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TNO report

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Uncertainty of the NOx, SOx, NH_3, PM10, PM2.5, EC2.5 and NMVOC emissions from transport

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Samenvatting

Nederland rapporteert emissiedata ten behoeve van de Convention on Long-Range Transboundary Air Pollution (CLRTAP) en maakt daarbij gebruik van de Guidelines for Reporting Emissions and Projections Data under the CLTAP 2014 (UNECE, 2014). Volgens deze richtlijnen dienen landen de onzekerheden in de emissieschattingen te kwantificeren.

In een bijeenkomst met een groep emissie-experts van de Taakgroep Verkeer van de Nederlandse Emissie Registratie is per NFR-categorie de onzekerheid in de gerapporteerde activiteit data en de gebruikte emissiefactoren ingeschat. Deze inschattingen zijn vergeleken met eerder gemaakte inschattingen van onzekerheden in de Nederlandse emissierapportages en gerapporteerde onzekerheden van een aantal andere landen. Hierop is geconcludeerd dat de nieuwe schattingen voor Nederland de meest geschikte zijn om de onzekerheden in emissiefactoren en activiteit data voor verkeer te representeren. Vervolgens is een Monte Carlo simulatie uitgevoerd waarmee de onzekerheid in de emissiecijfers voor de hele sector verkeer en voor de verschillende sub sectoren is bepaald.

De Monte Carlo simulatie laat zien dat de grootte van de relatieve onzekerheid het laagst is voor de emissies van NOx. Dit kan verklaard worden door het feit dat het wegverkeer de belangrijkste bron is voor NOx emissies en de onzekerheden hierin de laatste jaren flink zijn teruggebracht door herhaaldelijke meetprogramma's om de emissiefactoren nauwkeurig in kaart te brengen. De grootste relatieve onzekerheid geldt voor de emissies van ammoniak en NMVOS.

Het resultaat van de onzekerheidsanalyse kan gebruikt worden om te besluiten welke methodieken verbeterd moeten worden. Verbeteringen moeten vooral gericht zijn op emissiebronnen die een hoge bijdrage leveren aan de totale onzekerheid van een emissieschatting. De prioritering is geen onderdeel van dit onderzoek, maar de resultaten van dit onderzoek kunnen wel gebruikt worden bij het prioriteren van mogelijke verbeteringen in de emissieberekeningen.

Summary

The Netherlands report emission data under the Convention on Long-Range Transboundary Air Pollution (CLRTAP) using the Guidelines for Reporting Emissions and Projections Data under the CLRTAP 2014 (UNECE, 2014). According to these guidelines, the uncertainties in the emission data have to be quantified.

An expert elicitation session was held with a group of emission experts from the Taskforce Traffic and Transport of the Dutch emission inventorying community. In this session, the uncertainty in activity data and emission factors has been estimated per NFR category. These estimates have been compared with estimates made earlier for the Dutch emission inventory and have also been compared to uncertainty estimates reported by a number of other countries. As a result it has been concluded that the new estimates are the most appropriate to represent the uncertainties in the emission factors and activity data for traffic and transport used in the Dutch emission inventory. Using a Monte Carlo simulation, the uncertainty in reported emission values has been estimated for traffic and transport emissions as a whole and for the different subsectors.

The Monte Carlo simulation shows that NOx emissions have the lowest relative uncertainty, while the emissions of NH_3 and NMVOC have the highest relative uncertainty. The low uncertainty for NOx can be explained by the fact the road transport is the main source of NOx emissions in the traffic and transport sectors and successive measurement programs have succeeded in determining more accurately the relevant emission factors.

The result of the uncertainty analysis can be used to decide for which sectors the methodology needs to be improved. Any improvements should be focused on the emission sources which have the largest influence on the total uncertainty of the emission estimates. Prioritization of improvements in emission estimates is beyond the scope of this study. But the results of this study can be used to prioritize any future improvements in the emission inventory.

Contents

1 Introduction

The Netherlands report emission data under the Convention on Long-range Transboundary Air Pollution (CLRTAP) using the Guidelines for Reporting Emissions and Projections Data under the CLRTAP 2014 (UNECE, 2014). Paragraph 31 of these Reporting Guidelines states:

> Parties shall quantify uncertainties in their emission estimates using the most appropriate methodologies available, taking into account guidance provided in the EMEP/EEA Guidebook. Uncertainties should be described in the IIR.

An accurate quantification of the uncertainties can help in setting the priority for future measurement programs and other improvements in methodology.

This report describes the quantification of the uncertainties in the activity data and emission factors for the transport sector and presents the results on the uncertainty in the reported transport emissions. Chapter 2 describes the methodology to estimate the uncertainties and chapter 3 provides an overview of the uncertainty per NFR category. In chapter 4, the results of the Monte Carlo simulation with regards to the uncertainty in the aggregated reported emission values are presented. Details on estimated uncertainties per category are described in Appendix A.

2 Methodology to provide an expert judgement of the uncertainty

The IPCC 2006 Guidelines (IPCC, 2006) indicate that “When empirical data are lacking or are not considered fully representative for all causes of uncertainty, expert judgement may be necessary for estimating uncertainty” (Volume 1, chapter 3 of the IPCC 2006 Guidelines). Annex 2A.1 of Volume 1 of the IPCC 2006 Guidelines describes an example protocol for expert elicitation (see textbox 1).

Textbox 1: Protocol for expert elicitation, as described in volume 1, chapter 2 of the IPCC 2006 Guidelines (IPCC, 2006)

- Motivating: Establish a rapport with the expert, and describe the context of the elicitation. Explain the elicitation method to be used and the reason it was designed that way. The elicitor should also try to explain the most commonly occurring biases to the expert, and to identify possible biases in the expert.
- Structuring: Clearly define the quantities for which judgements are to be sought, including, for example, the year and country, the source/sink category, the averaging time to be used (one year), the focus activity data, emission factor or, for uncertainty, the mean value of emission factors or other estimation parameter, and the structure of the inventory model. Clearly identify conditioning factors and assumptions (e.g., resulting emissions or removals should be for typical conditions averaged over a one-year period).
- Conditioning: Work with the expert to identify and record all relevant data, models, and theory relating to the formulation of the judgements.
- Encoding: Request and quantify the expert’s judgement. The specific qualification will differ for different elements and be present in the form of a probability distribution for uncertainty, and an activity or emission factor estimate for activity data and emission factors. If appropriately managed, information on uncertainty (probability density function) can be gathered at the same time as gathering estimates of activity or emission factor. The section on encoding in Chapter 3 describes some alternative methods to use for encoding uncertainty.
- Verification: Analyze the expert’s response and provide the expert with feedback as to what has been concluded regarding his or her judgement. Is what has been encoded really what the expert meant? Are there inconsistencies in the expert’s judgement?

The format of the expert elicitation protocol from the IPCC Guidelines (2006) is used as a basis to do the expert elicitation in the road transport sector. The expert elicitation has been done during a workshop with the relevant experts on 6 October 2016. The following five steps are followed, where steps 2 – 4 are followed for each sector separately:

1. Motivating: The workshop started with a detailed explanation of the context of the expert elicitation. The exact emission sources are shown, including the emissions, the relative share in emissions, the activity data and the emission factors.
2. Structuring: Each sector is discussed separately. This starts with defining the variable for which an expert judgement is needed (e.g. for the NOx emission factor from passenger cars in 2014).
3. Conditioning: The main expert on a subject describes how the variable is described and what are the main uncertainties in the calculation.

The other experts ask questions in order to discuss all relevant information relating to the uncertainty estimation.

4. Encoding: The expert provides an estimate of the uncertainty (95% confidence interval).
5. Verification: The uncertainty estimates are summarized and presented to the experts. The experts can check and correct these. The results are also compared to uncertainty estimates from other countries and earlier uncertainty estimates made for the Netherlands.

Possible biases have been explained to the group of experts prior to the workshop. Possible (unintended) biases include availability bias, representativeness bias and anchoring and adjustment bias (IPCC, 2006). To counteract these biases, it is important to discuss all available information regarding the emission estimates during the workshop.

The experts were asked for an uncertainty estimate of the emissions reported for the year 2014, as this was reported in the Informative Inventory Report of 2016 (RIVM, 2016).

3 Uncertainty of activity data and emission factors in the transport sector

This chapter provides a general overview of the uncertainty of the activity data and emission factors per NFR category. The uncertainty is expressed in percentages, which show the 95% confidence interval. Details regarding the estimation of uncertainties are described in Appendix A. The expert judgement of the uncertainty is also compared with uncertainty estimates from Sweden (Swedish Environmental Protection Agency, 2016), France (CITEPA, 2016) and Finland (Finish Environment Institute, 2016) and with expert judgements from the Netherlands in 2004 (Van Gijlswijk et.al., 2004 and Van Harmelen et.al., 2004). Furthermore, the uncertainties are compared to the default (tier 1) emission ranges in the EMEP/EEA Guidebook (EMEP/EEA, 2016), hereafter referred to as the guidebook. Not all uncertainties are quantified. Some sectors do not (significantly) contribute to the emission of certain pollutants. In these cases the table cells are empty.

