Uncertainty estimates and guidance for road transport emission calculations

A JRC/IES project performed by EMISIA SA

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Project ID

- Project was initiated Dec. 17, 2008 with an official duration of 9 months
- Objectives:
  - Evaluate the uncertainty linked with the various input parameters of the COPERT 4 model,
  - Assess the uncertainty of road transport emissions in two test cases, at national level,
  - Include these uncertainty estimates in the COPERT 4 model, and
  - Prepare guidance on the assessment of uncertainty for the Tier 3 methods (COPERT 4).

Operational Definitions

- **Item:** Any value required by the software to calculate the final output
- **Input Variable:** Any item for which actual values are not included in the software (stock size, mileage, speeds, temperatures, …)
- **Internal Parameter:** An item included for which actual values are included in the software and have been derived from experiments (emission factors, cold-trip distance, …)
- **Uncertainty:** Variance of final output (pollutant emission) due to the non exact knowledge of input variables and experimental variability of internal parameters
- **Sensitivity:** Part of the output variance explained by the variance of individual variables and parameters

Approach

- Select two countries to simulate different cases
  - Italy: South, new vehicles, good stock description
  - Poland: North, old vehicles, poor stock description
- Quantify uncertainty range of variables and parameters
- Perform screening test to identify influential items
- Perform uncertainty simulations to characterise total uncertainty, including only influential items
- Limit output according to statistical fuel consumption
- Develop software to perform uncertainty estimates for other countries

Items for which uncertainty has been assessed

Item	Description	Item	Description
Ncat	Vehicle population at category level	LFHDV	Load Factor
Nsub	Vehicle population at sub-category level	tmin	Average min monthly temperature
Ntech	Vehicle population at technology level	tmax	Average max monthly temperature
Mtech	Annual mileage	Mm,tech	Mean fleet mileage
UStech	Urban share	RVP	Fuel reid vapour pressure
Hstech	Highway share	H:C	Hydrogen-to-carbon ratio
RStech	Rural share	O:C	Oxygen-to-carbon ratio
USPtech	Urban speed	S	Sulfur level in fuel
HSPtech	Highway speed	ehot,tech	Hot emission factor
RSPtech	Rural speed	ecold/ehot,tech	Cold-start emission factor
Ltrip	Mean trip length	b	Cold-trip distance

Variance of the total stock

POLAND	ACEA	ACEM	Poland Stat	Eurostat	μ	σ
	2005	2005	2005	2005		
Passenger Cars	12 339 353		12 339 000	12 339 000	12 339 118	204
Light Duty Vehicles	1 717 435		2 304 500	2 178 000	2 066 645	308 968
Heavy Duty Vehicles	587 070			737 000	662 035	106 017
Buses	79 567		79 600	80 000	79 722	241
Mopeds		337 511			337 511	0
Motorcycles		753 648		754 000	753 824	249

ITALY	ACEA	ACEM	ACI	Eurostat	μ	σ
	2005	2005	2005	2005		
Passenger Cars	34 667 485		34 667 485	34 636 400	34 657 123	17 947
Light Duty Vehicles	3 257 525			3 633 900	3 445 713	266 137
Heavy Duty Vehicles	1 070 308			958 400	1 014 354	79 131
Buses	94 437		94 437	94 100	94 325	195
Mopeds		5 325 000	4 560 907		4 942 954	540 295
Motorcycles		4 938 359	4 938 359	4 933 600	4 936 773	2 748

Subsector variance Italy

Sector	Subsector	Known Values	Unknown values
Passenger Cars	Gasoline <1,4 l	18.025.703	627
Passenger Cars	Gasoline 1,4 - 2,0 l	5.090.465	
Passenger Cars	Gasoline >2,0 l	408.278	
Passenger Cars	Diesel <2,0 l	7.987.956	145
Passenger Cars	Diesel >2,0 l	1.822.935	
Passenger Cars	LPG		
Passenger Cars	2-Stroke		
Light Duty Vehicles	Gasoline <3,5t	280.005	7.580
Heavy Duty Vehicles	Gasoline >3,5 t	4.343	
Light Duty Vehicles	Diesel <3,5 t	2.695.478	35.174
Heavy Duty Vehicles	Diesel 3,5 - 7,5 t	190.842	
Heavy Duty Vehicles	Diesel 7,5 - 16 t	187.804	
Heavy Duty Vehicles	Diesel 16 - 32 t	206.345	
Heavy Duty Vehicles	Diesel >32t	1.905	
Buses	Urban Buses	2.281	92
Buses	Coaches	66.548	
Mopeds			
Motorcycles		1.397.575	927
Motorcycles		1.545.423	
Motorcycles		1.488.571	
Motorcycles		505.863	

Standard deviation is produced by allocating the unknown values to the smaller class, the larger class and uniformly between classes

Subsector variance Poland

Sector	Subsector	Poland	
Passenger Cars	Gasoline <1,4 l	5.890.018	194.212
Passenger Cars	Gasoline 1,4 - 2,0 l	2.853.116	187.552
Passenger Cars	Gasoline >2,0 l	253.264	38.415
Passenger Cars	Diesel <2,0 l	1.660.117	113.710
Passenger Cars	Diesel >2,0 l	314.139	60.785
Passenger Cars	LPG	992.755	231.352
Light Duty Vehicles	Gasoline <3,5t	980.551	9.244,7
Heavy Duty Trucks	Gasoline >3,5 t	108.400	1.022,0
Light Duty Vehicles	Diesel <3,5 t	732.359	7.323,6
Heavy Duty Trucks	Rigid <=7,5 t	73.538	5.147,7
Heavy Duty Trucks	Rigid 7,5 - 12 t	53.445	3.741,1
Heavy Duty Trucks	Rigid 12 - 14 t	25.422	1.779,5
Heavy Duty Trucks	Rigid 14 - 20 t	31.993	2.239,5
Heavy Duty Trucks	Rigid 20 - 26 t	28.597	2.001,8
Heavy Duty Trucks	Rigid 26 - 28 t	7.342	513,9
Heavy Duty Trucks	Rigid 28 - 32 t	8.928	625,0
Heavy Duty Trucks	Rigid >32 t	10.925	764,7
Heavy Duty Trucks	Articulated 14 - 20 t	10.741	751,8
Heavy Duty Trucks	Articulated 20 - 28 t	9.284	649,9
Heavy Duty Trucks	Articulated 28 - 34 t	15.037	1.052,6
Heavy Duty Trucks	Articulated 34 - 40 t	35.608	2.492,6
Heavy Duty Trucks	Articulated 40 - 50 t	8.083	565,8
Heavy Duty Trucks	Articulated 50 - 60 t	3.461	242,3
Buses	Urban Buses Midi <=15 t	1.813	126,9
Buses	Urban Buses Standard 15 - 18 t	35.035	2.452,5
Buses	Urban Buses Articulated >18 t	25.575	1.790,3
Buses	Coaches Standard <=18 t	15.944	1.116,0
Buses	Coaches Articulated >18 t	2.216	155,1
Mopeds		337.511	0,0
Motorcycles		454.508	31.815,5
Motorcycles		75.694	5.298,6
Motorcycles		128.674	9.007,2
Motorcycles		94.124	6.588,7

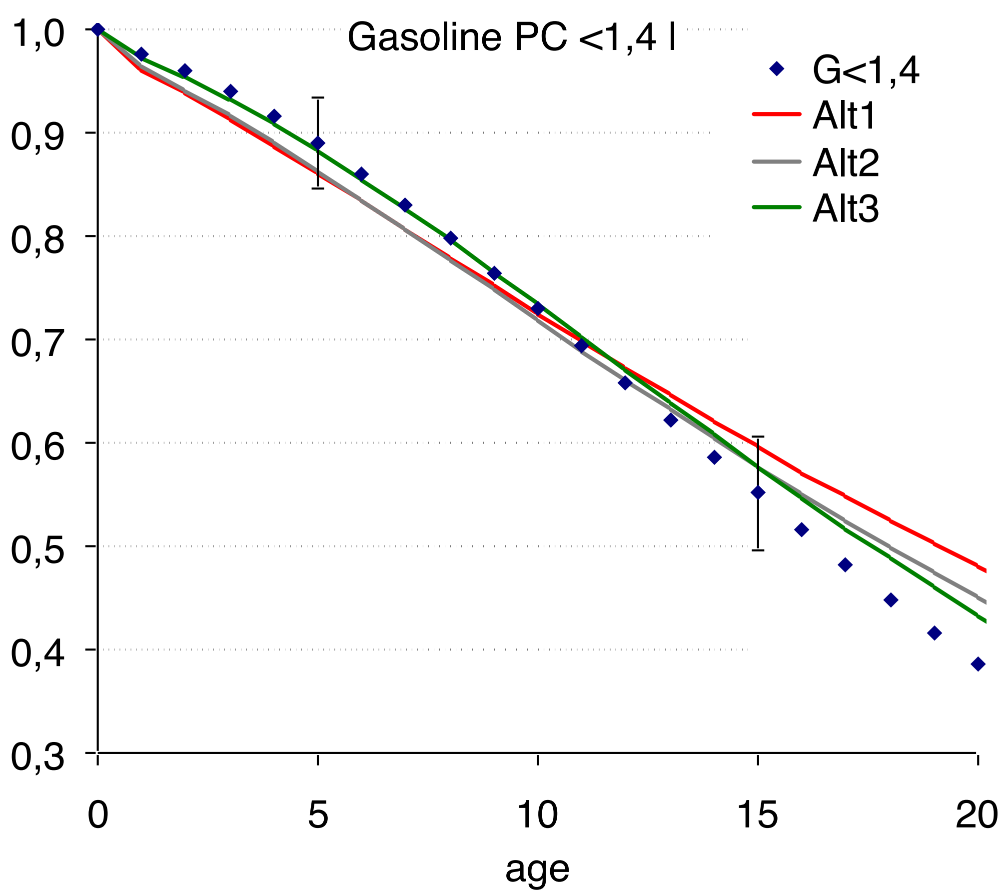
Passenger cars: standard deviation calculated as one third of the difference between national statistics and FLEETS

Light Duty Vehicles: uncertainty of stock proportionally allocated to stock of diesel and gasoline trucks.

