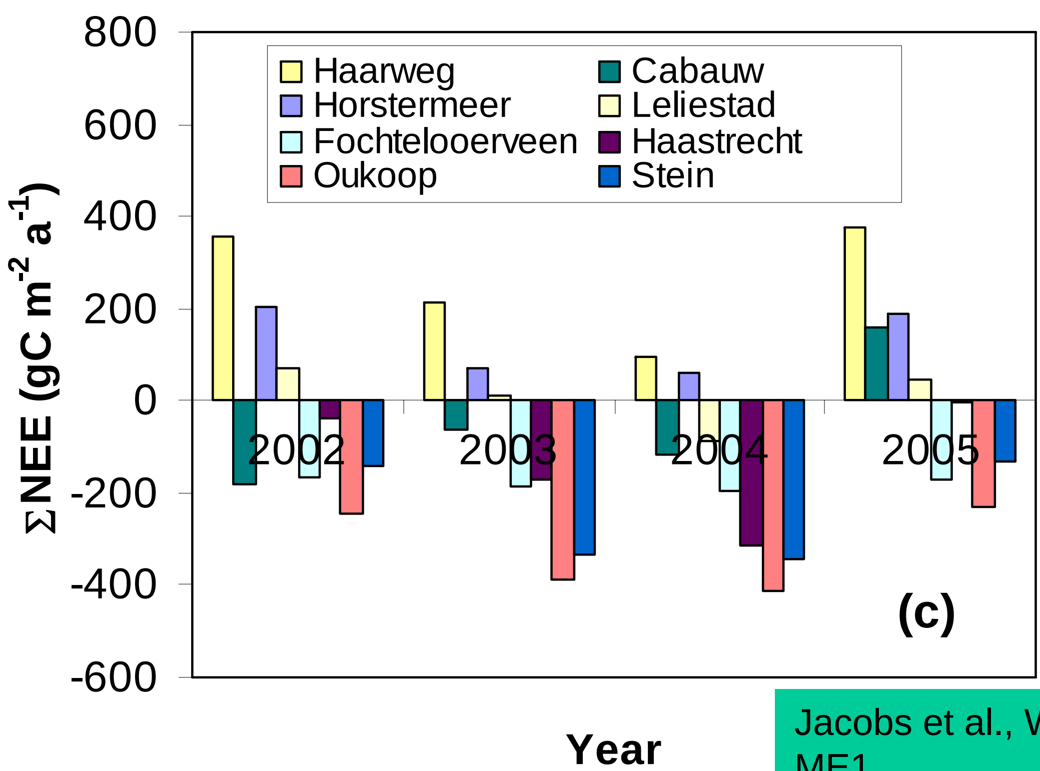
the Tier 1 assessment could also be improved by:

- adjusting the Tier 1 uncertainty inputs for landfills;
- adjusting the Tier 1 uncertainty of activity data for fuel combustion in the commercial sector and
- reconsidering the Tier 1 uncertainty inputs for indirect N_2O emissions from agricultural sources

- For future years, as long as the emission model does not change substantially and the share of CO_2 and non-CO_2 gases is not substantially different from 2004, it seems justified to use Tier 1 as main method for uncertainty analysis in the NIR.
- However, because of ongoing emission reduction efforts and changes over time in the fuel mix as well as in the shares of non-CO_2 greenhouse gases, we recommend repeating the Monte Carlo analysis regularly (every 4 years) as part of the QA/QC procedures.

Grassland emission variability

Slide borrowed from Pavel Kabat WUR



Flux tower network:
- average mineral soils:
  Uptake 0.9 ton C/ha/yr
- average organic soils:
  Source 2.2 ton C/ha/yr
- weighted average all Dutch grasslands:
  Uptake 0.28 ton C/ha/yr

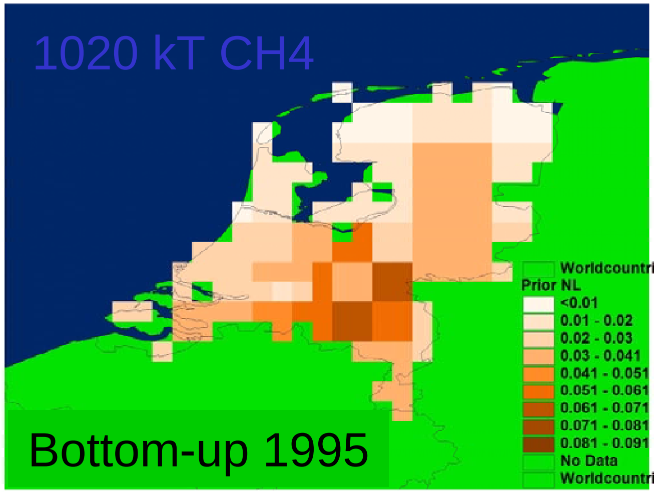
NIR: drained organic soils
Source 5.18 ton C/ha/yr
x 223000 ha =
Source of 4.2 Mton C

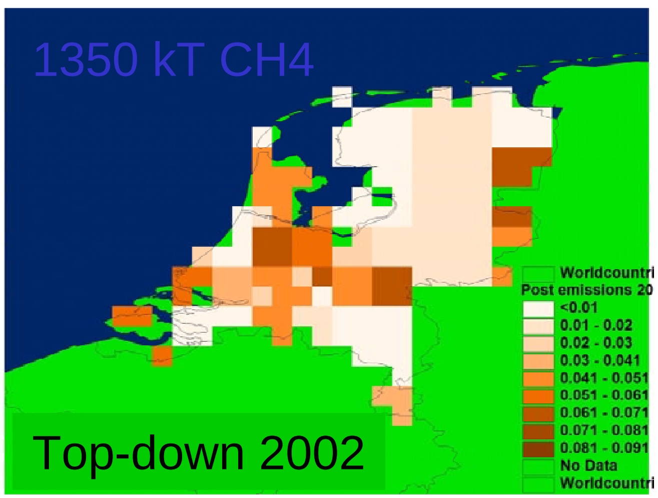
Need for regionally specific and spatially explicit CO2 emission factors

Jacobs et al., WUR, 2007
ME1

climate changes spatial planning

Inverse modelling: methane





Vermeulen, ECN, in prep ME2

Atmospheric verification suggests substantially higher CH4 emissions than reported:

- Top-down (inversion): average 1641kT CH4 for yrs 2000-2006
- Bottum-up (NIR): declining trend
  - 1211 Kt in 1990 decreasing to
  - 824 kT in 2004

Slide borrowed from Pavel Kabat WUR

climate changes spatial planning

QUESTIONS?

Full report downloadable from

www.jvds.nl

Direct link:

http://www.chem.uu.nl/nws/www/publica/publicaties2006/E2006-58.pdf