3.1 Civil aviation (1.A.3.a.i(i))

Table 1 gives the uncertainty values for the civil aviation sector in the Netherlands, distinguishing between emissions from aircraft landing and take-off (LTO), auxiliary power units (APU), fuelling and fuel handing, ground service equipment (GSE), tyre wear and brake wear. Typically, smaller piston engine aircraft use aviation gasoline (Avgas), while larger jet engine aircraft use jet kerosene. The main category for comparison are the LTO emissions.

Table 1 Expert judgement of uncertainty for NFR 1.A.3.ai(i) Civil aviation

NFR	Type	Fuel	Uncertainty activity data	Uncertainty emission factor						
				NOx	SOx	NH_3	PM10	PM2.5	EC2.5	NMVOC
1A3ai(i)	LTO	Jet Kerosene	10%	35%	50%		100%	100%	100%	200%
	LTO	Aviation gasoline	20%	100%	50%		100%	100%	100%	500%
	APU	Jet Kerosene	50%	35%	50%		100%	100%	100%	200%
	Fuelling and fuel handling		10%							100%
	GSE	Diesel	10%	50%	20%	200%	100%	100%	100%	
	Tyre wear		10%					100%		
	Brake wear		10%					100%		

Table 2 shows the previous uncertainty estimates for the civil aviation sector in the Netherlands. The LTO uncertainties appear to have been estimated significantly higher in the past, although different categories were used which makes comparison more difficult. Although the calculation process has been improved, in retrospect there seems to be little justification for the extremely high uncertainties in the activity data as estimated in 2004. For APU, the calculation methodology has been improved which explains why the new uncertainty estimates are lower.

The uncertainty estimated for PM emission factors from GSE, tyre and brake wear have not changed.

Table 2 Previous uncertainty estimate civil aviation for the Netherlands (Van Gijlswijk, et.al., 2004 and Van Harmelen et.al., 2004)

<table>
<tr><th rowspan="2">NFR</th><th rowspan="2">Type</th><th rowspan="2">Fuel</th><th rowspan="2">Airport</th><th rowspan="2">Uncertainty activity data</th><th colspan="5">Uncertainty emission factor</th></tr>
<tr><th>NOx</th><th>SOx</th><th>NH_3</th><th>PM10</th><th>PM2.5</th></tr>
<tr><td rowspan="9">1A3ai(i)</td><td>LTO, idle</td><td>Jet Kerosene</td><td>Schiphol</td><td>200%</td><td>200%</td><td>100%</td><td></td><td rowspan="6">100%</td><td rowspan="6">100%</td></tr>
<tr><td>LTO, take-off</td><td>Jet Kerosene</td><td>Schiphol</td><td>200%</td><td>200%</td><td>100%</td><td></td></tr>
<tr><td>LTO, climb-out</td><td>Jet Kerosene</td><td>Schiphol</td><td>200%</td><td>200%</td><td>100%</td><td></td></tr>
<tr><td>LTO, approach</td><td>Jet Kerosene</td><td>Schiphol</td><td>200%</td><td>200%</td><td>100%</td><td></td></tr>
<tr><td>LTO</td><td>Jet Kerosene, AvGas</td><td>Other</td><td>100%</td><td>100%</td><td>100%</td><td>100%</td></tr>
<tr><td>APU</td><td>Jet Kerosene</td><td>Schiphol</td><td>200%</td><td>200%</td><td>100%</td><td></td></tr>
<tr><td>GSE</td><td>Diesel</td><td></td><td></td><td></td><td></td><td></td><td>100%</td><td>100%</td></tr>
<tr><td>Tyre wear</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>100%</td></tr>
<tr><td>Brake wear</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td>100%</td></tr>
</table>

Table 3 shows the uncertainty as reported by Sweden, Finland and France for the civil aviation sector (LTO). For Finland, the uncertainty in the NOx and SOx emission factors applies to the entire NFR 1.A.3. sector, while the uncertainty in the NMVOC emission factor applies to 1.A.3.a. and 1.A.3.b.i through iv. These uncertainties can therefore not be compared to the values for the Netherlands. France estimates a very low uncertainty on the activity data and NOx, SOx and NMVOC emission factors. The values reported by Sweden are more in line with the uncertainties for the Netherlands, except for the relatively low uncertainty estimated by Sweden for the PM emission factors.

Table 3 Comparison uncertainty NFR 1.A.3.a. Aviation with Sweden, Finland and France (Swedish Environmental Protection Agency (2016), Finish Environment Institute (2016), CITEPA (2016))

NFR	AD			EF NOx			EF SOx			EF PM10 & PM2.5		EF EC2.5	EF NMVOC		
	SE	FI	FR	SE	FI[1]	FR	SE	FI[1]	FR	SE	FR	FR	SE	FI[1]	FR
1A3ai(i)	10%	20-50%	3%	100%	50%	10%	50%	50%	5%	20%	100%	100%	100%	80%	10%

The civil aviation emission factor uncertainties reported by the guidebook are shown in Table 4. The emissions for the Netherlands are calculated based on aircraft LTO's, however, the uncertainty estimated for the Netherlands is much higher than the estimates reported by the guidebook.

Table 4 Guidebook uncertainty ranges emission factors civil aviation (EMEP/EEA, 2016)

NFR	Type	NOx	SOx	NMVOC
1A3ai(i)	LTO	5-10%	5-10%	5-10%
	Tier 1	100%	100%	100%

[1] These uncertainties apply to the NFR 1.A.3. sector as a whole (except NMVOC emissions from petrol evaporation)

3.2 Road transport (1.A.3.b)

Table 5 to Table 9 show the uncertainty ranges for activity data and emission factors for road transport exhaust pipe emissions, differentiating between different vehicle types and fuels. Table 10 shows the uncertainty in petrol evaporation emission factors and Table 11 lists the uncertainty in wear and abrasion emission factors.

Table 5 Expert judgement of uncertainty for NFR 1.A.3.b.i Exhaust gases passenger cars

NFR	Fuel	Uncertainty activity data	Uncertainty emission factor						
			NOx	SOx	NH_3	PM10	PM2.5	EC2.5	NMVOC
1A3bi	Natural gas	5%			200%				
	Petrol	5%	20%	20%	200%	200%	200%	500%	100%
	Diesel	5%	20%	20%	100%	50%	50%	50%	100%
	LPG	5%	20%		200%	200%	200%	500%	50%

Table 6 Expert judgement of uncertainty for NFR 1.A.3.b.ii Exhaust gases light duty vehicles

NFR	Fuel	Uncertainty activity data	Uncertainty emission factor						
			NOx	SOx	NH_3	PM10	PM2.5	EC2.5	NMVOC
1A3bii	Natural gas	5%							
	Petrol	5%	20%	20%		200%	200%	500%	50%
	Diesel	5%	20%	20%		50%	50%	50%	100%
	LPG	5%				200%	200%	500%	

Table 7 Expert judgement of uncertainty for NFR 1.A.3.b.iii Exhaust gases heavy duty vehicles

NFR	Fuel	Uncertainty activity data	Uncertainty emission factor						
			NOx	SOx	NH_3	PM10	PM2.5	EC2.5	NMVOC
1A3biii	Natural gas	10%							
	Petrol	10%	20%	20%		200%	200%	500%	.
	Diesel	10%	20%	20%	100%	50%	50%	50%	100%
	LPG	10%				200%	200%	500%	

Table 8 Expert judgement of uncertainty for NFR 1.A.3.b.iii Exhaust gases buses

NFR	Fuel	Uncertainty activity data	Uncertainty emission factor						
			NOx	SOx	NH_3	PM10	PM2.5	EC2.5	NMVOC
1A3biii	Natural gas	5%							
	Petrol	5%	20%	20%		200%	200%	500%	
	Diesel	5%	20%	20%		50%	50%	50%	
	LPG	5%				200%	200%	500%	

Table 9 Expert judgement of uncertainty for NFR 1.A.3.b.iv Exhaust gases mopeds and motorcycles

NFR	Fuel	Uncertainty activity data	Uncertainty emission factor						
			NOx	SOx	NH_3	PM10	PM2.5	EC2.5	NMVOC
1A3biv	Petrol	20%	200%	20%		500%	500%	500%	500%
	Diesel	20%	100%	20%		500%	500%	500%	

Table 10 Expert judgement of uncertainty for NFR 1.A.3.b.v Petrol evaporation emission factors cars and mopeds and motorcycles

NFR	Fuel	Vehicle type	Uncertainty emission factor NMVOC
1A3bv	Petrol	Passenger vehicles	200%
	Petrol	mopeds and motorcycles	500%

Table 11 Expert judgement of uncertainty for NFR 1.A.3.b.vi and 1.A.3.b.vii Automobile tyre and brake wear and road abrasion

NFR	Type	Uncertainty emission factor	
		PM10	PM2.5
1A3bvi	Tyre wear	100%	200%
1A3bvi	Brake wear	100%	200%
1A3bvii	Road surface wear	200%	500%

Table 12 shows the previous uncertainty estimates for exhaust emissions from passenger vehicles in the Netherlands. The previous estimates also distinguished between road types, making a direct comparison more difficult. Still, it seems that the new uncertainty estimates for the NOx and SOx emission factors are lower than the previous estimate. For NOx there have been many recent measuring programs to estimate the emission factors more accurately. In contrast, the uncertainty for PM emissions appears to be estimated higher in the latest estimates. This can be explained by the fact that most vehicles are equipped with particle filters that cause PM emissions to be much lower, but also cause small variations to have a large relative impact.

