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Reporting of biomass in CRF tables and reallocation of emissions from spent liquor combustion

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SMED (Swedish Environmental Emissions Data), is a collaboration between IVL Swedish Environmental Research Institute, Statistics Sweden (SCB), Swedish University of Agricultural Sciences (SLU) and the Swedish Meteorological and Hydrological Institute (SMHI). The collaboration commenced in 2001 with the long-term aim of gathering and developing the competence in Sweden within emission statistics. SMED is, on behalf of the Swedish Environmental Protection Agency and the Swedish Agency for Marine and Water Management, heavily involved in the work related to Sweden's international reporting obligations on emissions within six subject areas (air, water, waste, hazardous substances, noise and measures). A central objective of the SMED collaboration is to develop and operate national emission databases. SMED data also supports national, regional and local governmental authorities for decision making. For more information visit the SMED website www.smed.se (in Swedish).

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Sammanfattning

Sverige rapporterar bränslen och emissioner från förbränning av biomassa till UNFCCC i standardiserade tabeller för energisektorn (CRF 1). Eftersom avlutar är en biprodukt från produktionsprocessen i massaindustrin har Sverige valt att allokera emissioner från förbränning av avlutar till industrisektorn (CRF 2). CRF-tabeller för industrisektorn tillåter dock inte rapporteringen av bränslen eller utsläpp av biogen CO_2. Därför saknas de betydande biogena CO_2-emissioner från förbränning av avlutar inom massaindustrin i de svenska CRF-tabeller.

I den här studien har utsläpp av biogent CO_2 från förbränning av avlutar rapporterade till SMP, EU ETS och CRF jämförts med beräknade emissioner av mängder avlutar rapporterade till Kvartalsbränslestatistiken (KvBr). Om biogen CO_2 från förbränning av avlutar skulle rapporteras i CRF 1, skulle CRF-tabellerna inkludera alla biogena utsläpp och bränslen till SMP, EU ETS och KvBr.

Övriga utsläpp från förbränning av avlutar rapporteras i CRF/NFR 2H1 i submission 2021. För att rapportera samtliga utsläpp från avlutar i samma kod, skulle det krävas en omallokering av utsläpp från två förbränningsenheter som är i nuläget allokerade till CRF/NFR 2H1. Utvecklingen av bränslespecifika emissionsfaktorer för bränslen eldade i mesaugnen och tidskrävande årliga rutiner gör en sådan omallokering svårt. Testberäkningar med emissionsfaktorer för avlutar som föreslogs i en studie från 2017 genomfördes. Resultaten indikerade ingen kvalitativ förbättring för utsläppsberäkningen.

I den här studien jämfördes även övriga rapporterade utsläpp i CRF/NFR 1A2d och 2H1 med motsvarande utsläpp i SMP. Det visade sig att utsläpp för framförallt NO_X, SO_2 och TSP överskattas i utsläppsrapporteringen. En årlig rutin inom SMED för att justera utsläpp för dessa ämnen rapporterade i NFR 1A2d skulle innebära en bättre överenstämmelse gentemot SMP.

SMED rekommenderar att inkludera biogent CO_2 från förbränning av avlutar i CRF 1.A.2.d. Omallokeringar av övriga utsläpp inom massaindustrin är svåra att motivera baserad på projektets resultat och rekommenderas därför inte. För att öka kvalitén i rapporteringen föreslås det att införa en rutin inom det årliga rapporteringsprojektet för att säkerställa att utsläpp av NO_X, SO_2 och TSP från sulfat- och sulfitbruk motsvarar utsläppen rapporterade i SMP.

Summary

SMED is short for Swedish Environmental Emissions Data, which is a collaboration between IVL Swedish Environmental Research Institute, SCB Statistics Sweden, SLU Swedish University of Agricultural Sciences, and SMHI Swedish Meteorological and Hydrological Institute.

Sweden reports energy consumption and emissions from biomass combustion to the UNFCCC in standardized tables for the energy sector (CRF 1). Due to the nature of spent liquor as a by-product from the pulp and paper processes, Sweden has chosen to allocate the emissions from spent liquor combustion to the Industrial Processes and Product Use sector (IPPU, CRF 2). As the CRF tables for the IPPU sector do not accommodate reporting of fuel consumption or biogenic CO_2 emissions, significant biogenic CO_2 emissions from spent liquor combustion within the pulp and paper industry are missing in the Swedish CRF tables.

In this study, biogenic CO_2 emissions from spent liquor combustion reported to the Swedish Portal for Environmental Reporting (SMP) and EU ETS have been compared to emissions calculated from amounts of spent liquor reported to the Quarterly Fuel Statistics. If biogenic CO_2 from spent liquor combustion was reported in CRF 1, CRF tables would include all biogenic emissions and biomass reported to SMP, EU ETS and the Quarterly Fuel Statistics.

