Comparison of Two Methods of Estimating Uncertainty in National Greenhouse Gas Inventories

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Introduction

- ❑ The parties to the UNFCCC Convention and its Kyoto Protocol were required to provide annual data on GHG emissions, according to the established **IPCC Guidelines**

- IPCC (1996) IPCC Guidelines for National Greenhouse Gas Inventories
- Good Practice Guidance and Uncertainty Management in National Greenhouse Inventories, IPCC, 2000
- IPCC Guidelines for National Greenhouse Gas Inventories, IPCC, 2006
- IPCC 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

- ❑ This is done in the form of the National Inventory Reports (NIRs), containing the GHG emission data in given year and revisions of the data for past years, recalculated according to new knowledge and methodology.

- ❑ Each NIR should
- provide a revision data series,
- take into account possible reduction or increase in the emissions, compared to the previous and to the base year,
- contain uncertainty assessment.

Motivation

- The uncertainty analysis can be performed using one of the two approaches: Tier 1 or Tier 2.
- The IPCCC guidelines for uncertainty assessment have evolved over the years, leading to the use of various approaches, inconsistency in the application of the approach, and often only partial or inaccurate analysis.
- This makes it difficult to compare uncertainty between individual reporting countries, but also to assess changes in uncertainty over time, as a reporting country may change the approach from revision to revision.
- Problems with the EU-15 uncertainty assessment: With the enlargement of the EU, the report had to cover the EU-28, and for a few years the EU-15 was analyzed separately (in addition to the analysis for the EU-28). It stopped in 2013 (NIR2015), and the uncertainty assessments for the EU-15 are no longer available.

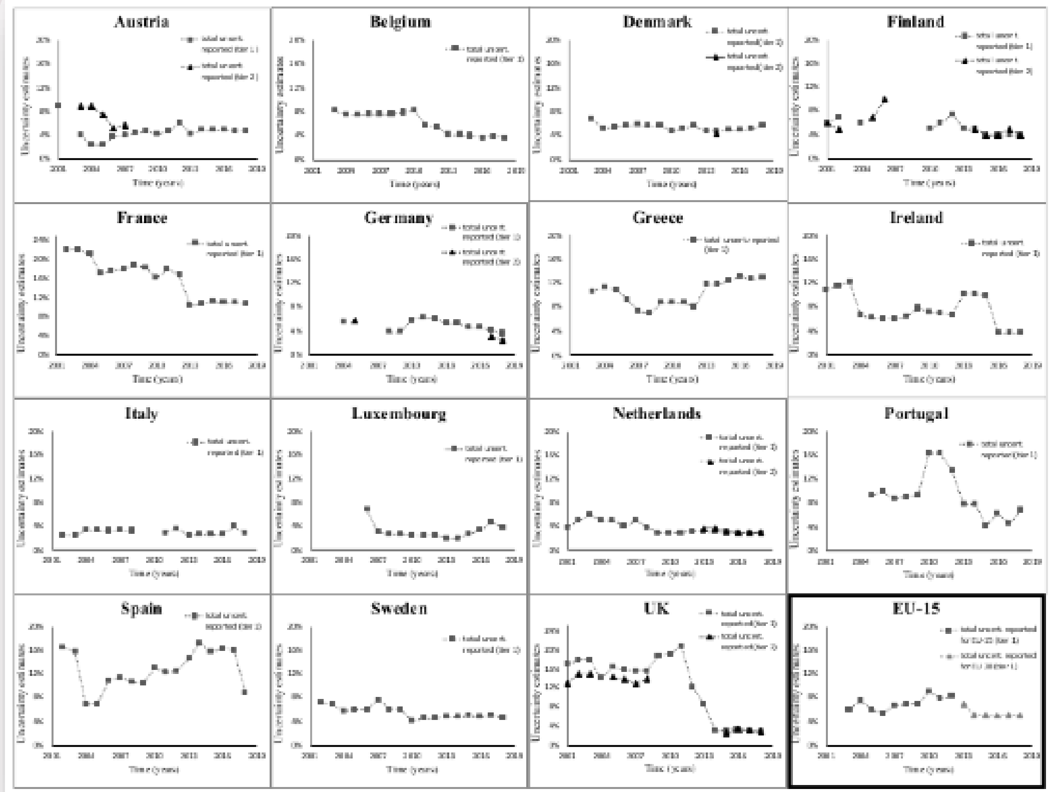

Fig. 1. The available NIR's total uncertainty assessments in national GHG inventories 2001-2018, for EU-15 individual member countries and the EU-15.

