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Uncertainties in atmospheric emission projections

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OUTLINE

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1. Introduction

- Work developed under contracts with the Ministry of Environment (Spain) to estimate emission projections

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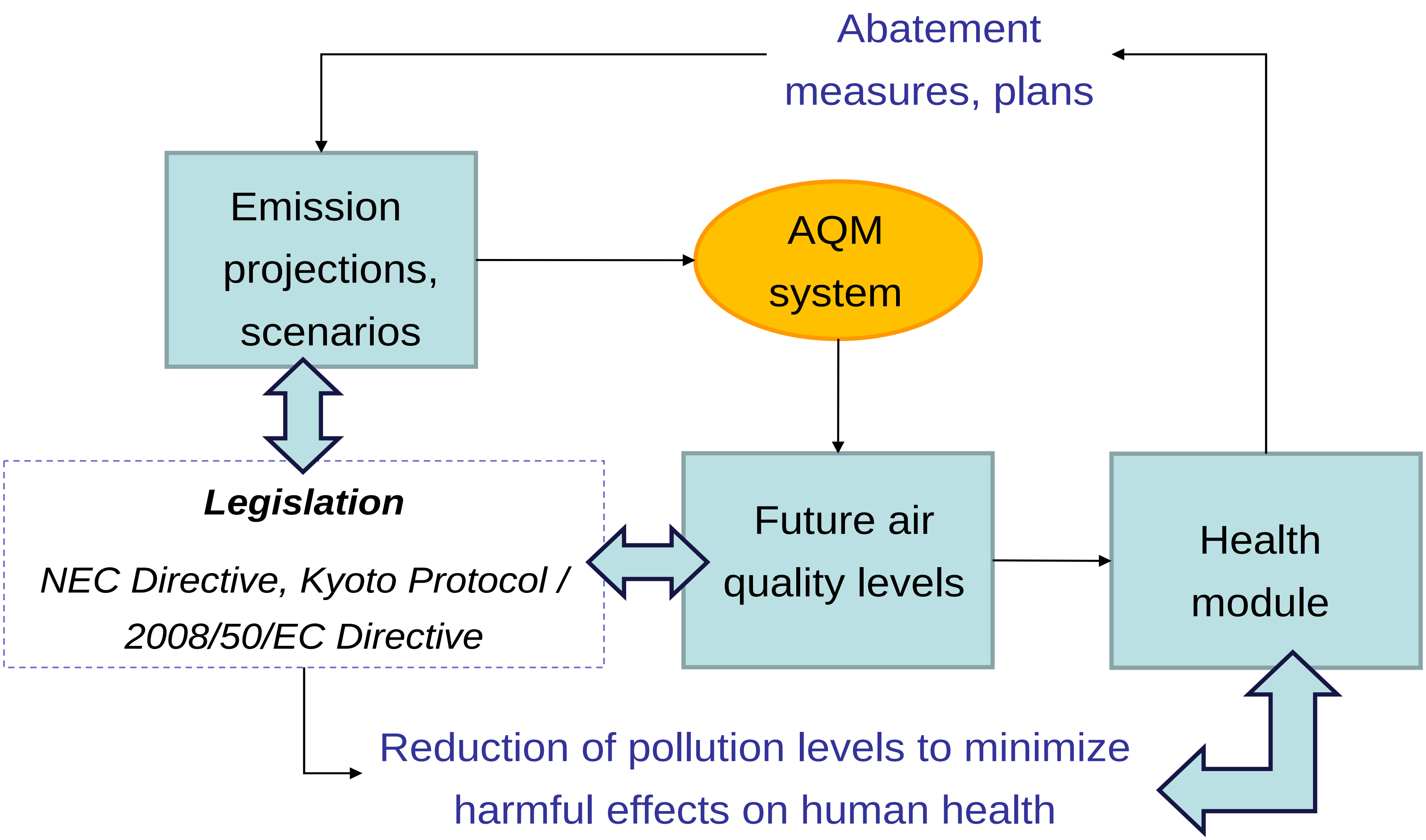
- Part of a Integrated Assessment Modeling system developed to:

  ✓ Design Policies and Measures (P&M) to reduce both air pollution and Greenhouse Gas emissions