For light duty vehicles, the previous uncertainty estimates were very similar to those for passenger vehicles, only with lower uncertainty estimated for urban use.
The previous estimates for heavy duty vehicles can be found in Table 13. Similarly to passenger vehicles, uncertainty estimates for the NOx and SOx emission factors were higher in the previous study. For buses there was only an uncertainty of 100% estimated on the PM emissions.
Concerning motorcycles and mopeds, Table 14 shows a very high uncertainty on the activity data, although the uncertainty on PM is modest compared to the current estimate.

The uncertainty on PM10 emissions from tyre wear, brake wear and road surface wear were all estimated as being 100% in the previous study. Only for road surface wear the current estimated uncertainty is higher.

Table 12 Previous uncertainty estimate for exhaust emissions from passenger vehicles (Van Gijlswijk, et.al., 2004 and Van Harmelen et.al., 2004)

NFR	Vehicle type	Fuel	Road type	Uncertainty activity data	Uncertainty emission factor				
					NOx	SOx	NH_3	PM10	PM2.5
1A3bi	Passenger vehicle	Diesel	Urban	100%	100%	100%	1000%	35%	35%
		Diesel	Highway	10%	70%	70%	405%		
		Diesel	Country road	10%	70%	70%	405%		
		Petrol	Urban	100%	100%	100%	1000%	35%	35%
		Petrol	Highway	30%	70%	70%	405%		
		Petrol	Country road	30%	70%	70%	405%		
		LPG	Urban	100%	100%		100%	35%	35%
		LPG	Highway	30%	100%		1000%		
		LPG	Country road	30%	100%		1000%		

Table 13 Previous uncertainty estimate for exhaust emissions from heavy duty vehicles (Van Gijlswijk, et.al., 2004 and Van Harmelen et.al., 2004)

NFR	Vehicle type	Road type	Uncertainty activity data	Uncertainty emission factor				
				NOx	SOx	NH_3	PM10	PM2.5
1A3biii	Heavy duty vehicle	Urban	50%	70%	70%	405%	50%	50%
		Highway	5%	70%	70%	405%		
		Country road	5%	70%	70%	405%		

Table 14 Previous uncertainty estimate for exhaust emissions from motorcycles and mopeds (Van Gijlswijk, et.al., 2004 and Van Harmelen et.al., 2004)

NFR	Vehicle type	Road type	Uncertainty activity data	Uncertainty emission factor				
				NOx	SOx	NH_3	PM10	PM2.5
1A3biv	Motorcycles	Urban	100%	100%	100%	100%	100%	100%
	Motorcycles	Highway	100%	100%	100%	100%		
	Motorcycles	Country road	100%	100%	100%	100%		
	Mopeds	Urban	100%	100%	100%	100%	100%	100%
	Mopeds	Country road	100%	100%	100%	100%		

Table 15 lists the uncertainty values reported by other countries for the road transport sector. For France, most uncertainty values apply to the NFR 1.A.3.b. sector in its entirety, while for Finland, most values apply to the NFR 1.A.3. sector as a whole. These values are therefore not suitable for comparison.

The uncertainty estimated for the activity data of road transport exhaust gases for the Netherlands is higher than the estimates for Finland. Regarding the NOx emission factor, the Netherlands has a lower uncertainty compared to Sweden. For SOx, Sweden reports a similar uncertainty.

For NH_3, all countries report a high uncertainty. For PM emissions, the uncertainty estimated for the Netherlands is much higher than for Sweden. The same holds for NMVOC emissions.

Table 15 Comparison uncertainty NFR 1.A.3.b Road transport with Sweden, Finland and France (Swedish Environmental Protection Agency (2016), Finish Environment Institute (2016), CITEPA (2016))

	AD			EF NOx			EF SOx			EF NH_3		
	SE	FI	FR[2]	SE	FI[3]	FR[2]	SE	FI[3]	FR[2]	SE	FI[3]	FR[2]
1A3bi	3-10%	1-3%		50%			20%			400%		
1A3bii	3-5%	1-3%		50%			20%			400%		
1A3biii	3-10%	1-3%		42-50%			17-20%			347-400%		
1A3biv	3%	1%	3%	50%	50%	10%	20%	50%	5%	400%	100%	50%
1A3bv												
1A3bvi												
1A3bvii												

	EF PM10		EF PM2.5		EF EC2.5	EF NMVOC		
	SE	FR	SE	FR[2]	FR[2]	SE	FI[3]	FR[2]
1A3bi	15%		15%			50%		
1A3bii	15%		15%			50%	80%	
1A3biii	13-15%		13-15%			42-50%		
1A3biv	15%	48%	15%	36%	16%	50%		18%
1A3bv						50%	100%	
1A3bvi	15%		15%				80%	
1A3bvii	15%		15%					

Table 16 shows the uncertainty ranges listed in the guidebook for road transport emission factors. For passenger cars, there is a low uncertainty in the NOx emission factors for diesel, petrol and LPG passenger cars, which corresponds with the uncertainty estimate for the Netherlands. The guidebook, however, estimates much lower uncertainty regarding the NH_3 and NMVOC emission factors than the estimates for the Netherlands. One possible explanation is that the estimate for the Netherlands incorporates the uncertainty related to a cold start while this is not specifically considered in the guidebook.

Regarding the category of light duty vehicles, the uncertainty for the NOx emission factor for the Netherlands is low, while for PM10 and NMVOC the uncertainty falls within the wide uncertainty range reported by the guidebook.

The large difference in the PM10 emission factor uncertainty between diesel and petrol is reflected both in the guidebook values and the uncertainty values for the Netherlands.

[2] These uncertainties apply to the NFR 1.A.3.b. sector as a whole
[3] These uncertainties apply to the NFR 1.A.3. sector as a whole (except NMVOC emissions from petrol evaporation)

However, the very high uncertainty in NOx emission factors given in the guidebook does not correspond with the low uncertainty estimated for the Netherlands.

The most remarkable difference occurs in the category of mopeds and motorcycles. While the guidebook reports a relatively low uncertainty, for the Netherlands the uncertainty was estimated to be very high for all pollutants due to a lack of suitable measurement programs to determine these emission factors.

Table 16 Guidebook uncertainty ranges road transport (EMEP/EEA, 2016)

NFR	**NOx**	**NH_3**	**PM10**	**NMVOC**
1A3bi	A (diesel, petrol and LPG w/o catalyst) B (2-stroke) D (LPG with catalyst) A-C (cold start)	A (petrol with catalyst) B (diesel) C (petrol w/o cat. And LPG w/o cat. D (LPG with cat. and 2-stroke)	A (diesel) A-C (cold start) D (LPG)	A (diesel, petrol and LPG w/o catalyst) B (2-stroke) D (LPG with catalyst) A-C (cold start)
1A3bii	B (regular emissions) D (cold start)	B	A (regular emissions) D (cold start)	B (regular emissions) D (cold start)
1A3biii	A (diesel) D (petrol)	B (diesel) D (petrol)	A (diesel) D (petrol)	A (diesel) D (petrol)
1A3biv	A	B		A

3.3 Railways (1.A.3.c)

Table 17 shows the uncertainty results for the railway sector in the Netherlands, including particle emissions from the wear of pantographs on electrical trains.

