Uncertainties and recalculations of emission inventories submitted under CLRTAP

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1 Summary

Uncertainty information should be part of every emission inventory, however less than half of the Parties to the Convention on Long Range Transboundary Air pollution reported uncertainty estimates in their inventory submission in 2020. This paper analyses three aspects linked to uncertainty of emission inventories submitted under the Convention on Long Range Transboundary Air Pollution: (1) Recalculation and variance of reported data for the year 2005, (2) Linking uncertainty information provided by Parties in the Informative Inventory Reports to recalculations and (3) a comparison of expert data (alternative inventories) and reported data.

The analysis of the recalculations showed that the magnitude of the recalculations (in both absolute and relative terms) varies between the countries and that there appears to be no overall trend in the year-to-year revisions. Collecting the uncertainty estimates from the Informative Inventory Reports showed that the majority of the Parties did not provide uncertainty estimates in the inventory submission 2020 and that the reported uncertainty estimates cover a wide range: (e.g. uncertainty estimates for NO_x ranged from 6.9% (Germany) to 56% (Denmark) in the inventory submission 2020). Comparing data reported by the Parties for the year 2005 and expert estimates showed that most IIASA expert estimates differed less than 25 % to the reported 2005 data. The match between the datasets varied widely between countries.

With the information provided by Parties it is currently not possible to estimate the uncertainty of pollutant emissions in the whole EMEP area. It would be possible to estimate the uncertainty for the whole EMEP area if uncertainty estimates are assigned to the Parties that do not report own uncertainty estimates. The assignment could be based on factors like the variance of recalculations, the difference of reported data to alternative inventories and on a general assessment of the quality of the inventory based on the Informative Inventory Reports.

2 Introduction

All emissions inventories bear uncertainties. Given that emissions inventories form an important basis for air pollution abatement and climate change mitigation, it is important that these uncertainties be estimated. Uncertainty information puts emissions estimates into perspective and helps interpretation in terms of setting reduction targets as well as designing and implementing policies. Furthermore, uncertainty estimates at the source-sector level help to prioritise efforts to improve the accuracy of inventories and guide decisions on methodological choice (IPCC, 2000).

Uncertainty estimates thus *should* be a core part of every national inventory system; however, only a limited number of countries report uncertainty estimates for their air pollutant emissions inventories. As this report details, a large number of Parties to the UNECE Convention on Long-range Transboundary Air Pollution (CLRTAP) do not include uncertainty estimates in their inventory submissions. The availability of uncertainty estimates has increased in recent years although progress has been rather slow. The lack of uncertainty data is perhaps surprising given that the Guidelines for Reporting Emissions and Projections Data under the Convention on Long-range Transboundary Air Pollution (UNECE, 2014) require that "Parties *shall* quantify uncertainties in their emission estimates using the most appropriate methodologies available, taking into account guidance provided in the EMEP/EEA Guidebook" (current version EMEP/EEA, 2019). However, despite this requirement, the same document only recommends that Parties *should* describe these uncertainties in their respective Informative Inventory Reports (IIRs). It should be furthermore noted that only the EMEP Countries are obliged to follow these Guidelines, while the non-EMEP countries (Canada and USA) are *invited* to use and follow these guidelines.

It is thus necessary to utilise various data sources when assessing the uncertainty in emissions reported under CLRTAP. Uncertainty estimates require a thorough understanding of the various data streams into the respective inventory systems and thus are best assessed by the national inventory compilers. If no uncertainty estimate is provided by the Party, it is nonetheless desirable to have a rough uncertainty estimate for the emission estimates being reported under CLRTAP.

This report synthesizes the limited uncertainty information that has been provided by CLRTAP Parties and furthermore assesses uncertainties using data that are independent of formal uncertainty assessments. Specifically, this paper analyses three aspects linked to the uncertainty of emission inventories submitted under the Convention on Long Range Transboundary Air Pollution:

- Recalculation and variance of reported data for the year 2005 as contained in the inventory submissions between 2007 and 2020
- Uncertainty (level uncertainty) information provided by Parties in the Informative Inventory Reports
- A comparison of reported national data with emissions estimates from the independent emissions inventory datasets, EDGAR and GAINS.

3 Selection of Parties

The UNECE Convention on Long Range Transboundary Air Pollution has been ratified by 51 Parties: Albania, Armenia, Austria, Azerbaijan, Belarus, Belgium, Bosnia & Herzegovina, Bulgaria, Canada, Croatia, Cyprus, Czechia, Denmark, Estonia, EU, Finland, France, North Macedonia, Georgia, Germany, Greece, Hungary, Iceland, Ireland, Italy, Kazakhstan, Kyrgyzstan, Latvia, Liechtenstein, Lithuania, Luxembourg, Malta, Monaco, Montenegro, the Netherlands, Norway, Poland, Portugal, Rep. of Moldova, Romania, Russian Federation, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, Ukraine, United Kingdom and the United States.

For the assessments in this report a selection of Parties had to be taken for the various analyses due to the varying extent to which the required information has been reported/is available. The selected Parties are documented in each section.

4 Recalculation and variance of reported data

Recalculations in national emissions inventories (i.e. revisions of emission estimates for years that were previously reported) are caused by combinations of various factors. Recalculations can be due to corrections of errors in the inventory system, improvements in source-sector resolution of the inventory (e.g. change to higher tier methods), implementation of updates of the EMEP/EEA inventory Guidebook (EMEP/EEA 2019), new emission factors from elsewhere as well as inclusions of previously overlooked sources. Recalculations and uncertainty estimates are of course linked in theory; however, in practise they are rather independent of one another, reflecting Parties' respective efforts to improve the national inventory and to formally estimate uncertainties. If for example activity data and emission factors are assumed to be known with a certain uncertainty and the source of the activity data and the emission factors do not change in the submitted reports, this uncertainty will not be reflected in recalculations. Furthermore, certain factors such errors associated with *missing* source categories lead to recalculations are not inherently considered in an uncertainty assessment. Thus the variance calculated from the recalculations cannot be used as a surrogate for uncertainty estimates. However, this variance does shed light on uncertainties, and potentially biases, in reported emissions. Part of this paper is therefore dedicated to analysing how emissions estimates for certain years vary due to recalculations.

The recalculations of NO_x and SO_x emissions reported by selected CLRTAP Parties were investigated by examining the emission estimates for the year 2005 as reported in the inventory submissions between 2007 and 2020.

Summary statistics of the recalculations for 2005 NO_x and SO_x emissions are reported in Table 1 and Table 2, respectively. As the Tables demonstrate, the magnitude of the recalculations (in both absolute and relative terms) varies between the countries. While the coefficients of variation differed between countries (0 to 48.4 % for NO_x, 0 to 61.8 % for SO_x), the range in the reported values generally scaled with the magnitude of the emissions (Figure 1): linear functions of mean 2005 emissions explained 84 and 45 % of the inter-Party variation in the respective ranges in reported NO_x and SO_x emissions for the year 2005. In fact, only Georgia represents an obvious outlier from this trend, due to it's near-zero (< 0.01 kt) standard deviations for both pollutant groups.

As mentioned previously one must be careful in interpreting what such variance means in terms of inventory quality and/or inventory uncertainty. A low variance can be the result of an inventory of high quality where the revision of the inventory does not lead to major changes, or it could equally be the result of a basic inventory system for which substantial improvement efforts have yet to be undertaken. In this paper only the variance of the total NO_x and SO_x emissions was assessed but recalculations are typically made at the level of source categories. Thus it has to be kept in mind that a total that seems rather constant over time may mask several major recalculations which took place in the same year yet had opposing effects on the total.

Table 1: Summary statistics on NOx emissions for the year 2005 as reported in the IIR submissions between 2007 and 2020.