Other vehicle categories: standard deviation was estimated as 7% of the average (assumption).

Technology classification variance – 1(2)

- Italy: Exact technology classification
- Poland: Technology classification varying, depended on variable scrappage rate



Boundaries Introduced:

Age of five years: ±5 perc.units

Age of fifteen years: ±10 perc.units

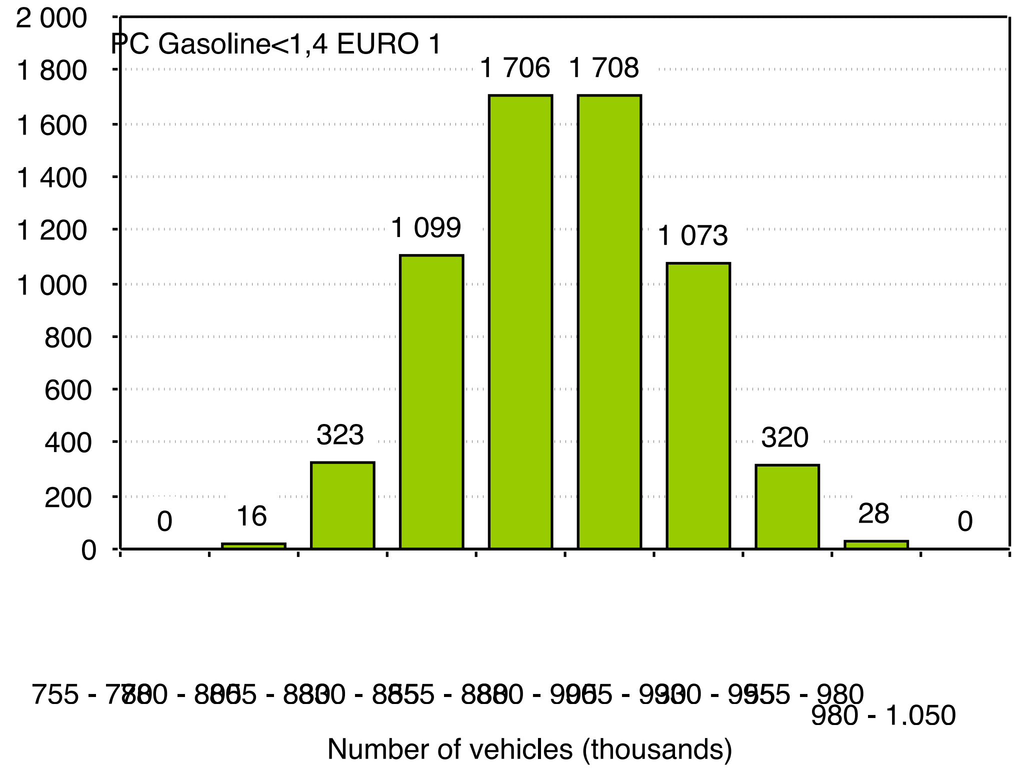
All scrappage rates respecting boundaries are accepted → these induce uncertainty

100 pairs finally selected by selecting percentiles

Fleet Breakdown Model

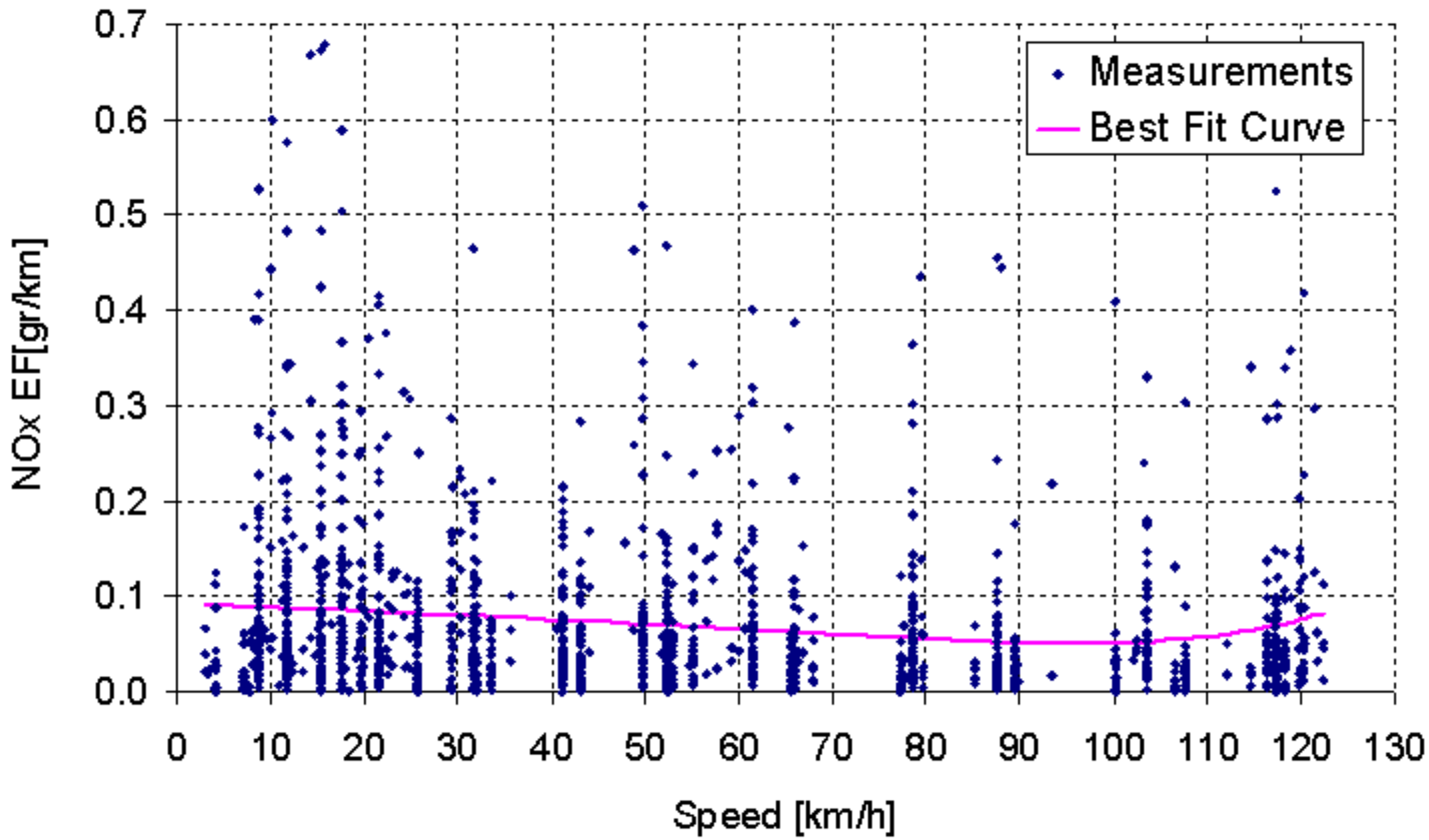
- The stock at technology level is calculated top-down by a fleet breakdown model (FBM), in order to respect total uncertainty at sector, subsector and technology level.
- That is, the final stock variance should be such as not to violate any of the given uncertainties at any stock level.
- The FBM operates on the basis of dimensionless parameters to steer the stock distribution to the different levels. Details in the report, p.44.