Table 17 Expert judgement of uncertainty for NFR 1.A.3.c Railways

NFR	Type	Fuel	Uncertainty activity data	Uncertainty emission factor						
				NOx	SOx	NH_3	PM10	PM2.5	EC2.5	NMVOC
1A3c	Freight transport	Diesel	5%	100%	20%		100%	100%	100%	
	Passenger transport	Diesel	5%	100%	20%		100%	100%	100%	
	Pantograph wear	Electricity						200%	200%	

The uncertainty estimates from the previous study are shown in Table 18. Most notable are the higher uncertainties estimated for the activity data and SOx emission factor compared to the new estimates.

Table 18 Previous uncertainty estimate for the railways in the Netherlands (Van Gijlswijk, et.al., 2004 and Van Harmelen et.al., 2004)

NFR	Type	Fuel	Uncertainty activity data	Uncertainty emission factor				
				NOx	SOx	NH_3	PM10	PM2.5
1A3c	Freight transport	Diesel	100%	100%	100%	100%	100%	100%
	Passenger transport	Diesel	100%	100%	100%	100%		
	Pantograph wear	Electricity						100%

Table 19 gives the uncertainty values reported by Sweden, Finland and France for the railway sector. For all countries, the uncertainty in the AD is estimated to be very low. The uncertainty values for Finland apply to the 1.A.3. sector as a whole. France estimates a lower uncertainty on the NOx emission factor, whilst for SOx, the Dutch estimate matches that of Sweden. Emission factor uncertainties for NH_3 and NMVOC were not estimated for the Netherlands due to their small contribution to the national total. Regarding particle emissions, Sweden and France estimate a relatively low uncertainty.

Table 19 Comparison uncertainty NFR 1.A.3.c Railways with Sweden, Finland and France (Swedish Environmental Protection Agency (2016), Finish Environment Institute (2016), CITEPA (2016))

NFR	AD			EF NOx			EF SOx		EF NH_3	
	SE	FI	FR	SE	FI[4]	FR	SE	FI[4]	SE	FI[4]
1A3c	5%	5%	3%	100%	50%	40%	20%	50%	75%	100%

[4] These uncertainties apply to the NFR 1.A.3. sector as a whole (except NMVOC emissions from petrol evaporation)

NFR	EF PM10 & PM2.5		EF EC2.5	EF NMVOC		
	SE	FR	FR	SE	FI[4]	FR
1A3c	10%	40%	40%	75%	80%	40%

Table 20 gives the emission factor uncertainty ranges listed in the guidebook. The NOx and PM emission factor uncertainty ranges estimated for the Netherlands are similar to those reported by the guidebook.

Table 20 Guidebook uncertainty ranges railways (EMEP/EEA, 2016)

NFR	NOx	NH_3	PM10 & PM2.5	NMVOC
1A3c	50-75%	40-70%	100-200%	60-70%

3.4 Navigation (1.A.3.d.i(i), 1.A.3.d.i(ii), 1.A.3.d.ii)

Table 21 lists the uncertainty results for navigation (NFR sectors 1.A.3.d.i(i), 1.A.3.d.i(ii) and 1.A.3.d.ii) in the Netherlands. A distinction is made between emissions from navigation in the Netherlands (NL) and navigation in the Netherlands Exclusive Economic Zone (NCP).

Table 21 Expert judgement of uncertainty for NFR 1.A.3.d.i(i), 1.A.3.d.i(ii), 1.A.3.d.ii Shipping

NFR	Type	Fuel	Uncertainty activity data	Uncertainty emission factor						
				NOx	SOx	NH_3	PM10	PM2.5	EC2.5	NMVOC
1A3di(i)	Anchored NCP	HFO	20%	50%	50%	500%	50%	50%	200%	200%
1A3di(i)	Anchored NCP	MDO	20%	50%	50%	500%	50%	50%	200%	200%
1A3di(i)	Sailing NCP	HFO	20%	50%	50%	500%	50%	50%	200%	200%
1A3di(i)	Sailing NCP	LNG	50%	100%	100%			100%	200%	
1A3di(i)	Sailing NCP	MDO	20%	50%	50%	500%	50%	50%	200%	200%
1A3di(i)	Moored NL		50%	50%	50%	500%	50%	50%	200%	200%
1A3di(i)	Sailing NL	HFO	20%	50%	50%	500%	50%	50%	200%	200%
1A3di(i)	Sailing NL	LNG	50%	100%	100%			100%	200%	
1A3di(i)	Sailing NL	MDO	20%	50%	50%	500%	50%	50%	200%	200%
1A3di(ii)	Inland, international	Diesel	50%	35%	20%	500%	50%	50%	50%	100%
1A3dii	Inland, national	Diesel	50%	35%	20%	500%	50%	50%	50%	100%
1A3dii	Passenger and ferryboats	Diesel	100%	50%	20%	500%	100%	100%	100%	200%

Table 22 shows the previous uncertainty estimate for the navigation sector in the Netherlands. Since the categories are different, the values cannot be readily compared. Nevertheless, there do not seem to be any extreme values deviating from the current estimates.

Table 22 Previous uncertainty estimate for navigation in the Netherlands (Van Gijlswijk, et.al., 2004 and Van Harmelen et.al., 2004)

NFR	Type	Fuel	Uncertainty activity data	Uncertainty emission factor			
				NOx	SOx	PM10	PM2.5
1A3di(ii)	Inland, international	Diesel					
1A3di(ii)	Inland, international, push towing	Diesel	-15% - +5%	-10% - +5%	25%		
1A3dii	Inland, national	Diesel				50%	50%
1A3dii	Passenger and ferryboats	Diesel					
1A3dii	Inland, national, push towing	Diesel	-15% - +5%	-10% - +5%	25%		
1A3di(i)	Sailing NCP and NL	MDO and HFO	30%	-15% - +5%	-30% - +0%		
1A3di(i)	Moored NL	MDO and HFO				100%	100%
1A3di(i)	Anchored NCP	MDO and HFO	-50% - +20%	-20% - +10%	-40% - +0%		

Table 23 shows the uncertainty in the navigation sectors for Sweden, Finland and France. For France, the uncertainties apply to the NFR 1.A.3.d sector as a whole. The uncertainty values for Finland apply to the 1.A.3. sector as a whole. These values can thus not be easily compared.
Uncertainty in the activity data is low for all countries. Compared to the Netherlands, Sweden estimates the uncertainty in the NOx emission factor to be very low. For SOx, France deviates from the other countries with a very low estimated uncertainty of only 5%, although it applies to all three sectors taken together. The extremely high uncertainty in NH_3 estimated for the Netherlands is not reflected in the figures for the other countries. Uncertainty in PM10 and PM2.5 emission factors is similar, but the Netherlands estimates higher uncertainty for the EC2.5 and NMVOC emission factors.

Table 23 Comparison uncertainty NFR 1.A.3.d.i(i), 1.A.3.d.i(ii), 1.A.3.d.ii Shipping with Sweden, Finland and France (Swedish Environmental Protection Agency (2016), Finish Environment Institute (2016), CITEPA (2016))

NFR	AD			EF NOx			EF SOx			EF NH_3	
	SE	FI	FR[5]	SE	FI[6]	FR[5]	SE	FI[6]	FR[5]	SE	FI[6]
1A3di(i)											
1A3di(ii)			3%		50%	50%		50%	5%		100%
1A3dii	3-15%	10%		6-10%			31-40%			24%	

NFR	EF PM10 & PM2.5		EF EC2.5	EF NMVOC		
	SE	FR[5]	FR[5]	SE	FI[6]	FR[5]
1A3di(i)						
1A3di(ii)		50%	50%		80%	50%
1A3dii	27-40%			20%		

[5] These uncertainties apply to the NFR 1.A.3.d. sector as a whole
[6] These uncertainties apply to the NFR 1.A.3. sector as a whole (except NMVOC emissions from petrol evaporation)

Table 24 gives the uncertainty ranges a listed in the guidebook. Generally, the uncertainties as listed in the guidebook are a bit lower than those estimated for the Netherlands. For NMVOC, however, the difference is very large, since a significant uncertainty between 100-200% is estimated for the Netherlands while the guidebook gives a range of 25-50% uncertainty.

Table 24 Guidebook uncertainty ranges navigation (EMEP/EEA, 2016)

NFR	Type	Fuel use	NOx	SOx	PM	NMVOC
1A3d	At sea	10%	20%	10%	25%	25%
	Manoeuvring	30%	40%	30%	50%	50%
	In port	20%	30%	20%	40%	40%

3.5 Mobile machinery (1.A.2.g.vii, 1.A.4.a.ii, 1.A.4.b.ii, 1.A.4.c.ii)

Table 25 gives the uncertainty for the mobile machinery sectors in the Netherlands. A distinction is made between different subsectors and fuel types.

