43rd Task Force on Integrated Assessment Modelling

Evaluation of air quality impacts with an integrated assessment model for Spain

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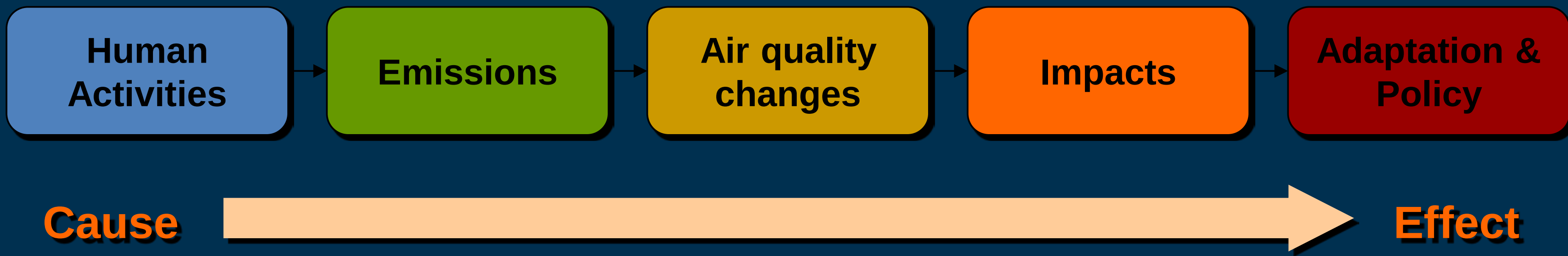
Introduction

Integrated Assessment Modeling



- Provides a holistic description of environmental problems under a policy-driven framework.

- Methodology for gaining insight about the complex interactions between phenomena.

- Intended to satisfy the needs of a wide range of stakeholders. Quick response. No intensive computations involved.

- Broader scope – description of phenomena is simplified.

The AERIS model

- **AERIS – Atmospheric Evaluation and Research Integrated system for Spain.**

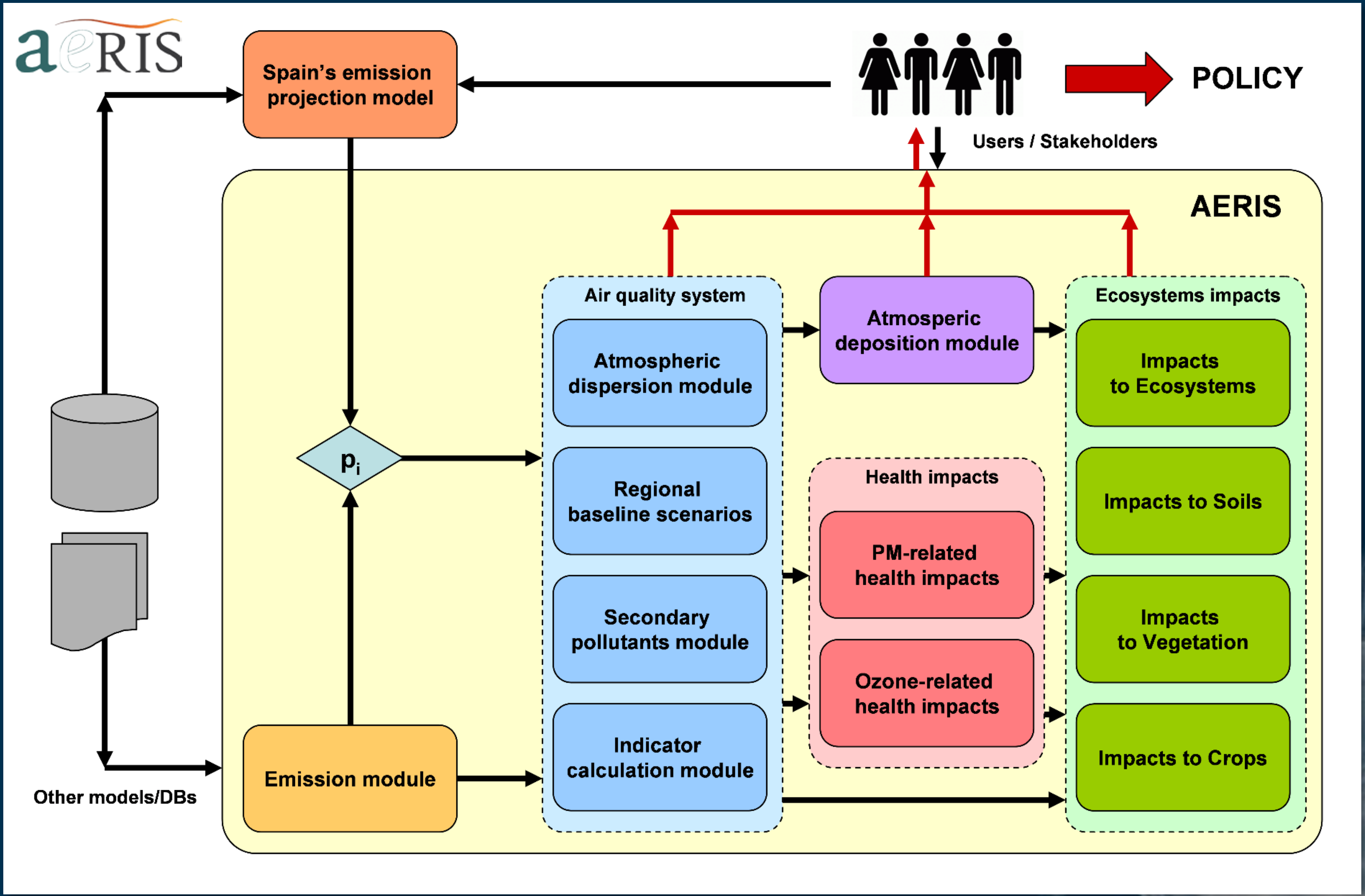
- **Multi – pollutant approach: SO_2, NO_2, NH_3, PM_{10}, $PM_{2.5}$. Describes formation of O_3 and secondary PM. Deposition of nitrogen (N_{dep}) and sulphur (S_{dep}) species.**