Example of technology classification variance



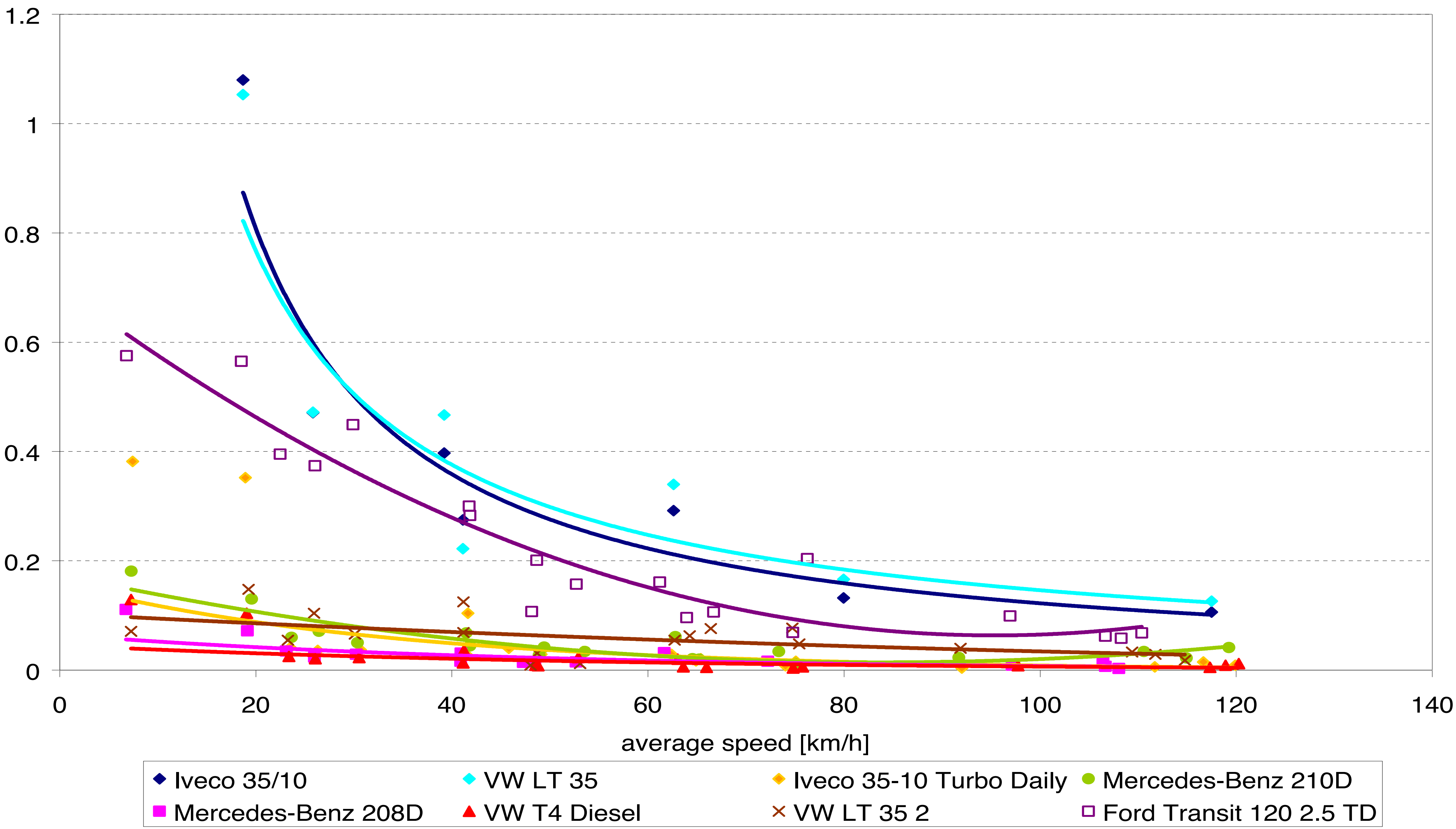
- Example for GPC<1.4 l Poland
- Standard deviation: 3.7%, i.e. 95% confidence interval is ±11%

Emission Factor Uncertainty

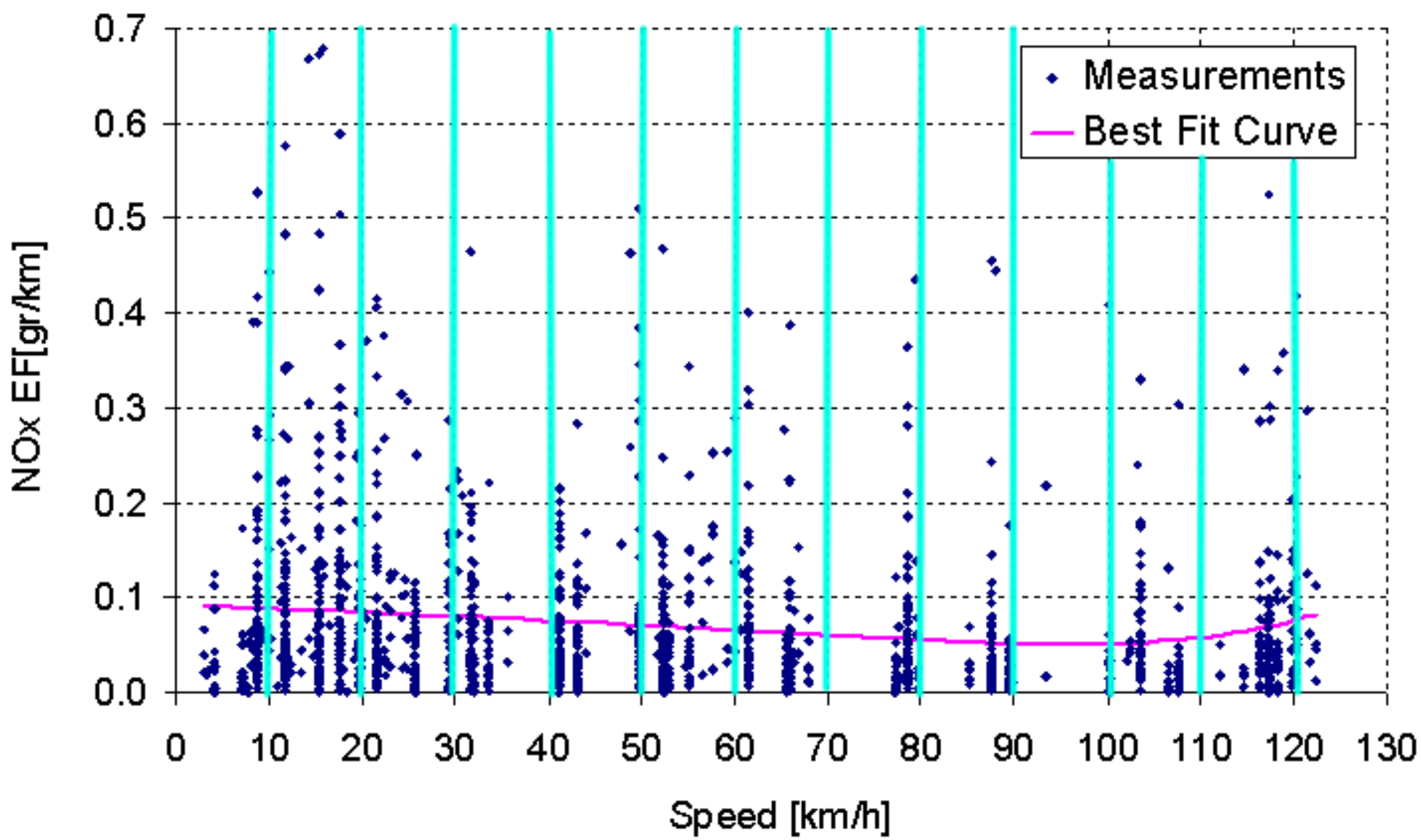


- Emission factor functions are derived from several experimental measurements over speed
- (Example Gasoline Euro 3 cars)

Performance of Individual Vehicles

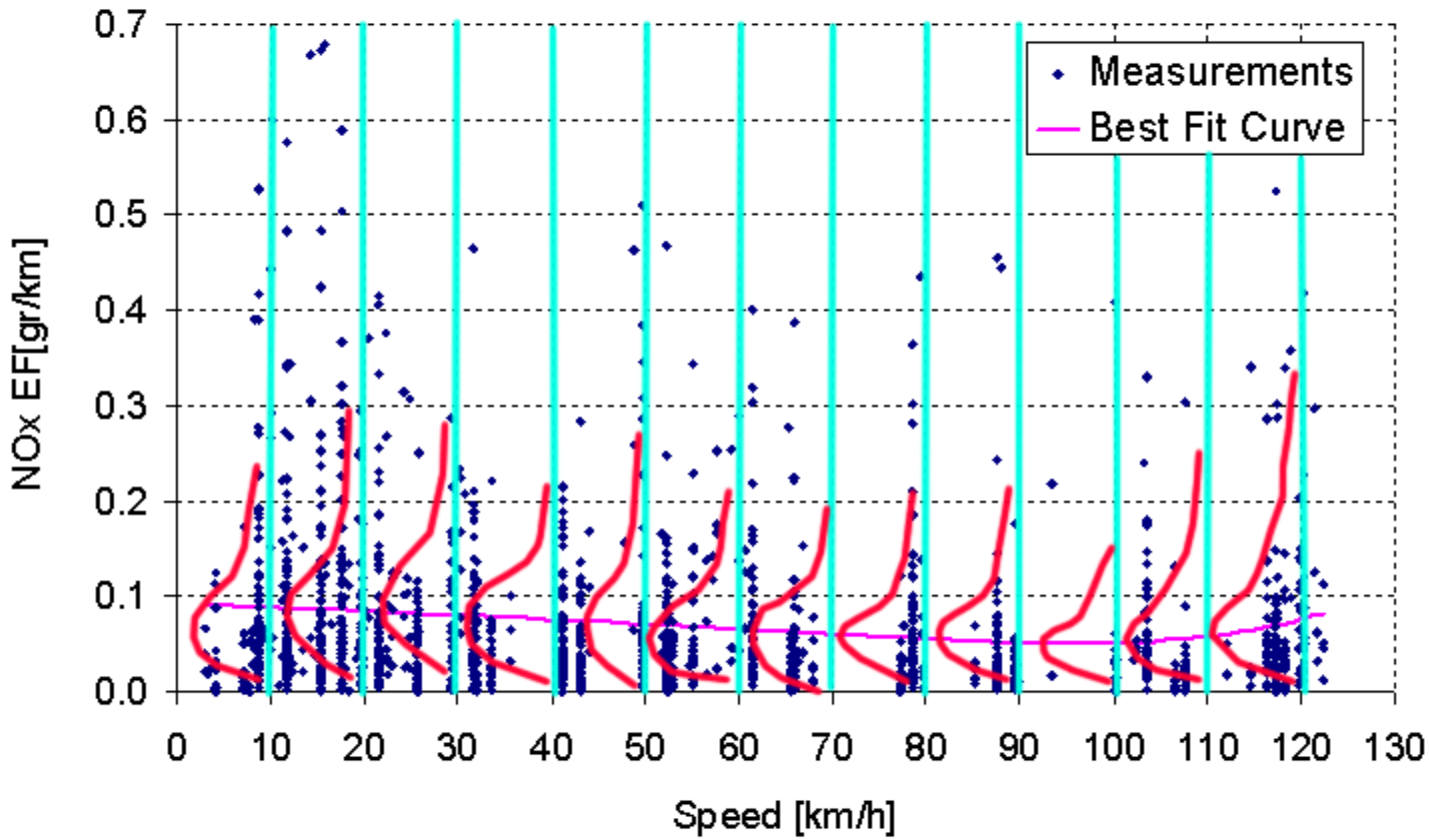


Emission Factor Uncertainty



- Fourteen speed classes distinguished from 0 km/h to 140 km/h

Emission Factor Uncertainty



- A lognormal distribution is fit per speed class, derived by the experimental data. Parameters for the lognormal distribution are given for all pollutants and all vehicle technologies in the Annex A of the report.