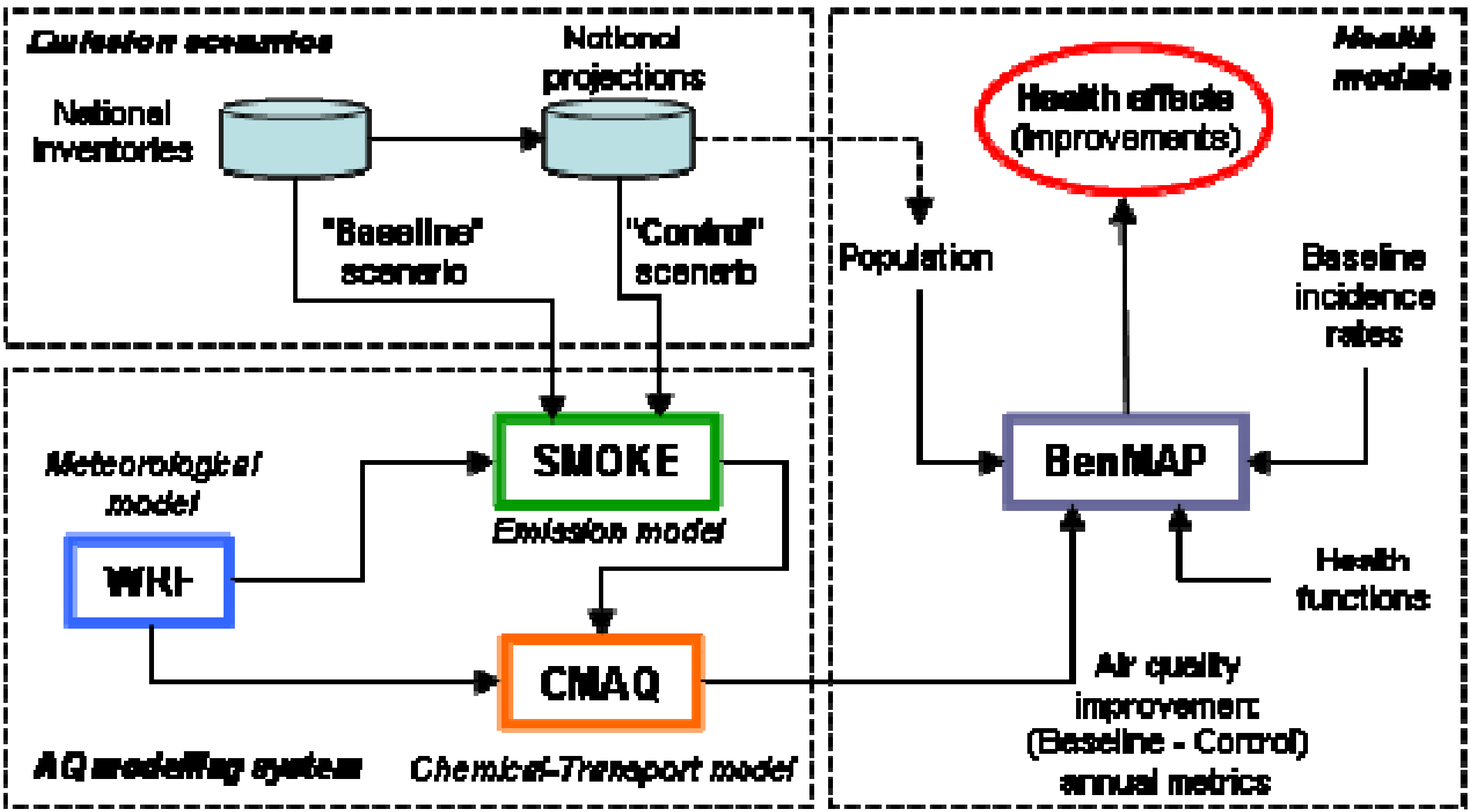
  ✓ Analyze P&M impact on air quality, human health and ecosystems