- **Addresses air quality variations and impacts as a function of percentual variations in emissions against a reference scenario:**

  - **Impacts on forests and crops (O_3, SO_2).**
  - **Impacts on human health ($PM_{2.5}$, O_3).**
  - **Impacts on ecosystems and soils (N_{dep}, S_{dep}) – under development.**

- **Basic methodology described in Vedrenne et al., (2014) – *Environmental Modelling & Software* – (in press).**

Structure of AERIS



Impacts on forests and crops

Impacts are quantified in terms of:

•Critical levels of SO_2 and NO_2 for forests.
•Relative yield losses caused by O_3 to 9 crop species.

Forests – broadleaved deciduous, broadleaved evergreen, mixed leaf, needle-leaved evergreen and flooded forests.

Crops – grape, maize, potato, rice, sunflower, tobacco, tomato, watermelon and wheat.

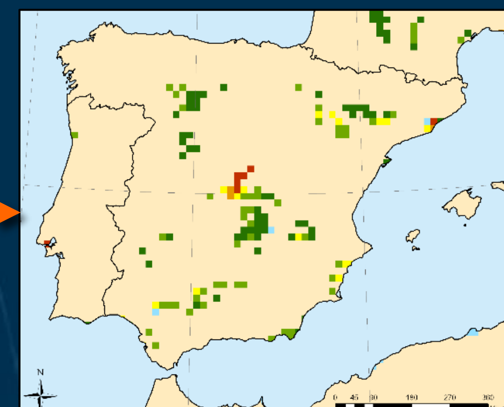
Concentration levels for the before mentioned pollutants are crossed with relevant spatial information (i.e. CORINE Land Cover 2000, FAO) and impact quantification models (Ashmore et al., 2004; Mills et al., 2007).

Impacts on forests and crops

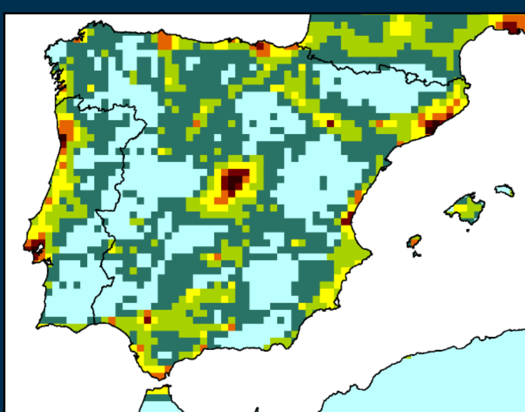
NO_2 critical level exceedances for forests.

CLC 2000 Forests

$$Ex_{C\ell} = \max\{C_i - C\ell_i, 0\}$$



$Ex_{Cl,NO2}$



NO_2 Mean Annual Concentration (e.g. 2007)

Impacts on health

Derived from exposure. Impacts are quantified in terms of:

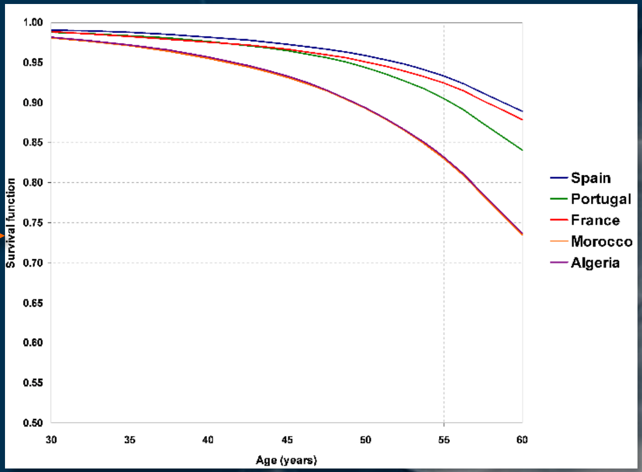
- **Change in the statistical life expectancy (months).**
- **Total number of life years lost (YOLL).**

Methodological framework adapted from IIASA (Mechler et al., 2002) and WHO (Murray et al. 2002). Based on the survival function and population counts for Spain, Portugal, Andorra, France, Morocco and Algeria.