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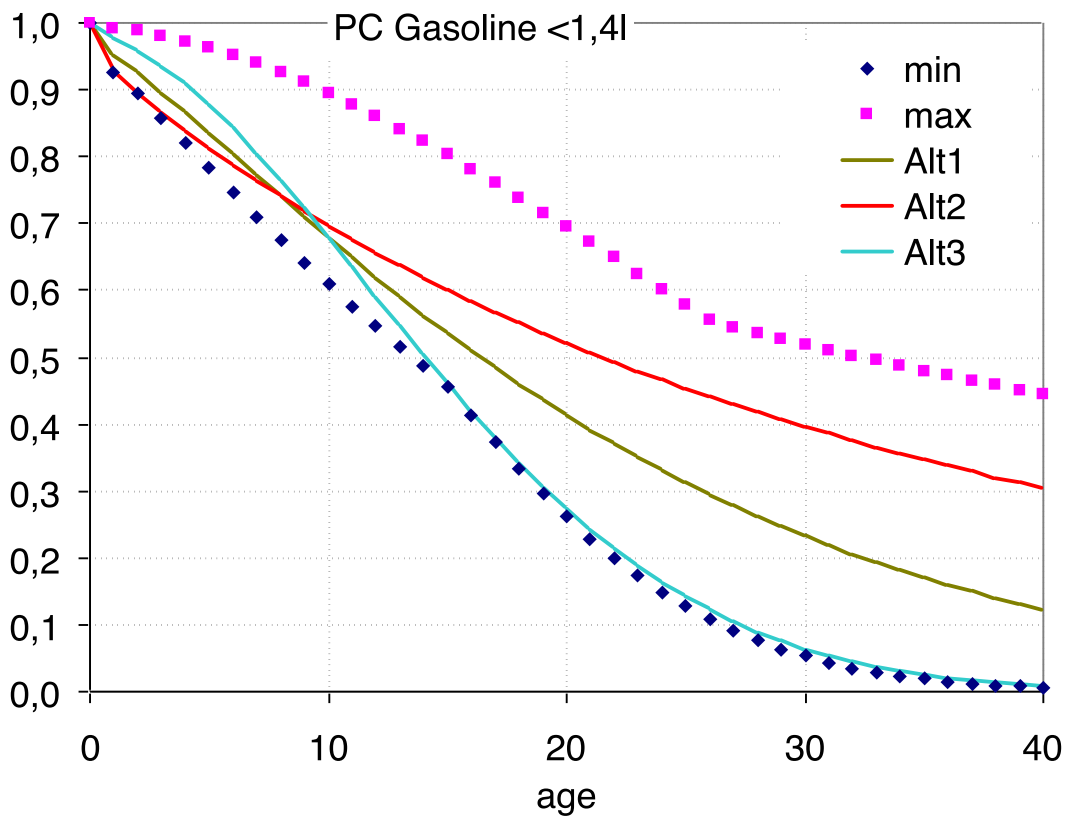
Mileage Uncertainty – M0

- Mileage is a function of vehicle age and is calculated as the product of mileage at age 0 (M0) and a decreasing function of age:

- M0 was fixed for Italy based on experimental data
- M0 was variable for Poland (s=0.1*M0) due to no experimental data available

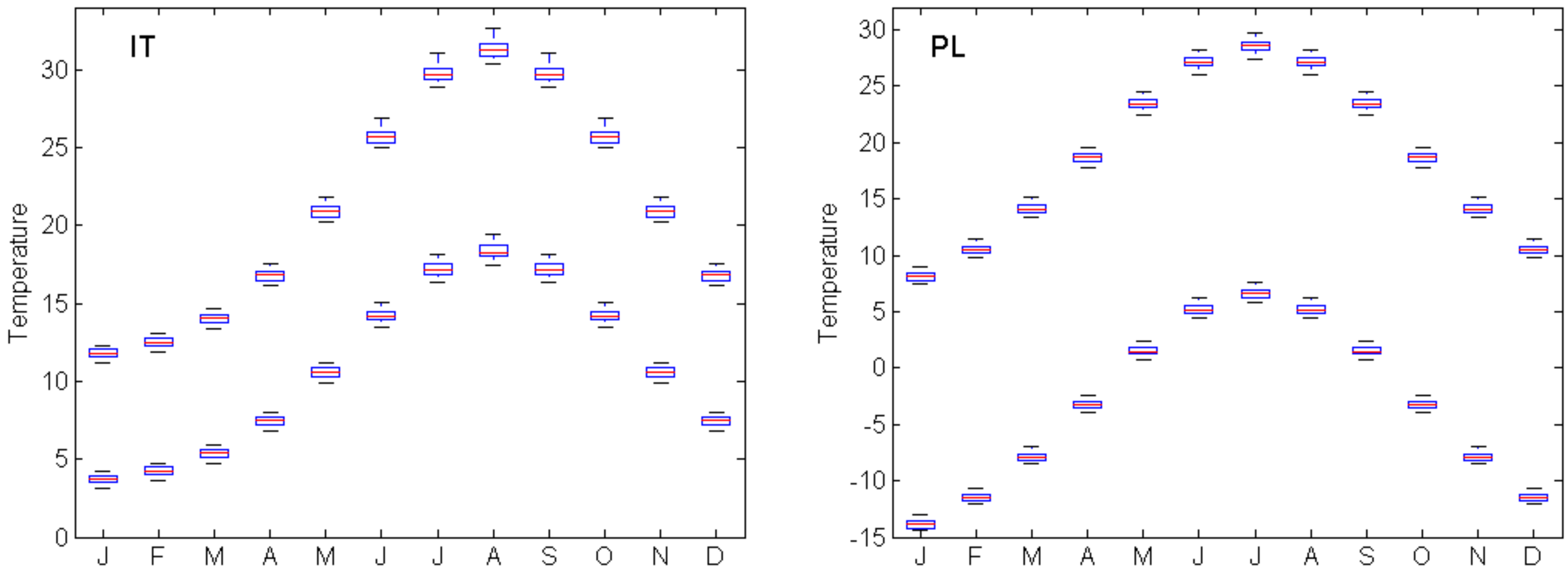
Mileage Uncertainty – Age



- The uncertainty in the decreasing mileage function with age was assessed by utilizing data from all countries (8 countries of EU15)
- The boundaries are the extents from the countries that submitted data
- Bm and Tm samples were selected for all curves that respected the boundaries

Other variables - temperature

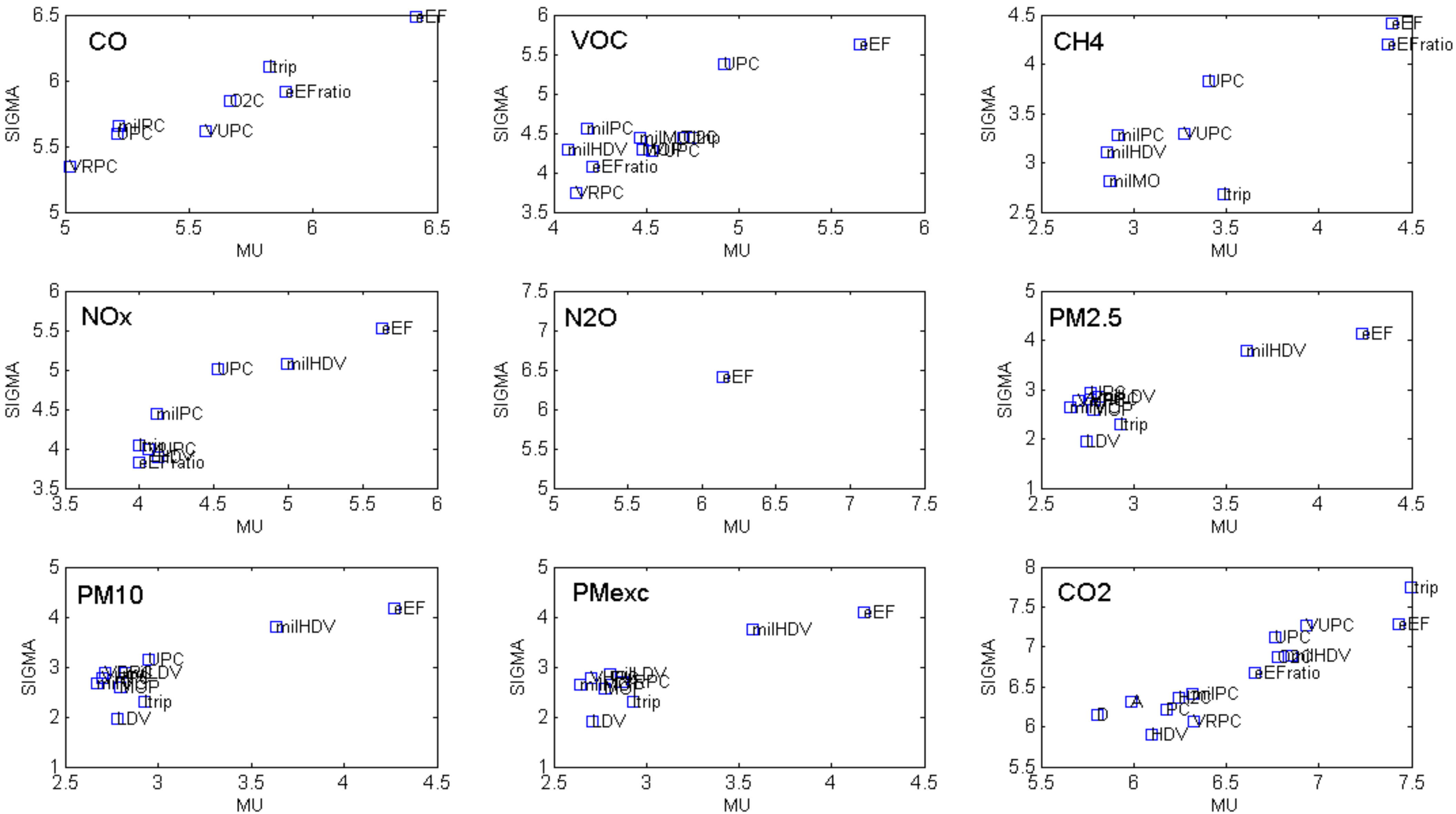
- Uncertainty of other variables was quantified based on literature data where available or best guess assumptions, when no data were available.
- Models were built for the temperature distribution over the months for the two countries.



