Project Number 282910

ÉCLAIRE

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

Seventh Framework Programme

Theme: Environment

D20.4: Description of the consequences of management change as an adaptation strategy on the scenarios investigated
D20.5 Preliminary report on cost optimization for 2050 scenarios

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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

Please note that due to the interlinkages of deliverables 20.4 and 20.5 we have decided to report on both of these deliverables in the same report. This report will be uploaded twice to the participants portal, to show that both deliverables have been met.

Future impacts of air pollution on ecosystems (and the effects of policies to improve the situation) are affected by many different elements and feedbacks. First of all, different levels of emissions (some of which influenced by future climatic conditions) may influence atmospheric concentrations. Next, a different pattern of land management and use, e.g. regarding agriculture and forestry, may alter plant communities and ecosystems which then are susceptible to air pollution in a different manner. Moreover, climate change may impact the response of plant communities to additional stressors such as air pollution. Finally, the structure of anthropogenic activities and the management practices will change under altered economic conditions, with consequences on measures available to reduce emissions and the related costs. Here we address each of these topics in a quantitative manner and derive parameters to describe them according to the current state of knowledge. We use the GAINS model to develop an integrated understanding of the effects and the interferences of these parameters.

2. Objectives:

In a consistent assessment of future air pollution impacts on vegetation, a framework had to be created to include in the GAINS structure the respective boundary conditions of a future situation. This included topics such as the consideration of management change, the effects of climate on emission factors, and the possibility and extent of technology learning effects on future emission abatement. Geographical extent of the exercise is Europe (40 GAINS regions), temporally the year 2050 and an unspecified date beyond 2050 (we term it “end of the century”) need to be provided. The latter is a clear extension of GAINS beyond its current range.

3. Activities:

A structure was created as an add-on to GAINS which allows assessing emissions and costs of measures on the most detailed level (by country, sector, activity and technology) while remaining consistent with the GAINS approach of emission stages for manure treatment. This structure is available as an MS Access database, an interface to directly import from GAINS scenarios has been provided. Current legislation and maximum feasible reduction scenarios have been provided for this structure, to allow quantification of the future effects, which also allow for an allocation of technology improvements as is urgently needed in a setting discussing emissions at the end of this century.

4. Results:

Not unexpectedly, factors describing changes beyond 2050 have a considerable impact on overall emissions and cost structures. Influences are very different by country, depending on the respective source structure and, even more so, the level of emission abatement already implemented. Currently responses can be assessed only on the emission level. Identifying a meaningful metric to assess ecosystem damage that also is somewhat robust towards the uncertain change parameters developed here will clearly benefit the overall project.

5. Milestones achieved:

MS 97, First complete set of scenario results (2050 and beyond)

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. Although the new recommended metrics of ECLAIRE, to be used for cost-optimization, have not been agreed upon yet, the structure for implementing them is ready, so there is no need for concern. Good communication (including during the 4th General Assembly) will continue to be implemented to further the work on the necessary metrics.

7. Publications:

Wilfried Winiwarter, Jan Willem Erisman, James N. Galloway, Zbigniew Klimont and Mark A. Sutton. Estimating environmentally relevant fixed nitrogen demand in the 21st century. Climatic Change 120, 889-901 (2013).

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

James N. Galloway, Wilfried Winiwarter, Adrian Leip, Allison M. Leach, Albert Bleeker, Jan-Willem Erisman. Nitrogen Footprints: Past, Present and Future. Accepted for publication in Environmental Research Letters (2014).

8. Meetings:

- ECLAIRE 3rd General Assembly, Zagreb, October 22-24, 2013
- NEBEI workshop, Task Force on Integrated Assessment Modelling, Zagreb, October 24-25, 2013
- 24th CCE Workshop and 30th Task Force Meeting of the ICP Modelling and Mapping, 7-10th April 2014, Rome, Italy (Component 5 workshop)

9. List of Documents/Annexes:

Documentation: Modelling future impacts on ecosystems: integrating the parameters required for GAINS

Modelling future impacts on ecosystems: integrating the parameters required for GAINS

1. The GAINS modelling system: introduction

GAINS – the "Greenhouse gas - Air pollution INteractions and Synergies" model – has been developed to investigate the relationship between the release of air pollution and greenhouse gases, their effects and the options to mitigate/abate such release and in consequence also the related impacts (see e.g. Amann et al., 2011). In the framework of ECLAIRE, GAINS is tasked to simulate the impact of air pollution on vegetation and ecosystems under the condition of a changing climate. This requires to develop GAINS beyond its standard set of applications, specifically considering the influences to the model environment of a future on a climate timescale, i.e. 30 years and beyond.

