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ÉCLAIRE

Effects of Climate Change on Air Pollution Impacts and Response Strategies for European Ecosystems

Seventh Framework Programme

Theme: Environment

D20.6: Assessment of sensitivities and uncertainties of the scenarios, considering the effects of management changes

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Dissemination Level		
PU	Public	☒
PP	Restricted to other programme participants (including the Commission Services)	☐
RE	Restricted to a group specified by the consortium (including the Commission Services)	☐
CO	Confidential, only for members of the consortium (including the Commission Services)	☐

1. Executive Summary

This report discusses data used to extend GAINS emission estimates beyond the year 2050, and ways to use a national understanding of plant impact (following the “habitat suitability” approach) to create an ÉCLAIRE policy scenario. The range of available measures (both in terms of climate policy and air quality policy) is used to display the significant effects found for sulfur and nitrogen deposition reductions. Specific parameters have been used to characterize emissions beyond 2050 (with a focus towards a “nominal” year 2100 (nominal 2100 scenario), and the sensitivity of the resulting emissions on the expected variation of inputs has been quantified. Clearly the largest variation is seen in the difference between a standard-run scenario (“current legislation”) and a maximum abatement scenario (“maximum feasible reductions”). Other parameters are much less important, proving that human action indeed is meaningful and the purpose of emission reduction supersedes any of the more arbitrary variations. Another direct anthropogenic effect addressing the quantities of material use (“activities”) is less important but still very relevant. Indirect effects of anthropogenic activities, in contrast, seem to be less important to the overall effects in terms of emissions, and also in terms of atmospheric deposition. Quantification of impacts and cost assessment of the policy scenarios is missing at this stage and will require further input.

2. Objectives:

A framework to extend GAINS to 2050 and towards the end of this century (“indicative 2100”) has been established. In order to understand the influences on the results from certain assumptions needed to create the scenarios, the sensitivities with respect to input conditions need to be tested, and a qualitative understanding of the uncertainties involved has to be formulated. This analysis needs to separate the impacts of the individual parameters (management change, the effects of climate on emission factors, and the possibility and extent of technology learning effects on future emission abatement).

3. Activities:

Concepts were developed that are required to guide optimization algorithms of an ÉCLAIRE policy scenario, using the novel metrics developed as an important element of the project. The GAINS add-on structure described in Deliverable D20.4-5 (Winiwarter et al., 2014a) was used to specifically detect impacts of the respective extension parameters used to project future conditions for current legislation and maximum feasible reduction scenarios, and foundations were laid to implement towards policy scenarios. As the policy scenario impacts are of special relevance, a pre-assessment of sensitivities was done using a policy scenario definition developed during the ÉCLAIRE GA in Budapest (2014).

4. Results:

With a structure for optimization available, a final (country-specific) development of metrics needs to be attained from national experts before optimization of measures for an ÉCLAIRE policy scenario. In the meantime, sensitivity tests of the underlying scenarios show that the direct human impacts exert much larger effects on emissions, specifically those of ammonia, than the consequences of human action. This means, that sensitivity is large for specific human action to decrease the nitrogen cycle and abatement measures, or for the size of this nitrogen cycle itself. Other parameters that drive future changes, like the average temperature, the extent of technological development, or the on-going management changes due to farm-size increase are not considered as important. The most decisive difference is whether abatement measures are taken or not. This impact is also clearly visible in quantifying future atmospheric deposition of nitrogen and sulphur, which clearly shows the available potential of future measures.

5. Milestones achieved:

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6. Deviations and reasons:

This deliverable was provided late due to internal project restructuring to maximise the use of available information from both within the project and other work. Discussion was also then possible during the Budapest General Assembly and project meeting, which allowed the finalisation of the optimisation metrics and the subsequent delivery of the results in this deliverable.

7. Publications:

Wilfried Winiwarter, Fabian Wagner, Lena Höglund-Isaksson, Zbigniew Klimont, Markus Amann. Modelling future impacts on ecosystems: integrating required parameters in GAINS. Paper presented at the ÉCLAIRE Open Science Conference, Budapest, October 1-2, 2014.

