SMED

Swedish Environmental Emissions Data

Revision of N$_2$O emission factors for combustion of gaseous and solid fuels

Memorandum

Ingrid Mawdsley, Håkan Stripple
IVL Swedish Environmental Research Institute

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Background

A review of emission factors used in the Swedish greenhouse gas inventory carried out in 2010 on behalf of the Swedish Energy Agency and the Swedish Environmental Protection Agency, revealed that the emission factors applied for N_2O in combustion of gaseous and solid fuels are most likely too high (Fridell, Stripple and Gustafsson, 2010).

The current Swedish emission factor for N_2O for all gaseous fuels used in stationary applications is 2.0 kg N_2O/TJ, which is substantially higher than the IPCC default emission factor of 0.1 kg/TJ. A proposal for revision of the Swedish emission factor was brought forth in the review from 2010, where the authors suggest implementation of the IPCC default emission factor for gaseous fuels. Until now, no revision has been made since the Swedish EPA during the first commitment period found that further references were needed to motivate lowering the emission factor.

Sweden has repeatedly received comments from the ERT concerning the high implied emission factor for solid fuel combustion in the stationary combustion sector; a result of some emission factors being substantially higher than the default emission factors (Table 1); and the ERT has recommended Sweden to review these. As the emission factors for waste and wood fuels are reviewed in another on-going study by SMED, this study considers the N_2O emission factors for combustion of coke, coal and peat.

Table 1: Current N_2O emission factors (EF) for solid fuel combustion used in the Swedish emission inventory with reference as well as the corresponding default emission factors from 2006 IPCC Guidelines.

Fuel	CRF	N_2O EF (kg/TJ)	Default N_2O EF IPCC 2006	Reference
Coke	1A2, 1A4	20	1.5	Boström et al., 2004
Hard coal, hard coal briquettes	1A1, 1A2, 1A4	20	1.5	Boström et al., 2004
Waste	1A1a	6	4	Boström et al., 2004
Wood fuel	1A1a	6	4	Boström et al., 2004
Peat and peat briquettes	1A1, 1A2	5	1.5	Boström et al., 2004
Other biomass	1A1, 1A2	5	4	SEPA 1995
Wood fuel	1A1b, 1A1c, 1A2, 1A4	5	4	Boström et al., 2004
Other solid fossil fuels	1A1, 1A2	2	-	SEPA 1995

Aim

The aim of the present study is to find and analyze literature and other information concerning emissions of N_2O for solid fuels (coke, coal and peat) and gaseous fuels (propane, butane, town gas, natural gas, coke oven gas, blast furnace gas, LD-gas, landfill gas and refinery gas) in the stationary combustion sector to use as decision basis for a revision of the Swedish emission factors. The study will result in a recommendation for revision of the emission factors where motivated.

Methodology

References to the current emission factors were reviewed and a review of other available literature was made. Scientific studies as well as measurements made at combustion plants were considered. Furthermore, emission factors used in other countries, which have similar conditions regarding combustion of solid and gaseous fuels within the stationary energy sector, were examined as comparison. This information, together with generally accepted scientific and theoretical arguments on formation of N_2O during combustion of various fuels, served as decision basis to suggestions for revised emission factors.

Results and discussion

## Reaction mechanisms of nitrous oxide (N_2O) in combustion systems

Research on the NO_X formation mechanisms in combustion has mainly focused on NO_X (NO and NO_2). The main emission studies concerning the formation mechanisms of nitrous oxide, N_2O, were started later. The environmental effects of NO_X and N_2O are also completely different. NO_X has an acidifying and eutrophic effect on the environment, while N_2O is primarily a greenhouse gas which thereby affects the climate. The acidification and NO_X issue have been in focus for a much longer time compared to the climate change issue. However, an increased interest in the issue of climate change has also led to an increased interest in the N_2O emissions and its formation.

There are two sources of nitrogen to the nitrogen oxides formed during combustion; nitrogen from the combustion air and nitrogen bound in the fuel (fuel nitrogen), the latter often termed "prompt NO_X formation". Based on current knowledge, there is no evidence to suggest that nitrous oxide (N_2O) can be formed directly by thermal reactions from atmospheric nitrogen. Nitrogen monoxide (NO) can, however, be formed in this way at high temperatures (> 1200 °C), but under such conditions, there is no conversion of the nitrogen monoxide to dinitrogen oxide (N_2O). It is important to note that there is no direct general relationship between NO_X and N_2O concentrations from the different combustion sources. The amount of nitrous oxide formed is dependent on the fuel nitrogen content and the combustion conditions. At combustion plants, it has been observed that coal generally gives the highest N_2O emissions, followed by peat, oil and natural gas.