Life tables

(UN, WHO)

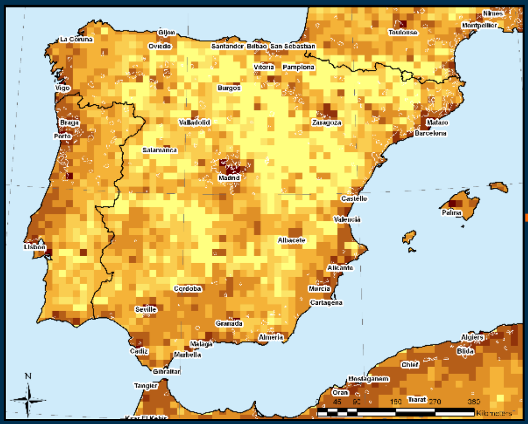
$$l_c(t) = \exp\left(-\sum_{z=c}^{t} \mu_{z,z-c+s}\right)$$



Survival functions

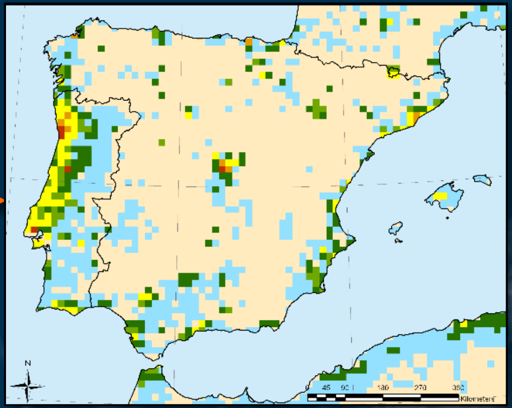
Impacts on health

YOLL due to exposure to $PM_{2.5}$

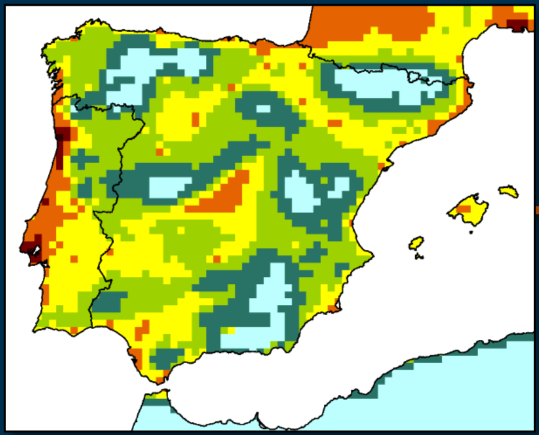


Population counts

$$YOLL = \beta \cdot PM \cdot Pop_j \cdot f_c \cdot \int_c^{w_1} l_c(t) \cdot \log l_c \cdot dt$$



$YOLL_{PM25}$



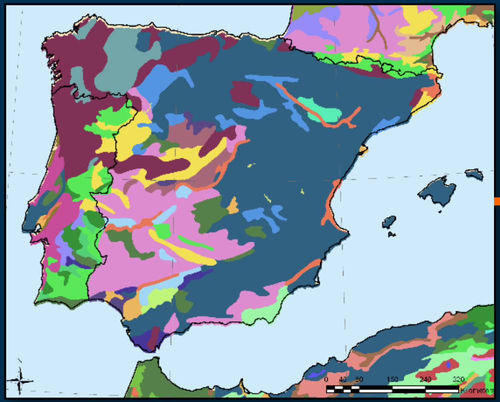
$PM_{2.5}$ Mean Annual Concentration (e.g. 2007)

Impacts on ecosystems/soils

Estimated as an exceedance of a critical load.

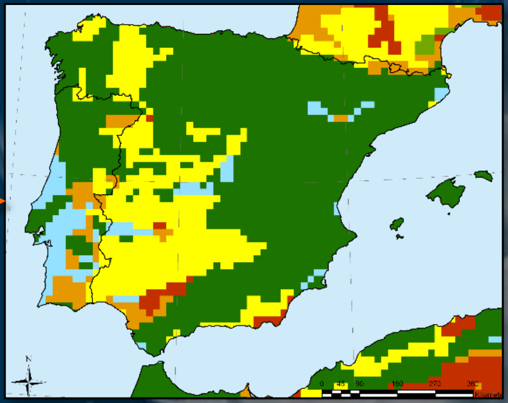
- Absolute exceedance of critical loads for soils.
- Under development. Currently quantified: $CL_{nut}(N)$, $CL_{min}(S)$, $CL_{max}(S)$.

The general approach is outlined by the Coordination Centre for Effects (CCE) (Posch et al., 2001; Reinds et al., 2008). Quantified for soils with the VSD model provided by CCE.



Soil types and properties

VSD model



$CL_{max}(S)$

Model testing and validation

Model testing

The impacts estimated by AERIS were compared to the outputs produced by reference models: SERCA and GAINS. Emissions are the same in both cases.

Comparison with SERCA → Relative yield loss of wheat (*triticum aestivum*) produced by exposure to O_3.

Comparison with GAINS → Change in the statistical life expectancy due to exposure to $PM_{2.5}$ in cohorts of >30 years old.

Testing involved conducting a concurrent comparison based in statistical performance (Pearson correlation coefficients, mean scores and scatterplots).

Comparison with SERCA

SERCA (Sistema de Evaluación de Riesgos de la Contaminación Atmosférica) estimates damage to crops and forests due to exposure to O_3 (de Andrés et al., 2012).

•Emission scenario: 2014 National Emission Scenario. Quantified with the SEP model (projections).

•Emission sectors and activities in SERCA and AERIS are identical → SNAP sectors (no adaptation needed).