Emissions of other gases from spent liquor combustion is reported in CRF/NFR 2H1 in submission 2021. In order to report all emissions from spent liquor combustion in the same CRF/NFR category, reallocating emissions from both the recovery boiler and the lime kiln, currently allocated to CRF/NFR 2H1, is required. Developing fuel-specific emissions factors for fuels combusted in one of the units (lime kiln) and time-consuming annual routines make such a reallocation challenging. Test calculations with emission factors proposed in a study from 2017 were conducted. The results do not indicate a higher accuracy in terms of emission calculations.

In this study, emissions of non-CO_2 gases reported in CRF/NFR 1A2d and 2H1 were compared to corresponding emissions reported in SMP. Especially for NO_x, SO_2 and TSP, emissions seem to be overestimated in the inventory. An annual procedure to adjust emissions for these gases reported in NFR 1A2d would result in much better accordance with SMP.

SMED recommends to include biogenic CO_2 from spent liquor in CRF 1.A.2.d. Reallocating non-CO_2 emissions within the pulp and paper industry

from CRF/NFR 2H1 to 1A2d cannot be motivated based on the results obtained in this project and is therefore not recommended. To increase accuracy in the inventory it is suggested to introduce a procedure within the annual inventory compiling to ensure that emissions of NO_x, SO_2 and TSP from sulphate and sulfite plants match the emissions reported in SMP.

Keywords: biogenic CO_2, CRF-tables, spent liquor, pulp and paper

Background and objective

Biogenic CO_2 emissions are not included in the national total emissions of greenhouse gases reported to UNFCCC. However, these emissions can still be included in the standardized reporting tables (CRF tables) submitted to the UNFCCC as a memo item, if emissions are reported under the energy sector (CRF 1). Biogenic CO_2 emissions cannot be reported in the IPPU (Industrial Processes and Product Use) sector though. Monitoring and reporting of biogenic CO_2 emissions are of increasing interest as the BECCS (Bio-energy with carbon capture and storage) technology is developing, which has the potential of leading to "negative emissions".

In a recent study[1] amounts of biogenic CO_2 emissions reported by Sweden in the CRF tables were compared to amounts reported by emitting facilities to the Swedish Portal for Environmental Reporting (SMP, Svenska Miljörapporteringsportalen[2]). It was concluded that far more biogenic CO_2 emissions are reported to SMP than in the CRF tables as memo item. Combustion of spent liquor in the pulp and paper industry was found to be the major activity missing in the CRF tables as corresponding emissions are currently allocated to the IPPU sector (CRF 2).

The Swedish pulp and paper industry, along with the Finnish, is the biggest in Europe. Greenhouse gas emissions from the pulp and paper industry consist mainly of biogenic CO_2 originating from the wood raw material. At present, Sweden reports biogenic CO_2 from combustion of residues from the wood raw material, such as bark, in the energy sector, while biogenic CO_2 from combustion of spent liquor is not reported. Regarding air pollutants, the pulp and paper industry is a considerable emission source of SO_2, NO_x and $PM_{2.5}$. About a quarter of Sweden's total SO_2 emissions and 11% of total NO_x emissions in 2019 are emitted by the pulp and paper industry.

The sulfate process (Kraft process) is the most common process applied to produce pulp in Sweden. A smaller number of pulp and paper plants apply the sulfite process, mechanical or semi-chemical processes for pulp production. In both the sulfate and the sulfite process, the process chemicals (NaOH, NaS_2) are recovered in recovery boilers. Together with leftover biomass from wood raw material, these used process chemicals constitute spent liquor. The spent liquor is combusted, and resulting energy is used to cover the plant's energy demand. The chemicals are then recovered via a causticizing step and are reused in the digester to produce more pulp. The

[1] Kindbom, K., Gustafsson, G. (2018) Reporting of negative emissions in GHG emission inventories. SMED report 19, 2018.
[2] https://smp.lansstyrelsen.se

recovery boiler has therefore dual purposes; to recover process chemicals and to produce energy needed for the process. Sweden has allocated emissions from the recovery boiler to the IPPU sector (CRF 2) although biogenic CO_2 cannot be reported in CRF 2, which makes it difficult to follow up on these emissions. Sweden has received several recommendations from international reviewers (EC Internal review 2008, UNFCCC ERT Centralized review 2009, UNFCCC ERT Centralized review 2010) to reallocate these emissions to the energy sector. For a more complete and transparent reporting of biomass and emissions of biogenic CO_2, amounts of spent liquor and corresponding biogenic CO_2 emissions should be reported as memo item in CRF 1.

The objective of this project is to compare biomass and biogenic CO_2 emissions reported in the CRF tables, SMP and the EU ETS. This is done to identify missing biogenic CO_2 emissions in the CRF tables and possibly include them in the inventory. Since spent liquor combustion was already identified as the major source of biogenic CO_2 emissions missing in the CRF tables, the focus of including missing biogenic CO_2 emissions in the CRF tables lies on the pulp and paper industry. Activity data and emission factors are compiled, and a method is developed that allows reallocation of emissions from spent liquor combustion from CRF/NFR 2H1 to CRF/NFR 1A2d.