Nitrous oxide is formed either by gas phase reactions (homogeneous reactions) or by reactions between gas and solids (heterogeneous reactions). Depending on the temperature of combustion, most of the nitrogen in the fuel is released in the form of nitrogen-containing gases (HCN, RCN, NH_3, NR_3, and others), which then are involved in homogeneous or surface catalyzed heterogeneous oxidation reactions, where a small part forms nitrous oxide. The nitrogen remaining in the fuel can also contribute to nitrous oxide formation by heterogeneous reactions, such as between the coke surface and oxygen in the combustion air.

Of the different reaction pathways, the homogeneous mechanisms are the most well-known, (Hulgaard, 1989; Hupa and Kilpinen, 1990). In particular, the presence of hydrogen cyanide (HCN),

oxygen (O_2) and nitrogen monoxide (NO) in the temperature interval of 750-850 °C is important for the nitrous oxide formation:

$$HCN + O_2 \longrightarrow NCO + OH$$
$$NCO + NO \longrightarrow N_2O + CO$$
$$NH + NO \longrightarrow N_2O + H$$
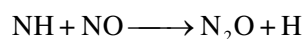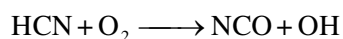
The presence of ammonia in the combustion can be considered a minor source of nitrous oxide. N_2O is often formed by oxidation of different amine radicals. Combustion in fluidized beds, with relatively low combustion temperatures (~850 °C), often gives rise to relatively strong formation of N_2O (flue gas concentrations up to ~50 ppm). Some catalytic reactions with particles (e.g. char, limestone) can, possibly, contribute to an explanation of this. In the reaction of prompt NO_X formation, different organic nitrogen compounds are formed as intermediates (e.g. HCN, CN, NH, N...) by reactions between hydrocarbon radicals and N_2 in the combustion air. These intermediate organic nitrogen compounds could, possibly, also be a source for formation of N_2O, thus also for fuels containing no or very little nitrogen. The concentration of prompt NO_X in flue gases increases with increasing combustion temperature. The share of prompt NO_X becomes significant starting from temperatures of 1300-1400 °C.

At high temperatures (> 900 °C) the formation reactions above slow down and nitrous oxide decomposes, e.g. according to the following reaction:

$$N_2O + H \longrightarrow N_2 + OH$$
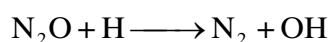
From a thermodynamic standpoint, nitrous oxide is unstable at high temperatures (> 400 °C), but often a short residence time and the temperature profile along the flue gas duct result in measurable concentrations from the combustion plant. Although the homogeneous reactions above explain most observations obtained from controlled measurements, some researchers argue that the heterogeneous reactions are equally important, especially in fluidized bed combustion (De Soete, 1990). Mechanisms in the form of a direct reaction between oxygen and nitrogen in the fuel has been proposed as well as a catalytic reaction pathways of NO and $CaSO_3$/$CaSO_4$. Surface catalyzed reactions also appear to play a role, especially for the reduction of nitrous oxide (Miettinen, Strömberg and Lindqvist, 1991).

From the reaction mechanisms above, it is obvious that there is no realistic possibility of a theoretic calculation of the N_2O emission from a combustion plant. However, empirical models based on measurements and theoretical considerations should be possible to use. These can hopefully be made sufficiently reliable to be used in practical applications. However, direct measurements of N_2O emissions are preferable.

References to the current Swedish emission factors

Gaseous fuels

The reference to the Swedish N_2O emission factor for combustion of gaseous fuels is reported to be a SMED report from 2004 (Boström et al., 2004). In that study, the emission factor was however left unchanged from the previous value which can be traced back to a Swedish EPA report from 1995 (Swedish EPA, 1995). However, this report in turn refers to Statistics Sweden where the emission factor cannot be traced further. There is thus no knowledge of the decision basis for the current emission factor, which further motivates a review of available data followed by a revision if motivated.

Solid fuels

The current Swedish emission factors are based on the references shown in Table 1. In the study from 2004 (Boström et al, 2004), the N_2O emission factor for combustion of coal is unchanged from the previous value since the measurement data from the few plants that use coal did not motivate a revision. Also the emission factor for coke remained unchanged. The emission factor for peat was however thought to be too high in the 2004 report, based on measurements from Swedish combustion plants, and thus lowered to the current value of 5 kg/TJ. Since 2004, new data has likely become available in the environmental reports of the large combustion plants. There was no specific data supporting the current emission factor for combustion of coke, which in fact seems to be based on the emission factor for coal; a questionable estimation since the uses of coal and coke are different.

Literature review and plant-specific data

Gaseous fuels

The review of available studies on emissions of N_2O from combustion of gaseous fuels revealed that few measurements have been made on these emissions. A few studies were made in the early 1990's concerning the method of measurements of N_2O from combustion in general. In a LCA study, Lipman and Deluchi (2003) compiled N_2O emission measurement data for combustion of various fuels. The measurements of N_2O from gaseous fuels are again dated from the beginning of the 90's and are listed in

Table 2. Since N_2O emissions are presented as ppm in the flue gas, it is assumed that the amount of flue gas is 294.5 m^3/GJ (Beychok, 2014). A majority of the listed measurements are lower than the current Swedish emission factor, but higher than the IPCC default emission factor, which supports a revision to a value somewhere in between the default value and the current factor.