•Spatial resolution in SERCA and AERIS for the Iberian domain are the same (16 km × 16 km).

•Comparison based on a statistical analysis.

Comparison with SERCA

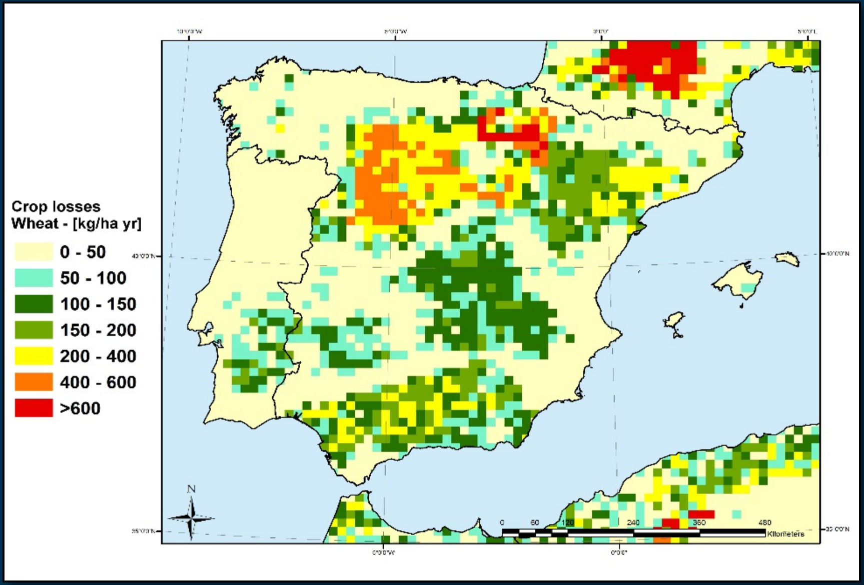
2014 National Emission Scenario (SERCA & AERIS)

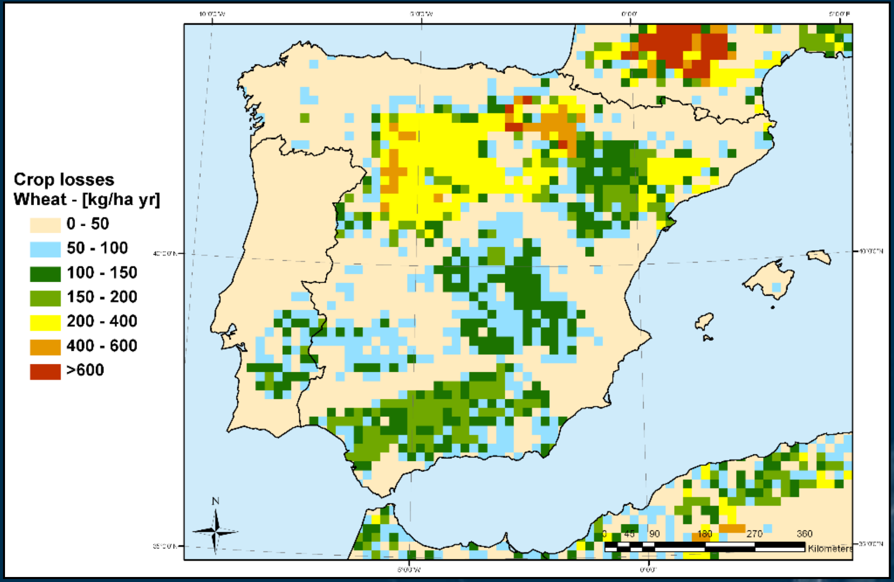
SNAP code	Activity name	NO_x	SO_2	PM_{10}	$PM_{2.5}$	NH_3
010000	Coal - fired power plants $\geq 300MW$	-58.80	-88.22	0	0	0
020202	Residential plants $< 50MW$ 15.56	-59.75	-5.74	-5.33	0	
030000	Combustion in manufacturing	-58.85	-33.05	0	0	0
040000	Production processes	0	-7.30	0	0	0
070101	Passenger cars - highway driving	-62.11	0	-48.16	-48.16	0
070103	Passenger cars - urban driving	-17.35	0	-67.53	-67.53	0
070201	Light - duty vehicles - highway driving	-47.70	0	-68.37	-68.37	0
070203	Light - duty vehicles - urban driving	-83.20	0	-90.11	-90.11	0
070301	Heavy - duty vehicles - highway driving	-3.93	0	-69.11	-69.11	0
070303	Heavy - duty vehicles - urban driving	-65.04	0	-88.61	-88.61	0
0707/08	Break, tire and road abrasion	0	0	-17.52	-16.75	0
080500	Airports (air traffic)	-27.52	0	0	0	0
080600	Agriculture (machinery)	-41.39	-51.54	-90.41	-90.41	8.73
080800	Industry (machinery)	-20.05	103.89	-42.33	-42.33	3.48
100101	Culture w/ fertilizers - permanent crops	0	0	0	0	-20.41
100102	Culture w/ fertilizers - arable land crops	0	0	0	0.00	-11.15
100500	Other agricultural activities	0	0	22.63	38.71	-7.33
110000	Other sources and sinks	0	0	0	0	-12.31
–	Portugal	-20.11	-21.01	13.11	-3.81	42.11
–	**Total** (t/yr)	947735	427555	121644.8	75850	397518
–	$\%_{Total}$ (2007)	-39.5%	-64.7%	-35.7%	-48.0%	-12.1 %