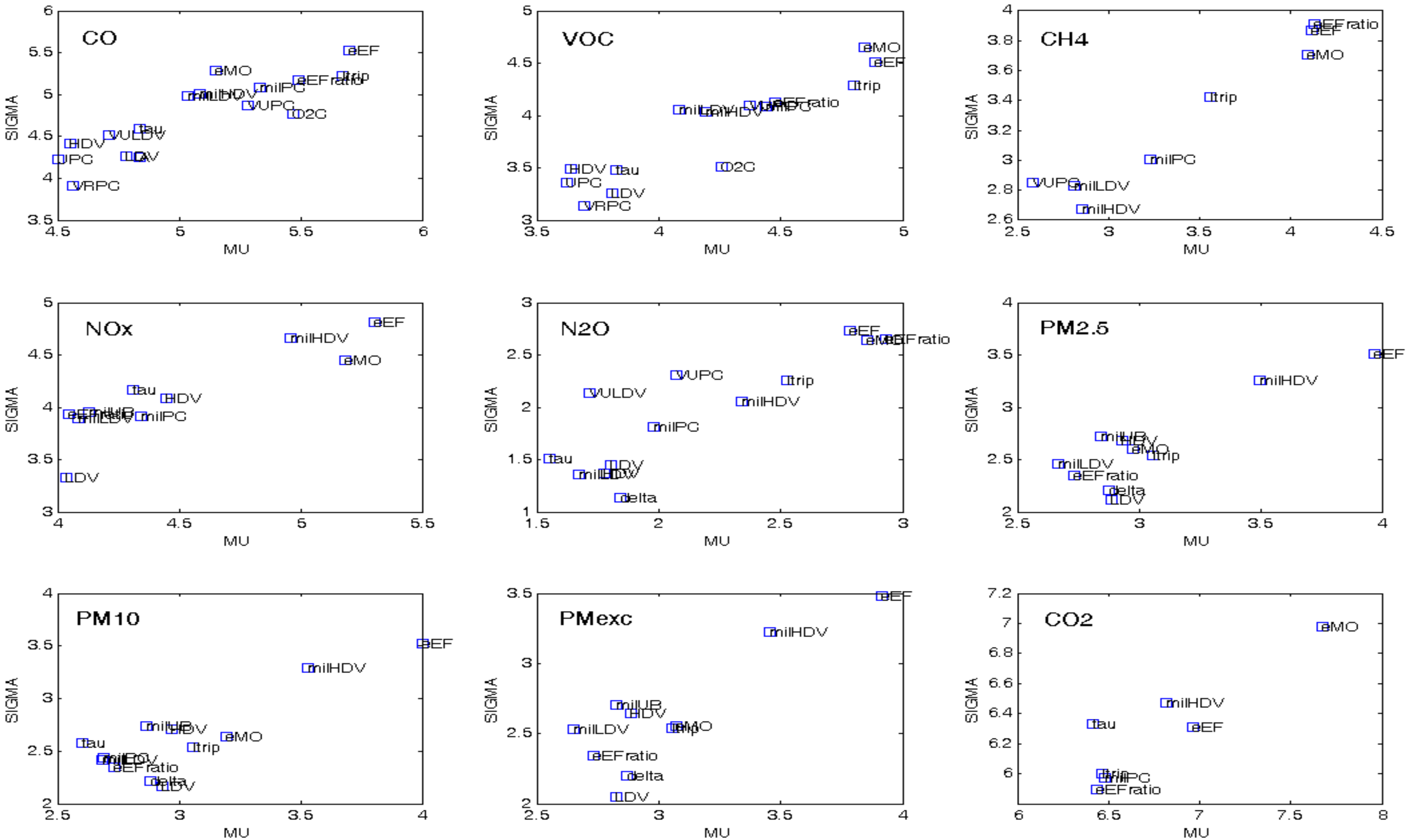
Statistical approach

1. Prepare the Monte Carlo sample for the screening experiment using the Morris design.
2. Execute the Monte Carlo simulations and collect the results.
3. Compute the sensitivity measures corresponding to the elementary effects in order to isolate the non-influential inputs.
4. Prepare the Monte Carlo sample for the variance-based sensitivity analysis, for the influential variables identified important in the previous step.
5. Execute the Monte Carlo simulations and collect the results
6. Quantify the importance of the uncertain inputs, taken singularly as well as their interactions.
7. Determine the input factors that are most responsible for producing model outputs within the targeted bounds of fuel consumption.