Table 2: Summary of N$_2$O emission factors for combustion of gaseous fuels from measurements. All values except for one are below the current Swedish emission factor. The variation, however, is large.

Technology	Fuel	N$_2$O, ppm	N$_2$O, kg/TJ (294,5 m^3/GJ)	Reference
Front fired boiler	Natural gas	2	0.95	Kokkinos (1990)
Combustin turbine	Natural gas	4	1.90	Kokkinos (1990)
733 kW boiler	Natural gas (0 ppm S in gas)	<0.24	<0.11	Linak, et al. (1990)
588 kW boiler, Low-NO$_X$-burner	Natural gas (4-6 ppm S in gas)	<0.24/0.72	<0.11/0.34	Linak et al. (1990)
15 175-1000 MW, Low-NO$_X$-burner	LNG (S removed from gas)	0.1	0.047	Yokoyama, et al. (1990)
35 MW turbine, no water injection	Natural gas	0.5-1.9	0.24-0.9	De Soete (1993)
35 MW turbine, water injection	Natural gas	0.75-1.65	0.36-0.78	De Soete (1993)

Reference: Lipman och Delucchi, 2003

Solid fuels

More measurements have been carried out on N$_2$O emissions from combustion of solid fuels than from combustion of gaseous fuels. A comprehensive review of the literature was made in the SMED report by Fridell et al., (2010), and a summary of the relevant measurement data is reproduced in Appendix A.

Coal

A comprehensive study was made by VTT, Technical Research Centre of Finland (Tsupari, 2007), where measurements were made at seven Finnish combustion plants using either circulating fluidized bed combustion technology (CFB) or bubbling fluidized bed combustion technology (BFB) (Results are included in Appendix A). The one plant which was solely using coal as fuel emitted 13.9-27.7 kg N$_2$O/TJ. However, the suggested emission factor for CFB and BFB combustion to implement in the Finnish emission inventory was 30 kg/TJ due to additional data from unpublished material. The report emphasizes that the combustion conditions differ between countries, and that these emission factors should not be adopted by other countries without further investigation into the country-specific combustion conditions.

In Sweden, coal is only used to a small extent, and according to the Swedish PRTR, 97% of all coal combustion took place at only two plants in 2013. One of these facilities (Värtaverket) uses a pressurized fluidized bed, resulting in relatively low temperatures and therefore higher emissions of N$_2$O. The other plant, however, uses conventional combustion, resulting in substantially lower emissions. Data from the environmental reports of the combustion plants were used to calculate the emission factors listed in

Table 3.

Table 3: Emission factors constructed from data on fuel consumption and N$_2$O emissions from the plants which consume the main portion of coal in Sweden. Emission factors from the two plants are very different from each other.

Combustion plant	Year	N$_2$O EF (kg/TJ)
Värtaverket	2011	28.8
Värtaverket	2012	38.2
Värtaverket	2013	32.9
Västerås heat and power plant	2013	2.8

References: Värtaverket heat and power plant (2012, 2013 and 2014) and Västerås heat and power plant (2014)

Peat

Peat is also a fuel which is used only to a small extent in Sweden; only 0.5% of the Swedish energy production was based on peat in 2012 (Statistics Sweden, 2013), and the use of peat as fuel for energy production is decreasing.

Emission factors have been calculated from two of the combustion plants using peat (Table 4). It is common to co-fire peat with other fuels; consequently available data from units with only peat combustion is scarce. The current emission factor is within the range of the calculated emission factors.

Table 4: Emission factors for peat combustion calculated from data from two Swedish combustion plants. The current emission factor of 5 kg/TJ is within the range of these emission factors.

Combustion plant	Year	N$_2$O EF (kg/TJ)
Västerås combustion plant	2011	8.1
Västerås combustion plant	2012	7.2
Igelsta combustion plant	2012	5.1
Igelsta combustion plant	2013	4.1

References: Västerås kraftvärmeverk (2012 and 2013) and Igelsta kraftvärmeverk (2013 and 2014)

Coke

No literature or data could be found on emissions of N$_2$O from coke combustion.