Project activities

Biogenic CO_2 and biomass consumption in CRF tables and other data sources

Comparison of biogenic CO_2 and fuel amounts for heat and power reported to CRF tables, SMP and EU ETS

In Table 1 biomass combustion and corresponding CO_2 emissions from heat and power production plants in 2019 are compared, as reported in CRF 1.A.1.a, the SMP and the EU ETS (Emissions Trading System). The reported data differs significantly from each other, mainly due to the different scope of plants and emissions included. Therefore, biomass reported to the SMP and biogenic CO_2 emissions reported to the EU ETS are not comparable to CRF 1.A.1.a.

Data in CRF 1.A.1.a are based on the Quarterly Fuel Statistics which include all consumed fuel reported by all plants in Sweden, regardless of size. Biogenic CO_2 emissions reported in CRF 1.A.1.a sum up to 16 152 kt, accounting for about half of total biogenic CO_2 emissions reported as memo item in CRF table 1s2. Reporting to the SMP is only mandatory for plants whose emissions are above a threshold of 100 kt biogenic and fossil CO_2. This leads to reduced coverage of smaller plants. Consequently, biogenic CO_2 from heat and power plants reported in the SMP (11 686 kt) amount to about 72% of biogenic CO_2 emissions (16 152 kt) reported in CRF 1.A.1.a (Table 1). Furthermore, reporting of fuel amounts to the SMP is mandatory only for combustion plants with a thermal rated input of more than 50 MW, excluding waste incineration plants. 85 PJ biofuel is reported in SMP from heat and power plants, which is about 51% of the biomass consumption reported in the CRF (168 PJ). The quantity of biofuels reported to the EU ETS for the heat and power plants (155 PJ) is comparable to amounts reported in CRF 1.A.1.a. When it comes to biogenic emissions, reporting to the EU ETS has become mandatory in 2021 but data for 2019 is scarce. Thus, total biogenic CO_2 emissions reported by the plants to the EU ETS are likely underestimated and not comparable to other data sources.

Table 1. Reported biogenic CO_2 emissions and biomass to SMP, the EU ETS and CRF tables from heat and power plants (CRF 1.A.1.a)

	SMP 2019		EU ETS 2019		CRF 1.A.1.a 2019	
Bio-genic CO_2 [kt]	**Mandatory reporting**	**Emissions**	**Mandatory reporting**	**Emissions**	**Mandatory reporting**	**Emissions**
	All plants with emissions exceeding 100 kt	11 686	No mandatory reporting	2 012	All plants	16 152
Bio-mass [TJ]	**Mandatory reporting**	**Fuel combusted**	**Mandatory reporting**	**Fuel combusted**	**Mandatory reporting**	**Fuel combusted**
	Plants with a rated thermal input exceeding 50 MW, waste incineration plants excepted	85 380	All plants exceeding a rated thermal input of 20 MW or connected to district heating system exceeding 20 MW	155 313	All plants	167 758

Fuel amounts reported to SMP as well as EU ETS are lower than reported fuel amounts in CRF tables, indicating that there is no significant source of biogenic CO_2 emissions missing from this CRF category.

Comparison of spent liquor amounts reported to the Swedish Quarterly Fuel Statistics, SMP and EU ETS

As mentioned above, far more biogenic CO_2 is reported to SMP than as memo item in CRF tables due to emissions from spent liquor combustion not being accounted for in CRF tables. In the following section, energy amounts of spent liquor and corresponding biogenic CO_2 emissions are compared between the Quarterly Fuel Statistics of Statistics Sweden, SMP and EU ETS.

To be able to compare biogenic CO_2 emissions from spent liquor combustion reported to the Quarterly Fuel Statistics, an emission factor needs to be applied to calculate these emissions. Since the sulfate process is the most common one both globally and in Sweden, most information on emissions are based on the sulfate process and black liquor combustion. The amount of CO_2 emitted from black liquor combustion varies depending on the production process. Black liquor consists of cooking chemicals, lignin and water, and biogenic CO_2 emissions originate from combustion of the lignin. Normally, most of the lignin is removed from the pulp in the cooking

process and the rest is removed in the bleaching process. The lignin removed in the cooking process is contained in the black liquor. In the case of certain products, for example linerboard, some lignin is however kept in the product and the black liquor thus contains less lignin. A general emission factor is therefore difficult to determine and is associated with high uncertainties.

In the recovery boiler, some carbon contained in the black liquor forms sodium carbonate (Na_2CO_3), which is released as CO_2 in the lime kiln. The emission factor for spent liquor should include all CO_2 emissions from spent liquor, including these emissions.