  ✓ Assess P&M in terms of cost-benefit

Integrated Assessment Modelling (IAM) System

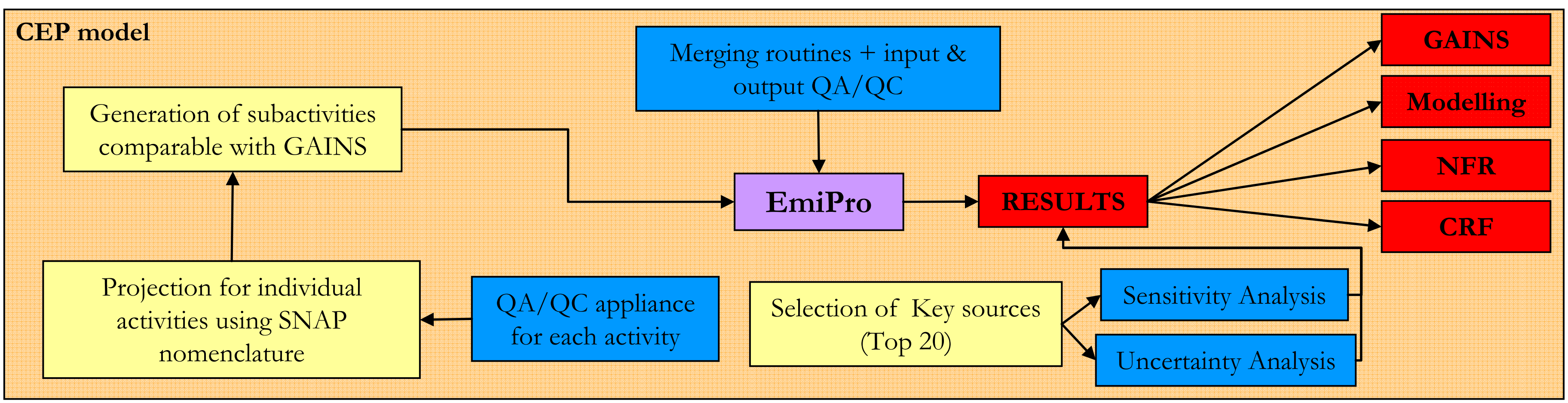


Implementation of the IAM system for scenario comparison



Emission subsystem (CEP Model)

- Anthropogenic and natural sources using SNAP classification
- Pollutants included in the Geneva Convention and the Kyoto Protocol
- Temporal horizon: from the current inventory year to 2020
- Full consistency with the Spain's National Atmospheric Emission Inventory (SNAEI)



Scenarios developed

- Without Measures (WoM): how emissions would grow in the absence of any technical or non-technical control measure implemented, adopted or planned after the base year
- With Measures (WM): including implemented policies and measures for reducing emissions through technology improvements and dissemination, demand-side efficiency gains, more efficient regulatory procedures and shifts to cleaner fuels
- With Additional Measures (WAM): including planned but not yet adopted P&M. Presents a picture of the expected outcome of emissions if, on top of WM, planned P&M with a realistic chance of being adopted and implemented in time to influence the emissions are included

Why uncertainty calculation?

- Because uncertainty is inherent in emission projections
- To allow a more reliable estimation of commitments compliance in future years (such as Kyoto Protocol or EU Directives)
- To offer a wider range of future emissions usable for negotiations
- To estimate the uncertainty of the effect of policies and measures to reduce emissions

2. Methodology

WoM scenario

- ARIMA time series modeling
  - Statistical Software
  - Alternative WoM Sc
  - Evaluate WM behavior (difference statistically significant)

WM scenario

- Non-parametric technique (bootstrap)
  - Ad-hoc program
  - Applied to existing WM Sc
  - Complex technique
- UFSA method (Uncertainties From Sensitivity Analysis)
  - Excel spreadsheets
  - Based on Sensitivity Analysis
  - Simple method
  - Non-statistical

Uncertainty bands

ARIMA for WoM scenario

- Univariate time series analysis:
  - Models capable of explaining the structure and predicting the evolution of a variable which is observed over time
- The AutoRegressive Integrated Moving-Average process of orders p and q, which is referred to as the ARIMA (p,d,q), is a process defined by:

$$(1-B)^d(1 - \Phi_1 B - \Phi_2 B^2 - \Phi_3 B^3 - \dots - \Phi_p B^p)z_t = (1 - \theta_1 B - \theta_2 B^2 - \dots - \theta_q B^q)\, a_t$$

Where:
-*B* is the backshift operator such that Byt=yt-1. the roots of $\Phi(B)=(1-\Phi 1B\dots)=0$ are on or outside the unit circle. and the roots of $\theta(B)=(1-\theta 1B\dots)$ are outside the unit circle and
-a_t are the innovations which are serially uncorrelated
-*p* is the order of the autoregressive component
-*q* is the order of the moving average component
-*d* is the order of the integration

Bootstrap method applied to WM scenario

- Resampling technique: evaluation of statistics through resampling or subsampling of the original data
- Two main techniques:
  - Jackknife consists of, for a sample of size n, obtaining n new artificial samples of size n-1 by deleting in turn each of the observations and computing the n estimates corresponding to each artificial sample → obtain a sample of size n of the estimator, which can be used to estimate variances and compute confidence intervals
  - Bootstrap is a more sophisticated version of artificial sampling: given the original sample of size n, obtain new artificial samples by selecting at random with replacement n elements of the sample

UFSA method (Uncertainties From Sensitivity Analysis)