Country	Mean [kt NOx]	Median [kt NOx]	Skewness [-]	Shapiro test [*p* value]	SD [kt NOx]	CV [%]	Min [kt NOx]	Max [kt NOx]	Range [kt NOx]	Range [%]	*n*
Albania	25.1	24.7	2.3	Sig	1.3	5.0	24.7	28.7	4.0	15.8	10
Armenia	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0
Austria	237.3	237.4	-0.8	Sig	4.6	1.9	225.1	246.1	21.1	8.9	14
Azerbaijan	25.0	24.4	1.4	Sig	1.5	5.9	24.4	28.1	3.6	14.5	6
Belarus	166.5	170.9	-0.5	Sig	6.1	3.6	158.6	170.9	12.2	7.3	14
Belgium	302.1	292.4	0.2	Sig	15.4	5.1	284.8	322.1	37.3	12.3	14
Bosnia & Herzegovina	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0
Bulgaria	194.8	185.0	0.1	Sig	32.2	16.5	153.9	233.4	79.6	40.9	14
Canada	2376.1	2379.0	0.7	Sig	43.4	1.8	2327.0	2483.4	156.4	6.6	14
Croatia	81.4	81.4	0.0	n.s.	3.5	4.3	76.6	87.5	10.9	13.4	14
Cyprus	20.6	21.2	-1.5	Sig	1.5	7.2	17.3	22.0	4.7	22.8	14
Czechia	277.2	277.8	-1.4	Sig	1.9	0.7	272.3	279.3	6.9	2.5	14
Denmark	192.1	186.2	0.2	Sig	10.8	5.6	179.7	205.6	25.9	13.5	14
Estonia	37.3	36.6	0.0	Sig	3.7	9.9	32.1	42.1	10.0	26.8	14
EU27+UK	11962.6	11985.9	-0.2	n.s.	251.5	2.1	11611.0	12273.8	662.8	5.5	7
Finland	183.9	177.4	0.6	Sig	15.1	8.2	169.4	207.7	38.3	20.8	14
France	1411.8	1419.9	-2.3	Sig	62.9	4.5	1206.9	1489.2	282.3	20.0	14
Georgia	25.5	25.5	1.7	Sig	0.0	0.0	25.5	25.5	0.0	0.0	13
Germany	1544.4	1573.6	-0.9	Sig	69.1	4.5	1393.2	1641.5	248.3	16.1	14
Greece	400.2	416.6	-0.2	Sig	57.0	14.2	331.6	476.8	145.2	36.3	14
Hungary	187.1	190.3	-0.1	Sig	16.9	9.0	164.9	203.1	38.2	20.4	14
Iceland	26.6	26.1	0.8	Sig	1.4	5.3	25.4	29.1	3.7	14.0	11
Ireland	137.1	128.3	1.0	Sig	18.4	13.4	119.1	170.3	51.2	37.4	14
Italy	1222.0	1224.9	-0.9	Sig	53.4	4.4	1111.6	1291.3	179.6	14.7	14
Kazakhstan	515.7	524.1	NA	NA	NA	NA	488.5	526.3	37.8	7.3	4
Kyrgyzstan	62.8	62.8	NA	NA	0.0	0.0	62.8	62.8	0.0	0.0	12
Latvia	41.5	41.8	-0.5	n.s.	2.7	6.4	37.3	45.2	8.0	19.2	14
Liechtenstein	0.6	0.7	-1.3	Sig	0.1	12.5	0.4	0.7	0.3	40.9	12
Lithuania	59.3	58.1	1.3	Sig	3.4	5.7	54.3	68.5	14.2	23.9	14
Luxembourg	47.1	55.4	-1.0	Sig	20.2	42.9	13.9	62.1	48.2	102.4	12
Malta	10.0	9.3	0.8	Sig	1.2	11.7	9.0	11.9	3.0	29.6	14
Moldova	26.1	31.0	-0.4	Sig	6.4	24.6	16.7	33.4	16.6	63.6	14
Monaco	0.3	0.3	-0.8	Sig	0.0	7.5	0.3	0.4	0.1	28.3	14
Montenegro	7.8	7.5	2.1	Sig	1.0	12.4	7.5	10.4	2.9	37.1	9
Netherlands	356.7	344.2	0.7	Sig	30.0	8.4	323.1	407.5	84.4	23.7	14
North Macedonia	35.5	34.4	1.1	Sig	1.6	4.6	34.4	39.5	5.1	14.4	14
Norway	200.2	199.3	0.5	n.s.	8.3	4.2	186.9	217.4	30.5	15.3	14
Poland	841.3	850.8	-0.3	Sig	24.4	2.9	810.9	869.5	58.6	7.0	14
Portugal	270.8	268.6	0.5	n.s.	14.2	5.3	252.6	297.5	44.9	16.6	14
Romania	317.1	317.0	0.1	n.s.	6.7	2.1	309.1	327.2	18.1	5.7	14
Russia	2795.0	2795.0	NA	NA	0.0	0.0	2795.0	2795.0	0.0	0.0	14
Serbia	127.3	166.4	-0.5	Sig	61.6	48.4	48.1	184.2	136.1	106.9	14

Country	Mean [kt NOx]	Median [kt NOx]	Skewness [-]	Shapiro test [*p* value]	SD [kt NOx]	CV [%]	Min [kt NOx]	Max [kt NOx]	Range [kt NOx]	Range [%]	*n*
Slovakia	103.0	102.6	0.7	n.s.	3.8	3.7	98.0	112.0	13.9	13.5	14
Slovenia	50.4	48.9	0.5	Sig	4.3	8.5	46.3	57.7	11.5	22.7	14
Spain	1436.7	1421.1	0.5	Sig	63.6	4.4	1357.3	1544.6	187.4	13.0	14
Sweden	180.4	179.5	1.9	Sig	8.0	4.5	173.6	204.9	31.3	17.3	14
Switzerland	90.6	92.0	-0.8	Sig	3.9	4.3	83.6	93.9	10.3	11.4	14
Turkey	858.3	876.2	1.0	Sig	204.3	23.8	659.3	1302.8	643.5	75.0	8
Ukraine	513.4	513.4	NA	NA	0.0	0.0	513.4	513.4	0.0	0.0	14
United Kingdom	1640.5	1618.3	0.8	Sig	76.6	4.7	1553.2	1777.3	224.1	13.7	14
United States	17903.0	18380.7	-0.6	Sig	697.5	3.9	16719.5	18456.1	1736.6	9.7	14

Note: Shapiro test [p value]: Sig … significant, n.s. … not significant, NA … not applicable

Table 2: Summary statistics on SOx emissions for the year 2005 as reported in the IIR submissions between 2007 and 2020.

Country	Mean [kt SOx]	Median [kt SOx]	Skewness [-]	Shapiro test [*p* value]	SD [kt SOx]	CV [%]	Min [kt SOx]	Max [kt SOx]	Range [kt SOx]	Range [%]	*n*
Albania	34.9	34.4	2.3	Sig	1.5	4.3	34.4	39.1	4.7	13.6	10
Armenia	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0
Austria	26.6	26.7	-0.3	n.s.	0.7	2.5	25.5	27.5	2.1	7.8	14
Azerbaijan	6.2	4.6	1.4	Sig	3.8	61.8	4.6	14.0	9.4	151.3	6
Belarus	78.6	79.5	-0.5	Sig	1.2	1.6	77.0	79.5	2.5	3.2	14
Belgium	144.0	143.9	0.2	n.s.	1.4	0.9	142.1	146.6	4.4	3.1	14
Bosnia & Herzegovina	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	0
Bulgaria	821.5	778.8	0.5	Sig	61.0	7.4	776.3	900.3	124.0	15.1	14
Canada	2132.4	2127.8	-0.1	n.s.	49.4	2.3	2066.0	2200.4	134.4	6.3	14
Croatia	61.8	63.5	-0.2	Sig	3.0	4.8	58.0	64.8	6.8	11.0	14
Cyprus	38.5	37.9	0.7	Sig	2.2	5.7	35.5	42.5	6.9	18.0	14
Czechia	214.2	218.6	-0.3	Sig	5.4	2.5	207.7	218.6	10.9	5.1	14
Denmark	24.3	24.5	-0.1	Sig	1.8	7.5	21.8	26.3	4.5	18.4	14
Estonia	76.5	76.3	1.2	Sig	0.4	0.5	76.2	77.2	1.0	1.3	14
EU27+UK	7687.7	7698.8	-0.4	n.s.	40.7	0.5	7621.3	7733.0	111.7	1.5	7
Finland	69.3	69.2	0.5	Sig	0.2	0.3	69.2	69.6	0.5	0.7	14
France	465.7	462.8	1.1	Sig	9.5	2.0	454.7	486.0	31.3	6.7	14
Georgia	9.7	9.7	-1.7	Sig	0.0	0.0	9.7	9.7	0.0	0.0	13
Germany	500.0	477.2	0.7	Sig	37.1	7.4	460.5	573.5	113.0	22.6	14
Greece	546.0	544.9	2.0	Sig	7.9	1.4	537.9	570.4	32.6	6.0	14
Hungary	85.6	86.1	0.0	Sig	45.2	52.8	41.2	129.2	88.0	102.8	14
Iceland	39.7	39.3	0.8	Sig	1.6	3.9	38.3	42.5	4.3	10.7	11
Ireland	71.9	71.4	0.3	n.s.	1.4	2.0	69.9	74.0	4.1	5.7	14
Italy	406.6	406.9	0.7	n.s.	4.3	1.1	401.1	417.3	16.3	4.0	14
Kazakhstan	1249.1	1485.4	NA	NA	NA	NA	540.2	1485.4	945.2	75.7	4
Kyrgyzstan	25.9	25.9	NA	NA	0.0	0.0	25.9	25.9	0.0	0.0	12
Latvia	6.6	6.6	-0.3	n.s.	1.9	28.6	3.6	8.8	5.3	80.0	14
Liechtenstein	0.0	0.0	0.7	Sig	0.0	10.3	0.0	0.0	0.0	26.8	12
Lithuania	37.7	43.4	-0.3	Sig	7.8	20.7	26.4	47.3	20.9	55.3	14