8. Meetings:

- ÉCLAIRE 4rd General Assembly, Budapest, September 29-30, 2014
- ÉCLAIRE Open Science Conference, Budapest, October 1-2, 2014
- Bilateral meeting at IIASA, Oct 6 & 8 (Max Posch, Wolfgang Schöpp, Wilfried Winiwarter)
- Seventh International Symposium on Non-CO_2 Greenhouse Gases (NCGG7), November 5-7, 2014, Amsterdam, the Netherlands & bilateral side meeting (David Simpson / Wilfried Winiwarter)

9. List of Documents/Annexes:

Documentation: Sensitivity analyses of future impacts on ecosystems using the GAINS system

Sensitivity analyses of modelling future impacts on ecosystems using the GAINS system

1. Introduction

In the framework of the ÉCLAIRE project, the current report aims to provide insight on the importance of different input parameters to the results produced by the GAINS modelling system. The overall setup of the GAINS system has been described in detail by Winiwarter et al. (2014a). In this paper, we intend to describe the following aspects:

- definition of a GAINS policy scenario, i.e. a certain environmental target to be achieved from a variety of emission pathways and for different base years.
- impacts of emission changes on deposition and hence critical loads. The full range of possible effects, i.e. “current legislation” scenario to “maximum feasible reduction” are being explored for a time period till 2050.
- sensitivity of ammonia emissions with respect to different drivers for long-range scenarios (beyond 2100). This analysis varies the respective input and assesses the variations achieved in the output. Not only the “central” values, but also the upper and lower boundaries of each of the inputs are carefully selected to reflect an arguably realistic situation

While analyzing the extent of model influences executed by these aspects, other elements can not be considered, at least not in this paper. Such elements include an increased susceptibility of vegetation to threats under climate change conditions (such an effect may be expected from the fact that plants, especially long-living forests, would be removed from their ideal habitat and thus may be exposed to a basic level of stress even without pollution), or the impact of altered source-receptor relationships due to a change in weather and precipitation patterns. Such influences are beyond the scope of this report and may constitute elements of further study within ÉCLAIRE.

2. The GAINS policy scenario

In an attempt to develop an accounting framework for cost-benefit analysis, Holland and Maas (2014) investigated benefits of ecosystems services relevant for natural and semi-natural ecosystems. Maas (2014) extended this concept, which eventually covers the following elements:

- Marketed ecosystem services
- Willingness-to-pay for non-marketed services
- Restoration costs
- Elimination costs
- Legal requirement approach on conservation
- Nitrogen Use Efficiency approach

While the first bullet is the most obvious, it is basically limited to areas where good data exist (timber production); the “legal requirement” approach stands for a general obligation of society which at least in to some extent has already been met previously (e.g., Natura 2000 protection); this approach seems to be the most complete. The last bullet (Nitrogen use efficiency, NUE) should be seen somewhat distant as NUE improvements is in the financial interest of farmers and will happen anyway rather than being mandated as an air pollution abatement measure.

Thus the ÉCLAIRE policy target emerges as the protection of Natura 2000 in a strict interpretation of the goals of the legislation (i.e., without offsetting). GAINS optimization scenarios will be created that consider the new biodiversity thresholds related to the "Habitat suitability index" (which in their final form will not be available before the April 2015 Zagreb CCE meeting). The shape of the limitation zone in the N/S deposition graph will be re-created as a combination of current acidification critical loads combined with the nutrient critical loads, the latter being set at 15 kg/ha to also comply with the long-term forest related targets as set out at the ÉCLAIRE GA in Budapest.