Emission factors in other countries

Gaseous fuels

The majority of the EU member states have adopted the IPCC default emission factor for gaseous fuels in their emission inventories. The countries which are using national emission factors generally have lower emission factors than Sweden, but higher than the IPCC default factor (Figure 1). Only three countries have higher emission factors than Sweden: United Kingdom, France and Ireland. In the case of United Kingdom however, the high values are due to very high emission factors for certain applications and fuels, and when only including CRF 1.A.1.a the graph shows that for this sector the country is in fact using the IPCC default emission factor (Figure 2).
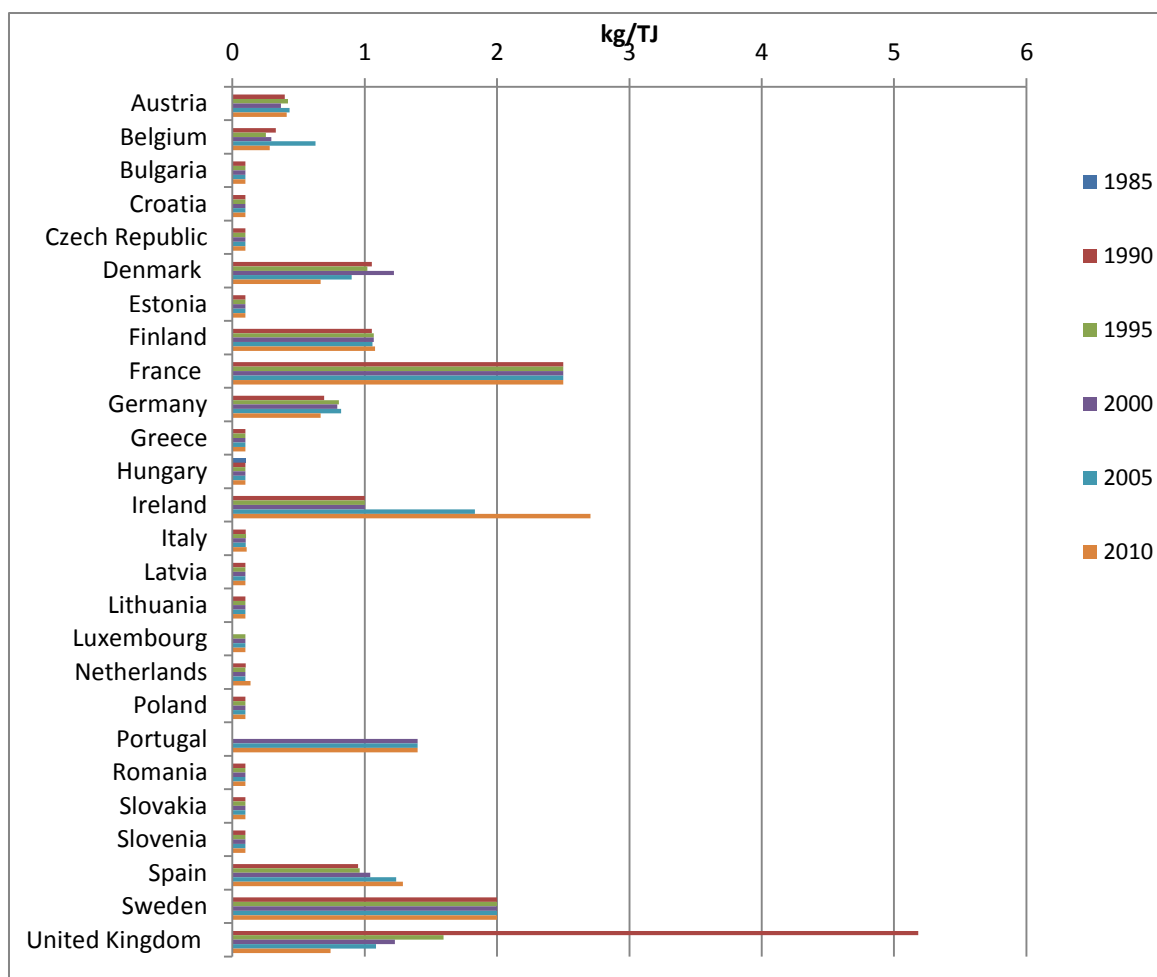
Figure 1: Summary of the EU member states implied emission factor for gaseous fuels in sector 1.A.1, submission 2012. For emission year 2012, only France and Ireland use a higher emission factor than Sweden.