Table 25 Expert judgement of uncertainty for NFR 1.A.2.g.vii, 1.A.4.a.ii, 1.A.4.b.ii, 1.A.4.c.ii Mobile machinery

NFR	Sector	Fuel	Uncertainty activity data	Uncertainty emission factor						
				NOx	SOx	NH_3	PM10	PM2.5	EC2.5	NMVOC
1A2gvii	Construction	Petrol	100%	50%	20%	200%	100%	100%	100%	100%
1A2gvii	Construction	Diesel	35%	50%	20%	200%	100%	100%	100%	100%
1A2gvii	Industry	Diesel	35%	50%	20%	200%	100%	100%	100%	100%
1A2gvii	Industry	LPG	35%	50%	20%	200%	100%	100%	100%	100%
1A4aii	Public services	Petrol	100%	50%	20%	200%	100%	100%	100%	100%
1A4aii	Public services	Diesel	35%	50%	20%	200%	100%	100%	100%	100%
1A4aii	Container handling	Diesel	35%	50%	20%	200%	100%	100%	100%	100%
1A4bii	Consumers	Petrol	100%	100%	20%	200%	200%	200%	200%	200%
1A4cii	Agriculture	Petrol	200%	100%	20%	200%	200%	200%	200%	200%
1A4cii	Agriculture	Diesel	35%	50%	20%	200%	100%	100%	100%	100%

In Table 26, the previous uncertainty estimates for mobile machinery are shown. The current estimates for the uncertainty in activity data and SOx emission factors appear to be lower than the previous estimates.

Table 26 Previous uncertainty estimate for mobile machinery in the Netherlands (Van Gijlswijk, et.al., 2004 and Van Harmelen et.al., 2004)

<table>
<tr><th rowspan="2">NFR</th><th rowspan="2">Sector</th><th rowspan="2">Uncertainty activity data</th><th colspan="4">Uncertainty emission factor</th></tr>
<tr><th>NOx</th><th>SOx</th><th>PM10</th><th>PM2.5</th></tr>
<tr><td>1A2gvii</td><td>Construction</td><td>200%</td><td>200%</td><td>100%</td><td rowspan="6">100%</td><td rowspan="6">100%</td></tr>
<tr><td>1A2gvii</td><td>Industry</td><td rowspan="3">200%</td><td rowspan="3">200%</td><td rowspan="3">100%</td></tr>
<tr><td>1A4aii</td><td>Public services</td></tr>
<tr><td>1A4bii</td><td>Consumers</td></tr>
<tr><td>1A4cii</td><td>Agriculture</td><td>15%</td><td>130%</td><td>70%</td></tr>
<tr><td>1A4aii</td><td>Container handling</td><td></td><td></td><td></td></tr>
</table>

In Table 27, the uncertainties as estimated by Sweden, Finland and France are given. Note that some uncertainty values apply to a combination of subsectors and can therefore not easily be compared.
The mobile machinery activity data uncertainty estimate for the Netherlands is higher than for the other countries, especially for petrol fuelled machinery. The uncertainties estimated by Sweden are significantly lower than those estimated by the other countries, especially for NOx, NH_3, PM and NMVOC. With regard to France, the low uncertainty in the SOx emission factor is notable.

Table 27 Comparison uncertainty NFR 1.A.2.g.vii, 1.A.4.a.ii, 1.A.4.b.ii, 1.A.4.c.ii Mobile machinery with Sweden, Finland and France (Swedish Environmental Protection Agency (2016), Finish Environment Institute (2016), CITEPA (2016))

NFR	AD			EF NOx			EF SOx			EF NH_3
	SE	FI	FR[7]	SE	FI[8]	FR[7]	SE	FI[8]	FR[7]	SE
1A2gvii	5%	5%	3%	20%	50%	24%	19%	20%	5%	30%
1A4aii	5%	5-30%	5%	20%		50%	20%		5%	30%
1A4bii	3%	15%	5%	17%	50%	51%	68%	20%	5%	33%
1A4cii	3%	10-15%	5%	9%		40%	36%		5%	17%

NFR	EF PM10 & PM2.5		EF EC2.5	EF NMVOC		
	SE	FR[7]	FR[7]	SE	FI[8]	FR[7]
1A2gvii	30%	96%	100%	16%	80%	100%
1A4aii	30%	100%	100%	20%		200%
1A4bii	27%	100%	100%	20%	80%	198%
1A4cii	15%	50%	46%	13%		41%

Table 28 shows the uncertainty ranges for the mobile machinery emission factors given by the guidebook. The guidebook reports very wide uncertainty ranges of up to one order of magnitude. For the Netherlands, the uncertainties are also quite high, although for SOx the uncertainty is lower given that the sulphur content of the fuel is more certain.

Table 28 Guidebook uncertainty ranges mobile machinery (EMEP/EEA, 2016)

Sector	NOx	SOx	NH_3	PM10	PM2.5	NMVOC
Agriculture	B-E	B-E	E	B-E	B-E	B-E
Forestry	B-E	B-E	E	B-E	B-E	B-E
Industry	B-E	B-E	E	B-E	B-E	B-E
Households	E	E	E	E	E	E

[7] The uncertainty values apply respectively to the 1.A.2.g, 1.A.4.a, 1.A.4.b and 1.A.4.c. sectors as a whole
[8] The uncertainty values apply to the 1.A.4. sector as a whole

3.6 Other transport (1.A.4.c.iii, 1.A.5.b, 2.D.3.i)

Table 29 shows the uncertainty for the other transport sectors in the Netherlands. Note that the uncertainty in the activity data for fisheries applies to the bottom-up approach using AIS data, and does not apply to the top down approach which uses the fuel sales from the energy statistics to estimate the activity data. The top down approach is used for the reporting of emissions for the National Emission Ceilings Directive (NECD).

Table 29 Expert judgement of uncertainty for NFR 1.A.4.c.iii, 1.A.5.b, 2.D.3.i Other transport emissions

NFR	Type	Fuel	Uncertainty activity data	Uncertainty emission factor					
				NOx	SOx	PM10	PM2.5	EC2.5	NMVOC
1A4ciii	Fisheries	Diesel	15%	30%	20%	50%	50%	50%	100%
1A5b	Recreational shipping, exhaust gases	Petrol	200%	200%	20%	100%	100%	100%	100%
1A5b	Recreational shipping, exhaust gases	Diesel	200%	50%	20%	100%	100%	100%	100%
1A5b	Recreational shipping, petrol evaporation		100%						200%
2D3i	Inland shipping, degassing cargo		100%						100%

Table 30 shows the previous uncertainty estimates for fisheries and recreational shipping in the Netherlands. Most notable are the large decrease in uncertainty in activity data and NOx emission factor for fisheries and SOx emission factor for all sectors. The decrease in certainty for the activity data for fisheries is related to the Automatic Identification Systems (AIS) which register the location of (fishing) ships and are used to determine activity data for the emission calculations.

Table 30 Previous uncertainty estimate for other transport in the Netherlands (Van Gijlswijk, et.al., 2004 and Van Harmelen et.al., 2004)

NFR	Type	Fuel	Uncertainty activity data	Uncertainty emission factor				
				NOx	SOx	NH_3	PM10	PM2.5
1A4ciii	Fisheries	Diesel	130%	130%	130%	130%	100%	100%
1A5b	Recreational shipping, exhaust gases	Diesel	100%	100%	100%			
1A5b	Recreational shipping, exhaust gases	Gasoline	100%	100%	100%		100%	100%

The activity data uncertainty estimated for the Netherlands is very large compared to the uncertainty reported by Sweden, Finland and France, shown in Table 31.

Most remarkable are the low uncertainties in the PM and NMVOC emission factors reported by Sweden and the low uncertainty for SOx reported by France.
Since NFR sector 2.D.3.i is only represented by degassing cargo on inland shipping vessels, the uncertainties cannot be meaningfully compared with uncertainties for this sector from other countries or the guidebook.

Table 31 Comparison uncertainty NFR 1.A.4.c.iii, 1.A.5.b, 2.D.3.i Other transport emissions with Sweden, Finland and France (Swedish Environmental Protection Agency (2016), Finish Environment Institute (2016), CITEPA (2016))

NFR	AD			EF NOx			EF SOx			EF NH_3
	SE	FI	FR[9]	SE	FI	FR[9]	SE	FI	FR[9]	SE
1A4ciii		10%	5%		50%	40%		20%	5%	
1A5b	5%	30-50%		46-50%	50%		30%	20%		271-400%
2D3i										

NFR	EF PM10 & PM2.5		EF EC2.5	EF NMVOC		
	SE	FR[9]	FR[9]	SE	FI	FR[9]
1A4ciii		50%	46%		80%	41%
1A5b	15-18%			50-68%	80%	
2D3i				16%		

Fisheries are not considered separately in the guidebook uncertainty chapter. Table 32 gives the uncertainty ranges listed for mobile machinery. The most notable difference is the low uncertainty on the SOx emission factor for the Netherlands compared to the large range reported by the guidebook.