This report describes the adaptations of the GAINS system (model and postprocessing) required in this respect, and the consideration of possible future management changes which may have their reason as a climate adaptation activity. While robust knowledge about the future boundary conditions is not available, especially in the timescales in question, we refer to existing initiatives and literature, especially with regard to the IPCC's RCPs and SSP's (van Vuuren et al., 2011; Nakicenovic et al., 2014). The aim here is to provide consistent information that allows to (a) be compared with other scenario datasets and (b) integrate results from earlier parts of the ECLAIRE project (novel thresholds, vegetation response under altered temperatures) once they become available.

The geographical extent of this exercise is Europe. We take advantage of the model and data improvements performed within GAINS, in part as a consequence of consultation processes with country experts. Activities were performed as part of the Gothenburg Protocol Revision process (see Amann et al., 2012) for all European countries, and for the European Union during the air pollution policy review (Amann et al., 2014) and the EU climate and energy strategy (Höglund et al., 2012 and Capros et al., 2013). The air pollutant related activities extended till 2020 and 2030, respectively. Only for the climate strategy, GAINS data were compiled to include 2050. While GAINS basically is able to cover multiple air pollutants and greenhouse gases, this report focuses on ammonia (NH3) as a key compound in ecosystems assessment. In addition to 2050 values, we allow here to extrapolate to climate-relevant situations termed "end of the century"

2. Parameters influencing the GAINS source /response/cost relationship

Implementing effects of climate change in GAINS is a challenging task, due to the rigid structure of an operative model. In order to properly assess the effects of real world changes in a complex model, best results can be achieved when model parameters vary only incremental. Model behavior then remains close to the validated regime, and the differences to a previous state is more easily explained. Implementing change thus is most easily performed with a minimum of interference, rather than maximizing the respective changes in attempt to cover all possible changes. Thus in the following we rather carefully dissect a carefully selected set of elements, most of which have to be dealt with outside the GAINS model proper (in form of a post-analysis) in order to understand the overall effect of the changes considered, ad their respective contributions.

Necessarily, keeping the majority of parameters constant over most of the modelling domain (space and time) is a simplification. This simplification is needed, however, to maintain operability of the model and moreover to provide the explanations needed to produce results that can be used for policy support.

In the following, we use literature information provided on a variety of individual topics that would provide indications of future directions (changes) as a consequence of climate change or other known developments. We attempt to separate this data into individual traceable pieces, each of which can provide a factor of change. All of these individual factors are subsequently applied to the GAINS results (post-processing), in order to arrive at a result covering all aspects.

Emission change

Assessing and implement expected changes in human activities, and in the technologies to produce and remove emissions, estimating future emissions is at the core of the GAINS model. Based on assuming some constant factors (like constant technology costs over time, and constant removal efficiencies/abated emission factors over time for a given abatement technology), emission changes are projected. GAINS, however, is not able to integrate improvements (in costs or efficiency) of the expected abatement technology, nor can it predict the onset of future technologies that might be developed.

In consequence, the strength of the GAINS model, in its core configuration, is in the analysis of issues on the term of a few decades rather than on the climate-related periods up to the end of this century. Different parameterizations have been developed as add-ons attempting to cover technological developments (see Höglund-Isakssen et al., 2013, but also the discussion provided below). Also, semi-quantitative methods have been discussed to cover future technologies in a GAINS-like fashion (emission change and cost estimates) which are barely visible on the horizon (Winiwarter et al., 2014), but never included in the model.

On a longer term, till the end of the century, it is thus worthwhile to consider which changes may be possible. We refer here to a global projection (Winiwarter et al., 2013) based on the RCP scenarios prepared for the IPCC (van Vuuren et al., 2011), which has been developed projecting industrial fixation of nitrogen as an indicator of nitrogen pollution. Using their global developments between the years 2050 and 2100 and applying this to activities in Europe for the “unabated” case (i.e., no carbon policy: RCP 8.5), we may identify an increase factor from 2050 to 2100 of 1.22 for population (as a proxy for animal production and animal N excretion), 1.04 for total N (which we use for mineral fertilizer) and 0.78 for NOx emissions. It may seem highly questionable to apply global factors to Europe, considering the general uncertainties in global trade e.g. of agricultural products, but based on the competitiveness of agricultural industry in a favourable climate it seems at least consistent to separate regional population projections (=demand) from production. Thus these factors at least allow for a hint of possible future variation till the end of this century.

Climate change

There are many elements in the relationship between human activities and impacts on ecosystems that are characterized by climatic conditions. Especially changes in temperature, atmospheric transport conditions and humidity/rainfall patterns may affect this relationship. Some of these impacts may be rather straightforward, others are more complex.