Motivation

- Uncertainty of reported revisions analysed separately
- All then-available revisions analyzed to assess changes in uncertainty
- Modeling changes in uncertainty over time: **two-step approach**
- Uncertainty in terms of learning
- Distinguishing between the uncertainty related to reported revisions and the uncertainty, related to emissions, in terms of errors in a **bivariate approach**

Approaches to assess uncertainty

- Z. Nahorski and W. Jęda, "Processing national CO2 inventory emission data and their total uncertainty estimates," Water, Air, and Soil Pollution: Focus, vol. 7, pp. 513–527, 2007. DOI: 10.1007/s11267-006-9114-6
- G. Marland, K. Hamal and M. Jonas, "How uncertain are estimates of CO2 emissions?" J. Industrial Ecology, vol. 13, 2009, pp. 4–7. DOI: 10.1111/j.1530- 9290.2009.00108.x
- K. Hamal, "Reporting GHG emissions: Change in uncertainty and its relevance for detection of emission changes," Interim Report IR-10-003, IIASA, Laxenburg, 2010
- Z. Nahorski and J. Jarnicka, "Modeling uncertainty structure of greenhouse gas inventories", Report RB/11/2010, SRI PAS, Warsaw, 2010
- J. Jarnicka and Z. Nahorski, "A method for estimating time evolution of precision and accuracy of greenhouse gases inventories from revised reports", in Proc. 4th Intl Workshop on Uncertainty in Atmospheric Emissions, Kraków, Poland, 2015, pp. 97–102
- **J. Jarnicka and Z. Nahorski, "Estimation of temporal uncertainty structure of GHG inventories for selected EU countries", In: M. Ganzha, L. Maciaszek, and M. Paprzycki (eds.) Proceedings of the 2016 FedCSiS Conference ACSIS, vol. 8, pp. 459– 465, IEEE (2016), DOI: 10.15439/2016F318**
- P. Żebrowski, M. Jonas, and E. Rovenskaya, "Assessing the improvement of greenhouse gases inventories: can we capture diagnostic learning?" in Proc. 4th Intl Workshop on Uncertainty in Atmospheric Emissions, Kraków, Poland, 2015, pp. 90–96
- J. Jarnicka and P. Żebrowski, Learning in greenhouse gas emission inventories in terms of uncertainty improvement over time, Mitigation and Adaptation Strategies for Global Change (2019) 24:1143–1168, DOI:10.1007/s11027-019-09866-5
- **J. Jarnicka, Z. Nahorski: Estimation of means in a bivariate discrete-time process. In: K.T. Atanassov, et al. (eds.) Uncertainty and Imprecision in Decision Making and Decision Support: Cross Fertilization, New Models and Applications. Advances in Intelligent Systems and Computing, vol. 559, pp. 3–11. Springer (2018). DOI:10.1007/978-3-319-65545-11**
- **J. Jarnicka, Z. Nahorski (2021) Bivariate Analysis of Errors in National Inventory Reporting. In: K. Atanassov et al. (eds) Uncertainty and Imprecision in Decision Making and Decision Support: New Challenges, Solutions and Perspectives. IWIF- SGN 2018. Advances in Intelligent Systems and Computing, vol 1081. Springer, Cham. DOI:10.1007/978-3-030-47024-1-39**

Two-step approach: method 1

Model 1

$$\begin{matrix} \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \dots & E^n_{y_j} & E^{n+1}_{y_j} & \dots & E^{y_j}_{y_j} & 0 & \dots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \dots & E^n_{y_J} & E^{n+1}_{y_J} & \dots & E^{y_j}_{y_J} & E^{y_j+1}_{y_J} & \dots & E^{y_J}_{y_J} \end{matrix}$$

We assume that each revision consists of the 'real emission' (deterministic) and uncertainty (stochastic)

$$E^n_{y_j} = D^n_{y_j} + S^n_{y_j}$$

so, its uncertatinty

$$S^n_{y_j} = E^n_{y_j} - D^n_{y_j}$$

estimated by the smoothing spline

Step 1:

Estimated using the variance from the smoothing spline

$$S^n_{y_J} = E^n_{y_J} - \mathrm{Sp}_{y_J} \quad \text{where} \quad S^n_{y_J} \sim \mathcal{N}(0, \sigma_{y_J})$$

$$S^n_{y_j} = E^n_{y_j} - \mathrm{Sp}_{y_J} \quad \text{where} \quad S^n_{y_j} \sim \mathcal{N}\left(0, \sigma_{y_j}\right) \quad j = 1, \dots, J-1$$

Nonparametric approach

Step 2:

Estimating the remaining σ_{y_j} $j = 1, \dots, J-1$

$$\hat{\sigma}_{y_j} = \sqrt{\sigma^2_{y_J} + \beta(y_J - y_j)^{\gamma+2}}$$

with parameters estimated from

$$\alpha_j = \beta(y_J - y_j)^{\gamma}$$

where

$$\hat{\alpha}_j = \frac{1}{(y_J - y_j)^2}\left(\frac{1}{N_J}\sum (E^n_{y_j} - \mathrm{Sp}_{y_J})^2 - (\sigma_{y_J})^2\right)$$

The uncertainties can be estimated as follows

$$u_j = \frac{\hat{\sigma}_{y_j}}{\mathrm{Sp}_{y_j}}. \quad j = 1, \dots, J-1$$

Parametric model

Two-step approach: method 1

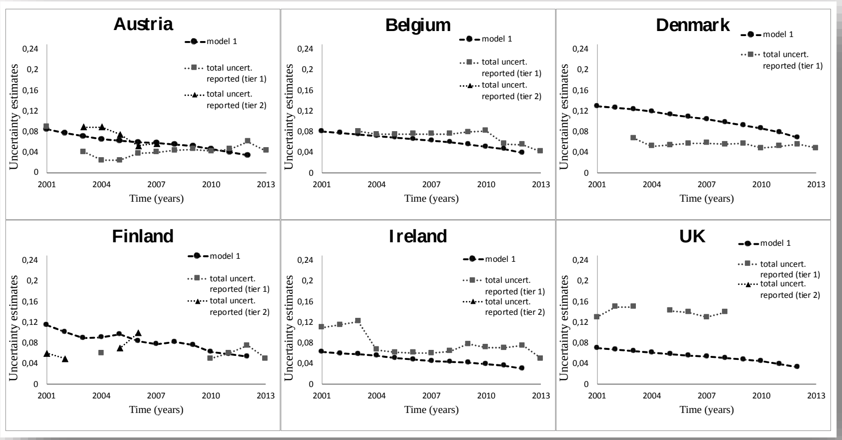

Fig. 2. Results of uncertainty estimation for the 2001-**2013** CO_2 inventories (without LULUCF), for six selected EU-15 countries, compared to the NIR's total uncertainties.

Uncertainty assessments for 2001-**2012**

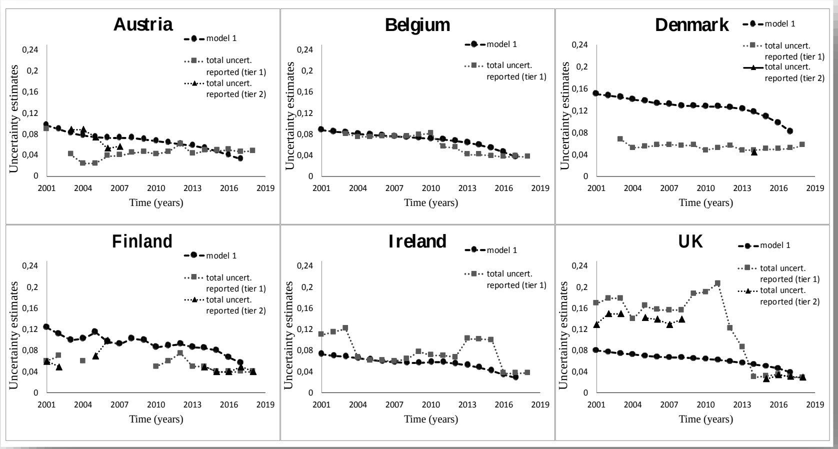

Fig. 3. Results of uncertainty estimation for the 2001-**2018** CO_2 inventories (without LULUCF), for the same six EU-15 countries, compared to the NIR's total uncertainties.