Table 32 Guidebook uncertainty ranges fisheries (mobile machinery) (EMEP/EEA, 2016)

NFR	NOx	SOx	NH_3	PM10	PM2.5	NMVOC
1.A.4	B-E	B-E	E	B-E	B-E	B-E

[9] The uncertainty values apply to the 1.A.4.c. sector as a whole

3.7 Conclusion

New estimates have been made for the uncertainties in activity data and emission factors for traffic and transport activities using an expert elicitation process. Compared to earlier uncertainty estimates made for the Dutch traffic and transport sector there are several differences. The most significant differences are lower uncertainties regarding activity data for railways, shipping, mobile machinery and aviation. This is both due to improved data collection methods and improved insight into the chain of data collection processes. The uncertainty in emission factors has in general decreased for NOx and SOx, due to measurement programmes and more stringent regulation of fuel sulphur contents respectively. The uncertainty with regard to PM emission factors remains very high, as does the uncertainty in NH_3 and NMVOC emission factors.

There are some large differences in the uncertainty estimates made for the Netherlands and those reported by Sweden, Finland and France. The consulted experts have considered these differences but did not change their estimate for the Dutch uncertainty figures as a result. A similar conclusion can be made with regard to the uncertainty ranges as estimated in the guidebook. There are some large discrepancies between the Dutch uncertainty ranges and those from the guidebook, but also in these cases the experts concluded that, for the Netherlands, the uncertainty ranges as resulting from the expert elicitation process were the most appropriate. For this reason, there uncertainty estimates were used in the Monte Carlo simulation to determine the 95% confidence interval for the reported emission values at a sector and subsector level.

4 Transport emissions uncertainty

The uncertainties in the activity data and emission factors of the individual NFR categories have been processed using a Monte Carlo simulation to estimate total uncertainty at a sub-sector and sector level. The analysis has been performed by running 10,000 simulations. Using this analysis, the 95% confidence interval has been determined, which signifies that there is a 95% probability that the interval encompasses the actual value (population parameter). As is prescribed by the IPCC 2006 Guidelines on uncertainty analysis, individual uncertainty values estimated to be smaller than +/- 30% are assumed to be normally distributed, while uncertainty values with a larger range are assumed to follow a log-normal distribution. The simulation has only been applied to emissions relevant to the NEC Directive.

The total uncertainty for transport emissions reported by the Netherlands can be seen in Table 33.

Table 33 Uncertainty in reported emissions (kiloton) for traffic and transport in the Netherlands

	NOx	SOx	NH_3	PM10	PM2.5	NMVOC
Average Monte Carlo value	142.8	0.45	4.18	7.28	5.05	31.7
Median value	142.5	0.44	3.05	7.01	4.94	27.4
Reported emission value	142.7	0.45	4.20	7.27	5.05	32.1
Confidence interval lower bound (%)	-11%	-21%	-79%	-27%	-22%	-48%
Confidence interval upper bound (%)	12%	28%	240%	49%	35%	133%
Lower bound (emission)	127.6	0.35	0.88	5.32	3.92	16.4
Upper bound (emission)	159.9	0.57	14.19	10.82	6.81	74.0

As can be seen, the relative uncertainty in the reported emission values is especially large for NH_3 and NMVOC, while the relative uncertainty is lowest for NOx emissions from transport. The emission ranges for the individual sub-sectors can be found in Table 34 to Table 39. Note that sea shipping is not included in these results since emissions from this sector are not reported under the NEC Directive.

Table 34 Uncertainty in reported emissions (kiloton) for road transport in the Netherlands

	NOx	SOx	NH_3	PM10	PM2.5	NMVOC
Average Monte Carlo value	84.8	0.18	4.16	4.95	2.86	24.1
Median value	84.8	0.18	3.03	4.67	2.75	19.7
Reported emission value	84.8	0.18	4.19	4.94	2.86	24.2
Confidence interval lower bound (%)	-12%	-11%	-79%	-35%	-31%	-60%
Confidence interval upper bound (%)	12%	11%	240%	70%	53%	173%
Lower bound (emission)	75.0	0.16	0.87	3.22	1.98	9.6
Upper bound (emission)	94.6	0.20	14.16	8.44	4.38	65.8

Table 35 Uncertainty in reported emissions (kiloton) for aviation in the Netherlands

	NOx	SOx	NH_3	PM10	PM2.5	NMVOC
Average Monte Carlo value	3.39	0.23	0.00009	0.049	0.036	0.42
Median value	3.35	0.23	0.00007	0.047	0.034	0.34
Reported emission value	3.39	0.23	0.00009	0.049	0.036	0.42
Confidence interval lower bound (%)	-28%	-39%	-87%	-39%	-44%	-65%
Confidence interval upper bound (%)	36%	55%	268%	58%	73%	181%
Confidence interval lower bound (emission)	2.44	0.14	0.00001	0.030	0.020	0.15
Confidence interval upper bound (emission)	4.60	0.36	0.00034	0.078	0.062	1.18

Table 36 Uncertainty in reported emissions (kiloton) for rail transport in the Netherlands

	NOx	SOx	NH_3	PM10	PM2.5	NMVOC
Average Monte Carlo value	1.84	0.0006	0.0003	0.064	0.061	0.085
Median value	1.70	0.0006	0.0003	0.061	0.058	0.079
Reported emission value	1.84	0.0006	0.0003	0.064	0.061	0.088
Confidence interval lower bound (%)	-56%	-15%	-54%	-51%	-50%	-53%
Confidence interval upper bound (%)	100%	15%	90%	86%	85%	93%
Confidence interval lower bound (emission)	0.81	0.0005	0.0002	0.032	0.030	0.040
Confidence interval upper bound (emission)	3.68	0.0007	0.0006	0.120	0.113	0.163

Table 37 Uncertainty in reported emissions (kiloton) for shipping (not sea shipping) in the Netherlands

	NOx	SOx	NH_3	PM10	PM2.5	NMVOC
Average Monte Carlo value	26.3	0.013	0.006	0.87	0.82	1.24
Median value	25.7	0.013	0.003	0.85	0.79	1.14
Reported emission value	26.3	0.013	0.006	0.87	0.82	1.29
Confidence interval lower bound (%)	-32%	-28%	-92%	-38%	-37%	-55%
Confidence interval upper bound (%)	45%	36%	371%	56%	58%	99%
Confidence interval lower bound (emission)	17.8	0.009	0.001	0.54	0.52	0.56
Confidence interval upper bound (emission)	38.1	0.018	0.030	1.37	1.29	2.47

Table 38 Uncertainty in reported emissions (kiloton) for mobile machinery in the Netherlands

	NOx	SOx	NH_3	PM10	PM2.5	NMVOC
Average Monte Carlo value	18.8	0.017	0.009	1.16	1.11	3.08
Median value	18.4	0.017	0.007	1.10	1.05	2.69
Reported emission value	18.8	0.017	0.009	1.16	1.11	3.21
Confidence interval lower bound (%)	-28%	-22%	-68%	-44%	-44%	-51%
Confidence interval upper bound (%)	39%	26%	168%	75%	74%	134%
Confidence interval lower bound (emission)	13.6	0.013	0.003	0.65	0.62	1.50
Confidence interval upper bound (emission)	26.1	0.022	0.023	2.04	1.92	7.18

Table 39 Uncertainty in reported emissions (kiloton) for other transport in the Netherlands

	NOx	SOx	NH_3	PM10	PM2.5	NMVOC
Average Monte Carlo value	7.6	0.0021	0.0009	0.18	0.17	2.85
Median value	7.2	0.0021	0.0008	0.16	0.16	2.46
Reported emission value	7.6	0.0021	0.0009	0.17	0.17	2.88
Confidence interval lower bound (%)	-38%	-28%	-67%	-45%	-45%	-63%
Confidence interval upper bound (%)	80%	46%	129%	90%	83%	144%
Confidence interval lower bound (emission)	4.7	0.0015	0.0003	0.10	0.09	1.04
Confidence interval upper bound (emission)	13.7	0.0031	0.0021	0.33	0.31	6.94

These results show that the uncertainty in the emissions of certain pollutants can differ significantly between sectors. The relative uncertainty in NOx emission in the road transport sector is low, while it is substantially higher for the other sectors. NH_3 and NMVOC typically have the widest confidence intervals. In Figure 1 the Monte Carlo results and the 95% confidence interval are shown graphically for the emissions of NOx for the traffic and transport sector as a whole.