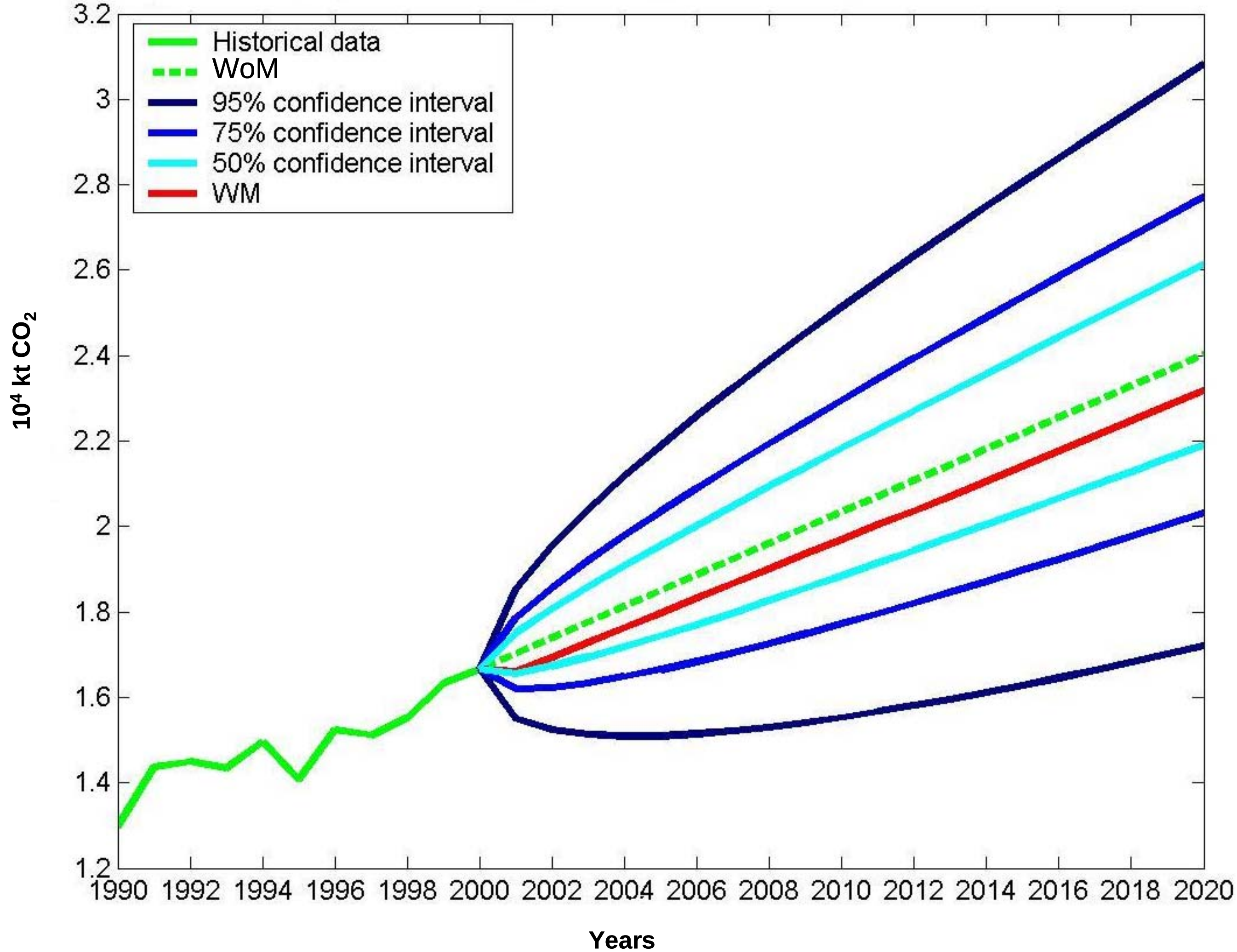
- Alternative method to obtain uncertainty bands for the WM scenario at National-level
- UPM developed a method consisting of six steps:
  1. Selection of the most relevant sectors from the emissions point of view
  2. List the key factors driving emissions for each selected sector
  3. Analysis of the influence of each factor on emissions both at sectoral and national level
  4. Definition of the most probable range of variation for each factor based on statistical analyses and expected evolution of drivers in the future (GDP, population, Policies and Measures, etc.)
  5. Computation of the impact (variation effect) on national total emissions using factor values within the abovementioned ranges
  6. Derivation of uncertainty bands from results on a national scale

3. Results

ARIMA for WoM scenario

The expression for the ARIMA model prediction errors variance is known. If a distribution is assumed (e.g. Normal), uncertainty bands can be computed:

Uncertainty bands for WoM scenario for CO_2 from combustion plants in the residential sector