Country	Mean [kt SOx]	Median [kt SOx]	Skewness [-]	Shapiro test [*p* value]	SD [kt SOx]	CV [%]	Min [kt SOx]	Max [kt SOx]	Range [kt SOx]	Range [%]	*n*
Luxembourg	2.2	2.4	-1.0	Sig	0.4	20.1	1.5	2.6	1.1	49.2	12
Malta	13.3	12.0	0.8	Sig	2.7	20.2	11.4	18.0	6.6	49.8	14
Moldova	9.3	10.0	-0.1	Sig	3.7	39.4	4.7	12.7	7.9	85.7	14
Monaco	0.1	0.1	-1.7	Sig	0.0	11.3	0.0	0.1	0.0	36.8	14
Montenegro	13.3	12.5	2.1	Sig	2.5	18.7	12.5	20.0	7.5	56.2	9
Netherlands	64.9	64.5	0.4	Sig	1.4	2.2	62.3	67.2	5.0	7.7	14
North Macedonia	99.4	100.6	-0.6	Sig	1.8	1.8	96.6	100.6	4.1	4.1	14
Norway	23.9	24.0	-1.6	Sig	0.2	1.0	23.2	24.1	0.8	3.5	14
Poland	1205.6	1221.9	-0.9	Sig	33.3	2.8	1132.3	1246.4	114.1	9.5	14
Portugal	181.9	184.5	-2.0	Sig	29.6	16.3	89.3	214.9	125.6	69.1	14
Romania	672.0	642.6	0.9	Sig	92.3	13.7	601.2	830.7	229.5	34.2	14
Russia	1847.0	1847.0	NA	NA	0.0	0.0	1847.0	1847.0	0.0	0.0	14
Serbia	376.9	375.1	-0.8	Sig	67.8	18.0	249.2	446.0	196.8	52.2	14
Slovakia	88.8	89.0	0.1	Sig	1.5	1.7	86.0	92.5	6.5	7.3	14
Slovenia	40.7	40.7	0.1	n.s.	0.5	1.3	39.9	41.8	1.9	4.6	14
Spain	1265.4	1273.3	-0.2	n.s.	36.8	2.9	1205.4	1325.6	120.2	9.5	14
Sweden	36.6	36.0	1.5	Sig	1.3	3.7	35.7	39.7	4.0	10.9	14
Switzerland	16.1	16.3	-0.2	n.s.	1.3	7.9	13.9	18.1	4.2	26.1	14
Turkey	2054.4	2054.6	0.0	Sig	54.5	2.7	2002.8	2106.0	103.2	5.0	8
Ukraine	1192.4	1192.4	NA	NA	0.0	0.0	1192.4	1192.4	0.0	0.0	14
United Kingdom	716.5	707.4	1.0	Sig	31.7	4.4	686.9	773.0	86.0	12.0	14
United States	13338.4	13145.2	1.5	Sig	335.7	2.5	13113.9	14093.9	980.0	7.3	14

Note: Shapiro test [p value]: Sig … significant, n.s. … not significant, NA … not applicable

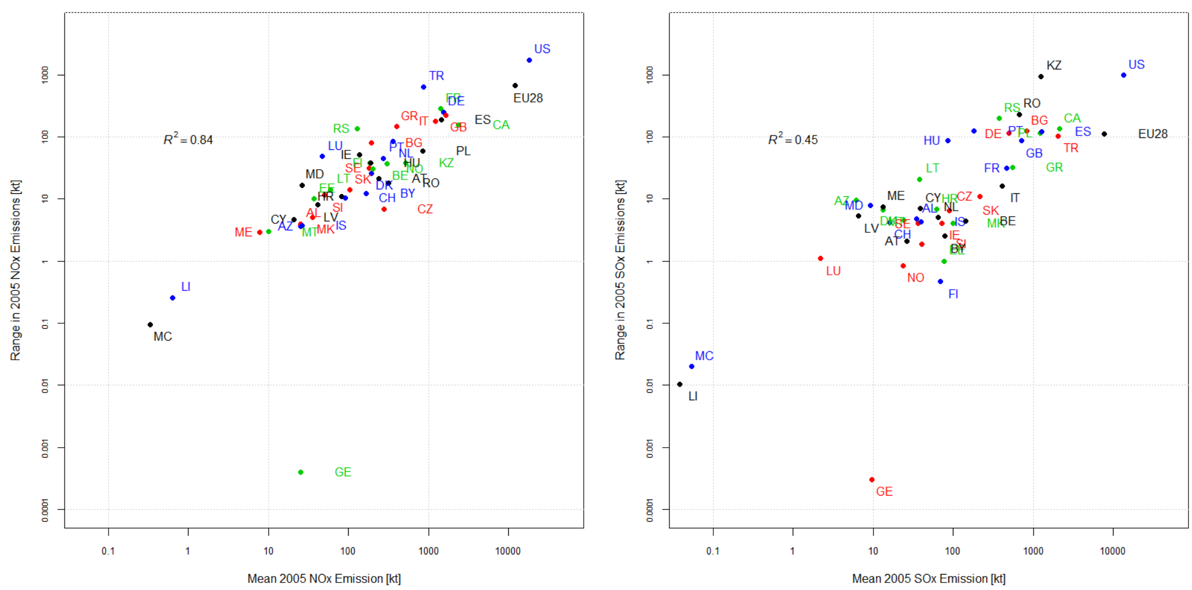

Figure 1: Scatter plots show dependency of the respective ranges in recalculations of 2005 national total emissions reported between 2007 and 2020 on the mean 2005 NO_x (left) and SO_x (right) emissions. In the top-left corner of each panel the coefficient of determination of the respective linear relationship is reported.

When looking at the recalculated 2005 emissions relative to the respective mean of all estimates reported between 2007 and 2020, a variety of patterns can be seen. Overall, slight overall trends emerge: When plotted over one another, it seems that over the reporting period 2007-2020, 2005 NO_x emissions have been revised upwards, while SO_x emissions have been revised downwards (Figure 2). Nonetheless, a number of Parties show diverging trends from these overall patterns and furthermore some Parties 2005 emissions estimates have been subject to significant recalculations between reporting years. The respective trends for each Party are plotted separately in Figure A 1 and Figure A 2. Some countries display a progressive increase in the recalculated emissions (e.g. Denmark, SO_x), while some show substantial step-wise increases every few years (e.g. Latvia, SO_x). A number of counties demonstrate an initial revision(s) downwards (Germany, SO_x) or upwards (France, NO_x), followed by subsequently stability. In contrast, NO_x emissions for Finland were rather stable for the first part of the period yet for the most recent years, the emissions were revised upwards. Finally, examples exist of year-to-year variations without a trend in an upward or downward direction (e.g. Austria and Romania, NO_x; Slovenia and Spain, SO_x) or only marginal year-to-year variations (e.g. Estonia and Finland SO_x). For Ukraine and Russia, despite reporting in all years, neither SO_x nor NO_x emissions have been revised at any point.