[a] Presented as variation percentages with respect to the 2007 National Emission Scenario

Comparison with SERCA

Results (yield losses)





SERCA

AERIS

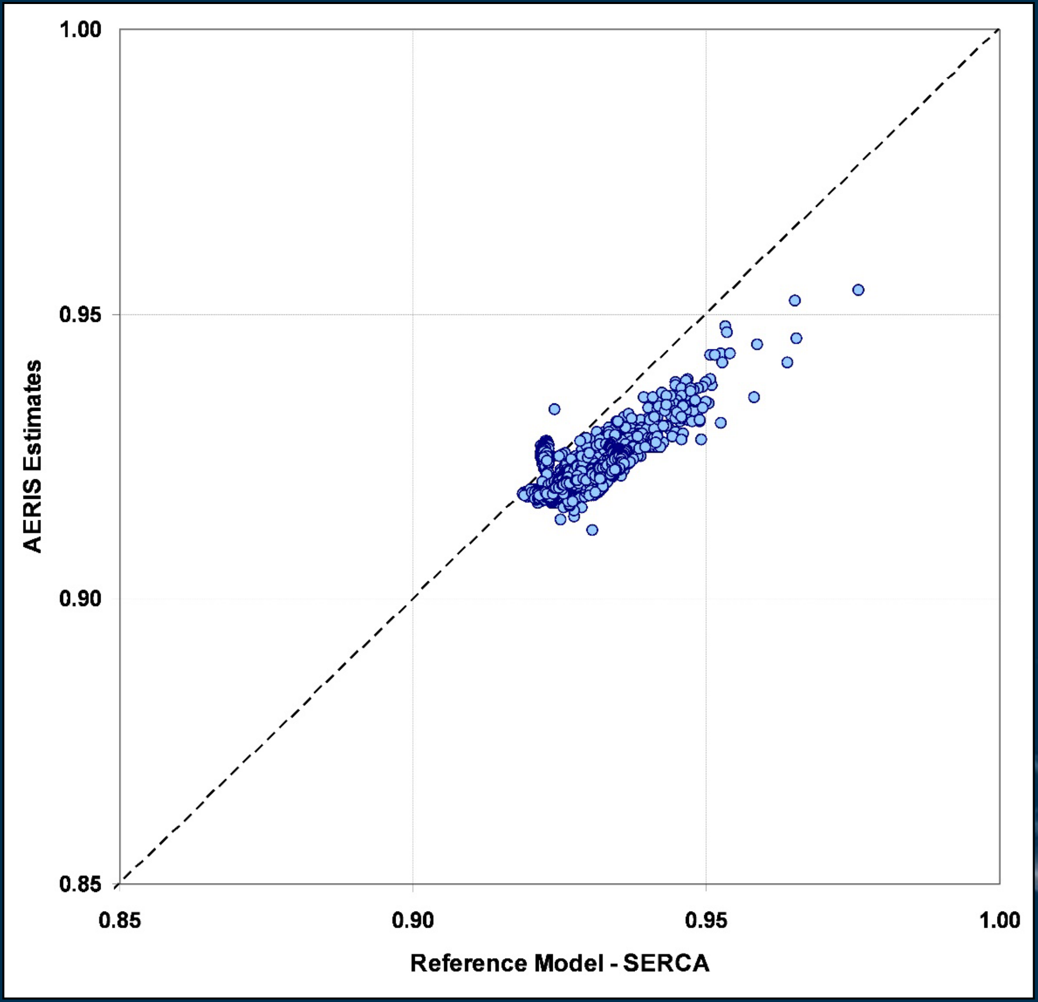
x_{SERCA} = 66 kg/ha yr

x_{AERIS} = 64 kg/ha yr

*Results presented as annual crop outputs.

Comparison with SERCA

Results



r = 0.8392

*Results presented as relative yield fractions.

Comparison with GAINS

GAINS is able to estimate health impacts caused by exposure to $PM_{2.5}$, according to the methodology published in Mechler et al., (2002) and Amann et al., (2011).

- Emission scenario: Gothenburg Protocol Revision (National Projections 2020).
- Referring GAINS emissions (aggregated by activity and sector) to SNAP groups considered by AERIS.
- Adapt the results of AERIS (16 × 16 km) to the minimum spatial resolution. In this case, to the scale of GAINS (50 × 50 km).
- Comparison based on a statistical analysis.