Uncertainty assessments for 2001-**2017**

Two-step approach: method 2

Model 2

$$\begin{array}{cccccccc} \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \ldots & E^{n}_{y_j} & E^{n+1}_{y_j} & \ldots & E^{y_j}_{y_j} & 0 & \ldots & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \ldots & E^{n}_{y_J} & E^{n+1}_{y_J} & \ldots & E^{y_j}_{y_J} & E^{y_j+1}_{y_J} & \ldots & E^{y_J}_{y_J} \end{array}$$

We assume that each revision consists of the 'real emission' (deterministic) and uncertainty (stochastic)

$$E^n_{y_j} = D^n_{y_j} + S^n_{y_j}$$

so, its uncertatinty

$$S^n_{y_j} = E^n_{y_j} - D^n_{y_j}$$

estimated by the smoothing spline

Step 1:

$$S^n_{y_j} = E^n_{y_j} - \mathrm{Sp}_{y_J}, \quad \text{where} \quad S^n_{y_j} \sim \mathcal{N}(0, \tilde{\sigma}_{y_j})$$

$$j = 1, \ldots, J$$

Nonparametric approach

Step 2:

Estimating all $\tilde{\sigma}_{y_j}$ $\quad j = 1, \ldots, J$

$$\tilde{\sigma}_{y_j} = \sqrt{\sigma^2_{y_J} + \beta(y_J - y_j + 1)^{\gamma+2}},$$

with parameters estimated from

$$\tilde{\alpha}_j = \beta(y_J - y_j + 1)^{\gamma}$$

where

$$\hat{\tilde{\alpha}}_j = \frac{1}{(y_J - y_j + 1)^2}\left(\frac{1}{N_J}\sum(E^n_{y_j} - \mathrm{Sp}_{y_J})^2 - (\sigma_{y_J})^2\right)$$

The uncertainties can be estimated as follows

$$\tilde{u}_j = \frac{\hat{\tilde{\sigma}}_{y_j}}{\mathrm{Sp}_{y_j}}, \quad j = 1, \ldots, J$$