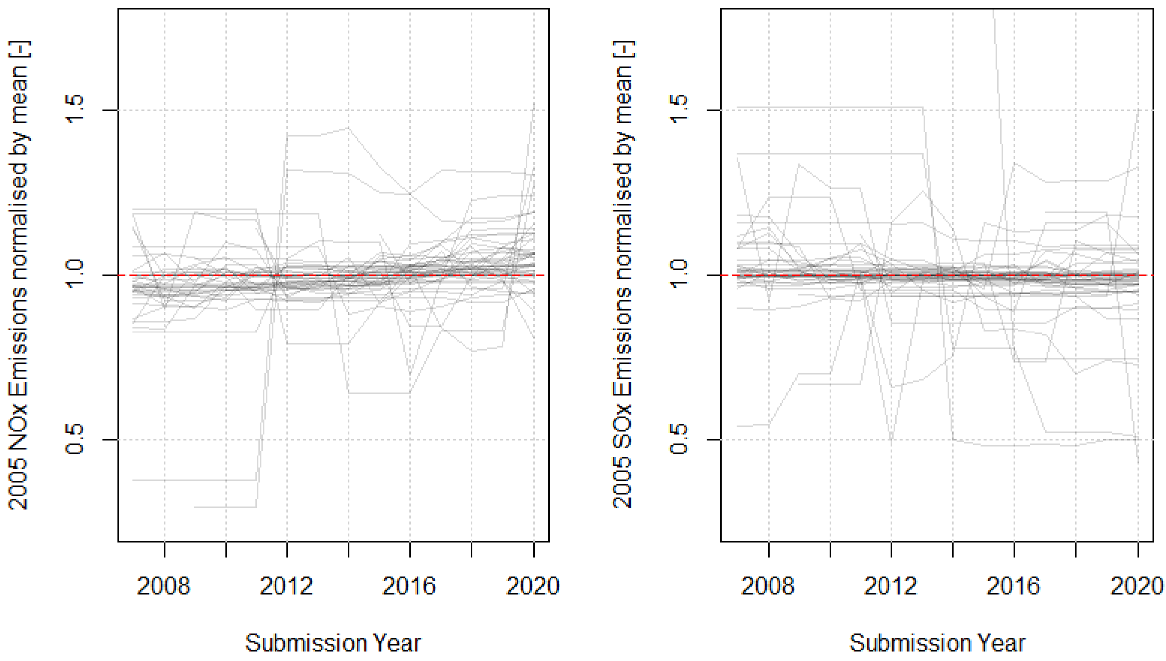

Figure 2: Time series of 2005 NO_x (left) and SO_x (right) emissions reported by Parties between 2007 and 2020. Note each estimate of each Party has been normalised by the respective mean value of all estimates reported by the respective Party over the 2007-2020 reporting period. Each line represents an individual CLRTAP Party.

Datasets such as recalculated emissions are likely to be inherently auto-correlated – a recalculation in the next submission is likely to be more similar to the previous/subsequent submission than a recalculated value further in the past/future. Of course, as demonstrated in Figure 2, sharp changes between submissions do occur (e.g. Turkey, Serbia and Luxembourg for NO_x Figure A 1; Hungary, Portugal and Kazakhstan for SO_x Figure A 2). Nonetheless, in most cases the emissions reported for a certain year in a specific submission were similar to the respective estimate in the previous and/or subsequent submission.

As the histograms in Figure 3 demonstrate, the relative yearly changes (expressed as a percentage relative to the preceding submission) were generally low often lying within ±5 %. The shape of these histograms, which include all submissions data from all available Parties, indicates that small adjustments of inventories occur often, while fundamental revisions causing increases or decreases of >5 % are rarer events, with absolute changes > 10 % rarer still. Separate histograms for each CLRTAP Party have also been generated and can be seen in Figure A 3 and Figure A 4.

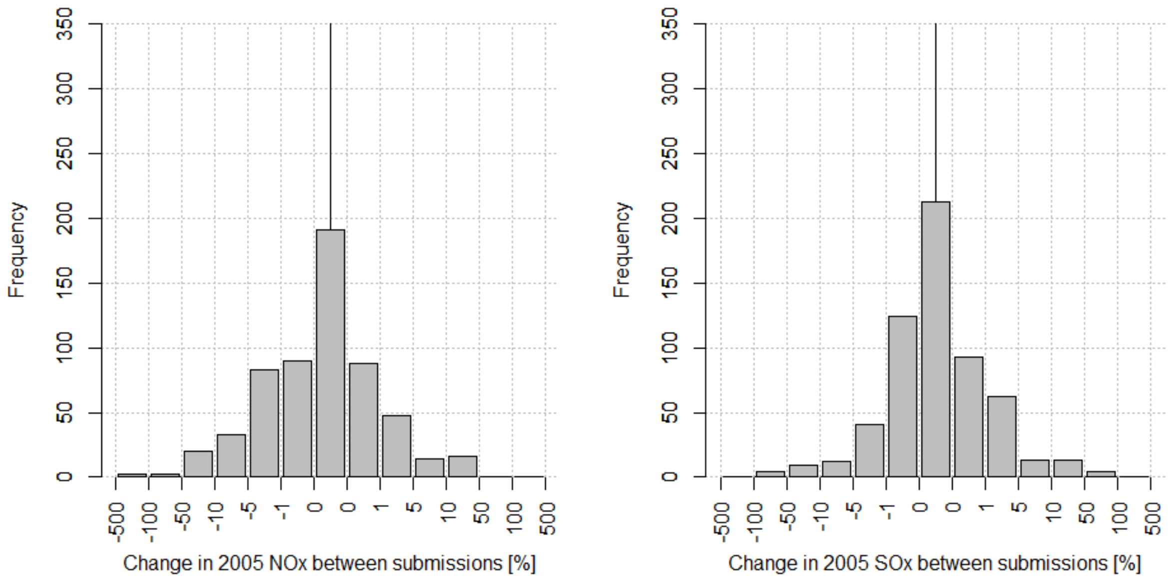

Figure 3: Histograms showing the distribution in relative submission-to-submission deviations in 2005 NO_x (left) and SO_x (right) emissions due to recalculations over the period between 2007 and 2020. The bins reflect relative changes as expressed as percentage of the respective previous submission value. In most cases, these reflect year to year changes; however, for Parties where annual submissions are not always available, the change is relative to the last previous submission.

5 Uncertainty according to Informative Inventory Reports

According to the "Guidelines for Reporting Emissions and Projections Data under the Convention on Long-range Transboundary Air Pollution" (UNECE, 2014) Parties shall quantify uncertainties in their emission estimates using the most appropriate methodologies available, taking into account guidance provided in the EMEP/EEA Guidebook (EMEP/EEA, 2019). Uncertainty estimates provided by the Parties is the primary source of uncertainty information and these estimates should be the result of a comprehensive uncertainty analysis of the inventory system. In this chapter we give an overview on the uncertainty information provided by Parties and put it into perspective by comparing the information to recalculations.

All available Informative Inventory Reports[1] for the year 2020 were reviewed to extract the uncertainty estimates, where available. In most cases uncertainty estimates were provided for the last reported year (i.e. 2018). The uncertainty estimates were listed in a table and the uncertainty estimates were applied to 2005 data (using the value reported for 2005 in the inventory submission 2020 or the last reported value for 2005) to calculate a lower and an upper bound of emissions for 2005 (Table 3 and Table 4). For comparison also the lowest and the highest value reported for 2005 emissions are given in the table. If these values are outside the lower or upper bound emission values were shaded (grey).

Collecting the uncertainty estimates from the Informative Inventory Reports showed that the majority of the Parties did not provide uncertainty estimates in the inventory submission 2020: 20 of the 47 analysed Parties provided quantitative uncertainty estimates of national total NO_x and SO_x emissions (Table 3 and Table 4). Many Parties indicated the provision of uncertainty estimates under the planned improvements and promise it for future inventory cycles. However, experience shows that these announcements were reiterated for several years until an uncertainty estimate was provided. But still the announcements show that Parties were aware that uncertainty estimates were an important area for improvement. The reported uncertainty estimates range from 6.9% (Germany) to 56% (Denmark) for NO_x and from 5% (Finland) to 39% (Denmark) for SO_x Table 3 and Table 4). Six Parties (Belgium, Cyprus, Denmark, Greece, Ireland and Sweden) reported uncertainty estimates of more than 20% for NO_x and two Parties for SO_x (Denmark and Croatia). For eight Parties (Germany (MC[2]), Estonia, Finland, Latvia, the Netherlands, Norway, the Republic of Moldova and the United Kingdom) the lowest reported national total NO_x emissions were lower than the lower bound calculated from the uncertainty estimates (Table 3). For one Party (Latvia) the lowest reported national total SO_x emissions were lower than the lower bound calculated from the uncertainty estimates. For three Parties (Germany (EP[3], MC), the Republic of Moldova and Switzerland) the highest reported national total SO_x emissions were higher than the upper bound calculated from the uncertainty estimates. For three Parties (Austria, Latvia and Sweden) it was identical (Table 4). The wide range of uncertainty estimates showed that uncertainty varied considerably between Parties. Part of this variation might be due to too optimistic and too pessimistic uncertainty estimates but also reflects real differences in the accuracy of inventories. It has to be considered here that the uncertainty ranges are usually given for

[1] For this analysis, all 51 Parties except the EU were analysed. Four Parties (Belarus, Canada and Turkey that provided an inventory did not provide an Informative Inventory Report in 2020). All available Informative Inventory Reports were downloaded at https://www.ceip.at/status-of-reporting-and-review-results/2020-submissions

[2] MC … Monte Carlo simulation (Tier 2)

[3] EP … error propagation (Tier 1)

the last reported year (usually 2018) and might not apply to emissions for 2005. Further the table only lists the uncertainties reported in the 2020 submission while the recalculations include data reported between 2007 and 2020.