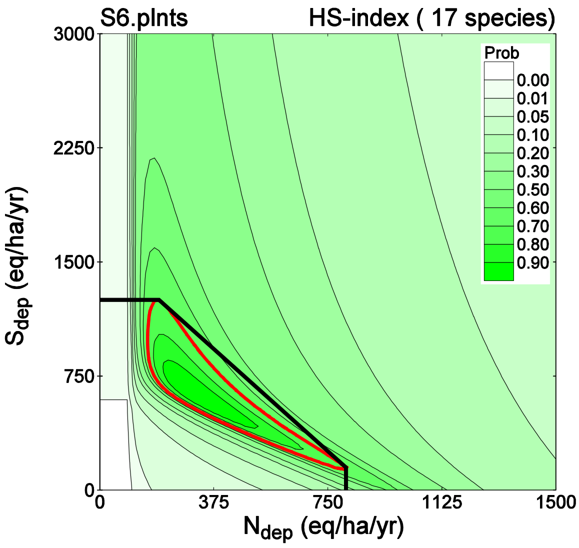


Fig. 1: Probability distribution of species occurrence for a given EUNIS vegetation unit as a function of S and N deposited. Area above and right of dark line will adversely affect species richness and thus should not be exceeded in Natura 2000 areas. (Figure from Hettelingh et al., 2014)

For a policy scenario, we understand that "habitat suitability" needs to be maintained in all Natura 2000 areas in order to fulfil the "no net loss of biodiversity" requirement, thus we will consider only such areas. Calculations can be done by receptor point, but optimization will allow for using national averages (to avoid the target to become unreachable for extreme situation). While this may be a matter of interest, the impact of large individual farms on the Natura 2000 areas need to be dealt with locally, no such simulation of single point sources will be performed.

The response curve of vegetation / forests to ozone and nitrogen given above will not allow a threshold to be identified. Instead, two levels of growth vs. POD (ozone damage) relationships will be provided, separately for different plant (i.e., tree) species. Using these functions and the spatial information on forest composition, the growth effect of the different scenarios created according to the above optimization (CLE, optimized, MFR) will be assessed.

With the details of the habitat suitability index (to be defined by the respective countries) not available yet, no final version of the policy scenario can be assessed at this time, and thus also optimization is not possible yet. However, it is evident that the level of measures needed in addition to CLE strongly will depend on the respective base scenario assumptions – and thus also the costs involved.

3. GAINS boundary scenario sets for 2050

In order to delineate the range of possible scenarios, we first of all define a "current legislation" (CLE) scenario. This scenario uses energy and agricultural projections to define the activity pathway, and air pollution legislation as currently implemented (including legislation in place that will be effective in the future only) for a description of the abatement technology expected in the future. On the other end of the scale, the "maximum feasible reduction" (MFR) scenario assumes all abatement possibilities defined in GAINS to be in place, thus drastically reducing emissions. The concept is very typically used in establishing policy scenarios (see e.g. Amann et al., 2014).

