Environment Canada Environnement Canada

Uncertainty Analysis of Emission Estimates for Selected Sectors

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Introduction

Uncertainty analysis of pollutant inventories can help prioritize efforts to improve the future accuracy of these inventories and guide decision makers on methodological choices. Uncertainty analysis can also provide information about the relative importance of the quality of input parameters (such as activity data and emission factors) used in estimations based on their relative contribution to overall uncertainties.

The overall objective of this study was to provide uncertainty analysis on substance releases to air from point sources (PS), and area sources (AS) where applicable from the inventory compiled as part of the National Pollutant Release Inventory (NPRI) program. The selected sectors included in the analysis are: aluminum industries, iron and steel industries, cement and concrete industries, and electric power generation. Due to its significant contribution to Canada-wide emissions, residential wood burning was also included in the analysis. The baseline year of this study was 2009. The following priority substances, as applicable to the selected sectors, were included in the analysis:

1. Air Pollutants (APs);
2. Heavy Metals;
3. Persistent Organic Pollutants (POPs); and,
4. Carbonyl sulphide and hydrogen fluoride (HF)

An initial assessment was conducted to identify significant contaminate emissions from various sectors. The table A below shows the substances considered in the analysis.

Table A: Priority Substances by Sector

Chemical Grouping	Chemicals	Aluminum Industry	Cement and Concrete Industry	Electric Power Generation	Iron and Steel Industries	Residential Wood Burning
Air Pollutants	Ammonia		Yes	Yes	Yes	Yes
	CO	Yes				Yes
	NO_x		Yes	Yes		Yes
	TPM	Yes	Yes	Yes	Yes	Yes
	PM_{10}	Yes	Yes	Yes	Yes	Yes
	$PM_{2.5}$	Yes	Yes	Yes	Yes	Yes
	SO_2	Yes		Yes		Yes
	VOCs	Yes		Yes	Yes	Yes

Chemical Grouping	Chemicals	Aluminum Industry	Cement and Concrete Industry	Electric Power Generation	Iron and Steel Industries	Residential Wood Burning
Heavy Metals			Yes	Yes	Yes	Yes
Heavy Metals Part 1				Yes	Yes	Yes
Others		Yes		Yes		Yes
POPs – Dioxins, furans, and HCB			Yes	Yes	Yes	
POPs – PAHs		Yes				

For residential wood burning and electric power generation area sources all the substances were selected, however, only particulate matter was considered for cement and concrete industries area sources.

Approach for the Study

A detailed analysis of emissions at the individual facility level was not within the scope of the study.

The following assumptions were made in this study:

- Information provided to Environment Canada was correct and current;
- Facilities correctly report emissions;
- The input parameters (e. g. activity levels and emission factors) were represented by normal or lognormal distributions; and,
- Activity level at the sector level was considered accurate with no uncertainty or bias.

The methodology prioritized the substances and sectors with respect to their contribution to the NPRI published emission values. The following steps were taken to complete the study:

- Identify input data and their sources.
- Establish Probability Density Functions (PDF) for input data based on data uncertainty and bias using calculation methods specific to each substance and subsector. (Note: The uncertainties in the input parameters were presented as PDFs which represent the difference in true emissions compared to reported emissions).

- Analyze gaps to identify input parameters with no available uncertainty information.
- Use scientific synthesis of expert opinion to fill identified gaps.
- Identify the relative importance and contribution of emission calculation methods and subsectors to the overall emission values.
- Use Monte Carlo analysis to perform uncertainty analysis on the sector-specific data and to aggregate the results across the calculation methods and subsector. The input values for each parameter were obtained by random sampling from PDFs to calculate the emission values and conduct the uncertainty analyses.

The following emission calculation methods were considered for the Monte Carlo simulations of uncertainty:

Table B: Emissions Calculation Methodology

Emissions Calculation Methodology

Code	Description
M1	Continuous Emission Monitoring (CEMs)
M2	Predictive Emission Monitoring
M3	Source Testing
C	Mass Balance
E1	Site Specific Emission Factors
E2	Published Emission Factors
O	Engineering Estimates

In order to conduct the simulation, probability density function (PDFs) were assigned to these values for variability and bias (two aspects of uncertainty) associated with the input parameters such as activity levels and emission parameters. A Monte Carlo sampling was conducted for uncertainty analysis.

Overall Results

Overall, the results indicated that area source estimates have a much higher relative variability for each substance than the NPRI reported (point source) estimates. This is due in part to the higher variability in the activity level PDFs along with the combination of two uncertainty contributions compared to the NPRI reported emissions assessment.

Monte Carlo simulation results indicated that the contribution to the variability of the NPRI reported estimates by published emission factors (E2 emission calculation method) is largest, considering its contribution to the overall emission values. On the other hand, the CEMs (M1), source testing (M3), and engineering estimates (O) contribute the least to uncertainty compared to the emission values attributed to these emission calculation methods. These results will be useful to set the priority for reducing the uncertainty of the parameters used to calculate the emissions reported to NPRI.