No conclusions for the whole EMEP area can be drawn from the provided uncertainty estimates. Among the Parties that do not provide an uncertainty estimate there might be several Parties that do not have the resources/possibilities to provide an inventory with an average accuracy and among the Parties that have provided uncertainty estimates Parties with rather accurate inventories might be overrepresented.

Table 3: Uncertainty estimates for total NO_x emissions as submitted in the Informative Inventory Reports 2020

Party Name	Uncertainty estimate for total NO_X emissions in % according to IIR [%]	Year for which uncertainty was estimated	National Total 2005 NO_X emissions reported in latest available year [kt]	Lower bound calculated from the uncertainty estimates [kt]	Upper bound calculated from the uncertainty estimates [kt]	Lowest reported National Total 2005 NO_X emissions [kt]	Highest reported National Total 2005 NO_X emissions [kt]
Austria	18.6	2018	246	200	292	225	246
Belgium	25.88	2018	322	239	406	285	322
Croatia	18.58	2018	86	70	102	77	87
Cyprus	41.4	2018	22	13	31	17	22
Denmark	56	2018	205	90	319	180	206
Estonia	12.96	2018	42	37	48	32	42
Finland	-11, 11	2016	208	185	231	169	208
France	19.8	2018	1420	1139	1701	1207	1489
Germany	17.97	2018	1641	1346	1936	1393	1641
Germany	-6.88, 8.34	2018	1641	1529	1778	1393	1641
Greece	34.68	2018	477	311	642	332	477
Ireland	44.5	2018	170	95	246	119	170
Latvia	10.75	2018	44	39	49	37	45
Netherlands	17	2018	407	338	477	323	408
North Macedonia	17.8	2018	40	32	47	34	40
Norway	12	2010	214	188	239	187	217
Republic of Moldova	18.85	2018	33	27	40	17	33
Spain	15.5	2018	1357	1147	1568	1357	1545
Sweden	27.32	2018	182	132	231	174	205
Switzerland	14	2018	94	81	107	84	94
United Kingdom	8.1	2018	1770	1626	1913	1553	1777

Notes: Shaded cells indicate that the lowest or highest reported national total for 2005 lies below/above the lower/upper bound.
Poland has only reported trend uncertainties, hence this values are not included here.

Table 4: Uncertainty estimates for total SOx emissions as submitted in the Informative Inventory Reports 2020

Party Name	Uncertainty estimate for total SO_X emissions in % according to IIR [%]	Year for which uncertainty was estimated	National Total 2005 SO_X emissions reported in latest available year [kt]	Lower bound calculated from the uncertainty estimates [kt]	Upper bound calculated from the uncertainty estimates [kt]	Lowest reported National Total 2005 SO_X emissions [kt]	Highest reported National Total 2005 SO_X emissions [kt]
Austria	6.6	2018	26	24	28	25	28
Belgium	17.19	2018	143	119	168	142	147
Croatia	20.19	2018	59	47	70	58	65
Cyprus	14.31	2018	38	32	43	36	42
Denmark	39	2018	26	16	37	22	26
Estonia	7.98	2018	76	70	82	76	77
Finland	-5, 5	2016	70	66	73	69	70
France	14.3	2018	458	392	523	455	486
Germany	9.36	2018	477	433	522	460	574
Germany	-7.61, 7.91	2018	477	441	515	460	574
Greece	14.1	2018	550	472	627	538	570
Ireland	11.6	2018	73	65	82	70	74
Latvia	6.23	2018	9	8	9	4	9
Netherlands	20	2018	67	54	81	62	67
North Macedonia	19.2	2018	97	78	115	97	101
Norway	5	2010	23	22	24	23	24
Republic of Moldova	11.37	2018	5	4	5	5	13
Spain	17.1	2018	1206	999	1412	1205	1326
Sweden	8.04	2018	37	34	40	36	40
Switzerland	7	2018	14	13	15	14	18
United Kingdom	17.7	2018	773	636	910	687	773

Notes: Shaded cells indicate that the lowest or highest reported national total for 2005 lies below/above the lower/upper bound.
Poland has only reported trend uncertainties hence this values are not included here.

6 Comparison: Expert data and reported data

"Parties that have obligations to report emission inventories of substances listed in paragraph 7 of these Guidelines under protocols that they have ratified and that are in force shall annually report emission inventories of those substances…" reads the respective text in the UNECE Reporting Guidelines (UNECE 2014). Most Parties report emission inventories (Figure 4), however these emission inventories are sometimes not complete e.g. not covering all pollutants, not all years or not all source categories. In addition to these emission inventories provided by Parties, alternative inventories of expert institutions exist e.g. data from the GAINS model (Greenhouse Gas and Air Pollution Interactions and Synergies), Amann et al. 2011) and the EDGAR v5.0 dataset (Crippa et al. 2019).

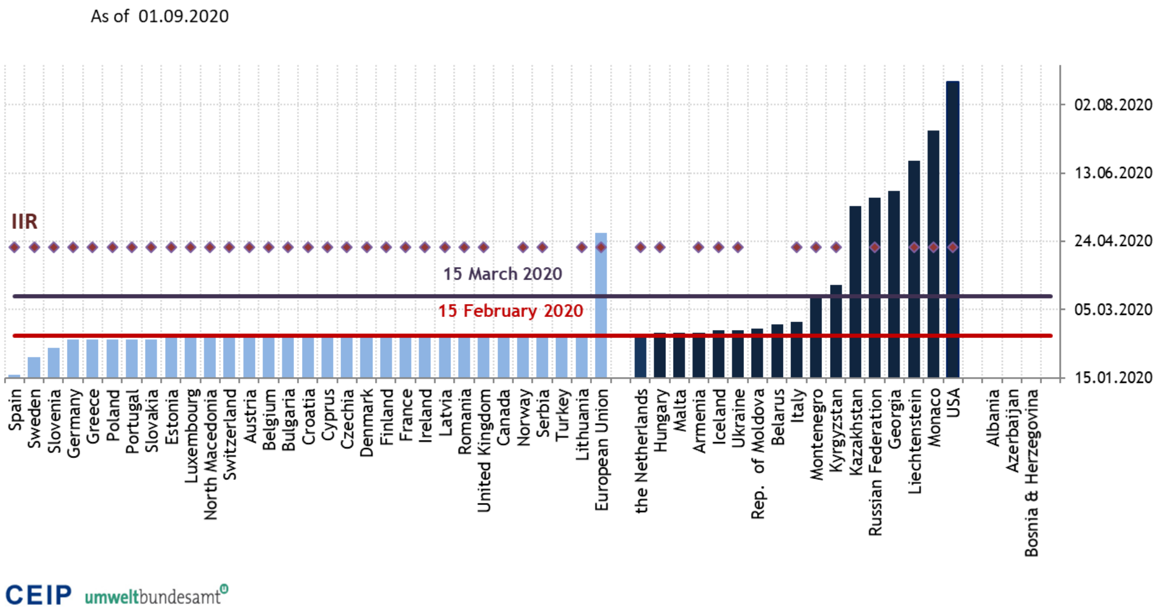

Figure 4: Timeliness of Reporting for inventory submission 2020, Source: CEIP (www.ceip.at, accessed 22.01.2021)

To assess emission uncertainties by comparison of Convention data with emission data from other sources the following data sets were used:

- Most recently reported emission inventories submitted under CLRTAP by the Parties
- GAINS data: Data from the GAINS model (Greenhouse Gas and Air Pollution Interactions and Synergies) (Amann et al. 2011) were provided by the International Institute for Applied Systems Analysis (IIASA)[4]. The GAINs dataset used was an advance version of the forthcoming Eclipse v6 dataset that is due to be published soon[5].
- EDGAR data: Global Emissions EDGAR v5.0 from January 2016 (Crippa et al. 2019)[6]. EDGARv5.0 relies on international energy balances of IEA, agricultural statistics of FAO and regional or national information and assumptions on technology use and emission control standards. The

[4] See http://www.iiasa.ac.at/web/home/research/researchPrograms/air/GAINS.html
[5] https://iiasa.ac.at/web/home/research/researchPrograms/air/Global_emissions.html
[6] The data was downloaded from https://edgar.jrc.ec.europa.eu/overview.php?v=50_AP in December 2020

EDGAR data sets are calculated using a consistent bottom-up approach with full time series of the activity data and allow straightforward implementation of scenario assumptions.