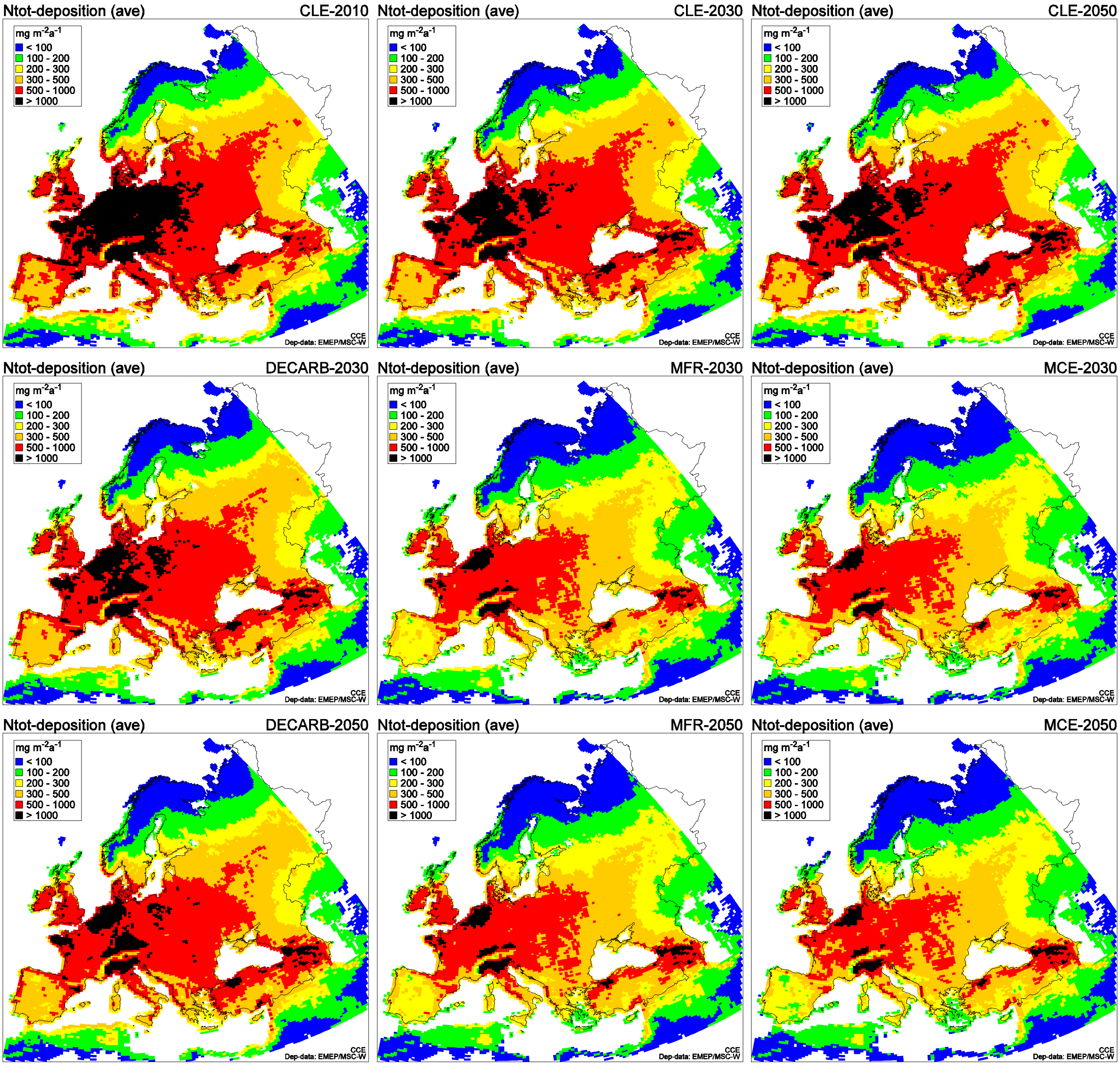
A set of scenarios is based on the assumption of climate mitigation measures to become effective: a "decarbonization" scenario (DECARB) considers strongly reduced fossil fuel use (activity number) and emission abatement measures at the CLE level, while the "maximum control efforts" (MCE) scenario reduces both energy inputs and pollution levels. Tab. 1 provides an overview of the data sources used, emissions for 2010, 2030 and 2050 were provided with GAINS on a country level for all European and some Caucasian countries.

Tab. 1: Data origin for boundary scenario sets

Scenario	EU-28	Europe non-EU	Armenia, Azerbaijan, Georgia	Sea regions (all from Campling et al., 2013)
CLE, MFR (all years)	ECLIPSE_V5	ECLIPSE_V5	ECLIPSE_V5	VITO CLE, VITO MFR
DECARB 2030	Amann et al., 2014	Extrapolation using ENERGEO "Open Europe" scenario	Not available (CLE instead)	VITO "slow steam"
DECARB 2050	Extrapolation using ENERGEO "Open Europe" scenario			
MCE	Extrapolation of DECARB assuming ratio of MFR/CLE	Extrapolation of DECARB assuming ratio of MFR/CLE	Not available (MFR instead)	VITO MCE