Comparison with GAINS

Gothenburg Protocol Revision - GAINS

GAINS	Activity name	NO_x	SO_2	PM_{10}	$PM_{2.5}$	NH_3
PP_EX_L	Power & district heat plants, existing coal	38.38	22.86	0	0	0
DOM	Residential, commercial, services, agriculture, etc.	38.13	15.34	2.71	2.21	0
IN_BO_CON	Industry: transformation sector, combustion in boilers	4.45	5.02	0	0	0
IN_BO_OTH	Industry: combustion of fossil fuels other than coal	19.52	8.91	0	0	0
IN_BO_OTH_L	Industry: combustion of coal in large boilers	0.06	0.11	0	0	0
IN_BO_OTH_S	Industry: combustion of coal in small boilers	0.01	0.03	0	0	0
IN_BO_PAP	Industry: paper and pulp production	9.32	7.82	0	0	0
IN_BO_CHEM	Industry: chemical industry	3.51	0	0	0	0
IN_OC	Industry: Other combustion (used in emission tables)	56.56	12.88	0	0	0
PR_CEM	Ind. Process: Cement production	0	37.93	0	0	0
PR_LIME	Ind. Process: Lime production	0	5.17	0	0	0
PR_COKE	Ind. Process: Coke oven	0	1.92	0	0	0
PR_GLASS	Ind. Process: Glass production (flat, blown, container glass)	0	3.57	0	0	0
PR_OT_NFME	Ind. Process: Other non-ferrous metals prod.	0	36.05	0	0	0
PR_PULP	Ind. Process: Paper pulp mills	0	19.22	0	0	0
PR_REF	Ind. Process: Crude oil & other products	0	43.77	0	0	0
PR_SINT	Ind. Process: Agglomeration plant - sinter	0	6.15	0	0	0
PR_SUAC	Ind. Process: Sulfuric acid	0	13.23	0	0	0
TRA_RD_LD4C	Light duty vehicles: cars and small buses	91.02	0	3.04	3.04	0
TRA_RD_LD4T	Light duty vehicles: light commercial trucks	30.17	0	1.17	1.17	0
TRA_RD_HDB	Heavy duty vehicles - buses	12.39	0	0.17	0.17	0
TRA_RD_HDT	Heavy duty vehicles - trucks	76.46	0	0.81	0.81	0
TRA_RD_HKX	Non-exhaust *PM* emissions	0	0	11.40	4.69	0
TRA_OT_AIR	Other transport: air traffic - civil aviation	13.76	0	0	0	0
TRA_OT_AGR	Other transport: agriculture and forestry	42.25	0.05	3.15	2.98	0
TRA_OT_CNS	Other transport: construction and industry	17.76	0.03	1.05	0.99	0
FCON_OTHN	Fertilizer use - other *N* fertilizers	0	0	0	0	37.54
FCON_UREA	Fertilizer use - urea	0	0	0	0	40.44
AGR_ARABLE	Agriculture: Ploughing, tilling, harvesting	0	0	8.06	1.79	0
AGR_BEEF	Agriculture: Livestock - other cattle	0	0	1.26	0.28	27.22
AGR_COWS	Agriculture: Livestock - dairy cattle	0	0	0.23	0.05	19.18
AGR_OTANI	Agriculture: Livestock - other animals (sheep, horses)	0	0	0	0	32.79
AGR_PIG	Agriculture: Livestock - pigs	0	0	12.41	2.21	101.9
AGR_POULT	Agriculture: Livestock - poultry	0	0	10.77	2.39	32.35
CONS_2000_MILK	Milk yield over 3000 *kg*/animal treshold	0	0	0	0	9.14
PORTUGAL	Portugal	115.7	67.26	91.15	62.35	69.62

[a] Emissions are presented in annual metric tons ($t \cdot yr^{-1}$)