Comparing data reported by the Parties for the year 2005 and expert estimates showed that most expert estimates differed less than 25 % to the reported 2005 data[7]. 82 % of the NO_x and SO_x estimates from IIASA (i.e. differed less than 25 %) to the reported data (Table 5 and Figure 5) . 64% (NO_x) and 75 % (SO_x) of the estimates differed only up to 10 % from the reported data sets. EDGAR data, especially for SOx, differed strongly to reported data. For example 61 % of the SO_x estimates from EDGAR differ more than 25 % to the reported data (Table 5).

Table 5: Comparison of reported data and expert estimates

2005 data	**Percentage of data sets**			
	IIASA		EDGAR	
	NO_x	SO_x	NO_x	SO_x
up to 10% difference to reported data	64%	75%	36%	11%
up to 20% difference to reported data	80%	82%	61%	27%
up to 25% difference to reported data	82%	82%	70%	39%

The degree of agreement between the datasets varied from country to country (Figure 5 and Figure 6). Iceland, Kyrgyzstan, Azerbaijan and the Ukraine for NO_x, and Norway, Iceland, Sweden, Azerbaijan and Hungary for SO_x are examples that showed a very high difference between expert estimates and data reported by the Party.

[7] For the comparison with expert estimates, data from 43 countries were compared. Data from Canada and the EU, as well as data from Armenia, Bosnia & Herzegovina, Liechtenstein, Montenegro and Monaco were not considered as emission data or expert data were not available.

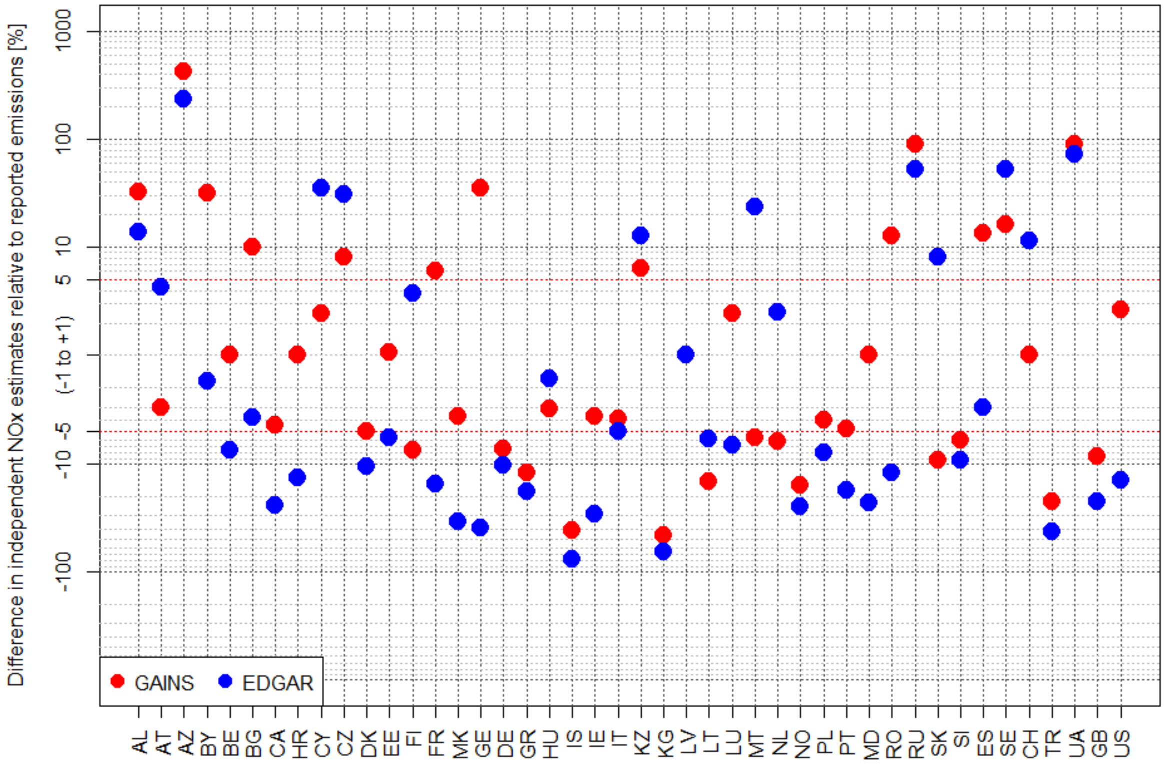

Figure 5: Difference of expert estimates and data reported by the Parties for the year 2005 (NO_x emissions)

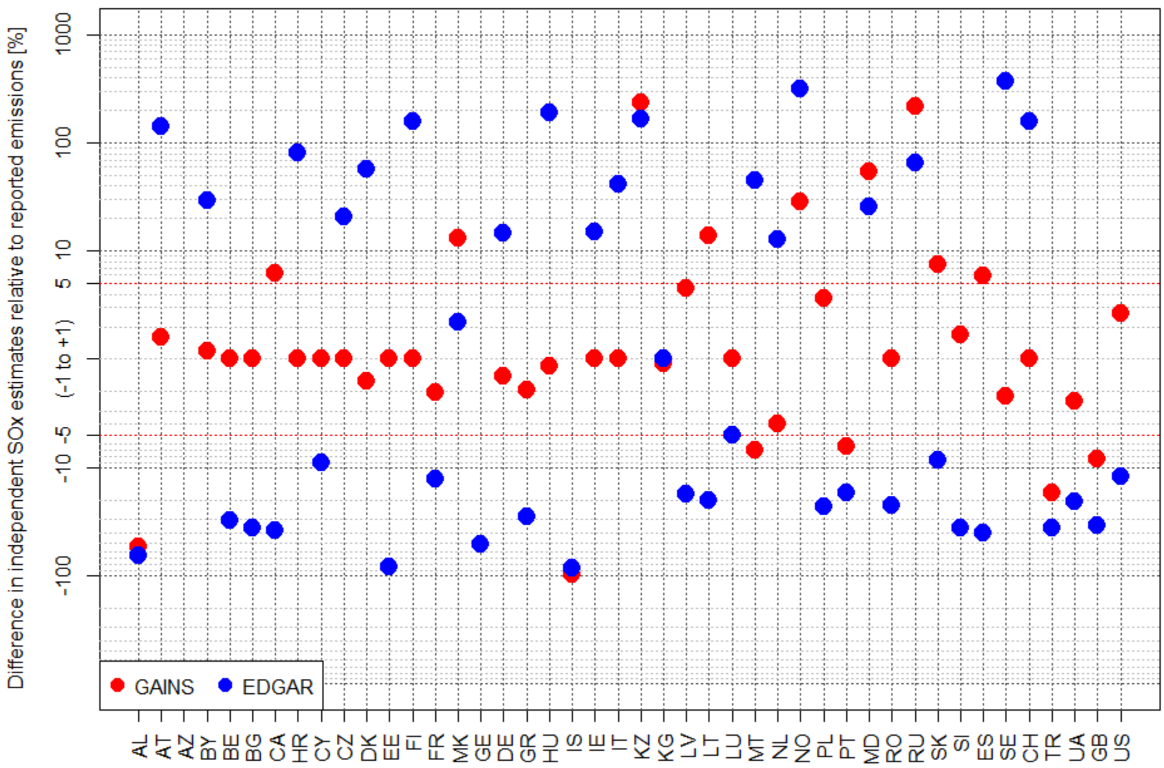

Figure 6: Difference of expert estimates and data reported by the Parties for the year 2005 (SO_x emissions). Note: differences for AZ are >1000% and are thus not visible in the graph.

Results show, that NO_x estimates from IIASA were very similar to the reported data, and nearly the same results have been achieved for the SO_x estimates. However, EDGAR data, especially for SO_x, differed strongly to the reported data. The size of the differences varied between Parties. For some Parties, expert estimates were close to the reported data, but others showed high or even very high differences. For these Parties (e.g. Azerbaijan, Kazakhstan), an analysis at the source sector level against expert estimates especially from IIASA could be helpful to improve their inventories.

Here it has to be kept in mind that the compared datasets are not really independent datasets, the alternative inventories are partly based on data reported by Parties and partly based on independent estimates and in some cases one alternative inventory uses another alternative inventory for gap-filling. For a robust assessment of the differences between the alternative inventories, the activity and emission factor datasets used by these inventories need to be considered as part of the analysis.

7 Conclusion

Uncertainty estimation is still a topic that receives too little attention in the Informative Inventory Reports of many Parties. Comparing data reported by the Parties for the year 2005 and expert estimates (alternative inventories) showed that most IIASA expert estimates mostly differed less than 25 % to the reported 2005 data. With the information provided by Parties it is currently not possible to estimate the uncertainty of pollutant emissions in the whole EMEP area. It would be possible to estimate the uncertainty for the whole EMEP area if uncertainty estimates are assigned to the Parties that do not report own uncertainty estimates. The assignment could be based on factors like the variance of recalculations, the difference of reported data to alternative inventories and on a general assessment of the quality of the inventory based on the Informative Inventory Reports.