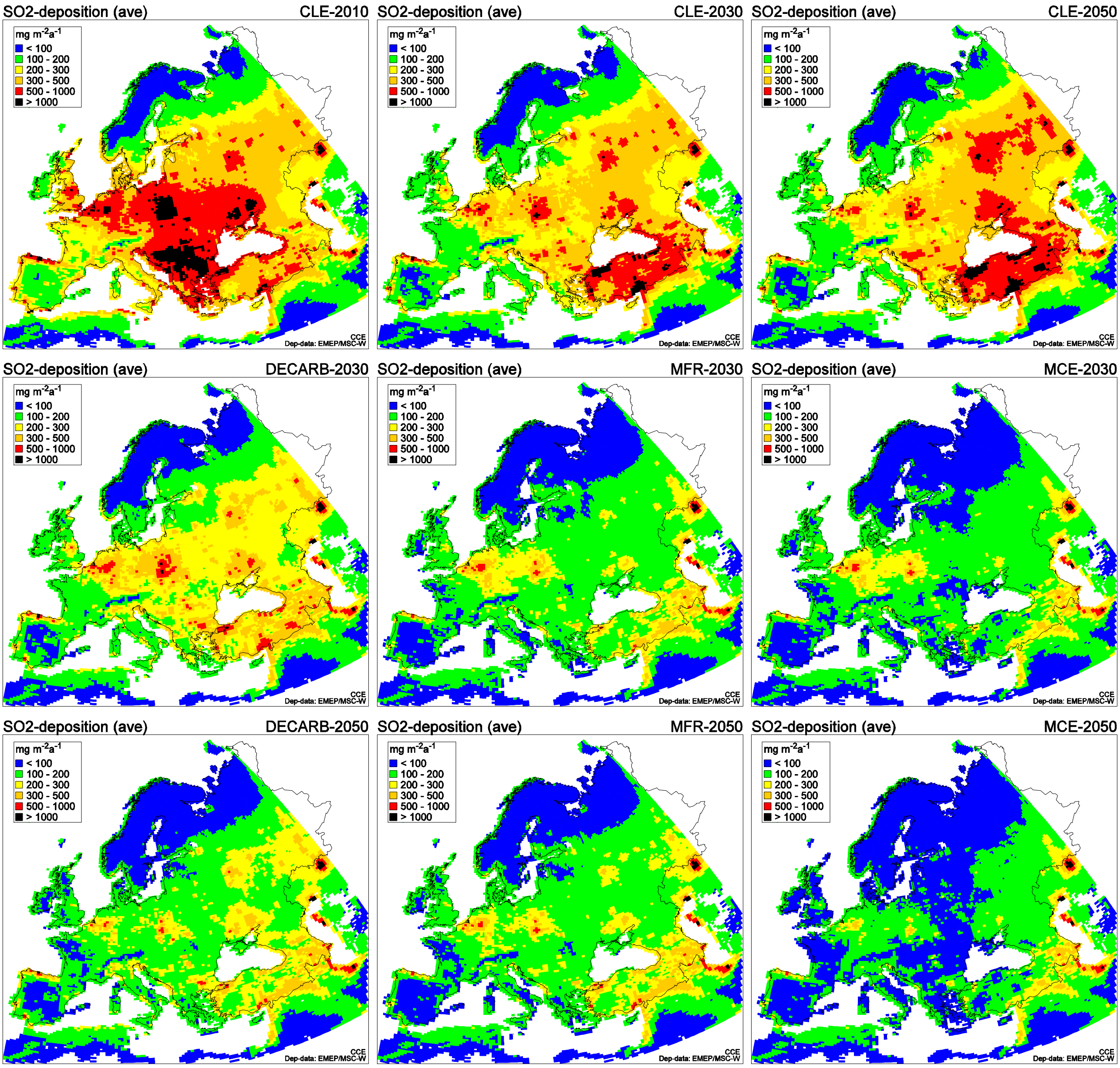
A source receptor matrix (developed with the EMEP model) was used to map the effects of the respective scenarios on total N and total S deposition (see Fig. 2 and 3). Original emission data (in kton/yr, for SO2, NOx and NH3) are thus being converted into deposition data (Units: mg/m^2/yr).

Fig. 2: Total N depositions (Units: mg N/m^2/yr) from ÉCLAIRE emission scenarios (100 mg/m^2 = 1 kg/ha)



While in the CLE case, considerable parts of Central and Western Europe are being exposed to N deposition in excess of 10 kg N / ha (black color in Fig. 2) this situation changes for all future scenarios. This is a consequence of improved NOx abatement expected in transport, mostly, and it extends just a little better for DECARB scenarios than for CLE. Only the more strigent MFR / CLE scenarios also cover NH3 emission reductions, so that eventually only in the densely populated and agriculturally used areas of Benelux the Po Valley and Switzerland emission levels remain beyond that threshold.