Based on research conducted at IVL in the 1980's and 1990's a national emission factor for black liquor of 95.5 kg CO_2/GJ was estimated (Boström 2001) and updated to 110 kg CO_2/GJ in 2006. The 2006 IPCC Guidelines propose a default factor very similar to the original factor, 95.3 kg CO_2/GJ, with 80.7 kg CO_2/GJ and 110 kg CO_2/GJ as lower and higher limits for a possible emission factor[3]. In a technical guidance document from 2009, the US EPA suggests somewhat lower emission factors for the Kraft pulping process with North American hardwood and softwood as word furnish[4]. Table 2 summarizes the emission factors proposed in different literature sources. All suggested emission factors include the emissions of biogenic CO_2 released when Na_2CO_3 is combusted in the lime kiln.

Table 2. Overview of possible emissions factors for biogenic CO_2 from spent liquor combustion.

Source	**CO_2 emission factor (kg CO_2/GJ)**
Previous national emission factor including carbon emitted in lime kiln	95.5
Revised national emission factor from 2006	110
EPA technical support document, North American Softwood	89.4
EPA technical support document, North American Hardwood	88.7
2006 IPCC Guidelines	95.3

To estimate biogenic CO_2 emissions from spent liquor combustion reported to Quarterly Fuels Statistics, the emission factor proposed in the 2006 IPCC

[3] 2006 IPCC Guidelines, volume 2 Energy, chapter 2, table 2.2
[4] US EPA 2009. Technical support document for the pulp and paper sector: proposed rule for mandatory reporting of greenhouse gases. Table 6-6

guidelines (95.3 kg CO_2/GJ) is applied. The estimated national emission factors are judged to be uncertain, especially in the light of the large difference between the previously estimated emission factor from 2001 and the updated one from 2006. Resulting biogenic CO_2 emissions in 2019 amount to 15 327 kt CO_2 (Table 3), accounting for 76 % of total biogenic CO_2 emissions from the pulp and paper industry. While biogenic emissions reported to the EU ETS are negligible and therefore marked in *italic*, total biogenic CO_2 reported to SMP is comparable to the Quarterly Fuels Statistics.

In 2019, 161 PJ of spent liquor have been combusted in Sweden according to the Quarterly Fuel Statistics. Similar amounts are reported to the EU ETS (168 PJ). To SMP, spent liquor is not reported separately from other liquid biomass which makes it difficult to compare amounts and biogenic CO_2 to the Quarterly Fuel Statistics and EU ETS. It is however likely that less spent liquor is reported to SMP due to not all plants being required to report amounts of fuel combusted to SMP. Therefore, amounts of biomass reported to SMP can be considered less complete and are therefore marked in *italic*. Biomass reported to EU ETS is however comparable to the Quarterly Fuel Statistics.

Table 3. Amounts of biomass, spent liquor and corresponding biogenic CO_2 reported to the Quarterly Fuel Statistics, SMP and EU ETS in 2019. Data assumed to be incomplete marked in italic.

		Quarterly Fuel Statistics 2019	SMP 2019	EU ETS 2019
Biogenic CO_2 [kt]	**Pulp and paper industry total**	20 158*	22 317	*33*
	Of which spent liquor combustion	15 327*		*2*
Biomass [TJ]	**Pulp and paper industry total**	212 896	*170 203*	230 411
	Of which spent liquor	160 833		167 548

*Emissions from spent liquor combustion calculated with emission factor 95.3 kg CO_2/GJ

When reporting to SMP, it is not always clear how companies are calculating biogenic emissions and which emission factors are applied. This must be considered when comparing emissions shown above.

Review of reallocation of emissions from spent liquor combustion

Current allocation

Currently, emissions from pulp and paper plants are reported in CRF/NFR 1A2d, 2H1 and 2A2 according to Table 4. In the case of NO_x, SO_2 and PM, companies are reporting emissions specifically for the recovery boiler as well as for the steam boiler, the lime kiln and the incinerator for non-condensable gases.

Table 4. Current allocation of emissions within the pulp and paper industry.

	CO_2 fossil	**CO_2 bio-genic**	**CH_4, NMVOC**	**SO_2**	**NO_X**	**PM**	**N_2O, NH_3, CO, HM, Dioxin, PAH**
Recovery boiler, spent liquor	-	Not reported	2H1	2H1	2H1	2H1	2H1
Recovery boiler, other fuels	1A2d	1A2d	1A2d, 2H1	1A2d (Adjusted), 2H1	1A2d (Adjusted), 2H1	1A2d (Adjusted), 2H1	1A2d, 2H1
Steam boiler, all fuels	1A2d	1A2d	1A2d	1A2d	1A2d	1A2d	1A2d
Lime kiln, fuels	1A2d	1A2d	1A2d, 2H1	1A2d (Adjusted), 2H1	1A2d (Adjusted), 2H1	1A2d (Adjusted), 2H1	1A2d, 2H1
Lime kiln, make-up lime	2A2	-	-	2H1	-	2H1	-
Incinerator for non-condensable gases, all fuels	1A2d	1A2d	1A2d, 2H1	1A2d (Adjusted), 2H1	1A2d (Adjusted), 2H1	1A2d (Adjusted), 2H1	1A2d, 2H1
Diffuse emissions	-	-	2H1 (EF)	2H1 (EF)	-	-	-