Comparison with GAINS

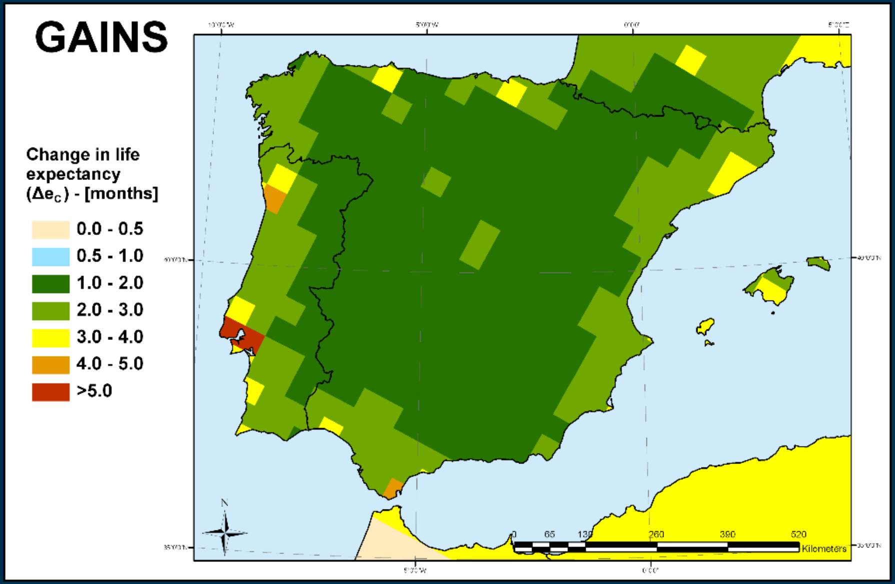
Gothenburg Protocol Revision - AERIS

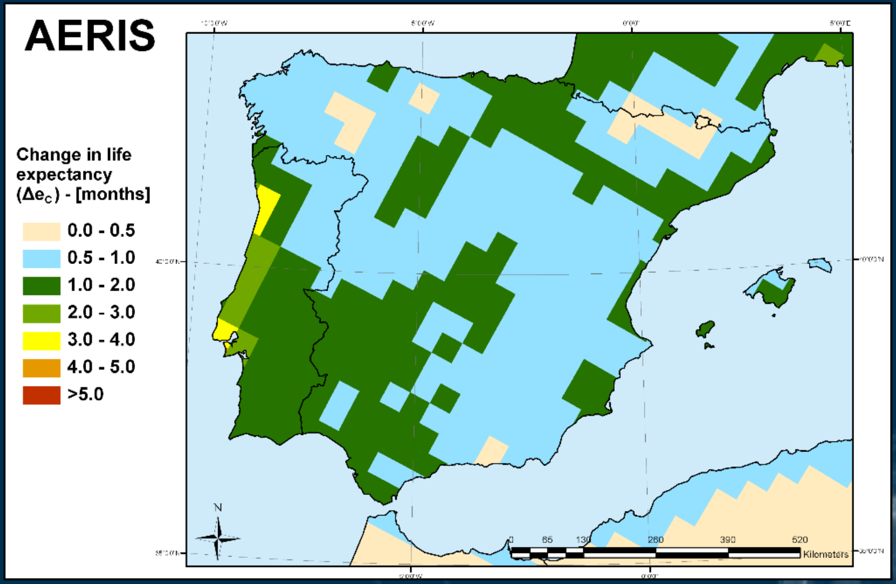
SNAP code	Activity name	NO_x	SO_2	PM_{10}	$PM_{2.5}$	NH_3
010000	Coal - fired power plants $\geq 300MW$	-81.2	-96.9	0	0	0
020202	Residential plants $< 50MW$	98.4	23.4	-84.7	-85.6	0
030000	Combustion in manufacturing	-66.0	-69.3	0	0	0
040000	Production processes	0	-50.4	0	0	0
070101	Passenger cars - highway driving	-52.2	0	-75.3	-75.3	0
070103	Passenger cars - urban driving	-52.2	0	-75.3	-75.3	0
070201	Light - duty vehicles - highway driving	-49.1	0	-76.2	-76.2	0
070203	Light - duty vehicles - urban driving	-49.0	0	-76.2	-76.2	0
070301	Heavy - duty vehicles - highway driving	-43.6	0	-95.1	-95.1	0
070303	Heavy - duty vehicles - urban driving	-43.6	0	-71.2	-71.2	0
0707/08	Break, tire and road abrasion	0	0	-1.1	-26.0	0
080500	Airports (air traffic)	70.7	0	0	0	0
080600	Agriculture (machinery)	-65.7	-99.5	-96.7	-96.9	0
080800	Industry (machinery)	-75.3	-82.3	-93.1	-93.5	0
100101	Culture w/ fertilizers - permanent crops	0	0	0	0	-38.5
100102	Culture w/ fertilizers - arable land crops	0	0	0	0	-38.5
100500	Other agricultural activities	0	0	97.8	138.1	84.5
110000	Other sources and sinks	0	0	0	0	-92.9
–	Portugal	-20.2	-21.0	13.1	-3.8	42.1
–	**Total** (t/yr)	1288962	747660	135323	94559	377361
–	$\%_{Total}$ (2007)	-17.7%	-38.3%	-25.7%	-25.3%	-19.8%

[a] Presented as variation percentages with respect to the 2007 National Emission Scenario

Comparison with GAINS

Results (change in life expectancy)