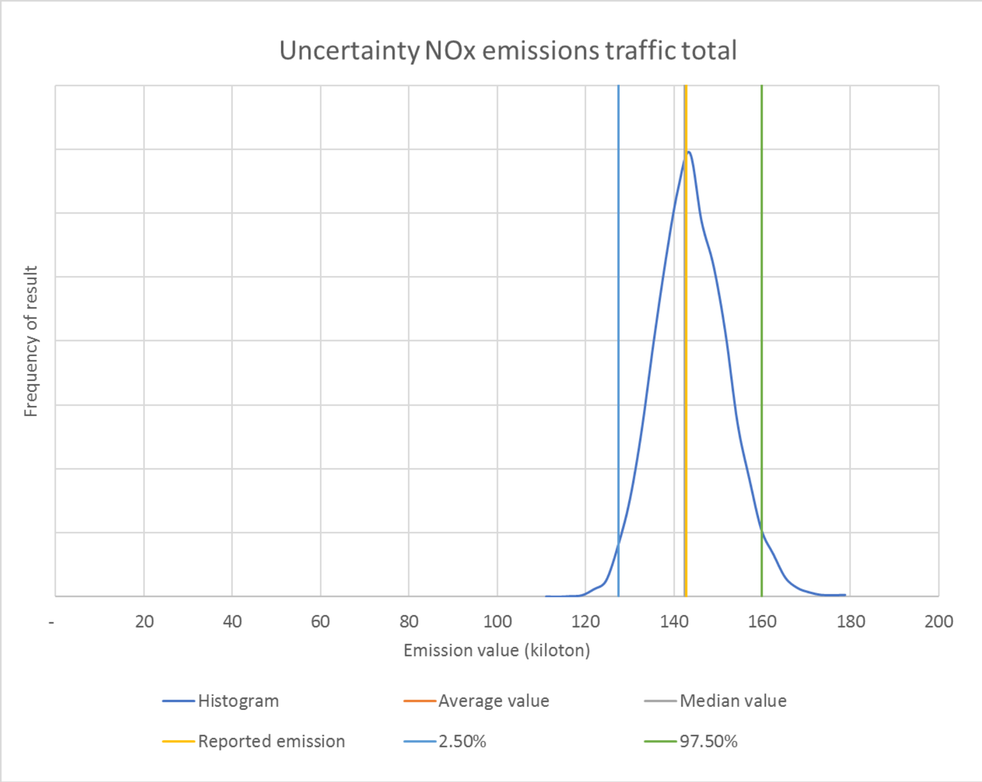

Figure 1 Uncertainty of traffic and transport emissions of NOx

5 Conclusion

A new estimate has been made for the uncertainties in activity data and emission factors for traffic and transport activities using an expert elicitation process. These new estimates can be considered the most appropriate to represent the uncertainties in the emission factors and activity data for traffic and transport used in the Dutch emission inventory. The results have been used to perform a Monte Carlo analysis to calculate the total uncertainty of the emissions from the transport sectors.

The relative uncertainty of the NOx emissions from road transport is the lowest, compared to the other pollutants, because these emissions are measured regularly. Since road transport is also the largest emission source (from the transport sector), the uncertainty of the NOx emissions from the entire transport sector is also rather low (between -11% and +12%). The uncertainty of the NH_3 and NMVOC emissions from transport is the highest, compared to the other pollutants. This is caused by the fact that these emissions are not measured on a regular basis.

The result of the uncertainty analysis can be used to decide for which sectors the methodology needs to be improved. Any improvements should be focused on the emission sources which have the largest influence on the total uncertainty of the emission estimates. This is not necessarily the emission source with the largest uncertainty, because this also depends on the contribution of the emission source to the total emission. Prioritization of improvements in emission estimates is beyond the scope of this study. But the results of this study can be used to prioritize any future improvements in the emission inventory.

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A Expert judgement of uncertainties per category

The following tables provide a description of the expert judgements made for the emissions in 2014 (as report in the Informative Inventory Report of 2016 (RIVM, 2016)). The workshop was held on 6 October 2016 with all of the emission experts that are involved in the Transport taskforce of the Dutch Emission Inventory. For each uncertainty estimate, the main expert in mentioned in the table. He/she provided the uncertainty estimate during the workshop.

Table A.1 Activity data road transport

Variable: 1.A.3.b. Activity data road transport (= kilometres per year and per vehicle type)
Expert: Hermine Molnar
Discussion of the uncertainty: Kilometres per vehicle are based on two registries that monitor road transport activity. These data are rather certain. The largest uncertainty is in the amount of kilometres from Dutch cars abroad and from foreign cars in the Netherlands. Activity of heavy duty vehicles is also more uncertain since a variety of sources for activity data are used. For mopeds and motorcycles the uncertainty in activity data is significant.
Uncertainty estimate from the expert: 5% for passenger cars 5% for light duty 10% for heavy duty 5% for buses 20% for mopeds and motorcycles

Table A.2 NOx emission factors road transport

Variable: 1.A.3.b. NOx emission factors road transport
Expert: Norbert Ligterink
Discussion of the uncertainty: There have been many measurement programs to determine the NOx emissions of different vehicle types. Nevertheless, some uncertainty remains since emissions can vary significantly based on types of use (highway, city etc.) and driving behaviour. For motorcycles and mopeds, emission measurements are hardly ever performed (since it is very difficult to mount measurement equipment on these vehicles), resulting in a very high uncertainty.
Uncertainty estimate from the expert: 20% for passenger cars, buses and light and heavy duty vehicles 200% for petrol fuelled mopeds and motorcycles 100% for diesel fuelled mopeds and motorcycles

Table A.3 SOx emission factors road transport

Variable: 1.A.3.b. SOx emission factors road transport
Expert: Norbert Ligterink
Discussion of the uncertainty: The emissions of SOx are dependent on the sulphur content of the fuels. Since these are routinely measured, the uncertainty is relatively low. The uncertainty may increase with the ultra-low sulphur fuels with sulphur fractions close to the measurement uncertainty.
Uncertainty estimate from the expert: 20% for all road transport exhaust emissions of SOx

Table A.4 NH_3 emission factors road transport

Variable: 1.A.3.b. NH_3 emission factors road transport
Expert: Norbert Ligterink
Discussion of the uncertainty: The emissions of NH_3 are very uncertain. The uncertainty is lower for diesel than for petrol and LPG fuelled vehicles since diesel fuels are included in the annual measurement program.
Uncertainty estimate from the expert: 100% for diesel fuelled passenger and heavy duty vehicles 200% for petrol and LPG fuelled passenger vehicles

Table A.5 Emission factors PM10, PM2.5 and EC2.5 road transport

Variable: 1.A.3.b. Emission factors PM10, PM2.5 and EC2.5 road transport
Expert: Norbert Ligterink
Discussion of the uncertainty: The exhaust emissions of PM and EC are very uncertain, especially for petrol and LPG fuelled vehicles, and for mopeds and motorcycles (which pose problems for measuring). The uncertainty is highest for EC2.5 emissions. Concerning PM emissions from brake and tyre wear the uncertainties are significant. Even larger are the uncertainties surrounding PM emissions from road abrasion
Uncertainty estimate from the expert: 200% for exhaust emissions of PM for petrol and LPG fuelled vehicles 500% for exhaust emissions of EC for petrol and LPG fuelled vehicles 50% for exhaust emissions of PM and EC for diesel fuelled vehicles 500% for exhaust emissions of PM and EC for motorcycles and mopeds 100% for tyre and brake wear emissions of PM10 200% for tyre and brake wear emissions of PM2.5 200% for road abrasion emissions of PM10 500% for road abrasion emissions of PM2.5

Table A.6 NMVOC emission factors road transport

Variable: 1.A.3.b. NMVOC emission factors road transport
Expert: Norbert Ligterink
Discussion of the uncertainty: The exhaust emissions of NMVOC are quite uncertain. The highest absolute contribution and uncertainty applies to petrol fuelled mopeds and motorcycles. Petrol evaporation emissions are highly uncertain, again the highest uncertainty applies to petrol fuelled mopeds and motorcycles.
Uncertainty estimate from the expert: 100% for exhaust emissions of NMVOC for diesel fuelled vehicles and petrol fuelled passenger vehicles. 50% for exhaust emissions of NMVOC for LPG fuelled vehicles and petrol fuelled light duty vehicles 500% for exhaust emissions of NMVOC for petrol fuelled mopeds and motorcycles 200% for evaporation emissions of NMVOC for petrol fuelled passenger vehicles 500% for evaporation emissions of NMVOC for petrol fuelled mopeds and motorcycles