According to the EMEP/EEA Guidebook 2019[5], emissions from combustion in boilers and the lime kiln are to be reported in NFR 1A2d. Emissions from treatment of non-condensable gases and chemical recovery of spent liquor in the Kraft-process are to be reported in NFR 2H1 (Table 5). It is debatable whether emissions from chemical recovery should be reported in the energy or industrial sector, as the combustion of spent liquor in the recovery boiler serves two purposes: recycling the cooking liquor as well as energy recovery to cover a part of the plant's energy demand.

Table 5. Emission sources according to the EMEP/EEA Guidebook 2019, 2H1 Pulp and paper industry.

Table 2.1 Emission sources in paper pulping — Kraft process.

Source							
	TPM	**PM 10**	**PM 2.5**	**SO_2**	**NO_x**	**VOC_s**	**CO**
Debarking, wood handling						x	
Washing							
Bleaching							
Non-condensable gases:							
— Collected, not incinerated				X (a)			
— Incinerated				X (a)	x		
Turpentine production							
Tall oil recovery							
Chemical recovery							
— Black liquor oxidation							
— Recovery furnace		X		X	X		x
— Lime kiln (b)		X		x	X		x
Pulp drying (b) (this will have to be confirmed based on source category 1.A.2.d)							
Boilers (fuel-dependent) (b)		x		X	X		

Major sources are marked with an 'X'; minor sources are marked with an 'x'.
(a) Depending on if the emissions are treated in a scrubber or if the incineration takes place in the lime kiln.
(b) Recorded under source category 1.A.2.d.

Although these contaminants are emitted in varying quantities, the major problem for this industry is odour due to TRS emissions.

The 2006 IPCC Guidelines offer no specific guidance for biogenic emissions from the pulp and paper industry. In box 1.1 of vol 3 IPPU[6] it is stated that "*Combustion emissions from fuels obtained directly or indirectly*

[5] EMEP/EEA air pollutant emission inventory guidebook 2019, 2.H.1 Pulp and paper industry
[6] 2006 IPCC Guidelines, volume 3 IPPU, chapter 1 introduction

from the feedstock for an IPPU process will normally be allocated to the part of the source category in which the process occurs". Assuming wood fuels as feedstocks for spent liquor, emissions from spent liquor combustion are to be reported in CRF 2.H.1 since spent liquor is obtained from wood fuels as part of the Kraft-process occurring in CRF 2.H.1.

Potential reallocation

In order to report fuel consumption and biogenic CO_2 from spent liquor combustion in the CRF tables, reallocating these and other emissions from spent liquor combustion needs to be considered. This would however require a method to determine the remaining emissions from the lime kiln and the incinerator reported in CFR/NFR 2H1. Alternatively, emissions from the lime kiln could be reallocated to CRF/NFR 1A2d as discussed in a previous study[7]. This would require developing emission factors for fuels combusted in the lime kiln. According to the Guidebook (Table 5), the remaining emissions to be reported in NFR 2H1 are NMVOC from debarking, diffuse emissions of SO_2 from non-condensable gases as well as SO_2 from the incineration of non-condensable gases. Neither NO_x nor PM are to be reported in NFR 2H1 in this scenario. Emissions of NO_x, SO_2 and TSP from the recovery boiler and lime kiln in NFR 1A2d would be reported according to the companies' environmental reports. If weak and odorous gases are combusted in the lime kiln or the recovery boiler, corresponding emissions would not be accounted for.

Companies report amounts of spent liquor combusted to the Quarterly Fuel Statistics, which could be included in the inventory fuel data. Emission factors for spent liquor have been suggested in a study from 2017[8] based on measurements conducted at IVL[9] in the 1980's and 1990's and need to be reviewed.

Reviewing emission factors and test calculations

Since there is no other recent studies or information on emission factors for spent liquor, test calculations have been performed with the proposed emission factors displayed in Table 6, except for biogenic CO_2. As mentioned above, test calculations for biogenic CO_2 have been conducted with the emission factor proposed in the 2006 IPCC Guidelines (95.3 kg/GJ). The emission factors for all pollutants are assumed to be constant for all years except Cd, Cr, Cu, Ni, Pb and Zn that are assumed to decrease at the same rate as particle emissions.

[7] Mawdsley, I., Stripple, H. (2017)
[8] Mawdsley, I., Stripple, H. (2017)
[9] Boström, C.-Å. (2001)

Table 6. Proposed emission factors for spent liquor (Mawdsley & Stripple 2017).