Results – Screening test Italy



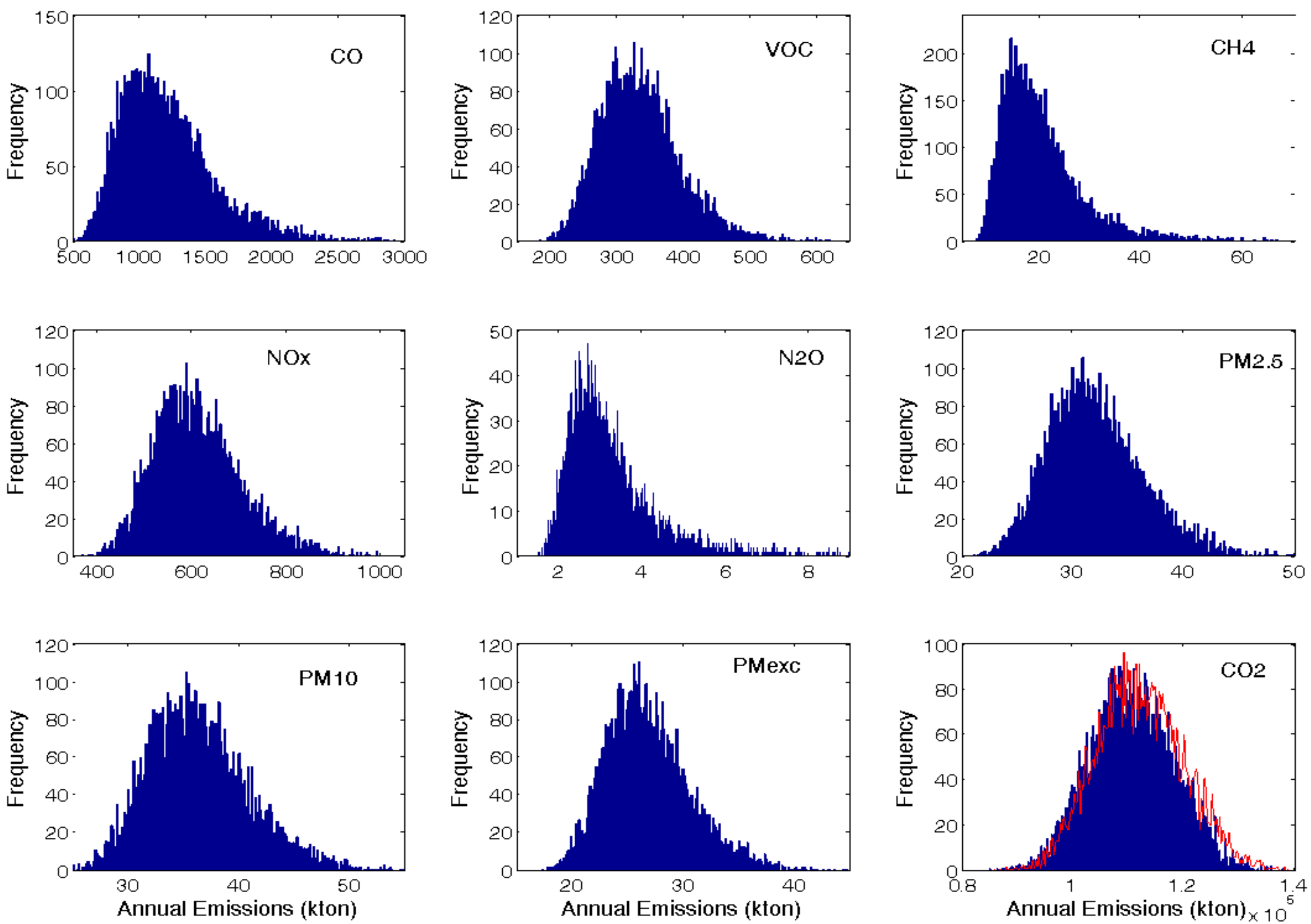
Results – Screening test Poland



Results – Influential Variables

Variable	Significant for Italy	Significant for Poland
Hot emission factor	☐	☐
Cold overemission	☐	☐
Mean trip distance	☐	☐
Oxygen to carbon ratio in the fuel	☐	☐
Population of passenger cars	☐	-
Population of light duty vehicles	☐	☐
Population of heavy duty vehicles	☐	☐
Population of mopeds	☐	-
Annual mileage of passenger cars	☐	☐
Annual mileage of light duty vehicles	☐	☐
Annual mileage of heavy duty vehicles	☐	☐
Annual mileage of urban busses	-	☐
Annual mileage of mopeds/motorcycles	☐	-
Urban passenger car speed	☐	☐
Highway passenger car speed	☐	-
Rural passenger car speed	☐	-
Urban speed of light duty vehicles	☐	-
Urban share of passenger cars	☐	-
Urban speed of light duty vehicles	-	☐
Urban speed of busses	-	☐
Annual mileage of vehicles at the year of their registration	-	☐
The split between diesel and gasoline cars	-	☐
Split of vehicles to capacity and weight classes	-	☐
Allocation to different technology classes	-	☐

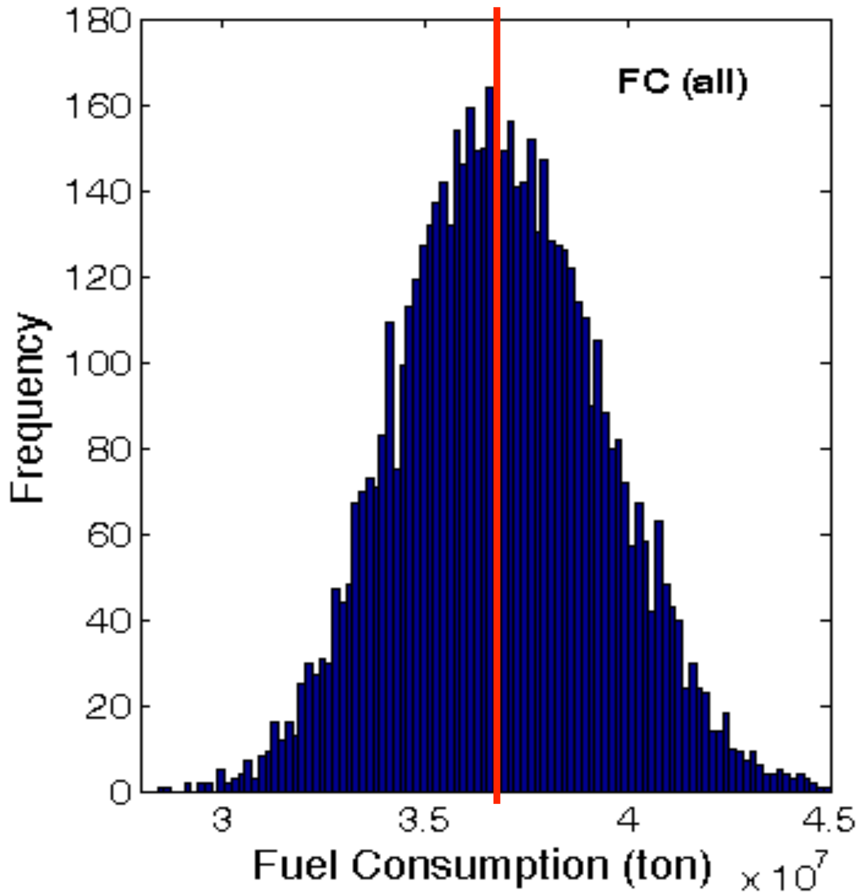
Results – total uncertainty Italy w/o fuel correction

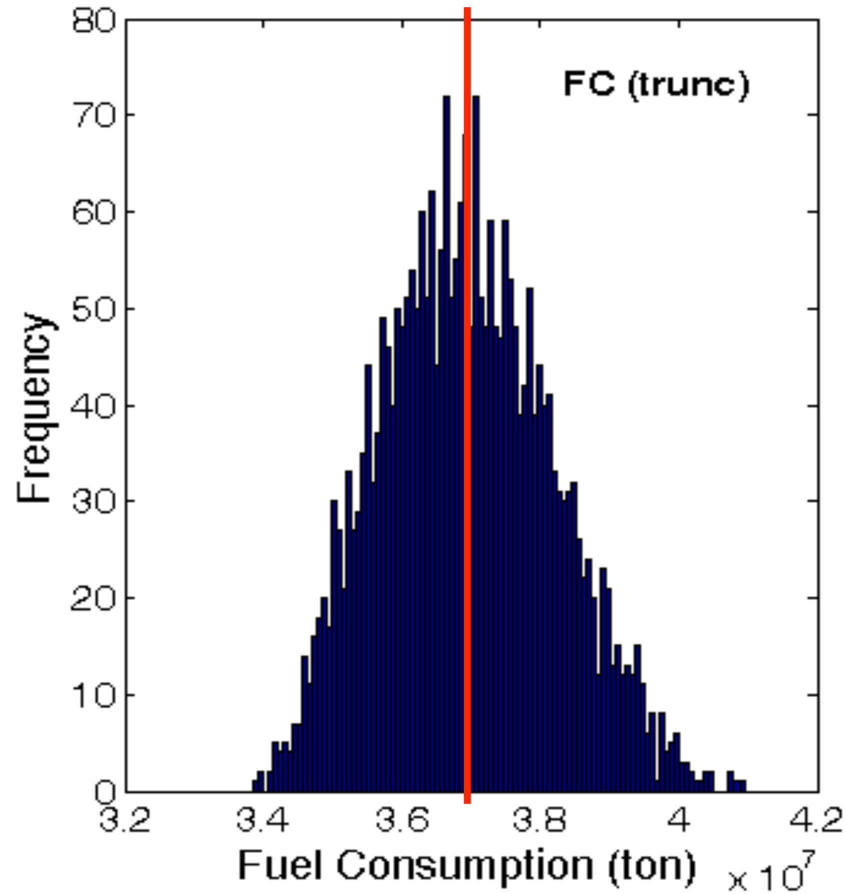


Results – Descriptive statistics of Italy w/o fuel correction

	CO	VOC	CH4	NOX	N2O	PM2.5	PM10	PMexh	FC	CO2	CO2e
Mean (t)	1,215	335	21	613	3.2	32	36	27	36,885	110,570	111,999
Median	1,150	329	19	603	2.9	32	36	26	36,828	110,357	111,751
St. Dev.	371	60	9	92	1.1	4	5	4	2,484	7,596	7,902
Coef. Var. (%)	30	18	44	15	33	13	13	14	7	7	7