Fig. 3: Total S depositions (Units: mg S/m^2/yr) from ÉCLAIRE emission scenarios (100 mg/m^2 = 1 kg/ha)



Much of the high sulfur deposition (more than 10 kg/ha) now assumed in Poland and in south-eastern Europe is expected to be covered by abatement in 2030, while increased productivity causes an increase in the areas concerned in Turkey. Decarbonization clearly causes a decrease of emissions, but measures are able to provide even more of that, a factor of three to five over very large areas. The MCE case of 2050 shows what actually can be achieved in terms of sulfur abatement, arriving at near pristine levels for large parts of Europe.

4. Sensitivity of ammonia emissions beyond 2050 ("nominal 2100" scenario)

One of the main challenges of this activity is an extension of scenarios beyond those normally used in GAINS. A timescale of more than 50 years requires more than considering just existing trends and abatement technologies. An outline of how these long-term scenarios may be considered in the GAINS system has been provided by Winiwarter et al. (2014a). Here we use the same algorithms and parameters, only that (following from IPCC AR5) we couple the “nominal 2100” scenario with an assumed temperature increase of 3.7°C (difference of RCP8.5, i.e. case without / with very little climate policy and increase observed to-date) instead of the 5°C listed in our earlier report. This decreases the impact of temperature sensitivity. All details of parameters, including ranges used, are presented in Table 2. Sensitivity assessment is performed for the “nominal 2100” case only, as an add-on effect to any scenario uncertainty of the 2050 scenario.

Table 2: Expected range of inputs for the “nominal 2100” scenario

Element of change	Central estimate	Low estimate	High estimate
Activity change	Increase factor 1.04 (N input) or 1.22 (animal production)	No increase (all imported)	High scenario as of Bodirsky et al (2012): 1.47 increase factor of N-input
Climate change (as a temperature difference to “current”, 2010 conditions)	3.7° temperature increase	1° (as of RCP2.6 central estimate)	4.8° (upper boundary estimate in RCP8.5)
Technology / cost change	1% per year emission reduction of most advanced technology, at same costs	0.5% per year emission reduction	2% emission reduction
Change of production conditions (management)	Country-level reduction of share of “no control” farms	No change of shares	Zero no-control farms (as already implemented, i.e. identical to central estimate)

The purpose of the sensitivity analysis is to understand the impact of each of these parameters on the overall result, the annual emissions at the end of the modelling period (“nominal 2100”). Thus, a series of simulations were performed, where three of these four parameters were kept at their central estimate, and only the fourth parameter was varied to the respective low and high estimate. The result, indicating the extent to which an impact of the respective parameter is to be expected, is shown in Fig. 4.

First of all, it becomes evident that the difference between CLE and MFR is large enough that there is no overlap, not for any of the parameters tested. This means that in any case, the largest effect on emissions will be exerted by anthropogenic action. Note that even the next largest effects is direct anthropogenic activity, too, the effects caused by altering activities. While the former refers to targeted action with a clear purpose to reduce emissions (ammonia abatement technologies), the latter is the consequence of different assumptions of the extent to which nitrogen application in Europe will be altered, and nitrogen cycles will be impacted. The fact that agricultural products can also be imported and exported adds to the uncertainty of the estimate, as demand estimates might not add clarity as demand can also be satisfied from imports.

Impacts of temperature change is important, but less so than the direct anthropogenic effects. It is interesting to note that variation to lower temperatures seems to impact sensitivity to a larger extent than the higher temperatures – here one needs to remember that, in its conception, the high end of the range was determined by the variation of the underlying RCP8.5 scenario, while the lower end refers to the climate policy scenario RCP2.6. Possibly, scenarios can be conceived that extend even higher than the upper range of RCP8.5. Moreover, temperature ranges discussed refer to a global average and not to a specifically European situations, where the expected temperature increase may be different (but difficult to obtain for individual European countries, as would be needed for data input).