Pollutant	EF for spent liquor in CRF/NFR 1A2d
Biogenic CO_2, kg/GJ	96
CH_4, kg/TJ	2
N_2O, kg/TJ	2
NH_3, kg/TJ	0.63
NMVOC, kg/TJ	6.3
CO, kg/TJ	100
Dioxin, mg/TJ	0.003
PAH, g/TJ	0.0013
As, g/TJ	0.76
Cd, g/TJ	0.15
Cr, g/TJ	0.29
Cu, g/TJ	0.79
Hg, g/TJ	0.13
Ni, g/TJ	0.75
Pb, g/TJ	0.15
Zn, g/TJ	0.75

Amounts of spent liquor are available from 2007 onwards in the Quarterly Fuel Statistics. If biogenic CO_2 from spent liquor combustion was to be reported in CRF 1.A.2.d, the revised national total would amount to roughly 47.9 Mt in 2019 (Figure 1). The emissions increase by about 50% on average throughout this time series.

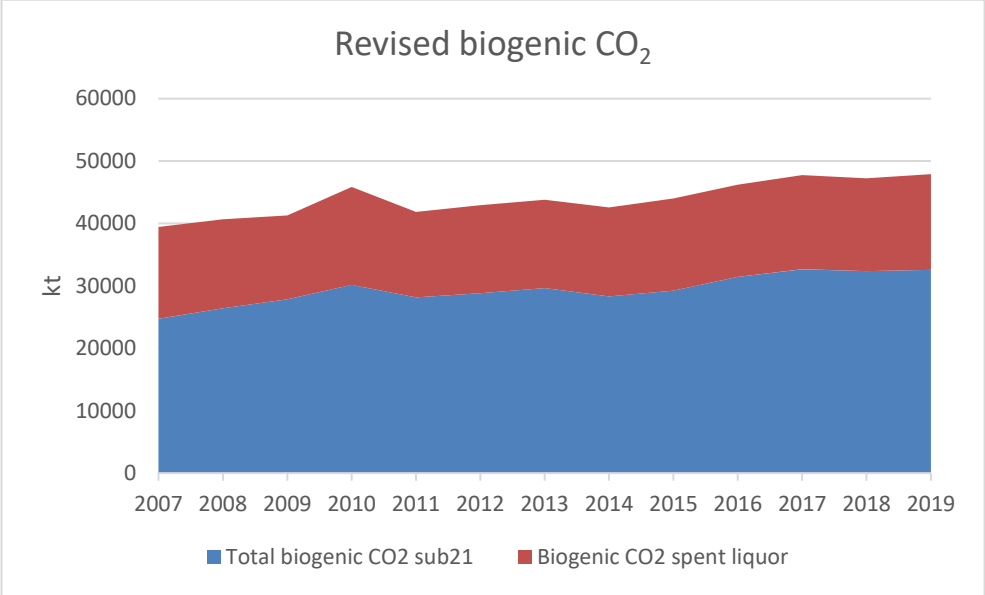

Figure 1. Revised total biogenic CO_2 reported in submission 2021 including spent liquor combustion.

Emission factors for the remaining pollutants are suspected to be more uncertain and have therefore been reviewed on a plant level basis. Emissions for the ten facilities with the highest amount of spent liquor combusted in 2019 were calculated and compared to the facilities' reported emissions in CRF/NFR 2H1. In submission 2021, all emissions from plants in CRF/NFR 2H1 are calculated with emission factors based on the plants total amount produced pulp except for NO_x, SO_2 and particles where data is retrieved from environmental reports. Since emissions from spent liquor combustion are, along with emissions from other processes, currently allocated to CRF/NFR 2H1 (Table 4), the newly calculated emissions from spent liquor combustion should account for a realistic share of total emissions reported in CRF/NFR 2H1.

The comparison showed that for certain plants and pollutants, calculated emissions from spent liquor combustion exceed the emissions that are reported for the plant in CRF/NFR 2H1. Those observations are mostly explained by the varying ratios of produced amount of pulp and combusted amount of spent liquor between plants. Within the ten examined facilities, the amount of combusted spent liquor per produced kiloton pulp varies between 12.6 and 23.6 TJ. Calculated emissions of e.g. CH_4 or N_2O from spent liquor combustion for plants with a higher ratio were larger than currently reported in CFR 2H1. Emissions from spent liquor combustion that were much smaller than emissions reported in NFR 2H1 include NMVOC and NH_3 for all plants.