The Swedish implied emission factor for CRF 1.A.1.a, public electricity and heat production, is significantly higher than most countries, including our neighboring countries and some countries that are considered to keep a high quality of their emission inventories (Figure 2).
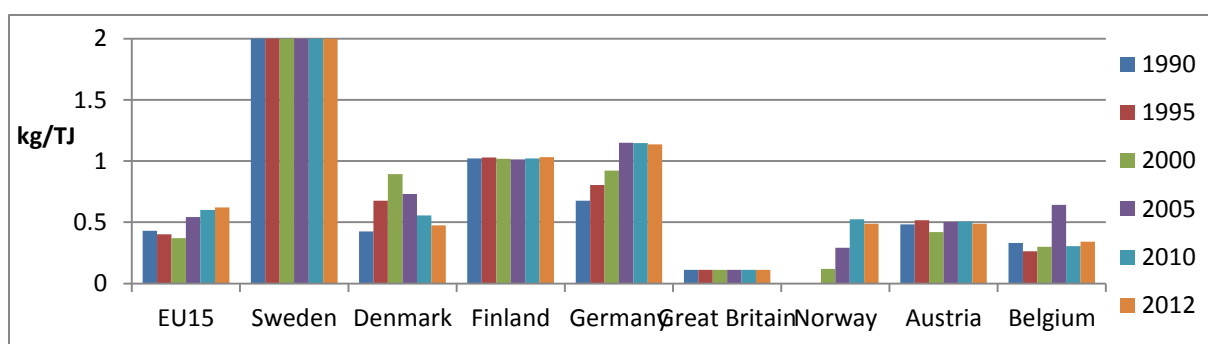
Figure 2: Implied emission factors according to submission 2014. The Swedish N$_2$O emission factor for gaseous fuels for CRF 1.A.1.a is 2 kg/TJ whereas the EU average is much lower; around 0.5 kg/TJ. One reason for the low average is that many member states use the IPCC default emission factor (0.1 kg/TJ). Neighboring countries to Sweden as well as Germany, UK, Belgium and Austria all have lower emission factors whereas Great Britain uses the IPCC default factor throughout CRF 1.A.1.a.

A summary of the emission factors as described in the NIR of the respective country is presented in Table 5. The Norwegian emission factors are presented as kg N_2O/ton fuel or kg N_2O/1000 m^3 fuel, and are recalculated to kg/TJ below.

Table 5: N_2O emission factors for gaseous fuels for some European countries. As all countries do not specify the emission factor in the same way, the allocation of emission factors to technique and fuel is an approximation.

N_2O emission factors for gaseous fuel combustion (kg/TJ)							
	Sweden	Norway	Finland	Denmark	Germany	Austria	Belgium
Natural gas, direct fired furnaces	2.0	0.31	-	0.1	-	0.1-1.0	0.1-1.5
Natural gas, gas turbines	2.0	0.29	1	1.0	1.7	-	0.1-1.5
Natural gas, boilers	2.0	0.06	1	0.1	0.5-0.6	0.1-1.0	0.1-1.5
Natural gas, flaring	2.0	0.31	-	-	-	-	
LPG, boilers	2.0	0.65	1	0.6	-	1.0	
LPG, small stoves	2.0	0.65	-	-	-	-	
Refinery gas, direct fired furnaces	2.0	0.49	-	0.1	-	0.1	
Refinery gas, turbines	2.0	-		1	-	0.1	
Refinery gas, boilers	2.0	0.10	1	-	-	0.1	
Refinery gas, flaring	2.0	0.49	-	-	-	-	
Land fill gas, direct fired furnaces	2.0	0.48	-	0.1	-	1.0	0.1
Landfill gas, boilers	2.0	0.10	1	0.1	-	1.0	0.1
Landfill gas, flaring	2.0	0.04	-	-	-	-	
Blast furnace gas, direct fired furnaces	2.0	2.4	-	-	-	-	0.1-0.3
Blast furnace gas, boilers	2.0	0.5	1	-	-	-	0.1-1.3
Other gaseous fuels, direct fired furnaces	2.0	0.48	-	-	-	-	
Other gaseous fuels, boilers	2.0	0.10	1	-	-	-	

Denmark, Austria and Belgium base part of their emission factors on the IPCC default emission factor and use country-specific factors for certain applications. The Finnish emission factors are largely based on studies by the VTT Technical Research Centre of Finland (Tsupari et al 2005, 2066 and 2007). Tsupari et al. (2005) suggest the current Finnish emission factor of 1 kg/TJ for natural gas and 2-3 kg/TJ for other gases, based on theoretical argumentation of formation of N_2O, comparison with other countries and on measurement data. In the Finnish NIR of submission 2014 however, an emission factor of 1 kg /TJ for all gases in the stationary energy sector is used.

Germany updated their N_2O emission factors in submission 2014 based on a comprehensive study carried out in 2008- 2011 (Fichtner et al. 2011), this reference is however not available. Norway differentiates the most between applications and techniques, and refers to a study by the Norwegian Pollution Control Authority (SFT), which deals with waste treatment but is not available, and a report by OLF the Norwegian Oil Industry Association. The latter report can be found in an updated version (OLF, 2012) and includes emission factors for combustion of natural gas.