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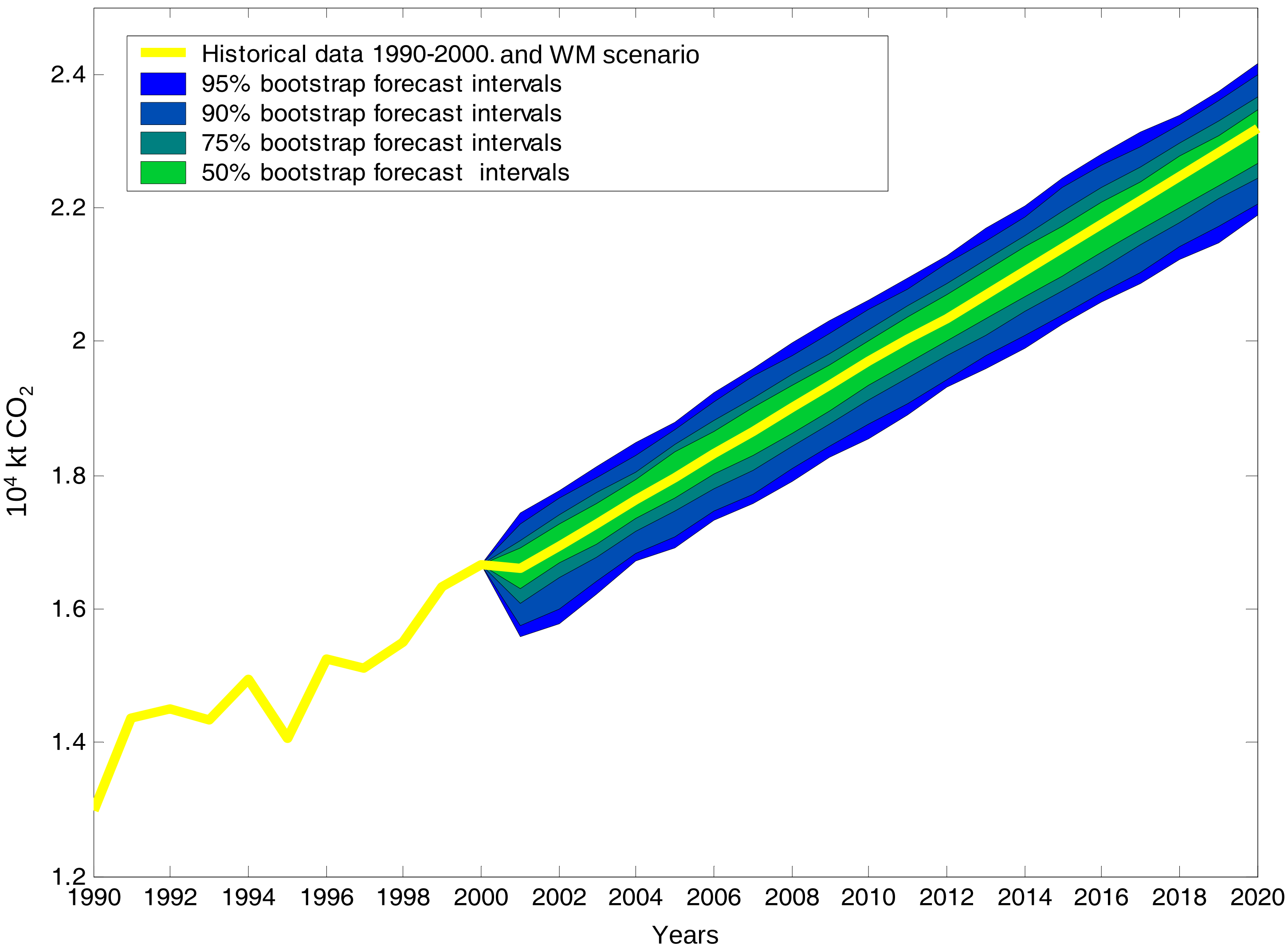
Bootstrap method applied to WM scenario

Emission projections for CO_2 from combustion plants in residential sector under WM scenario



1000 replicas. Percentile –derived confidence intervals

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UFSA method – step 1 (Selection of the most relevant sectors)

Sector	SO_2	NOx	VOC	NH_3	CO_2	N_2O	CH_4	SF_6	HFC	PFC	$PM_{2.5}$
Power Plants	70.6%	19.4%	0.8%	0.0%	28.0%	1.8%	0.2%	0.0%	0.0%	0.0%	7.1%
Residential sector	1.1%	1.2%	4.0%	0.0%	5.0%	0.7%	1.5%	0.0%	0.0%	0.0%	16.3%
Combustion in industry (exc. cement)	8.5%	15.3%	2.8%	0.0%	15.2%	1.6%	0.4%	0.0%	0.0%	0.0%	3.4%
Cement sector	1.5%	3.4%	0.2%	0.0%	7.9%	0.3%	0.0%	0.0%	0.0%	0.0%	0.5%
Aluminum	0.3%	0.1%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	55.5%	0.4%
Solvent. painting use	0.0%	0.0%	37.3%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Ref. equipments	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	76.1%	43.0%	0.0%
Electric equipments	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100%	0.0%	0.0%	0.0%
Road transport	0.2%	31.7%	17.5%	1.8%	26.5%	8.9%	0.4%	0.0%	0.0%	0.0%	24.6%
Rail transport	0.0%	0.25%	0.05%	0.0%	0.1%	0.1%	0.0%	0.0%	0.0%	0.0%	0.2%
Waste management	0.0%	0.1%	0.0%	1.7%	0.2%	0.2%	18.2%	0.0%	0.0%	0.0%	0.0%
Agriculture	1.2%	8.7%	11.5%	94.6%	2.1%	56.9%	59.7%	0.0%	0.0%	0.0%	0.0%
TOTAL	**83%**	**80%**	**74%**	**98%**	**85%**	**71%**	**81%**	**100%**	**76%**	**98%**	**52%**