Monte Carlo simulation results also showed that the distribution of the simulated emissions mostly followed normal and lognormal distributions depending on the type of distributions chosen for the input parameters. The 95th percentile of the simulated emission distributions (upper confidence limit) ranged from 1% to 130% greater than the NPRI values for various substances and sectors. The 5th percentile of the simulated emission distributions (lower confidence limit) ranged from 2% to 61% less than the NPRI values for various substances and sectors.

The letter ranking of the estimates was determined based on the difference of the 95th percentile of the simulated distributions and the published NPRI values. Table C below shows the letter ranking of the NPRI estimates, based on the legend in table D.

Table C: Letter Ranking by Substance for Selected Sectors.

Substances	Aluminum Industry	Iron and Steel Industries	Electric Power Generation			Cement and Concrete Industry		Residential Wood Burning
			Coal	Natural Gas	Area Sources	Point sources	Area Sources	
Ammonia	-	E	B	-	E	A	-	B
Arsenic	-	E	-	-	-	-	-	-
B(a)P	C	A	-	-	-	-	-	C
B(b)F	C	A	-	-	-	-	-	C
B(k)F	C	E	-	-	-	-	-	C
Cadmium	-	E	A	-	E	-	-	C
Chromium	-	A	E	-		-	-	-
CO	A	-	-	-	E	-	-	B
COS	A	-	-	-		-	-	-
D/F	-	A	A	-	E	A	-	C
HCB	-	-	A	-	-	A	-	-
HF	A	-	A	-	-	-	-	-

Substances	Aluminum Industry	Iron and Steel Industries	Electric Power Generation			Cement and Concrete Industry		Residential Wood Burning
			Coal	Natural Gas	Area Sources	Point sources	Area Sources	
I(1,2,3-c,d)P	B	A	-	-	-	-	-	D
Lead	-	C	B	-	D	-	-	E
Manganese	-	C	A	-	-	-	-	
Mercury	-	-	A	-	E	A	-	C
Nickel	-	E	A	-	-	A	-	-
NO_x	-	-	A	A	E	A	-	B
PM_{10}	A	B	A	-	E	A	E	B
$PM_{2.5}$	A	B	A	-	E	A	E	B
SO_2	A		A	-	E	-	-	B
TPM	A	A	A	-	E	A	E	B
VOCs	A	A	A	-	E	-	-	C

Table D: Legend of Data Quality Rankings

Data Ranking	Uncertainty / Variability
A : Excellent	25%
B : Above average	45%
C : Average	60%
D : Below average	65%
E : Poor	80%
U : Not used in AP 42	>80%
"-" : Not considered in the study	

Conclusion

The total uncertainty present in the emissions data comprises both variability and bias in the estimates. The variability of emission totals will tend to be lower if all streams are considered to be independently random from the uncertainty distribution. This is because streams that are based on an overestimate will tend to be balanced out by those streams that used an underestimate. The bias in the method, given that it is constant for all streams, will not be reduced.

The area source estimates have a much higher relative variability for each substance than the NPRI (point source) estimates. This is due in part to the higher variability in the area PDFs along with the combination of two uncertainty contributions compared to the NPRI assessment. Further there is more averaging in the NPRI simulation as there are usually many more streams sampled than process totals in the area assessment.

Overall, the simulation results also indicated that the contribution to the variability of the NPRI estimates by published emission factors is largest, considering its contribution to the overall emission values. On the other hand, the CEMs, stack testing, and engineering estimates contributes the least to the uncertainty compared to the emission values attributed to these emission calculation methods. These results will be useful to set the priority for reducing the uncertainty of the parameters used to calculate the emissions reported to NPRI.

The simulation results showed that the distribution of the simulated emissions mostly followed normal and lognormal distributions depending on the type of distributions chosen for the input parameters. The 95th percentile of the simulated emission distributions (upper confidence limit) ranged from 1% to 130% greater than the NPRI values for various substances and sectors. The 5th percentile of the simulated emission distributions (lower confidence limit) ranged from 2% to 61% less than the NPRI values for various substances and sectors.

In order to improve the quality of NPRI data, efforts should be focussed to:

- better characterize the bias of the emission calculation methods;
- gather higher quality emission factors published for various substances and sectors; and,
- improve the quality and availability of information regarding the activity level of area source emissions (e.g. the amount and type of wood burned by residences).

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Additional information can be obtained at:

Environment Canada
Inquiry Centre
10 Wellington Street, 23rd Floor
Gatineau QC K1A 0H3
Telephone: 1-800-668-6767 (in Canada only) or 819-997-2800
Fax: 819-994-1412
TTY: 819-994-0736
Email: enviroinfo@ec.gc.ca