Results – Necessary fuel correction for Italy

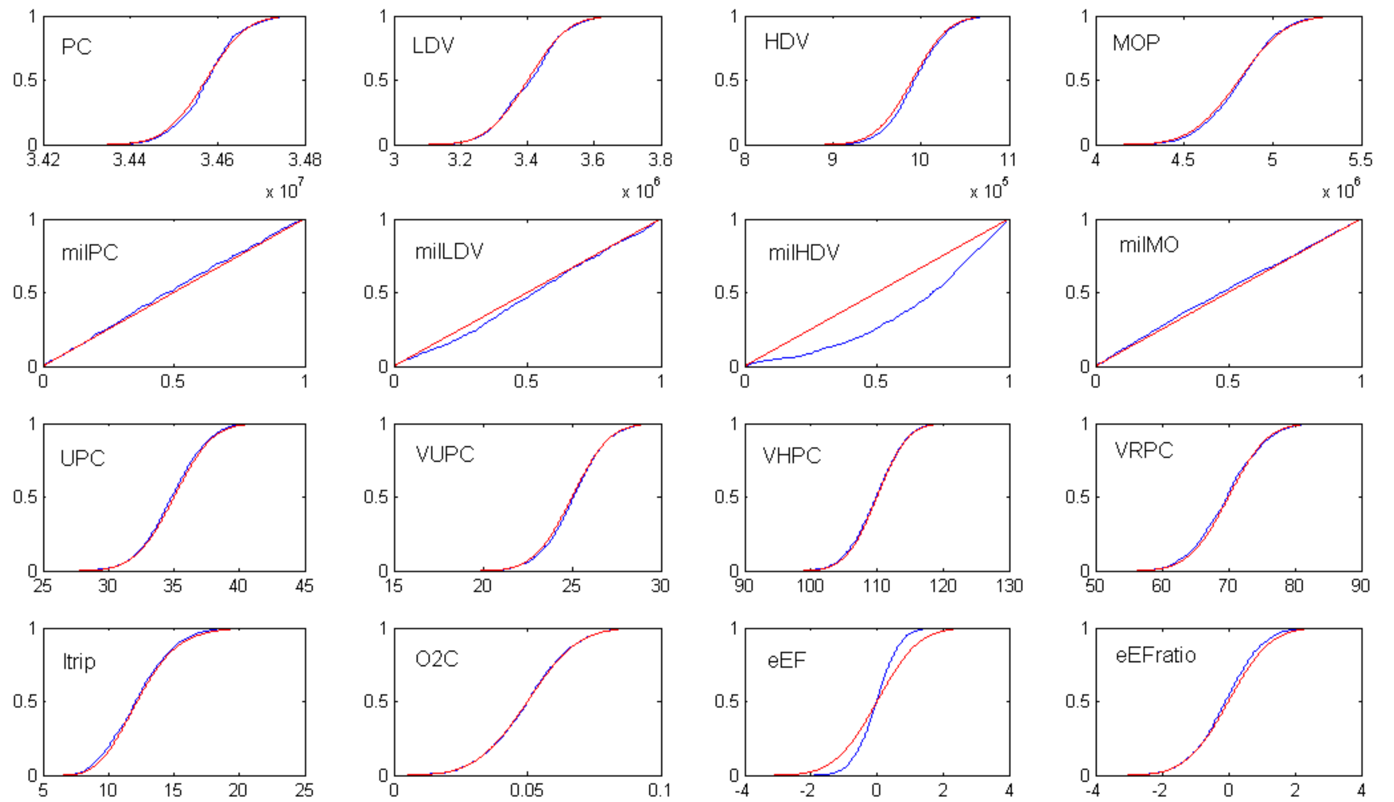




Unfiltered dataset: Std Dev = 7% of mean

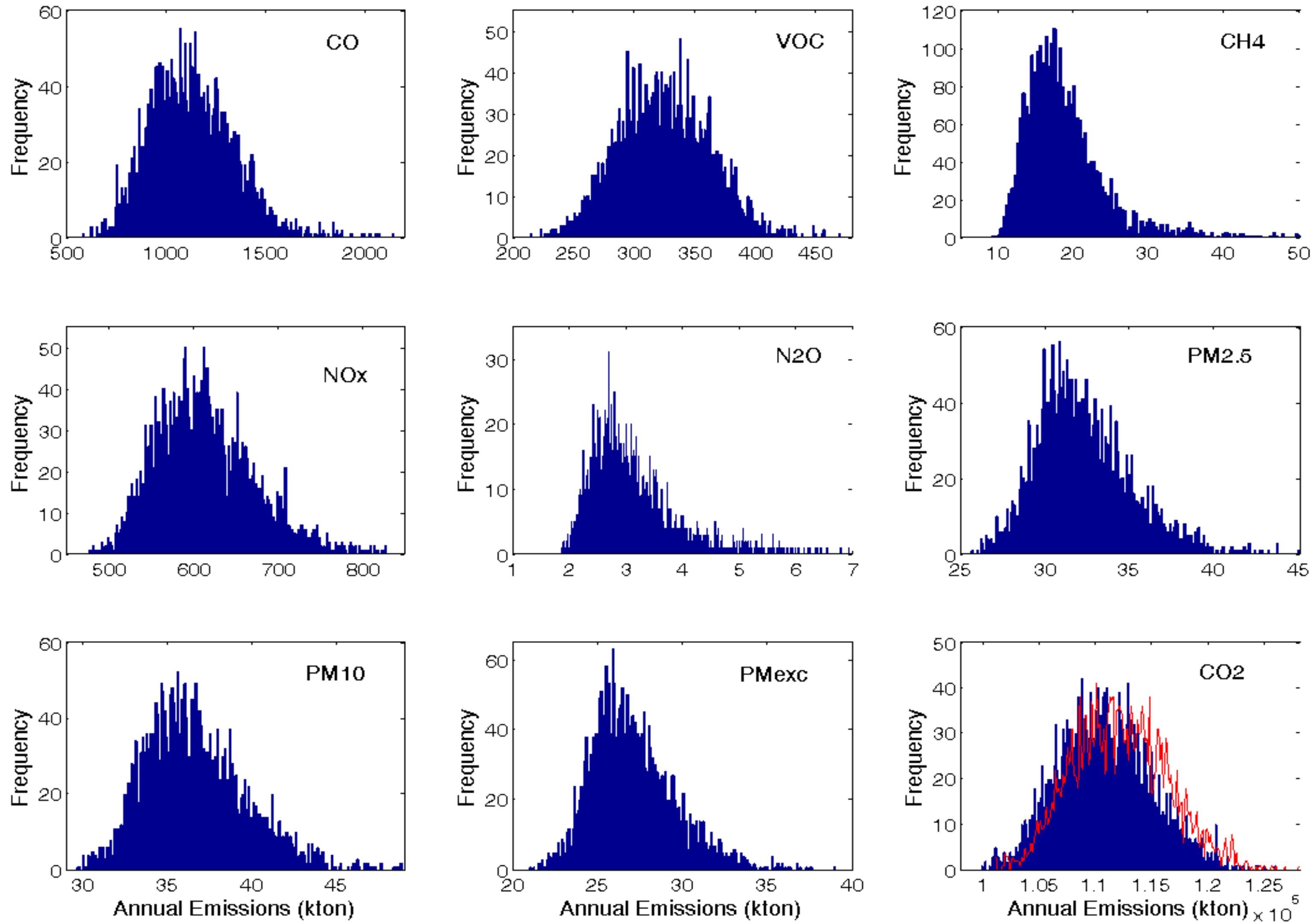
Filtered dataset: 3 Std Dev = 7% of mean

Correction of sample required

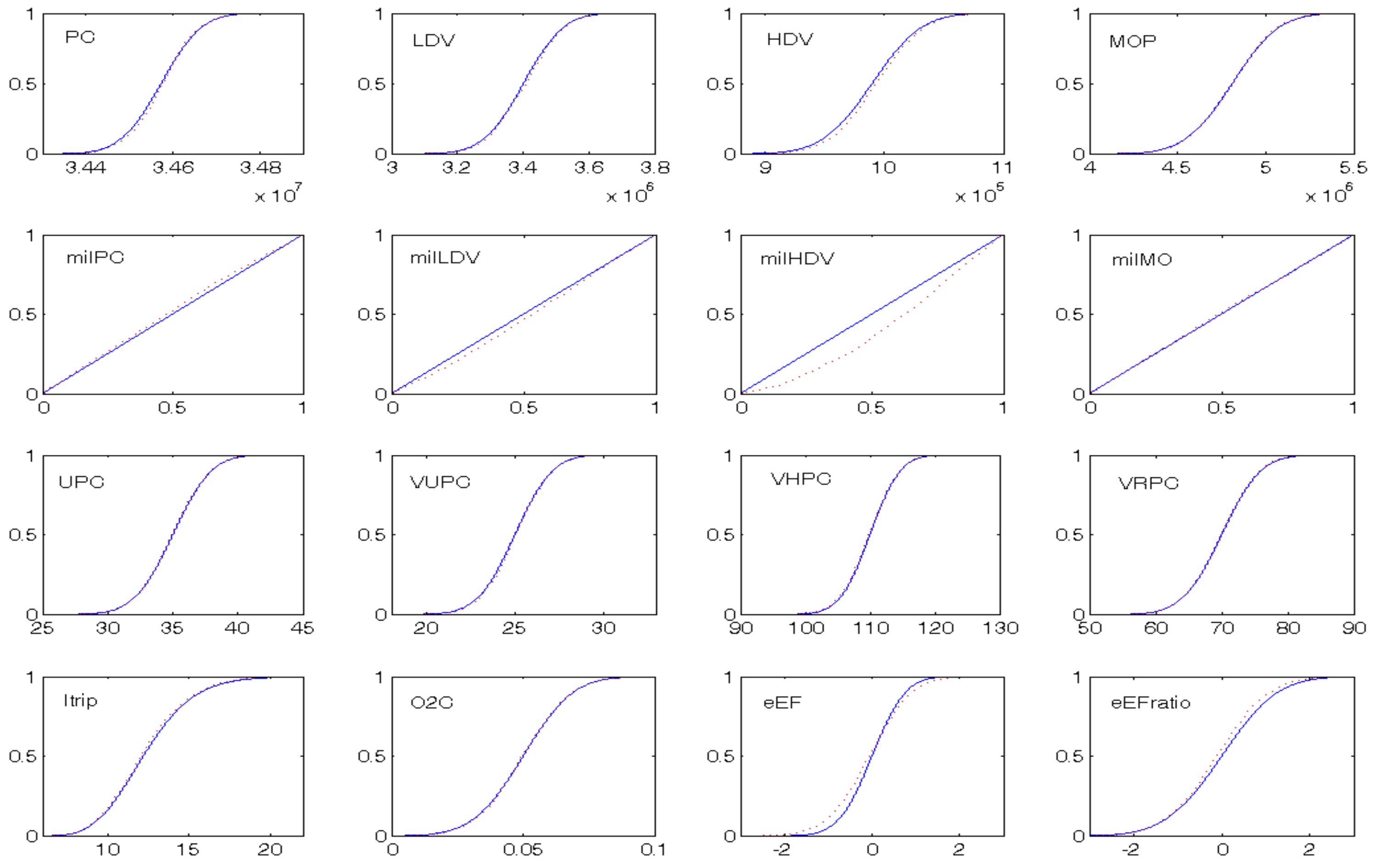


- Cumulative distributions of unfiltered (red) and of filtered (blue) datasets
- eEF, milHDV and milLDV are not equivalent
- A corrected dataset was built to respect the fuel consumption induced limitations