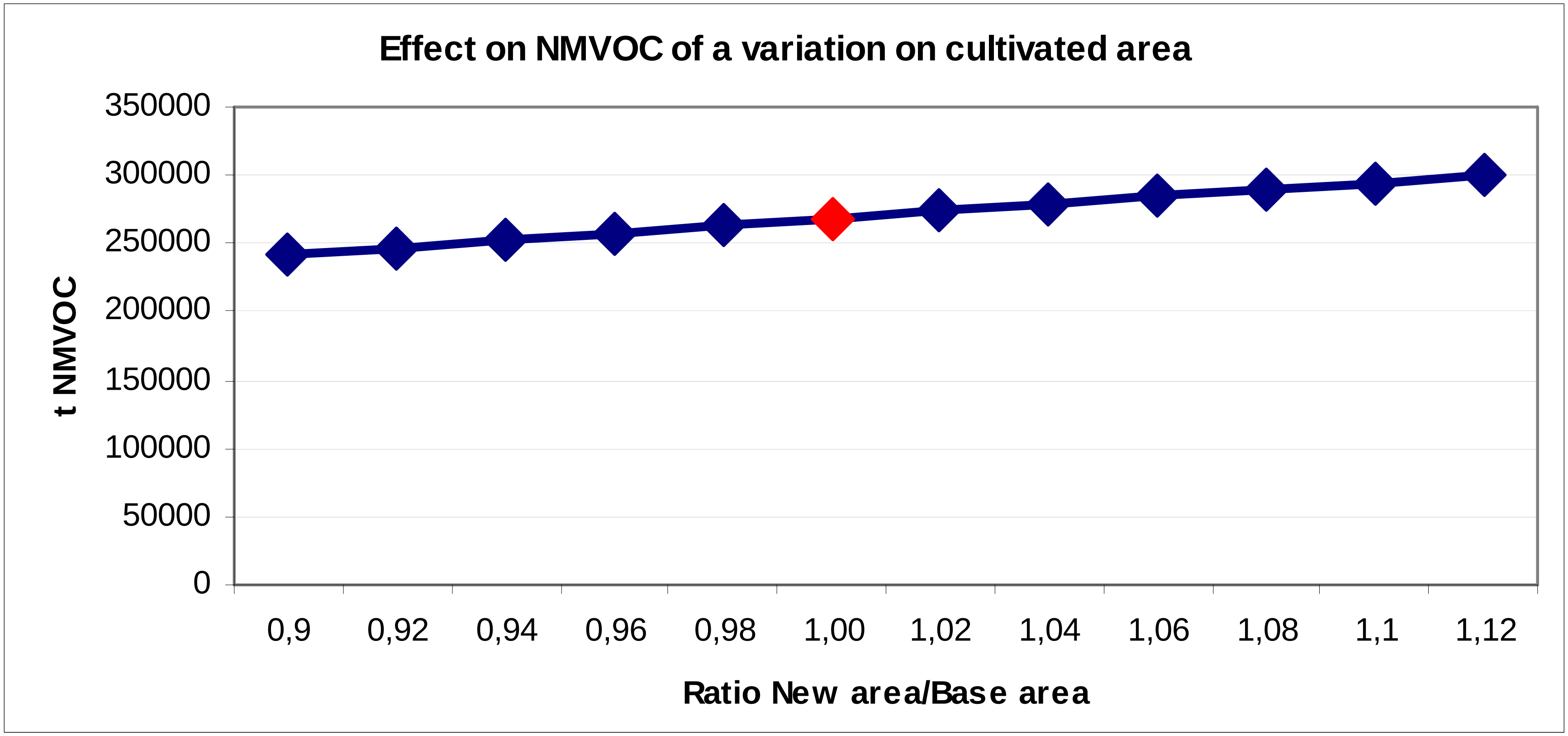
UFSA method – step 2 (List the key factors driving emissions)

Example for agriculture sector. Selected factors

Factor
Agricultural surface
Inorganic fertilization
Number of dairy cows
Number of other cattle
Number of fattening pigs
Number of sows
Number of ovine
Number of laying hens
% of urea use

- **UFSA method – step 3** (Analysis of the influence of each factor on emissions)