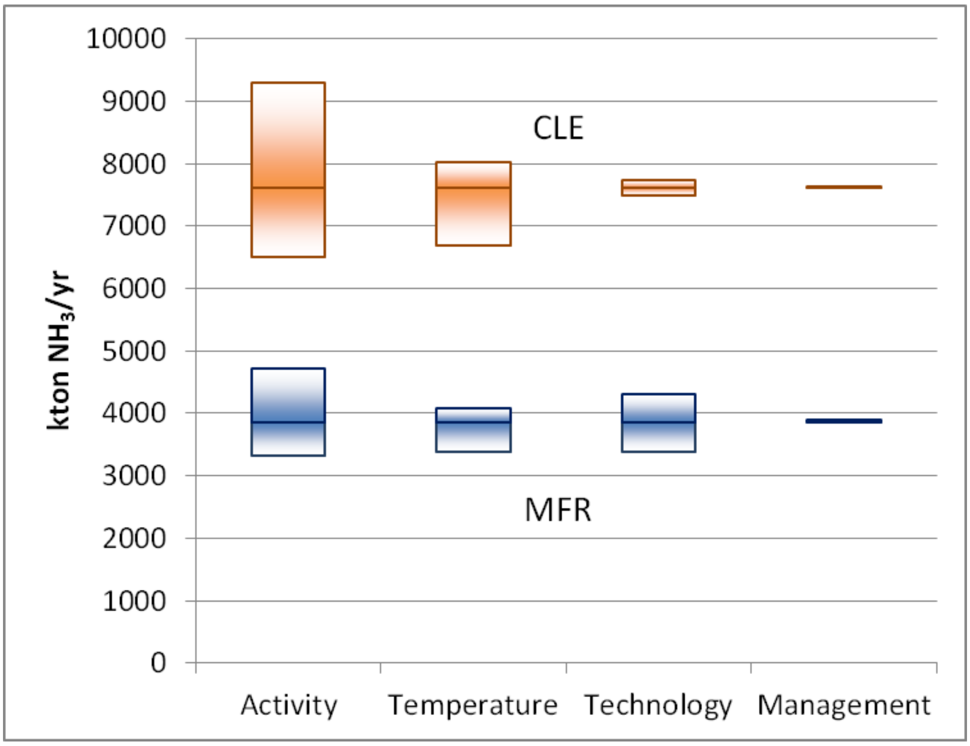


Fig. 4: Range of resulting emissions of NH_3 as the total of 40 European countries in "nominal 2100". Central estimate for CLE (upper part of the graph, orange bars) and MFR (lower part, blue) is presented together with results of sensitivity analysis.

Interestingly, expected technology improvements show a much larger impact to the MFR case than to the CLE case (in contrast to the other parameters, where differences are more or less proportional). This is as we assume improvements to occur on top of the most stringent emission control only. In case of less ambition emission control, no improvements due to technology learning can be expected. This is reflected also in the effect different rates of such learning should be expected.

Finally, it turns out that the impact of foreseeable change in management (the trend towards larger farm sizes) will be rather small. The number of subsistence farms that are excluded from any emission reduction and therefore will continue to emit without abatement under any scenario is quite small already for most of the European farming system – so the fact that these farms virtually will not exist towards the end of the century does not have much impact. In the central estimate this was assumed already, only the low assumption operated under a constant share of subsistence farms (same share in 2100 as exists now) for which no measures can be implemented. While this is clearly shown to be not important for Europe as a whole, there are a few individual countries for which the situation is very different (Romania, Bulgaria – details not shown here).

While, for this sensitivity analysis, we attempted to be inclusive in the low/high estimates, obviously there is a limitation when no data is available. As e.g. the discussion of mitigation measures by Winiwarter et al. (2014b) indicates, there is some potential (but not generally quantifiable) that a situation at the end of the 21st century indeed could look very different from now. That paper discusses agricultural technologies that do not merely follow a gradual change but could allow dramatic improvement of nitrogen release (albeit at huge costs, including energy costs). The same may be true for all other aspects, where we just limit to gradual, reasonably understood changes.