Comparison of inventory emissions and SMP

Emissions of TSP, SO_2 and NOx are in general measured continuously by the plants and are often reported to SMP specified to the different processing units. In order to increase the accuracy of reported emissions of these pollutants from the Swedish pulp and paper industry, emissions reported in CRF/NFR 1A2d and 2H1 have been compared to emissions reported in SMP for the above mentioned ten facilities. Emission factors applied in NFR 1A2d have been adjusted in submission 2018 by introducing correction factors proposed in Mawdsley et al. (2017) in order to report inventory emissions more accordingly to SMP. **Error! Reference source not found.**Figure 2 compares summed-up emissions of TSP, SO_2 and NOx from the ten facilities reported in 2019 in NFR 1A2d and 2H1 to corresponding emissions reported by these ten facilities to SMP.

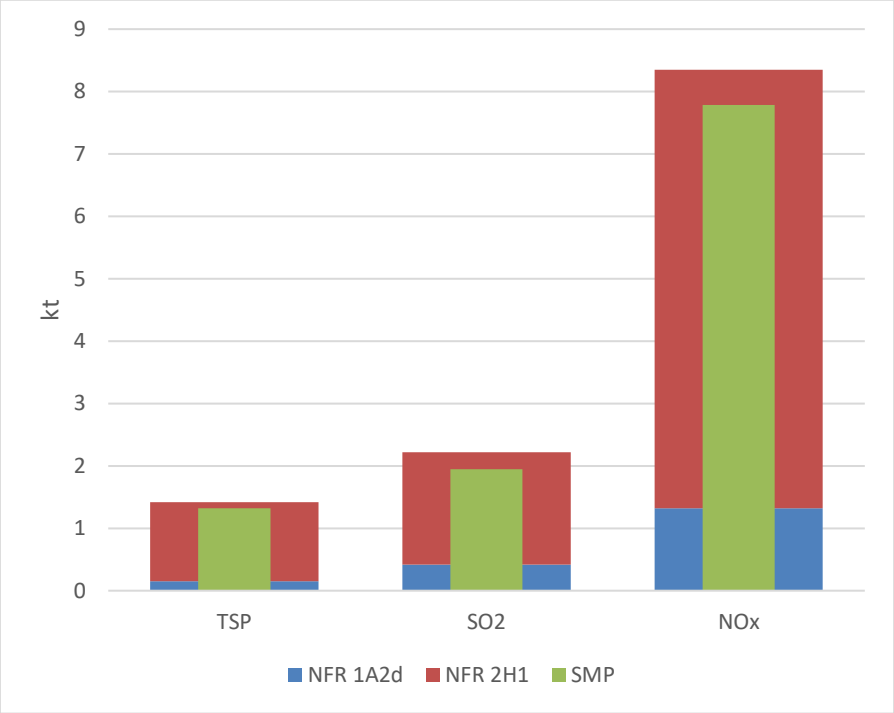

Figure 2. Emissions of TSP, SO_2 and NO_X reported in NFR 1A2d and 2H1 compared to SMP for ten facilities in 2019.

Emissions of all three pollutants from the considered plants are overestimated in 2019 when compared to SMP. Even though conclusions for the entire time series and all plants cannot be made from this comparison, there is a chance that emissions of TSP, SO_2 and NO_x are overestimated for later years for all plants.

Conclusions

Reporting of biogenic CO_2 from spent liquor combustion in CRF 1.A.2.d would include essentially all biogenic CO_2 reported to SMP and CRF-tables would therefore be more accurate and comparable to SMP. As spent liquor is included in the national energy statistics, the inventory fuel data would be more complete if spent liquor combustion was allocated to the energy sector.

When developing a method to reallocate emissions of remaining gases from spent liquor combustion, reallocating emissions from both the recovery boiler and the lime kiln to CRF/NFR 1A2d is preferable. This is due to difficulties in developing a solid method to determine remaining emissions reported in CRF/NFR 2H1 when reallocating emissions from the recovery boiler only. Since emissions from fuels combusted in the lime kiln are currently reported in NFR/CRF 1A2d as well as CRF/NFR 2H1, reallocating the emissions from the lime kiln would also eliminate the double counting of these emissions. During the review of fuels reported by the companies to the Quarterly Fuel Statistics, it became clear that fuels combusted in the lime kiln are difficult to separate from fuel combusted in other boilers. Proposing fuel-specific emissions factors for both the recovery boiler and lime kiln is therefore difficult. Since plants are combusting different kinds of fuels in the lime kiln, developing fuel-specific emission factors may introduce higher uncertainties and a lower accuracy. Also, the required annual procedures would increase the risk of mistakes in the different calculation steps.

Results from test calculations with emissions factors for spent liquor raise doubts if overall emission estimations can be improved. Emission factors of e.g. CH_4 and N_2O might be too high while emissions of e.g. NMVOC and NH_3 possibly are underestimated when applying the suggested emission factors. In certain cases, emissions from spent liquor combustion exceed reported emissions in CRF/NFR 2H1 which can be disputed. Based on the considerable differences in terms of combusted amounts of spent liquor in relation to produced amount of pulp, it appears to be difficult to apply the same emission factors for spent liquor on all plants. Emission factors expressing emissions per amount pulp produced are hardly transformable into factors that express emissions per amount combusted spent liquor. Overall, emission factors for spent liquor other than for biogenic CO_2 do not seem to be accurate enough to motivate applying them in the inventory.