Parametric model

Two-step approach: method 2

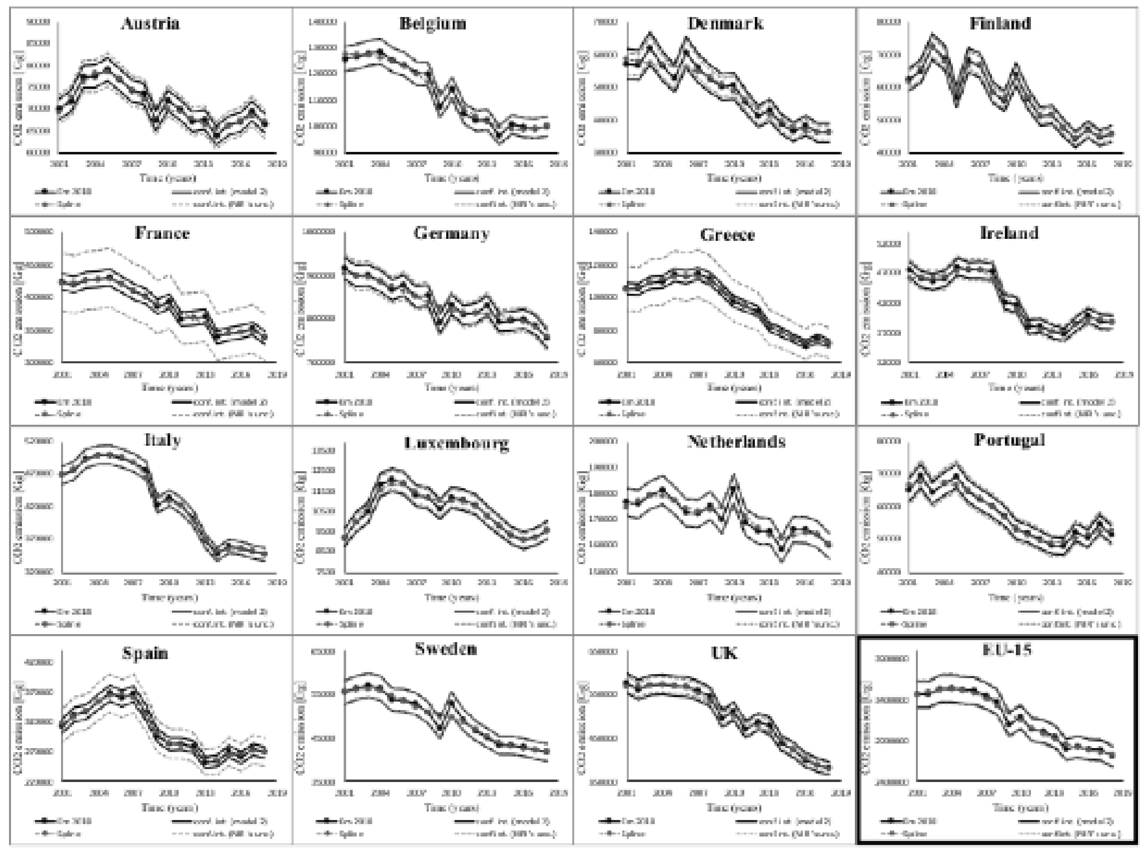

Fig. 4. The most recent revision and its confidence intervals: model 2 uncertainty estimate vs. NIR's total uncertainty.

Results: comparison of method 1 and method 2

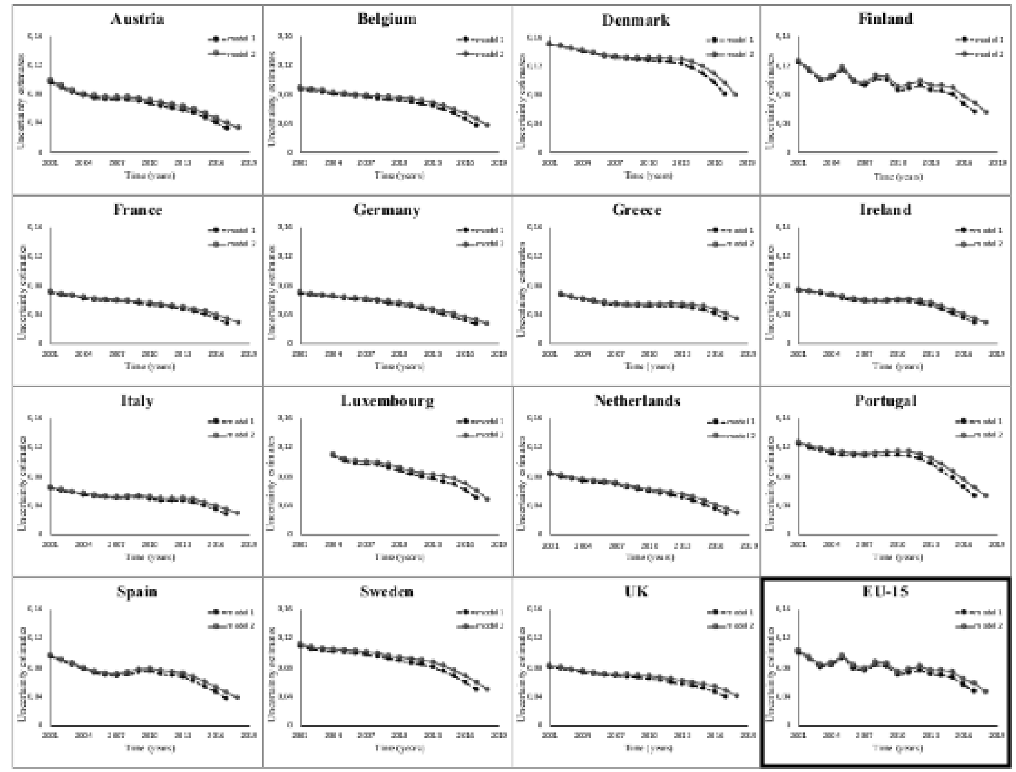

Fig. 5. Uncertainty estimates for **2001-2018** CO_2 inventories (without LULUCF): model 1 and model 2 results for EU-15 individual member countries and the EU-15.

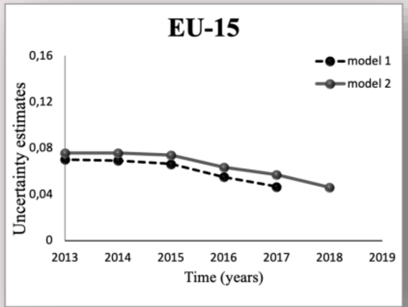

Fig. 6. Uncertainty estimates for **2013-2018** CO_2 inventories (without LULUCF) for the EU-15, i.e. uncertainty estimates for the period when no official assessments for the EU-15 are available.