Results – total uncertainty Italy with corrected sample



Confirmation of corrected sample



Results – Descriptive statistics of Italy with corrected sample

	CO	VOC	CH4	NOx	N2O	PM2.5	PM10	PMexh	FC	CO2	CO2e
Mean	1,134	325	19	614	3.1	32	37	27	36,945	110,735	112,094
Median	1,118	324	18	608	2.9	32	36	27	36,901	110,622	111,941
St. Dev.	218	38	7	59	0.8	3	3	3	1,241	4,079	4,203
Variation (%)	19	12	34	10	26	9	8	9	3	4	4

Italy – Contribution of items to total uncertainty 1(2)

VOC	SI	STI	NOX	SI	STI	PM2.5	SI	STI	PM10	SI	STI	PMexh	SI	STI
eEF	0.63	0.78	eEF	0.76	0.85	eEF	0.72	0.86	eEF	0.72	0.84	eEF	0.72	0.86
ltrip	0.08	0.22	milHDV	0.12	0.22	milHDV	0.08	0.22	milHDV	0.08	0.21	milHDV	0.09	0.23
eEFratio	0.05	0.15	HDV	0.01	0.08	ltrip	0.01	0.13	ltrip	0.01	0.13	ltrip	0.01	0.14
milMO	0.05	0.17	PC	0	0.08	HDV	0.01	0.12	HDV	0.01	0.11	HDV	0.01	0.14
VUPC	0.02	0.16	ltrip	0	0.08	eEFratio	0.01	0.13	milPC	0.01	0.12	eEFratio	0.01	0.14
O2C	0.02	0.15	LDV	0	0.08	LDV	0.01	0.12	LDV	0.01	0.11	LDV	0.01	0.12
HDV	0.01	0.13	VHPC	0	0.1	milPC	0.01	0.13	eEFratio	0.01	0.13	milPC	0.01	0.14
MOP	0.01	0.14	VUPC	0	0.08	PC	0	0.13	PC	0.01	0.13	milMO	0.01	0.12
milHDV	0.01	0.14	O2C	0	0.08	milMO	0	0.11	milMO	0.00	0.10	PC	0.00	0.14
LDV	0.01	0.12	milPC	0	0.08	milLDV	0	0.12	milLDV	0.00	0.12	milLDV	0.00	0.13
PC	0	0.15	UPC	0	0.08	VHPC	0	0.13	VHPC	0.00	0.12	VHPC	0.00	0.14
VRPC	0	0.15	MOP	0	0.09	MOP	0.00	0.13	MOP	0.00	0.12	MOP	0.00	0.15
milPC	0	0.14	eEFratio	0	0.1	O2C	0	0.11	O2C	0	0.1	O2C	0	0.12
VHPC	0	0.13	milMO	0	0.07	UPC	0	0.12	UPC	0	0.11	UPC	0	0.13
milLDV	0	0.14	VRPC	0	0.1	VUPC	0	0.12	VRPC	0	0.12	VRPC	0	0.13
UPC	0	0.14	milLDV	0	0.08	VRPC	0	0.12	VUPC	0	0.11	VUPC	0	0.13
ΣSi	**0.91**	**3.03**		**0.91**	**2.27**		**0.87**	**2.78**		**0.87**	**2.69**		**0.88**	**2.96**

Italy – Contribution of items to total uncertainty 2

CO	SI	STI	N2O	SI	STI	CH4	SI	STI	CO2	SI	STI	FC	SI	STI
eEF	0.44	0.56	eEFratio	0.59	0.76	eEFratio	0.61	0.76	eEF	0.40	0.51	eEF	0.43	0.54
eEFratio	0.19	0.29	ltrip	0.06	0.37	eEF	0.13	0.29	eEFratio	0.10	0.22	eEFratio	0.11	0.24
ltrip	0.05	0.21	VUPC	0.06	0.23	ltrip	0.03	0.26	milHDV	0.09	0.2	milHDV	0.09	0.21
O2C	0.03	0.16	eEF	0.04	0.16	VUPC	0.01	0.19	milPC	0.05	0.17	milPC	0.05	0.17
VUPC	0.03	0.17	milHDV	0.01	0.14	HDV	0	0.16	ltrip	0.04	0.21	ltrip	0.04	0.21
milMO	0.01	0.13	milPC	0.01	0.13	milMO	0	0.13	O2C	0.04	0.16	HDV	0.02	0.13
HDV	0.01	0.15	HDV	0	0.13	LDV	0	0.16	HDV	0.02	0.13	VUPC	0.01	0.11
LDV	0	0.12	MOP	0	0.18	MOP	0	0.18	VUPC	0.01	0.11	PC	0.01	0.12
VHPC	0	0.15	LDV	0	0.13	VHPC	0	0.21	PC	0.01	0.12	LDV	0.01	0.13
VRPC	0	0.17	milLDV	0	0.11	milHDV	0	0.16	LDV	0.01	0.12	UPC	0.01	0.14
MOP	0	0.17	milMO	0	0.11	VRPC	0	0.2	UPC	0.01	0.14	MOP	0.00	0.12
UPC	0	0.15	VRPC	0.00	0.18	UPC	0	0.16	MOP	0.00	0.12	milLDV	0.00	0.12
PC	0	0.14	UPC	0	0.13	PC	0	0.2	milLDV	0	0.12	VHPC	0	0.12
milHDV	0	0.12	VHPC	0	0.25	milLDV	0	0.13	VHPC	0	0.11	O2C	0	0.12
milPC	0	0.15	O2C	0	0.24	milPC	0	0.16	milMO	0	0.14	milMO	0	0.14
milLDV	0	0.1	PC	0	0.17	O2C	0	0.21	VRPC	0	0.12	VRPC	0	0.12
ΣSi	**0.79**	**2.94**		**0.79**	**3.44**		**0.80**	**3.58**		**0.78**	**2.68**		**0.79**	**2.72**

Results – Italy/Poland Comparison

Case	CO	VOC	CH4	NOx	N2O	PM2.5	PM10	PMexh	FC	CO2	CO2e
Italy w/o FC	30	18	44	15	33	13	13	14	7	7	7
Italy w. FC	19	12	34	10	26	9	8	9	3	4	4
Poland w/o FC	20	18	57	17	28	18	17	19	11	11	12
Poland w. FC	17	15	54	12	24	13	12	14	8	8	8

Comparison with Earlier Work

The improvements of the current study, in comparison to the previous one (Kioutsioukis et al., 2004) for Italy, include:

- use of the updated version of the COPERT model (version 4)
- incorporation of emission factors uncertainty for all sectors (not only PC & LDV) and all vehicle technologies through Euro 4 (Euro V for trucks)
- application of a more realistic fleet breakdown model due to the detailed fleet inventory available
- application of a detailed and more realistic mileage module based on the age distribution of the fleet (decomposition down to the technology level)
- inclusion of more uncertain inputs: cold emission factors, hydrogen-to-carbon ratio, oxygen-to-carbon ratio, sulphur level in fuel, RVP.
- validation of the output and input uncertainty

Conclusions – 1(3)

- The most uncertain emissions calculations are for CH4 and N2O followed by CO. The hot or the cold emission factor variance which explains most of the uncertainty. In all cases, the initial mileage value is a significant user-defined parameter.
- CO2 is calculated with the least uncertainty, as it directly depends on fuel consumption. It is followed by NOx and PM2.5 because diesel are less variable than gasoline emissions.
- The correction for fuel consumption within plus/minus one standard deviation is very critical as it significantly reduces the uncertainty of the calculation in all pollutants.
- The relative level of variance in Poland appears lower than Italy in some pollutants (CO, N2O). This is for three reasons, (a) Poland has an older stock and the variance of older technologies is smaller than new ones, (b) the colder conditions in Poland make the cold-start to be dominant, (c) artefact of the method as the uncertainty was not possible to quantify for some older technologies. Also, the contribution from PTWs much smaller than in Italy.
- Despite the relatively larger uncertainty in CH4 and N2O emissions, the uncertainty in total Greenhouse Gas emissions is dominated by CO2

Conclusions – 2(3)

The Italian inventory uncertainty is affected by:

- hot emission factors [eEF]: NOx (76%), PM (72%), VOC (63%), CO (44%), FC (43%), CO2 (40%), CH4 (13%)
- cold emission factors [eEFratio]: CH4 (61%), N2O (59%), CO (19%), FC (11%), CO2 (10%), VOC (5%)
- mileage of HDV [milHDV]: NOx (12%), PM (8-9%), FC (9%), CO2 (9%).
- mean trip length [ltrip]: VOC (8%), N2O (6%), CO (5%)

Conclusions – 3

The Polish inventory uncertainty is affected by:

- mileage parameter [eM0]: FC (68%), CO2 (67%), NOx (35%), VOC (27%), PM (25-31%), CO (22%), N2O (14%).
- cold emission factors [eEFratio]: CH4 (56%), N2O (48%), CO (15%), VOC (8%).
- hot emission factors [eEF]: PM (52-55%), NOx (49%), VOC (20%), CO (15%), CH4 (12%), N2O(11%), FC (10%), CO2 (9%).
- mean trip length [ltrip]: VOC (23%), CO (20%).
- the technology classification appears important for the uncertainty in conjunction to other variables

Recommendations

- There is little the Italian expert can do to reduce uncertainty. Most of it comes from emission factors
- Better stock and mileage description is required for Poland to improve the emission inventory.

More Information

- Report on COPERT uncertainty available at
  - Emisia web-site
  - TFEIP Transport expert panel web-site
- COPERT 4 Monte Carlo software version available
  - No (free) support provided
  - The report describes I/O for C4 MC version
  - Relatively data tedious