When comparing emissions reported in CRF/NFR 1A2d and 2H1 to SMP it became apparent that inventory emissions are overestimated for several

pollutants. With SO_2, NO_x and TSP being of special importance for this industry, adjusting inventory emissions of these pollutants according to SMP would contribute to a higher accuracy. If SO_2, NO_x and TSP were to be reported according to SMP, emissions from the ten facilities in 2019 would decrease by 12% for SO_2 and 7% for NO_x and TSP. Since emissions in NFR 2H1 are reported according to SMP, it is likely that emissions reported in NFR 1A2d are overestimated despite the already adjusted emission factors in submission 2018. Therefore, emissions reported in NFR 1A2d should be further adjusted in order to better correspond to emissions reported in SMP. This could be done as an annual routine by adjusting the emission factor for wood fuel as it is the fuel combusted the most in sulphate and sulfite plants and could act therefore as a buffer.

Uncertainties

Uncertainties for spent liquor as activity data are estimated based on uncertainties for liquid fuels reported in CRF 1.A.2.d. Since the emission factor for biogenic CO_2 is proposed according to the 2006 IPCC Guidelines, uncertainties are calculated based on the lower and higher limit given for that emission factor. Results are shown in Table 7.

Table 7. Estimated uncertainties for spent liquor as activity data and emission factor for biogenic CO_2.

	Base year 1990 (%)	**Emission year 2019 (%)**
Activity data (spent liquor)	2	5
Emission factor (biogenic CO_2)	15	15

Uncertainties for all other emissions and fuels remain the same since no methodological changes are proposed other than including biogenic CO_2 from spent liquor combustion in the inventory.

Recommendations

Include spent liquor and biogenic CO_2 emissions in the energy sector

In order to make reporting of biogenic CO_2 in the CRF-tables more complete, spent liquor consumption and corresponding biogenic CO_2 emissions should be reported in CRF 1.A.2.d. If, in the future, it is possible to report biogenic CO_2 emissions in CRF 2, allocating biogenic CO_2 from spent liquor combustion to CRF 2.H.1 should be considered. Other emissions from spent liquor combustion ought to be reported in CRF/NFR 2H1 as in submission 2021. Hence, no reallocations of non-CO_2 emissions in the pulp and paper industry would be made.

Annual adjustment of certain pollutants

Due to possibly overestimated emissions of SO_2, NO_x and TSP for later years, emissions reported in NFR 1A2d should be adjusted to match better those reported by the plants to the SMP. Annually, implied emission factors could be calculated for wood fuels based on emissions reported for the steam boiler in SMP. Hence, emission factors for all fuels remain the same except for wood fuels. This could be done for the group of sulphate plants and the group of sulfite plants since adjustments on a plant level are too time consuming. Consequently, reported emissions from all sulphate plant and all sulfite plants in the energy and industrial sector would match emissions reported to SMP. To ensure that these adjustments are correctly performed, applying the cross-sectoral control tool[10], which is to be extended by more gases, could serve as a quality control procedure.

Implications on projections

Projections are calculated for fossil CO_2, CH_4, N_2O, NOx, SO_2, NMVOC, NH_3, $PM_{2.5}$ and BC. The most important process emissions projections, i.e. NOx, $PM_{2.5}$, BC and SO_2 reported in CRF/NFR 2H1 were updated in 2020 (Yaramenka et al. 2020). Since we are recommending that no change is made to emissions reported in CRF/NFR 2H1, these projections will not be affected. For most pollutants, no change of emission projections in CRF/NFR 1A2d will be necessary. However, emissions projections for NOx, SO_2, $PM_{2.5}$ and BC from wood fuels for CRF/NFR 1A2d will have to be adjusted according to the proposed method to annually adjust these

[10] For explanation of the cross-sectoral control tool, see Sweden's NIR, chapter 1.3.5.1

emissions. Calculation of emission factors for projections should therefore be included in the adjustment method.

Suggestions for further work

Alternative estimates of biogenic emissions from spent liquor

Calculated biogenic CO_2 emissions from spent liquor depend on the heating value of the spent liquor, and a higher dry solids content gives a higher heating value. A higher dry solids content is desirable as the combustion will be more efficient and the recovery boiler may be utilized to a higher degree. In general, the dry solids content has increased over the years and is higher nowadays than in the beginning of the 90's. As the dry solids content of black liquor after evaporation can vary from 65 to 85 percent between plants, the heating value can differ substantially and cause emission calculations to be uncertain. An alternative method to using emission factors based on energy content of spent liquor to calculate CO_2 emissions would be to calculate emissions based on the lignin content of the wood raw material. This would require knowledge about total wood quantities that are used in chemical pulping processes.

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