First of all, the release of volatile compounds may be affected by increased temperatures, like water soluble compounds may be impacted by rainfall. Both aspects are relevant issues for ammonia. Sutton et al. (2013) estimate that a temperature increase of 5° C would increase ammonia emissions by 42%, based on empirical data from seabird colonies. Similar considerations have been transferred to anthropogenic emissions, such that e.g. for animal houses and manure storage, lower temperature is assumed to provide an effective abatement measure (Groenestein et al., 2014) – nevertheless the climatic conditions (e.g., Southern vs. Northern European housing) are not reflected in inventory guidelines (EEA, 2014). In fact, while the relationship as such seems plausible, many additional factors need to be taken into account.

However, management practices are intrinsically linked to environmental conditions – with fertilizer (manure) application linked to ambient temperatures rather than to the season. One may reasonably expect changes in the agricultural cycle which fully take account of climate change. Thus much of the changes to be expected due to temperature increase in agricultural practice may cancel out – in contrast to the above example of seabird colonies where no such feedback loop exists.

We basically follow the suggestions given by Sutton et al. (2013), who eventually differentiate between “marine” and “terrestrial” sources only, for which they derive an emission increase factor Q10 (emission increase at 10°temperature change) of 4 and 2, respectively. The factors used here, adjusted to be integrated in the GAINS model, are given in detail in Tab. 1. In breaking down a Q10 to an increase factor at 5°C (reflecting a possible temperature increase to the end of the century, according IPCC, 2013) or 1°C (for a 2050 scenario) we assume a geometric relationship, i.e. the increase factor remains constant at each equal temperature difference.

Tab. 1: Assumed temperature dependence for different stages / emission sectors of GAINS

	Q10	5°C increment	1°C increment
no T-related management changes			
grazing	4	100%	15%
storage	4	100%	15%
natural sources	4	100%	15%
T-related management changes			
housing	1.25	12%	2%
spreading/fertilizer application	1.25	12%	2%

Management change / change of production conditions

Management conditions in agriculture have been changing independently of climate change. EUROSTAT data (Eurostat, 2014) demonstrate that there has been a continuous shift in size classes of animal numbers on an individual farm, with numbers / shares of small farms decreasing and numbers / shares of larger farms increasing. This effect can be observed for almost all countries for most animal categories. It is so straightforward that it can be easily extrapolated into the future, based on animal counts available twice for every five year period.

Fig. 1 shows, for the pig industry in Austria, the results of such an extrapolation. We assume a first order decay function, indicating a constant fraction of animals moving out of each of the given size classes per time unit. Accordingly, we perform linear correlation to the logarithms of the respective shares from statistical data, and extrapolate that linear relationship as far as 2050. The figure displays the resulting transposed data. It becomes quite evident, with the trends shown, that the shares of animals on smaller farms strongly decrease over historic times, such that farms smaller than 50 LSU (livestock units) have become unimportant. In 2050 this will be true for all farms < 100 LSU. The turnover to very large farms, however, is extremely slow.