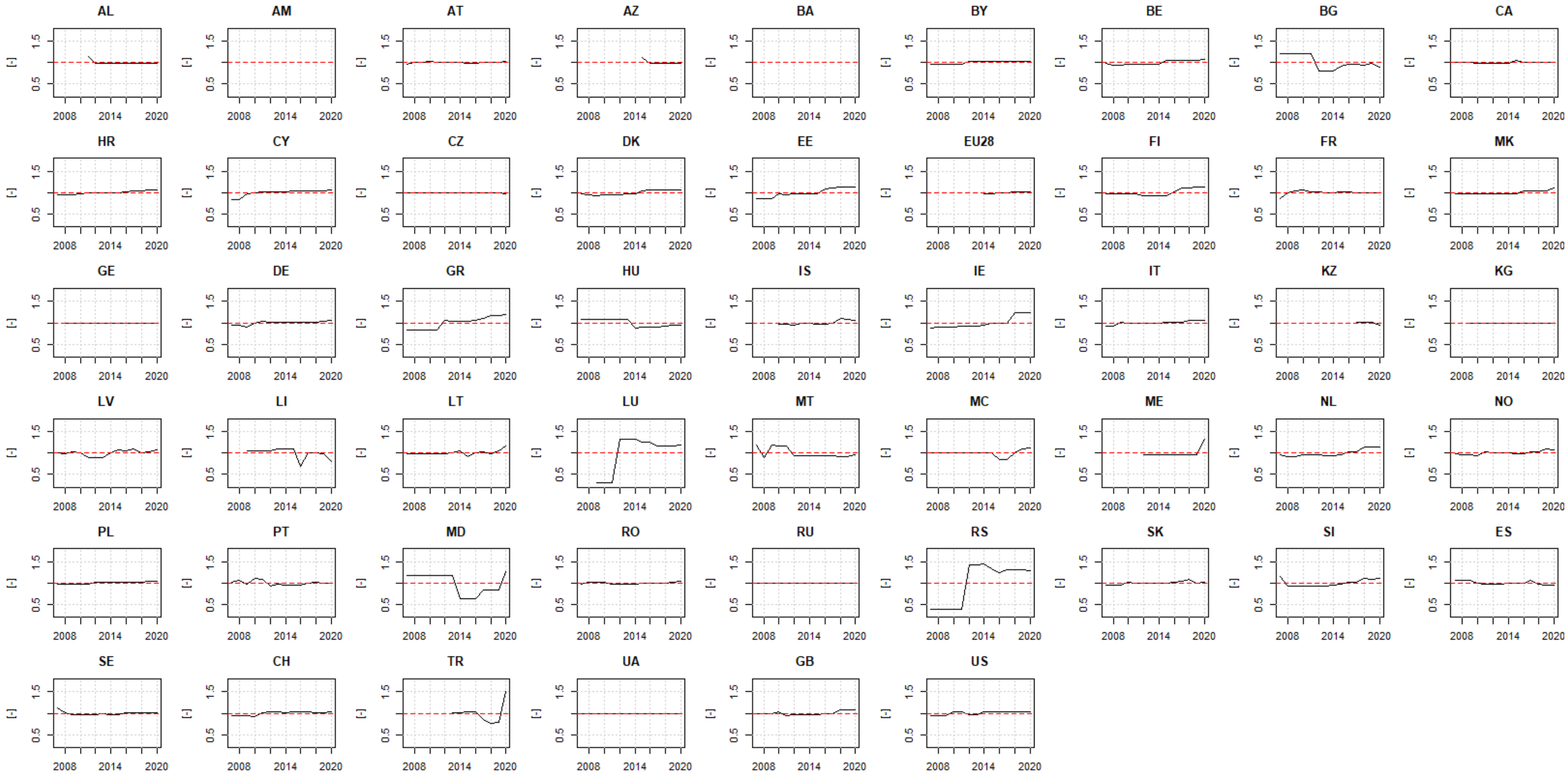

Figure A 1: Time series of 2005 NO_x emissions reported by Parties between 2007 and 2020. Note each estimate of each Party has been normalised by the respective mean value of all estimates reported by the respective Party over the 2007-2020 reporting period. Each panel represents the trend for each individual CLRTAP Party. Note that for certain Parties parts of- or the complete trend is missing due to incomplete reporting over the 2007-2020 period.

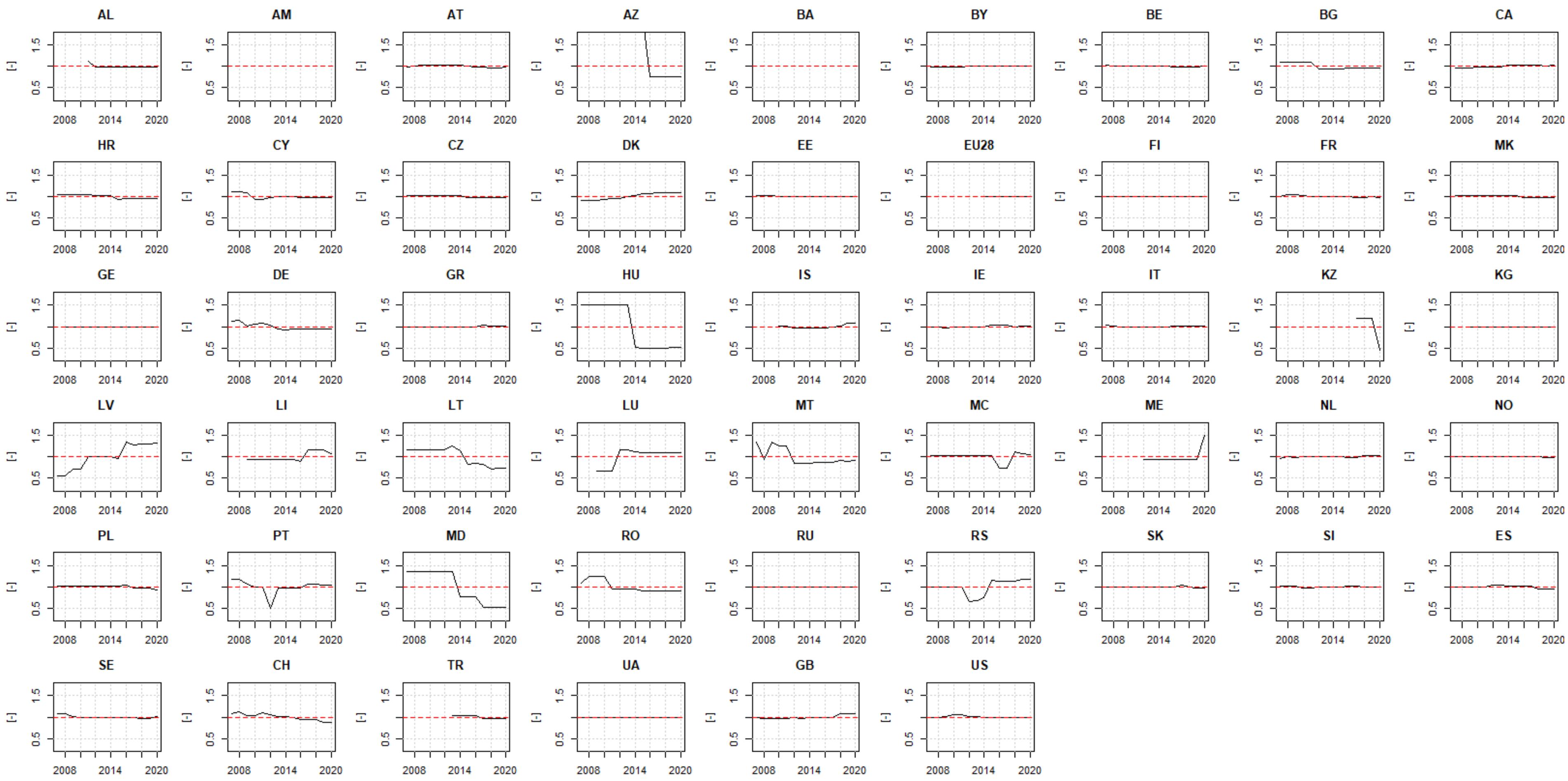

Figure A 2: Time series of 2005 SO_x emissions reported by Parties between 2007 and 2020. Note each estimate of each Party has been normalised by the respective mean value of all estimates reported by the respective Party over the 2007-2020 reporting period. Each panel represents the trend for each individual CLRTAP Party. Note that for certain Parties parts of- or the complete trend is missing due to incomplete reporting over the 2007-2020 period.