Solid fuels

Compared to other European countries, the Swedish implied emission factor for solid fuel use in sector 1.A is extremely high (Figure 3). The emission factors, compared to some of the other countries' (

Table 6), are however not exceptional except for that of coke, which is higher than any other of the countries included in the comparison. The Swedish emission factor for coal is the same for all combustion techniques whereas Finland and Germany have differentiated between fluidized bed combustion and conventional combustion.
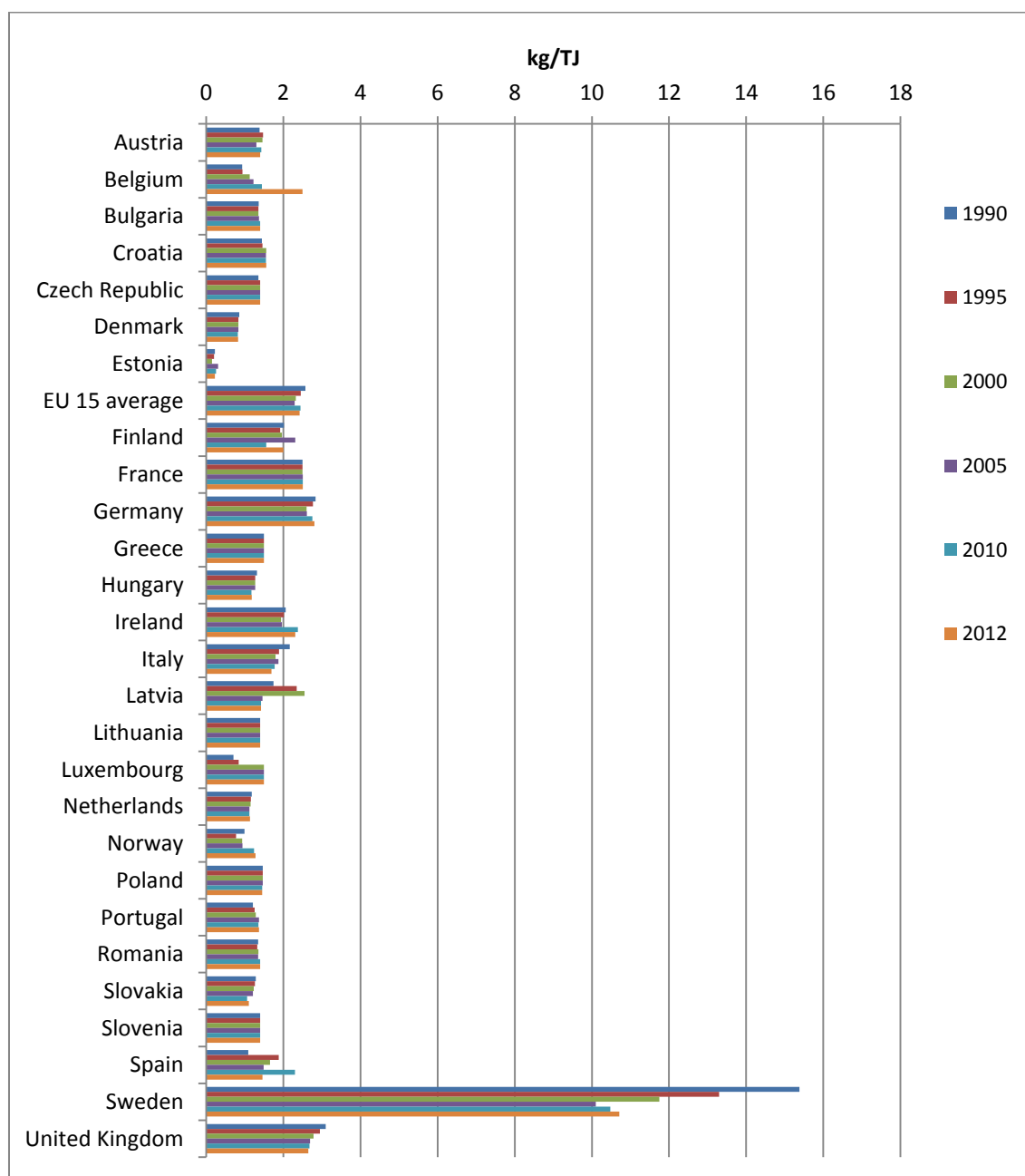

Figure 3: Implied emission factor for use of solid fuels in sector 1.A (submission 2014). Sweden has in comparison a very high implied emission factor with no other country nearly as high.

Table 6: N$_2$O emission factors for solid fuels for some European countries. As all countries do not specify the emission factor in the same way, the allocation of emission factors into technique and fuel is an approximation.