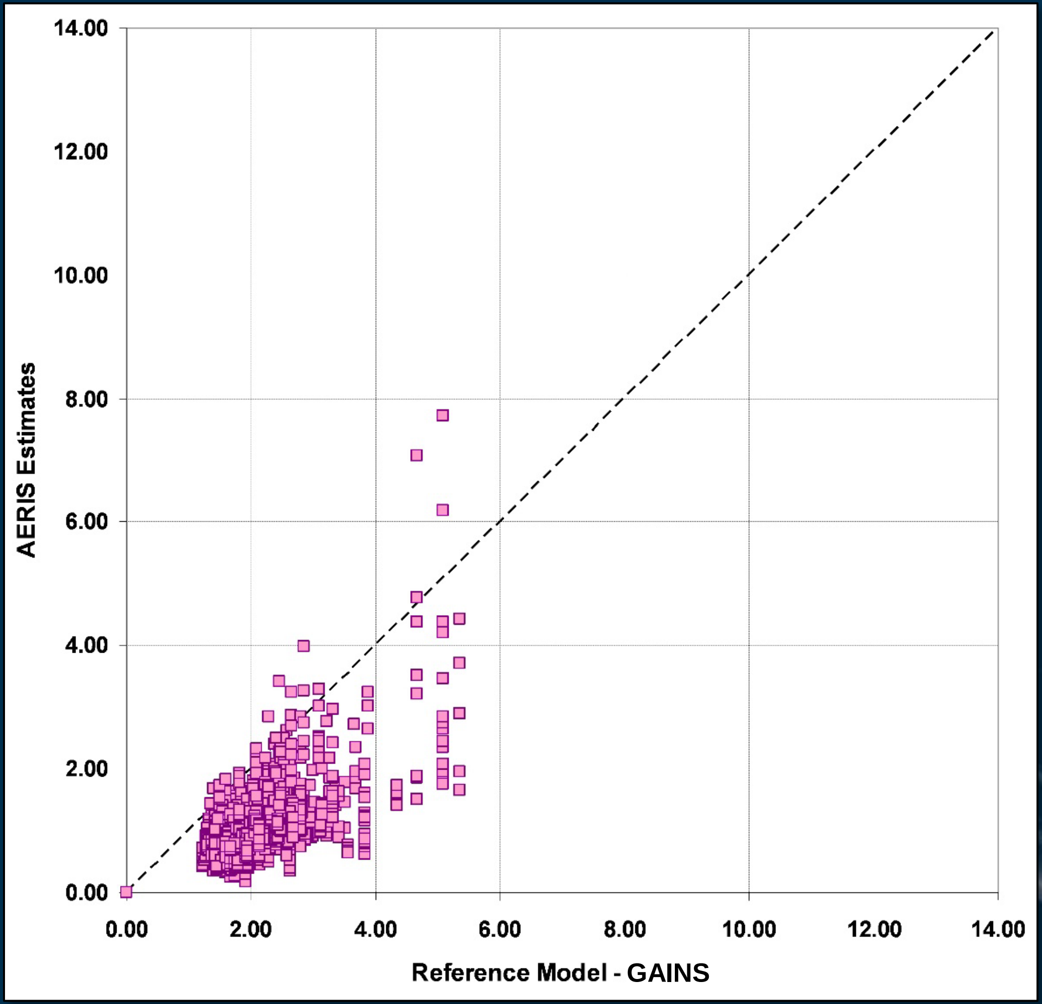
GAINS — x_{SERCA} = 2.03 months

AERIS — x_{AERIS} = 1.06 months

*Results presented as months of life expectancy losses.

Comparison with GAINS

Results



r = 0.7204

*Results presented as months of life expectancy losses.

Conclusions & Next Steps

Conclusions

• Adequate correlations were observed for both comparisons. Similar order of magnitude between outputs.

• Conducting a classical benchmarking exercise – limited for GAINS. IAMs developed with different air quality models. Impacts quantified with different data.

• Analysing the similarities between model outputs increases the perception of a "fitness-for-purpose" IAM among stakeholders.

• The comparison with reference models provides interesting starting points for legitimating the use of AERIS and have confidence in its results.

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Next steps

- **Full version** available in late **2014**. Results on the remaining modules will be introduced shortly (i.e. critical loads, ecosystems, etc.).

- Include an **extension** for the quantification of **cost-effective** results (abatement costs and optimization modules).

- The **evaluation** of models should be a **central part** of the model development process, not an **afterthought**. Therefore it should be refined in the future.

- **Circulate** AERIS among **stakeholders** and policy developers for feedback. Increasing model **legitimacy** and **reliability** perception.

- Possibly **reduce scale** and create a version for **Madrid**.

References

• Amann, M., Bertok, I., Borken-Kleefeld, J., Cofala, J., Heyes, C., Höglund Isaksson, L., Klimont, Z., Nguyen, B., Posch, M., Rafaj, P., Sandler, R., Schöpp, W., Wagner, F., and Winiwarter, W., 2011: Cost-effective control of air quality and greenhouse gases in Europe: Modeling and policy applications. Environ. Modell. Softw., 26, 1489-1501.

• Ashmore, M., Bermejo, V., Broadmeadow, M., Danielsson, H., Emberson, L., Fuhrer, J., Gimeno, B., Holland, M., Karlsson, P.E., Mills, G., Pihl Karlsson, G., Pleijel, H., Simpson, D., Braun, S., Harmens, H., Johansson, M., Lorenz, U., Posch, M., Spranger, T., Vipond, A., 2004. Mapping critical levels for vegetation. Chapter 3. In: Manual on Methodologies and Criteria for Modelling and Mapping Critical Loads & Levels and Air Pollution Effects, Risks and Trends. Umweltbundesamt. Berlin, Federal Republic of Germany.

•de Andrés, J.M., Borge, R., de la Paz, D., Lumbreras, J., Rodríguez, M.E., 2012. Implementation of a module for risk of ozone impacts assessment to vegetation in the Integrated Assessment Modelling system for the Iberian Peninsula. Evaluation for wheat and Holm oak. Environmental Pollution 165, 25 - 37.

• Mechler, R., Amann, M., Schöpp, W., 2002. A methodology to estimate changes in statistical life expectancy due to the control of particulate matter air pollution. Interim Report IR-02-035. International Institute for Applied Systems Analysis, Laxenburg, Austria.

• Mills, G., Buse, A., Gimeno, B., Bermejo, V., Holland, M., Emberson, L., Pleijel, H., 2007. A synthesis of AOT40-based response functions and critical levels of ozone for agricultural and horticultural crops. Atmospheric Environment 41, 2630 - 2643.

• Murray, C.J.L., Salomon, J.A., Mathers, C.D., López, A.D., 2002. Summary measures of population health: concepts, ethics, measurement and applications. World Health Organization (WHO). Geneva, Switzerland.

• Posch, M., Hettelingh, J.P., de Smet, P.A.M., 2001. Characterization of critical load exceedances in Europe. Water, Air, and Soil Pollution 130, 1139 - 1144.

•Reinds, G.J., Posch, M., de Vries, W., Slootweg, J., Hettelingh, J.P., 2008. Critical Loads of Sulphur and Nitrogen for Terrestrial Ecosystems in Europe and Northern Asia Using Different Soil Chemical Criteria. Water, Air and Soil Pollution 193, 269 - 287.

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Thank you for your attention!