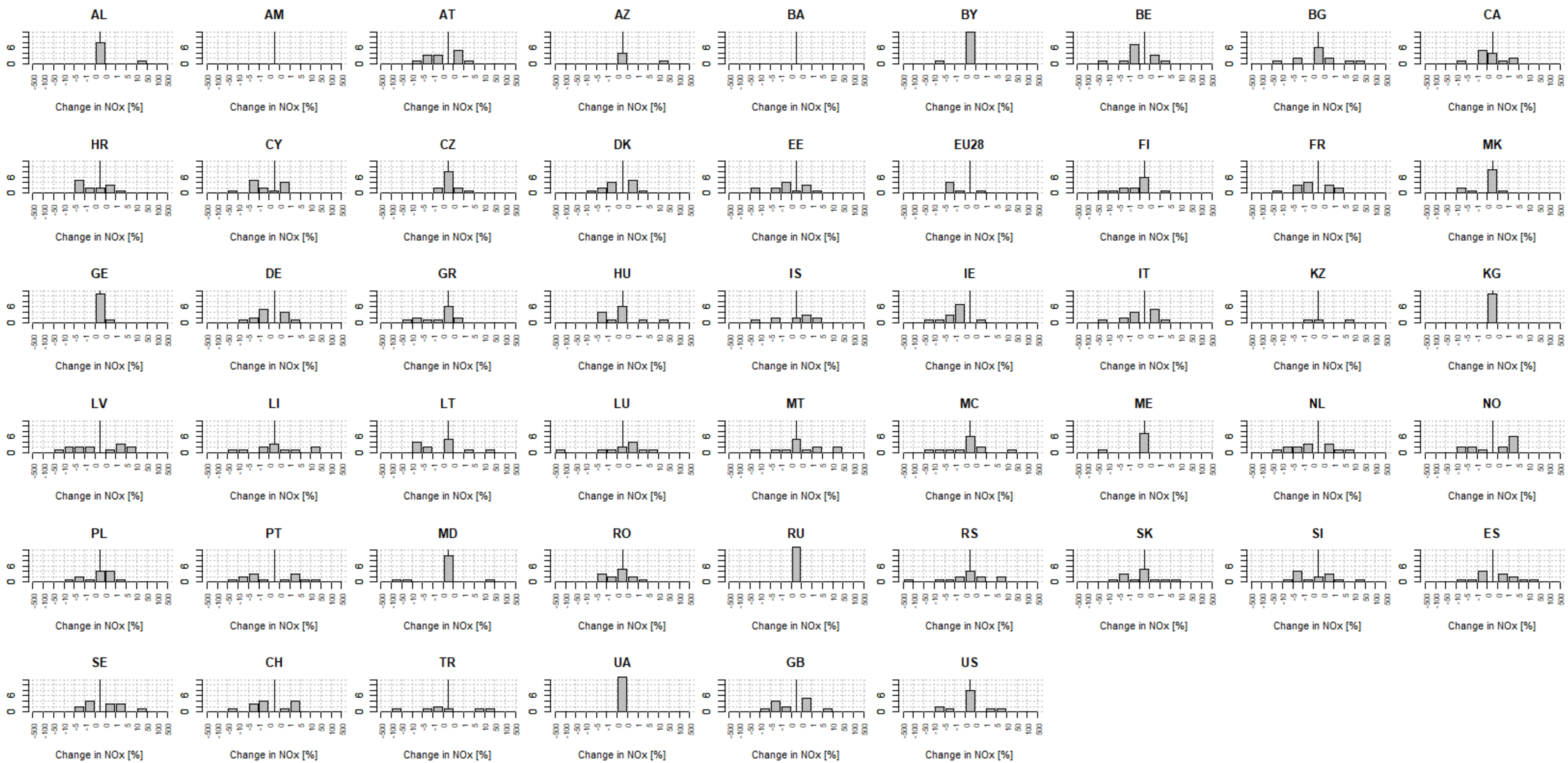

Figure A 3: Histograms showing the distribution in relative submission-to-submission deviations in 2005 NO_x emissions due to recalculations over the period between 2007 and 2020. The bins reflect relative changes as expressed as percentage of the respective previous submission value. In most cases, these reflect year to year changes; however, for Parties where annual submissions are not always available, the change is relative to the last previous submission. Each panel is a separate histogram for each CLRTAP Party.

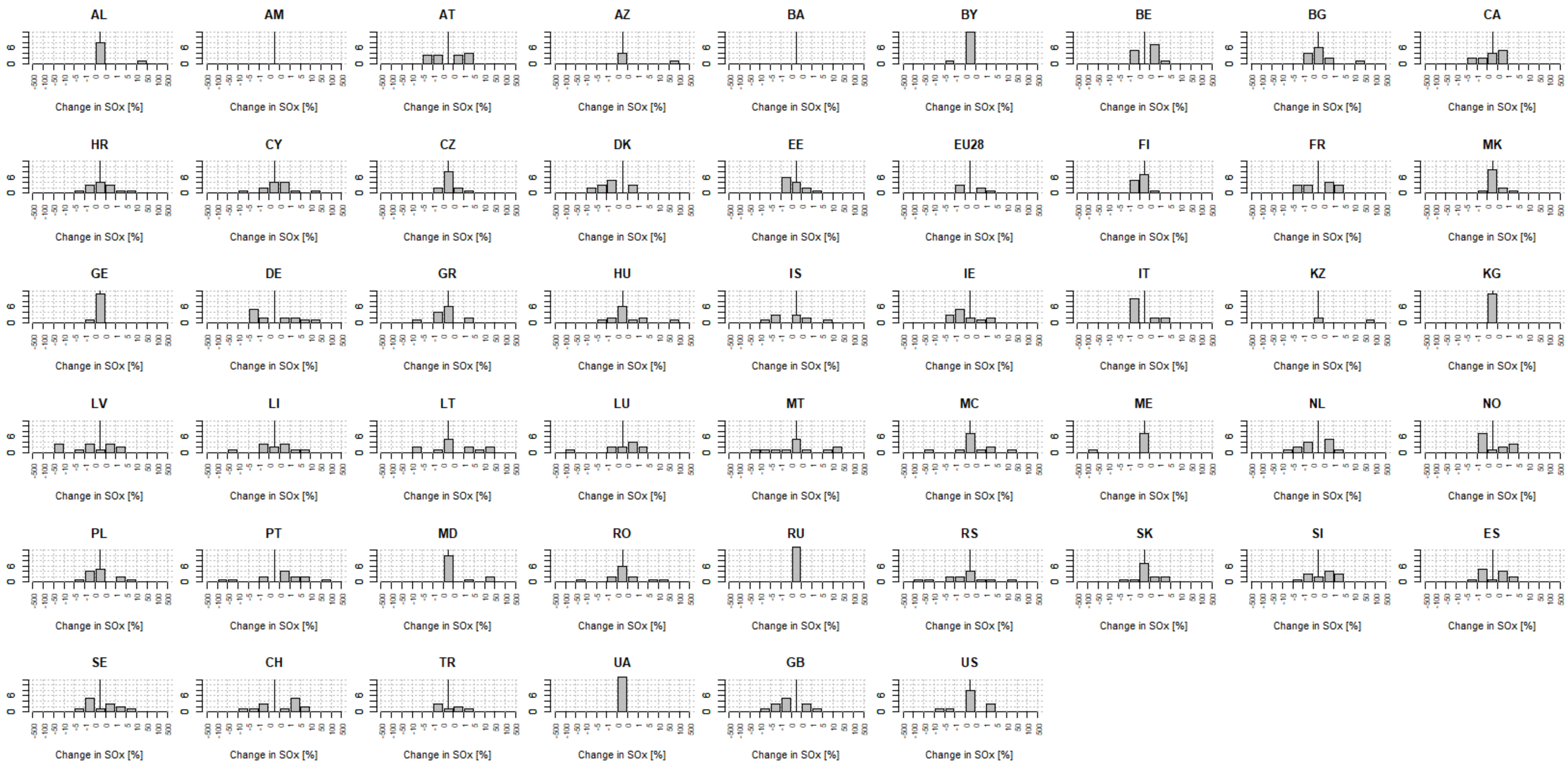

Figure A 4: Histograms showing the distribution in relative submission-to-submission deviations in 2005 SO_x emissions due to recalculations over the period between 2007 and 2020. The bins reflect relative changes as expressed as percentage of the respective previous submission value. In most cases, these reflect year to year changes; however, for Parties where annual submissions are not always available, the change is relative to the last previous submission. Each panel is a separate histogram for each CLRTAP Party.

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