Example for change in agriculture surface



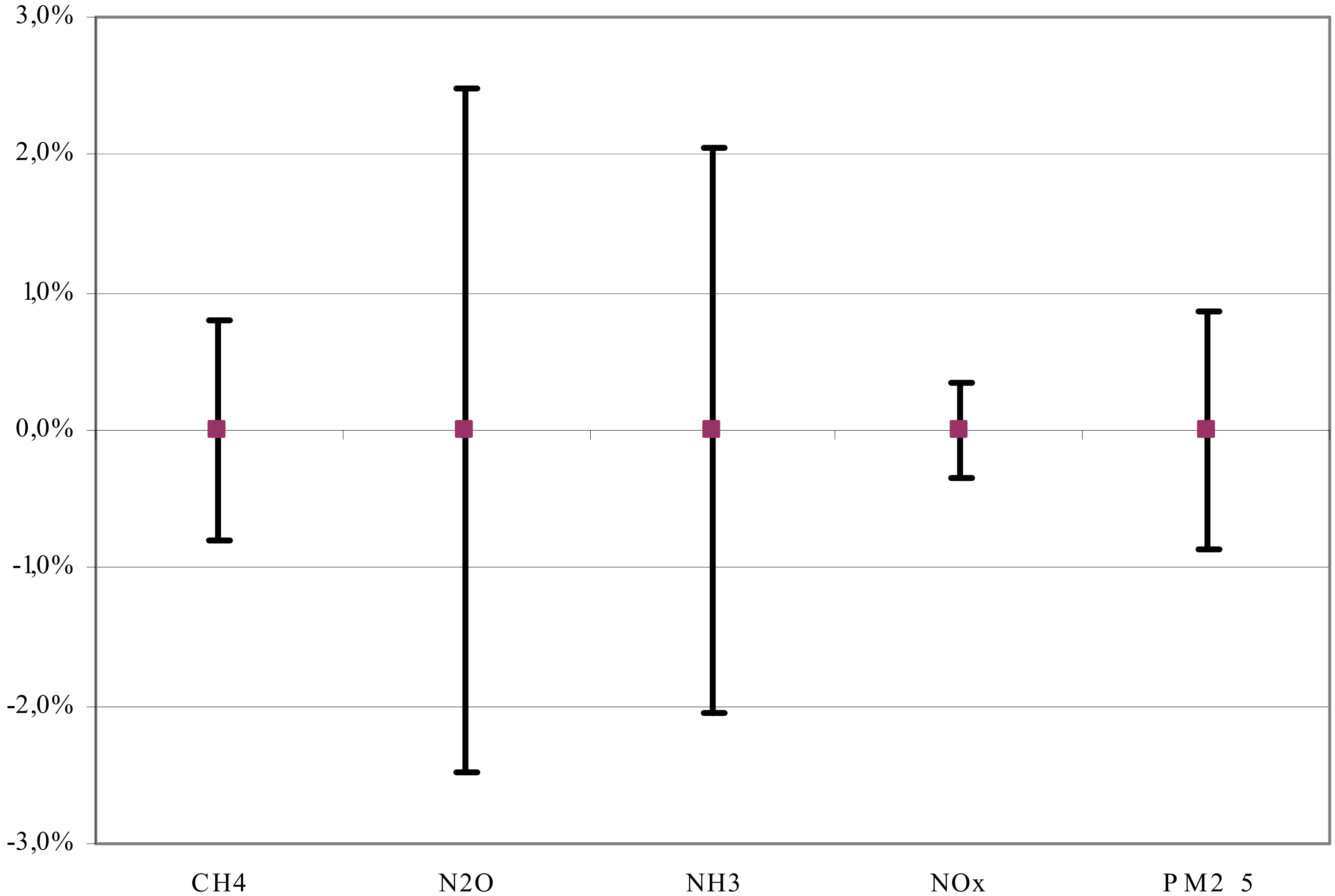
- **UFSA method – step 4** (Definition of the most probable range of variation for each factor)