N$_2$O emission factors for solid fuel combustion (kg/TJ)

	Sweden	Finland	Norway	Denmark	Germany	Austria	United Kingdom[a]
Coal, general	20	-	1.4	0.8/1.6[b]	-	0.5/5.0[b]	5.4-8.7
Coal fired boiler, CFB	-	30	-	-	20	-	-
Coal fired boiler, BFB/PFB	-	20	-	-	20	-	-
Coal fired boiler, grate	-	3	-	-	4.0/10[c]	-	-
Coal fired boiler, pulverised combustion	-	1	-	-	1.9-2.0	-	-
Coal, Industry	-	-	-	1.4	-	1.4	-
Coal, Residential and agricultural	-	-	-	1.4	-	-	4.5/5.4
Peat fired boiler, CFB	-	7	-	-	-	-	-
Peat fired boiler, BFB	-	3	-	-	-	-	-
Peat fired boiler, grate and other	5	2	-	-	-	-	-
Peat, domestic	-	-	-	-	-	-	5.2
Coke	20	1	1.4	1.4	-	1.4	5.3-8.2
Coke, residential	-	-	-	-	0.82	-	4.2

CFB = Circulating Fluidized Bed

BFB = Bubbling Fluidized Bed

PFB = Pressurized Fluidized Bed

[a] The unit of the emission factors for solid fuels in UK is given as kg/ton. As the national calorific values are not reported in submission 2014, the Swedish calorific values have been used to convert the emission factors to kg/TJ.

[b] Power and CHP plants/District heating plants

[c] 4.0 kg/TJ for large combustion plants >50 MW, 10 kg/TJ for small combustion plants <50 MW.

The only reference for the above listed emission factors which was found was the report by Tsupari et al. (2007) which is described above.

Recommendation for revision

Gaseous fuels

Due to the lack of measurement data, and since both measurements and the emission factors adopted by other countries show a large variation also when comparing with the same fuel and technique, we suggest using one and the same N$_2$O emission factor for all fuels and techniques in the Swedish emission inventory. There is no reason to believe that the emission factor has been either reduced or increased since 1990, thus we propose that the same emission factor is used throughout the time series.

Based on the measurement data found in the literature, comparison with other countries and the knowledge on nitrogen formation we believe there is sufficient motivation to lower the current

emission factor to a value somewhere in between the current value (2 kg/TJ) and the 2006 IPCC default emission factor (0.1 kg/TJ). Measurement data show a rather large variation, however most other countries which use country-specific emission factors have chosen a value between 0.1 and 1.0 kg/TJ. There is no scientific reason for any significant amounts of N_2O to form by combustion of gaseous fuels, which contain very little organic nitrogen. The emissions should be lower than combustion of liquid and solid fuels, which in general contain more of these compounds from which N_2O can be formed. Thus an emission factor of 0.5 kg/TJ is suggested for all gaseous fuels (Table 7).

Table 7: Suggested revised emission factors for N_2O for gaseous fuels and LPG. The revised emission factors are the same for all gaseous fuels and LPG for the entire time series.

Fuel	Sector	CRF	N_2O EF, kg/TJ
Landfill gas/Anaerobic digestion gas	All	1A1, 1A2	0.5
LPG (propane och butane)	All	1A1, 1A2, 1A4	0.5
Coke oven gas	All	1A1, 1A2	0.5
LD gas	All	1A1	0.5
Blast furnace gas	All	1A1, 1A2	0.5
Natural gas	All	1A1, 1A2, 1A4	0.5
Town gas	All	1A1, 1A2, 1A4	0.5
Carbide oven gas	All	1A2	0.5
Methane and fuel gas	Industry	1A1b, 1A1c, 1A2	0.5
Refinery gas	Industry	1A1b, 1A1c, 1A2	0.5

Solid fuels

The current emissions factors for both coal and coke combustion are much higher than the default IPCC 2006 emission factor. In the case of coal combustion, emission data from one of the two plants with any significant coal consumption verify a high emission factor from that plant due to the use of fluidized bed technique resulting in low temperatures. However, this particular plant is the only one in Sweden using this technique for coal combustion and since conventional combustion with high temperatures gives a much lower emission factor, technology-specific emission factors should be implemented. An emission factor for fluidized bed technology can be produced based on the plant-specific data from the plant using this technology. The plant's average value of the emission factors from the last three years is 33 kg/TJ; in line with the Finnish emission factors for this technology. As it can be assumed that all other coal combustion occurs with conventional technologies, the emission factor of 33 kg/TJ can be applied to this plant's coal consumption alone, and all other coal consumption within the stationary energy sector can be assigned a lower emission factor representing conventional coal combustion.

The 2006 IPCC default emission factor of 1.5 kg/TJ is suggested for all other coal combustion due to little national data with only one measurement from a coal firing combustion plant. As there is very little coal combustion is Sweden compared to other countries it is likely that the default emission factor better represents these emissions.

By implementing technology-specific N_2O emission factors for coal combustion all years will be updated according to the extent of each technology and as a result the entire time series will be more accurate.

There is little information to be found on N_2O emissions from combustion of coke. No plant-specific data or scientific reports were found on the topic during this project. It is however reasonable to believe that the Swedish emission factor is much overestimated as there is no other country with an equally high emission factor among the examined countries. The current value seems to be based on the emission factor for coal; the combustion conditions for coke is however different from those of coal. In the Swedish emission inventory, the coke emission factor is used for one company producing calcium carbide as well as some plants in the food and beverage industry and mineral industry. Since the temperature at these processes is high, N_2O molecules should in theory be decomposed and thus the emission factor should be low. As there is no information to support a country-specific value we propose to use the IPCC default factor (1.5 kg/TJ) for coke combustion throughout the time series.