This sensitivity analysis includes only four parameters to describe changes. In a similar way, other effects may also play a decisive role in the impacts of nitrogen pollution to plant ecosystems. We just intend to point out possible variations of temperature and precipitation patterns that could affect source-receptor relationships, or the altered response of vegetation to pollution under condition of a different climate and CO_2-concentration at the end of this century, to which plants might not be fully adapted. Including such aspects, however, is beyond the scope of this paper.

5. Conclusions

A framework has been established to implement an ÉCLAIRE policy scenario that covers new metrics to describe ecosystems effects of air pollution. This framework links the habitat suitability index (a detailed quantification of the index according to national features is currently being performed by country experts) as a new metrics to be used in an ÉCLAIRE policy scenario for 2050 and beyond. Analysis of deposition as a result of emission and emission abatement clearly shows the extent of emission reductions available for 2050 already.

Further extension of scenarios into the future requires additional scrutiny. A set of parameters was identified to be used for guiding such scenarios for a “nominal 2100” scenario. The sensitivity of the overall emissions calculated to variations of these parameters was tested in the present study. Using realistic variations in the inputs, their respective influence was quantified.

None of these parameters had an influence of a similar size as the difference between the standard (“current legislation”) and the abated (“maximum feasible reduction”) scenario. This shows that human activities to reduce emissions clearly have a larger effect than any ransom variations or secondary effects of human action. The only parameter coming close to the purposeful intervention to abate emissions is the magnitude of the underlying activity, here with respect to the nitrogen cycle. We may wish to regard this also as a direct anthropogenic effect.

Smaller impacts are visible from parameters expressing only an indirect human effect. This refers to the extent of technological improvement (how fast can technology develop?), on the emission increase due to temperature change, and on the management change of increased farm sizes. More and additional parameters may be needed to adequately characterize future emissions, but at least at this time sufficient quantitative data seem not available.

References

Amann, Markus, Jens Borken-Kleefeld, Janusz Cofala, Jean-Paul Hettelingh, Chris Heyes, Lena Höglund-Isaksson, Mike Holland, Gregor Kiesewetter, Zbigniew Klimont, Peter Rafaj, Maximilian Posch, Robert Sander, Wolfgang Schöpp, Fabian Wagner, Wilfried Winiwarter (2014). The Final Policy Scenarios of the EU Clean Air Policy Package TSAP Report #11 Version 1.1a. International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria.

Bodirsky, B.L., Popp, A., Weindl, I., Dietrich, J.P., Rolinski, S., Scheiffele, L., Schmitz, C., Lotze-Campen, H. (2012). N_2O emissions from the global agricultural nitrogen cycle – current state and future scenarios. Biogeosciences 9, 4169–4197.

Campling, Paul, Liliane Janssen, Kris Vanherle, Janusz Cofala, Chris Heyes, and Robert Sander (2013). Specific evaluation of emissions from shipping including assessment for the establishment of possible new emission control areas in European Seas, Final Report, VITO, Mol, Belgium , March 2013, http://ec.europa.eu/environment/archives/air/pdf/Main%20Report%20Shipping.pdf

Hettelingh J-P, M Posch, J Slootweg (2014). Critical Loads: Call for Data. 33rd session of the Working Group on Effects. Geneva,17-19 Sep 2014.

Holland, Mike, Rob Maas (2014). Quantification of economic damage to biodiversity. ECLAIRE Project, Work package 18. Ecometrics Research and Consulting (EMRC), Reading, UK, May 2014.

Maas, R. (2014) presentation at ÉCLAIRE Open Science Conference, Budapest, Oct. 1-2, 2014.

Winiwarter, Wilfried, Fabian Wagner, Lena Höglund-Isaksson, Zbigniew Klimont, Markus Amann. (2014a). Description of the consequences of management change as an adaptation strategy on the scenarios investigated & Preliminary report on cost optimization for 2050 scenarios. ÉCLAIRE deliverable D20.4-5. IIASA, Laxenburg, September 2014.

Winiwarter, Wilfried, Adrian Leip, Hanna L. Tuomisto, Palle Haastrup (2014b). A European perspective of innovations towards mitigation of nitrogen- related greenhouse gases. Current Opinion in Environmental Sustainability 9-10, 37-45.