Table A.7 Activity data civil aviation

Variable: 1.A.3.a.i(i), Activity data civil aviation
Expert: Jan Hulskotte
Discussion of the uncertainty: Detailed information on the landing and take-off of airplanes is available. Especially for larger, jet fuelled airplanes, the uncertainty is limited. The activity of auxiliary power units (APU's) is quite uncertain, since little is known about the average running time of APU's The uncertainty surrounding activity data for fuelling and fuel handling evaporation emissions is low since they have been provided by the largest provider of aircraft fuels in the Netherlands. The uncertainty for the activity data for ground service equipment (GSE) is also low, since detailed fuel use data is provided by KLM equipment services. The activity data for tyre and brake wear is also quite certain since these are based on the maximum take-off weight (MTOW) of large aircraft landing, which can be calculated using the data on LTO's of different aircraft types.
Uncertainty estimate from the expert: 10% for LTO activity of jet fuelled aircraft 20% for LTO activity of aviation gasoline fuelled aircraft 50% for APU activity 10% for fuelling volume, diesel use in GSE and MTOW of aircraft LTO's

Table A.8 Emission factors civil aviation

Variable: 1.A.3.a.i(i), Emission factors civil aviation
Expert: Jan Hulskotte
Discussion of the uncertainty: Large jet fuelled engines must undergo emission testing as part of their certification. Therefore the uncertainty in NOx emission factor is relatively low. For AvGas fuelled aircraft the uncertainty is much higher. Concerning SOx emissions, these are related to the sulphur content of the fuels, however, these are less well known than for road transport fuels, resulting in a higher uncertainty. The uncertainty is high for particle emissions and very high for NMVOC emissions from LTO. For APU's the same uncertainties as for Jet fuelled aircraft are assumed. For GSE the same uncertainties as for mobile machinery are assumed. NMVOC emission factors from fuelling are not measured and very uncertain. Particle emission factors for brake and tyre wear are also very uncertain.
Uncertainty estimate from the expert: 35% for NOx emission factors for jet fuelled LTO and APU 100% for NOx emission factors for AvGas fuelled LTO 50% for NOx emission factors for GSE 50% for SOx emission factors for LTO and APU 20% for SOx emission factors for GSE 200% for NH_3 emission factor for GSE 100% for all particle emission factors 200% for NMVOC emission factors for jet fuelled LTO and APU 500% for NMVOC emission factors for AvGas fuelled LTO 100% for NMVOC emission factors for fuelling and fuel handling

Table A.9 Railways activity data and emission factors

Variable: 1.A.3.c, Railways activity data and emission factors
Expert: Jan Hulskotte
Discussion of the uncertainty: The uncertainty in the activity data is very low since the travel distances are registered. Uncertainty in NOx and particle emission factors is high, but the uncertainty in SOx emission factors is low. The uncertainty in PM2.5 and EC2.5 emission factors for the abrasion of pantographs in case of electrically powered trains is very high.
Uncertainty estimate from the expert: 5% for diesel fuelled railway transport activity data 100% for NOx and particle emission factors for diesel fuelled trains 20% for SOx emission factors for diesel fuelled trains 200% for PM2.5 and EC2.5 emission factors for pantograph wear

Table A.10 Activity data shipping

Variable: 1.A.3.d, Activity data shipping
Expert: Jan Hulskotte
Discussion of the uncertainty: Most ships are equipped with positioning systems (Automatic Identification Systems, AIS) which allow to register the distance travelled. For moored ships the activity data is more uncertain since it is difficult to estimate fuel use, more so because some ships will be connected to shore power to provide electricity on board. Uncertainty is also higher for ships equipped with an LPG fuelled (hybrid) engine, since it cannot be determined what share of the time ships are fuelled by LPG. Uncertainty is relatively high for inland shipping. The activity data for passenger and ferryboats is very uncertain.
Uncertainty estimate from the expert: 10% for sailing sea ships 50% for moored sea ships 50% for LNG tank ships 35% for inland shipping 100% for passenger and ferryboats

Table A.11 Emission factors shipping

Variable: 1.A.3.d, Emission factors shipping
Expert: Jan Hulskotte
Discussion of the uncertainty: There is substantial uncertainty surrounding NOx emission factors for shipping. Uncertainty is highest for LNG tank ships and lower for inland shipping. The same holds true for the uncertainty in SOx emission factors. The NH_3 emission factors are extremely uncertain. The PM emission factors have a medium uncertainty while the EC2.5 have a very high uncertainty, as do the NMVOC emission factors. For these emission factors, the uncertainty is highest in the passenger and ferryboats sector.
Uncertainty estimate from the expert: 50% for NOx emission factors for sea ships and passenger and ferryboats 100% for NOx emission factors for LNG tank ships 35% for NOx emission factors for inland shipping 50% for SOx emission factors for sea ships 100% for SOx emission factors for LNG tank ships 20% for SOx emission factors for inland shipping and passenger and ferryboats 500% for all NH_3 emission factors 100% for PM emission factors for passenger and ferryboats and LNG tank ships 50% for all other PM emission factors 200% for EC2.5 emission factors for sea ships 50% for EC2.5 emission factors for inland shipping 100% for EC2.5 emission factors for passenger and ferryboats 200% for NMVOC emission factors for sea ships and passenger and ferryboats 100% for NMVOC emission factors for inland shipping

Table A.12 Activity data mobile machinery

Variable: 1.A.2.g.vii, 1.A.4.a.ii, 1.A.4.b.ii, 1.A.4.c.ii Mobile machinery activity data
Expert: Jan Hulskotte
Discussion of the uncertainty: There is medium certainty concerning the machine fleet and its activity pattern for diesel and LPG fuelled mobile machinery. Uncertainty surrounding petrol fuelled machines is much higher.
Uncertainty estimate from the expert: 35% for diesel and LPG fuelled mobile machines 200% for petrol fuelled agricultural machines 100% for other petrol fuelled machines

Table A.13 Emission factors mobile machinery

Variable: 1.A.2.g.vii, 1.A.4.a.ii, 1.A.4.b.ii, 1.A.4.c.ii. Mobile machinery emission factors
Expert: Jan Hulskotte
Discussion of the uncertainty: There is medium uncertainty concerning the NOx emission factors and relatively low uncertainty surrounding the SOx emission factors. The uncertainty in particle and NMVOC emission factors is significant, but for NH_3 it is even higher. For both NOx, particles and NMVOC, the uncertainty is higher for petrol fuelled agricultural and household machines than for the other machine types.
Uncertainty estimate from the expert: 100% for NOx emission factors for petrol fuelled agricultural and household machines 50% for NOx emission factors for all other machines 20% for SOx emission factors for all machines 200% for NH_3 emission factors for all machines 200% for particle emission factors for petrol fuelled agricultural and household machines 100% for particle emission factors for all other machines 200% for NMVOC emission factors for petrol fuelled agricultural and household machines 100% for particle emission factors for all other machines 100% for NMVOC emission factors for all other machines

Table A.14 Activity data for other transport

Variable: 1.A.5.b, 2.D.3.i., 1.A.4.c.iii. Other transport activity data
Expert: Jan Hulskotte
Discussion of the uncertainty: Similar to other sea ships, fishing ships are equipped with tracking equipment that registers position and distance sailed, resulting in a low uncertainty. The uncertainty surrounding recreational sailing is very high since little data is available. Regarding the degassing of inland shipping containers there is medium uncertainty on activity data.
Uncertainty estimate from the expert: 15% for fishing 200% for exhaust emissions recreational sailing 100% for evaporation emissions recreational sailing 50% for degassing containers in inland shipping

Table A.15 Emission factors for other transport

Variable: 1.A.5.b, 2.D.3.i., 1.A.4.c.iii. Other transport emission factors
Expert: Jan Hulskotte
Discussion of the uncertainty: There is medium uncertainty regarding the NOx emission factors for diesel fuelled fishing and recreational ships. For petrol fuelled recreational ships there is very high uncertainty. The SOx emission factor has a low uncertainty since it is related to the sulphur content of the fuels used. The particle emission factors have medium uncertainty for fishing but higher for recreational sailing. The uncertainties on NMVOC emission factors are high for shipping exhaust emissions but even higher for petrol evaporation emissions. The uncertainty surrounding the NMVOC emission factor for the degassing of inland shipping containers is not very high.
Uncertainty estimate from the expert: 30% for NOx emission factors for diesel fuelled fishing ships 50% for NOx emission factors for diesel fuelled recreational ships 200% for NOx emission factors for petrol fuelled ships 20% for SOx emission factors for all sources 50% for particle emission factors for fishing 100% for particle emission factors for recreational sailing 100% for NMVOC emission factors for ship exhaust emissions 200% for NMVOC emission factors for petrol evaporation emissions 50% for NMVOC emission factors for degassing inland shipping containers