Results: comparison of method 1 and method 2

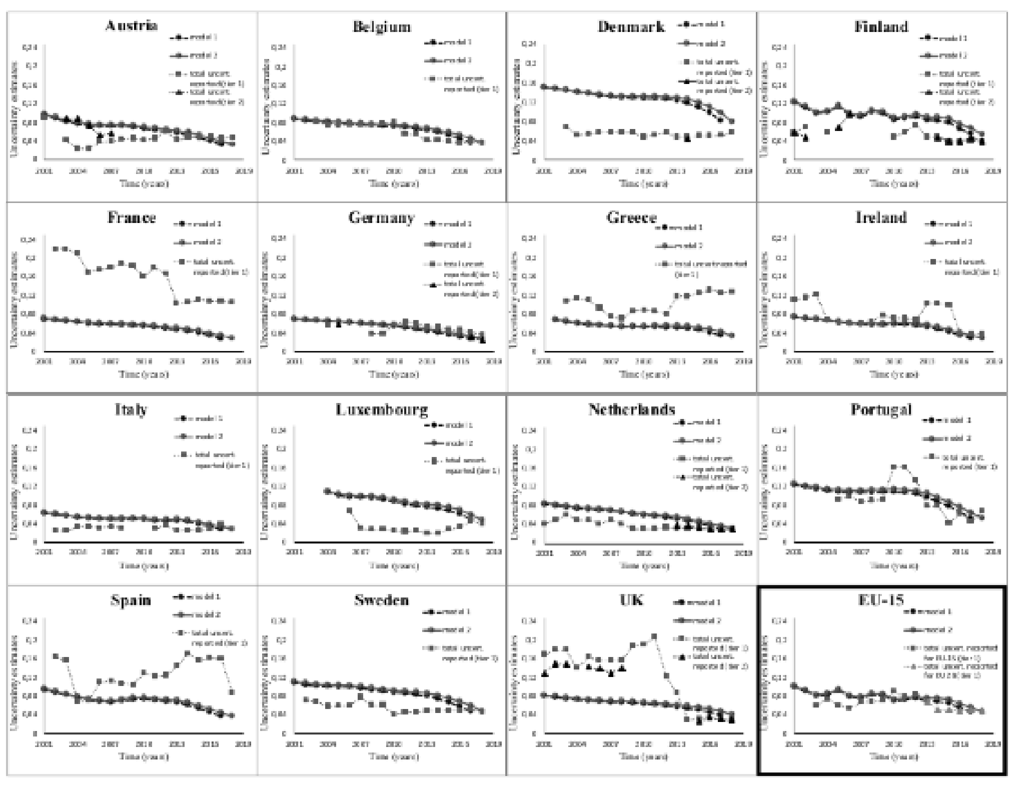

Fig. 7. Uncertainty estimates for **2001-2018** CO_2 inventories (without LULUCF) for EU-15 individual member countries and the EU-15, compared the NIR's total uncertainties.

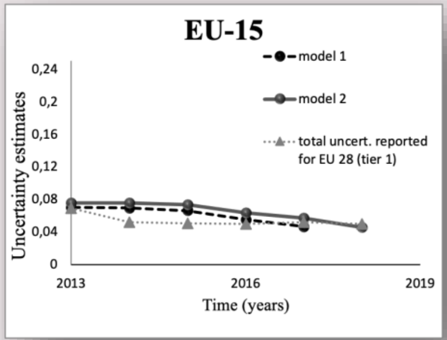

Fig. 8. Uncertainty estimates for the EU-15 **2013-2018** CO_2 inventories (without LULUCF), compared the NIR's total uncertainties reported for the EU-28..

Conclusions

- Both methods compared proved to be effective tools for assessing uncertainty in GHG inventories.
- Both are data-driven but depend on the smoothing spline (considered the estimate of the 'real emission').
- Method 1 allows us for a good estimation of uncertainty and their changes over time, except the assessment of uncertainty in the most recent revision.
- Method 2 enables the estimation of uncertainty also for this most recent revision, although at the cost of a slight loss of precision of the obtained estimates.
- By estimating the uncertainty in the last year analyzed, method 2 makes it possible to create confidence intervals based on this estimate.
- By applying the methods to the uncertainty assessment for the entire EU-15 and its member countries, we obtained comparable results to the official NIR's uncertainty for most cases, but there are also significant discrepancies in several cases (France, Greece, Spain, and the UK) explanation of which needs further research.

Thank you for your attention