Example for agriculture sector

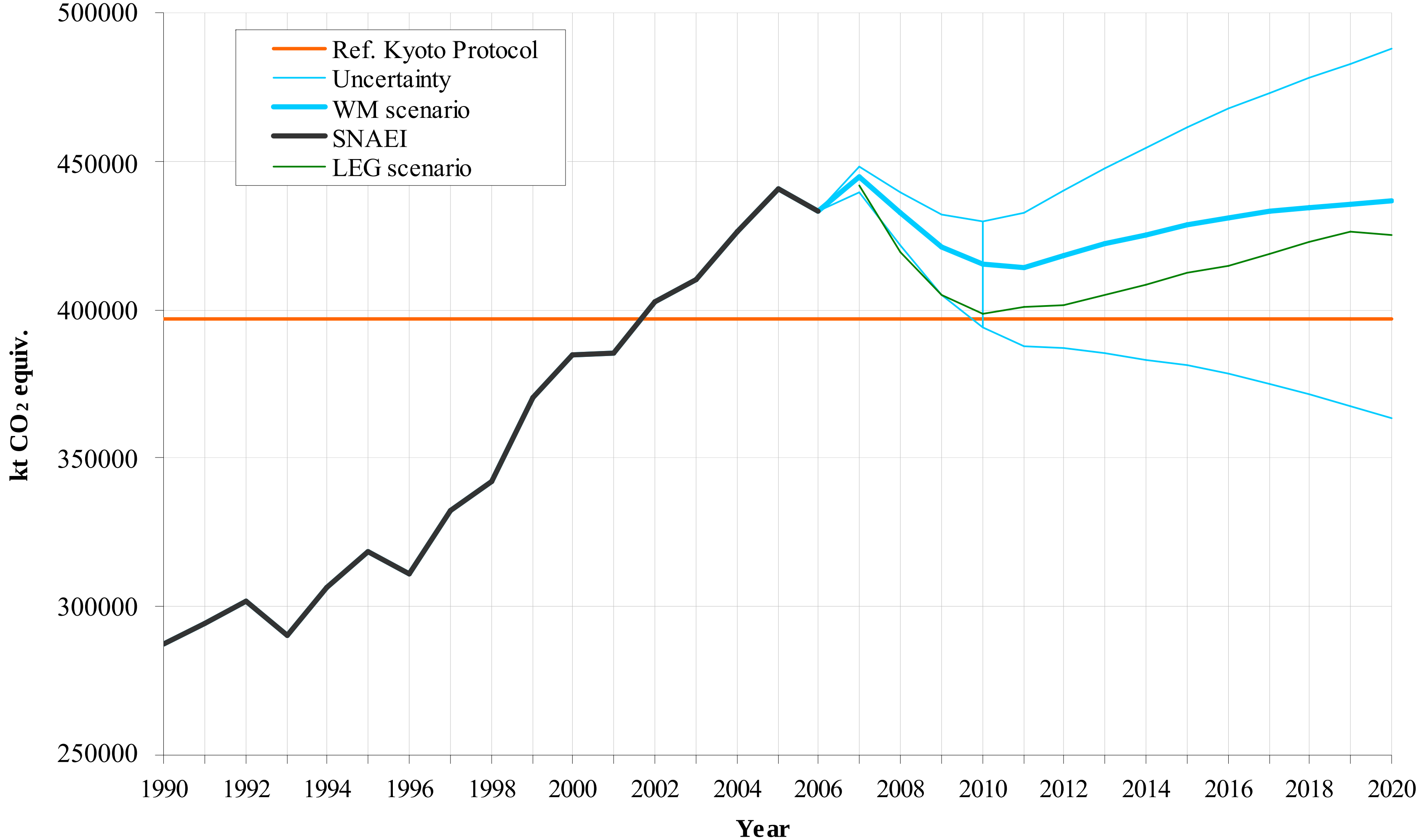
Factor	Upper limit	Lower limit
Agricultural surface	+ 4 %	- 4 %
Inorganic fertilization	+10 %	-10 %
Number of dairy cows	+ 4 %	- 4 %
Number of other cattle	+ 4 %	- 4 %
Number of fattening pigs	+ 4 %	- 2 %
Number of sows	+ 4 %	- 2 %
Number of ovine	+ 4 %	- 4 %
Number of laying hens	+ 4 %	- 4 %
% of urea use	+ 2 %	- 4 %

UFSA method – step 5 (Impact on national total emissions)

Plausible range of national emission changes due to agriculture projections uncertainty



UFSA method – step 6 (Derivation of non-statistical uncertainty bands on a national scale)



4. Conclusions

- Three different methods for uncertainty estimation have been tested for the Spanish Emission Projections
- Each method was applied to different emission projection scenario
- From the application of the first method (ARIMA model) it was found that in most of the cases projections for the WM scenario fell within the WoM uncertainty bands
- The second method allows the calculation of uncertainty bands for the WM scenario at activity level (vs. single-point estimate)
- The third method provides a rough estimate of total uncertainty in a simple way
- This method has been applied for National Spanish projections providing satisfactory results when compared with re-computed emission trends in a low economic growth perspective

4. Conclusions (future work and recommendations)

- The first method (less time-consuming than resampling techniques) may be adapted for the WM scenario by inclusion of intervention analysis
- Future research on combining WM uncertainties at activity level is necessary to evaluate a total uncertainty for statistical techniques
- Other strategies (statistical uncertainty for aggregated national scenarios)
- The UFSA method may constitute a reasonable approach to carry out uncertainty assessments for countries that are currently developing sensitivity analyses. Nevertheless, it should be further tested and developed

Thank you for your attention

- Further information / references:

- Lumbreras, J., Borge, R., de Andres, J.M., Rodriguez, E., 2008. A model to calculate consistent atmospheric emission projections and its application to Spain. Atmospheric Environment 42, 5251–5266
- Lumbreras, J., García-Martos, C., Mira, J., Borge, R., 2009. Computation of uncertainty for atmospheric emission projections from key pollutant sources in Spain. Atmospheric Environment 43, 1557–1564