Peat combustion is a very small energy source in Sweden, and although the current emission factor is substantially higher than the default value, there is no support from the measurement data to further decrease it. The current emission factor is within the range of recent emission data from the Swedish combustion plants, as well as within the range of the Finnish emission factors for peat, and so no revision of the emission factor for peat is suggested.

Suggested emission factors to be implemented in submission 2015 are presented in Table 8.

Table 8: Suggested N_2O emission factors for combustion of coal, coke and peat. A revision is suggested for coke combustion and technology-specific emission factors are suggested for coal combustion. (Revised emission factors in red)

Fuel	Sector	CRF	Combustion technology	N_2O EF (kg/TJ)
Coal	All	1A	CFB	33
Coal	All	1A	All other	1.5
Coke	All	1A		1.5
Peat	All	1A		5

The new emission factor for coke combustion would result in a substantially reduced implied emission factor within the fuel combustion sector for solid fuels (Table 9) in line with other European countries.

Table 9: Implied emission factor currently and as a result of implementation of the revised emission factor for coke combustion.

Year	Current IEF (kg/TJ)	New IEF (kg/TJ)
1990	15	1.4
1995	13	0.92
2000	12	0.73
2005	10	0.66
2010	10	0.58
2012	11	0.57

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Appendix A

Measurement data of N_2O from relevant fuels as summarized in the report by Fridell, Stripple and Gustafsson (2010).

Fuel	Technology	Capacity	Load	kg N_2O/TJ	Reference
Peat	CFB	299	98	<2	Tsupari et al. 2005
Peat	CFB	185	75	26	Tsupari et al. 2005
Peat	BFB	260	96	<1	Tsupari et al. 2005
Peat	Stoker	1	-	22	Tsupari et al. 2005
Peat + Sludge	BFB	78	74	<2	Tsupari et al. 2005
Peat + Wood	CFB	97	96	3	Tsupari et al. 2005
Peat + Wood	CFB	299	99	4	Tsupari et al. 2005
Peat + Bark	BFB	78	76	<2	Tsupari et al. 2005
Peat + Bark + Coal	CFB	300	100	18	Tsupari et al. 2005
Wood + Bark, Peat + Coal	CFB	>300	100	5	Tsupari et al. 2005
Biofuel + Peat	BFB	>100	80	4.3	Tsupari et al. 2007
Biofuel + Peat	CFB	>100	80	4	Tsupari et al. 2007
Biofuel + Peat	CFB	>100	60-80	7.7	Tsupari et al. 2007
Biofuel + Peat	CFB	>100	40-60	11.8	Tsupari et al. 2007
Biofuel + Peat	CFB	>100	0-40	12.6	Tsupari et al. 2007
Biofuel + Peat	CFB	>100	80	9.3	Tsupari et al. 2007
Biofuel + Peat	CFB	>100	60-80	7	Tsupari et al. 2007
Peat + Biofuel	CFB	>100	80	8.1	Tsupari et al. 2007
Peat + Biofuel	CFB	>100	60-80	6.9	Tsupari et al. 2007
Biofuel/Peat	BFB	>100	40-60	2.5	Tsupari et al. 2007
Biofuel/Peat	BFB	>100	0-40	4.2	Tsupari et al. 2007
Biofuel/Peat/Sludge	BFB	>100	80	0	Tsupari et al. 2007
Biofuel/Peat/Sludge	BFB	>100	60-80	<0.5	Tsupari et al. 2007
Biofuel/Peat/Sludge	BFB	>100	40-60	<0.5	Tsupari et al. 2007
Pulverized peat	Burner	120	-	8	Söderenergi, 2006
Peat/Chips	Roaster	-	-	9	SEPA, 2002
Coal/Rubber	Roaster	-	-	6	SEPA, 2002
Peat/Oil	Burner	-	-	5	SEPA, 2002
Biofuel/Peat	BFB	-	-	4	SEPA, 2002
Peat/Coal/Oil	Roaster	-	-	4	SEPA, 2002

Wood fuel/Peat	Steam boiler	38	-	5	Hemab, 2006
Pulverized coal	CFB	180	75	35	Tsupari et al. 2005
Coal	CFB	196	100	30	
Coal	CFB	>300	40-80	0.9-28	Tsupari et al. 2007
Coal	CFB	50-100	-	18-20	Fortum, 2004
Coal	FBC	-	-	14	Tsupari et al. 2005
Coal	GTCC	250	47	<3	Tsupari et al. 2005
Coal	GTCC	-	226	<3	Tsupari et al. 2005
Natural gas	Boiler	327	-	3	Tsupari et al. 2005
Natural gas	CHP	113	-	4	Tsupari et al. 2006