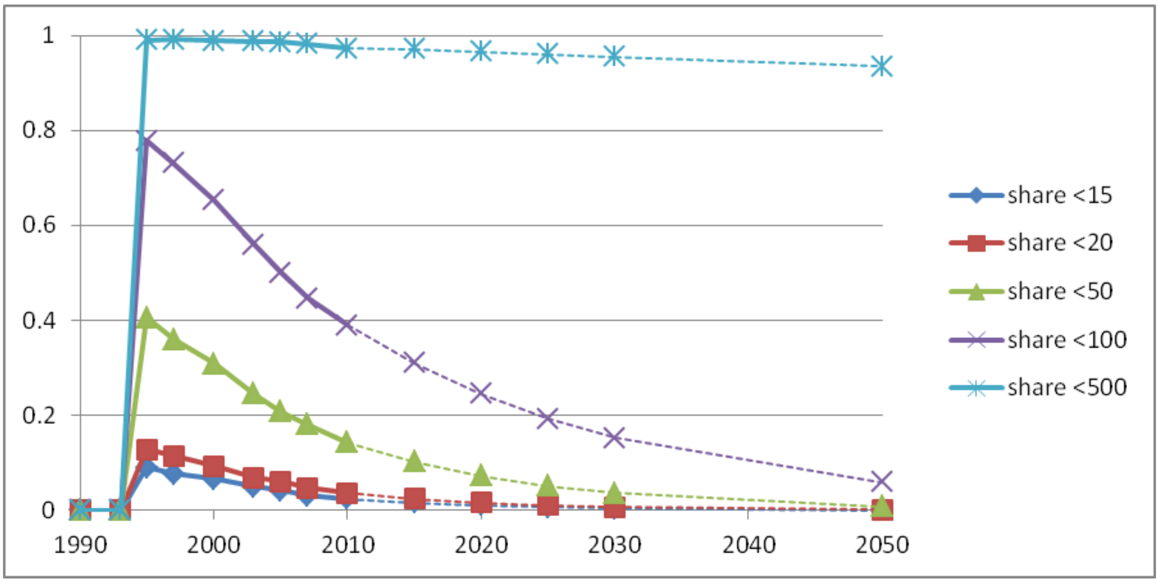

Fig. 1: Austria, share of pigs living on farms smaller than a given size (in livestock units). First valid data point is from 1995, up to 2010 statistical data is used, extrapolated towards 2050

It is worth comparing this result to that of Romania, here for dairy cows. Agriculture in Romania traditionally consists of a considerable fraction of subsistence farms. Statistical data, which here are available for a much shorter time period (only since 2003) still clearly indicate a process of change. While trends are not arriving at those low levels as for the Austrian example on pigs, clearly strong decrease may be expected till 2050 for all farms <20 LSU. It may be noted that, in contrast to the Austrian case, the initial (historical) points do not match the logarithmic decay line perfectly well, indicating that there is still considerable uncertainty in these trends. One may note that the initial decrease of shares, at the time of the country joining the EU, still was much weaker, with an EU-effect coming in only later. If that argument were to be confirmed, one would expect an even stronger increase in size. For consistency reasons, it seems however advantageous to stay with the identical algorithm everywhere.

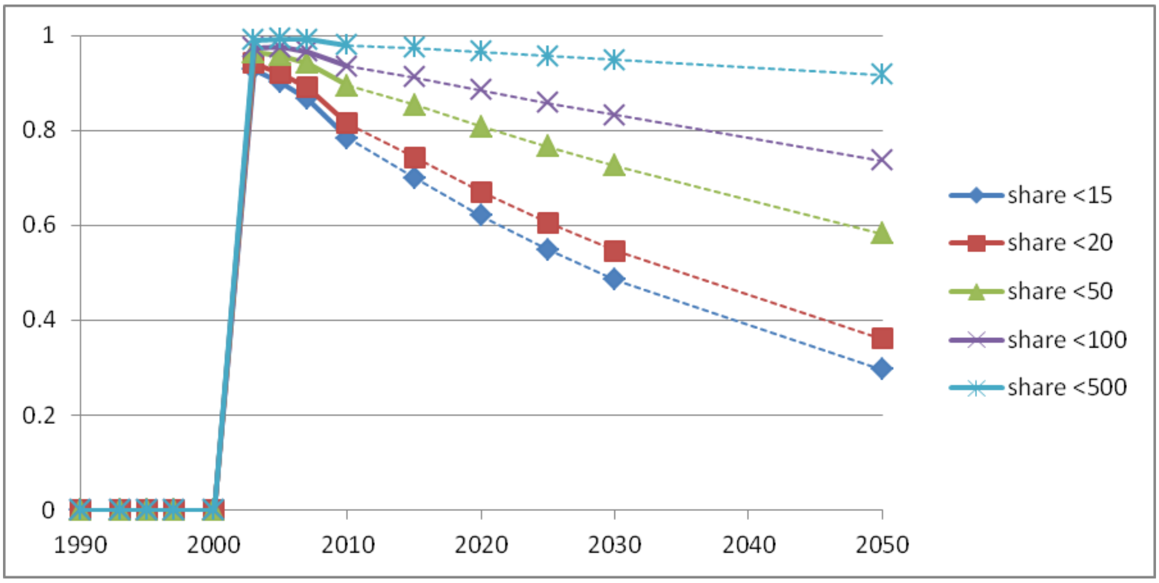

Fig. 2: Romania, share of dairy cows living on farms smaller than a given size (in livestock units). First valid data point is from 2003, up to 2010 statistical data is used, extrapolated towards 2050

Farm sizes have been used previously to estimate the respective costs of measures in the agricultural sector (Klimont and Winiwarter, 2011). At that point, a decision was also taken to exclude small subsistence-type farms from any of the measures that can be applied in GAINS optimization. This concerns all farms that have less than 15 LSU: even in a maximum reduction scenario, the share of activity related to these farms is not touched. Klimont and Winiwarter (2011) used for their "applicability" tables the latest available set of Eurostat data at that time, which then was from 2007. Using the extrapolation procedure described above, it is possible to estimate the share of farms for each animal category that will be larger than 15 LSU in 2050 and thus may be selected for measures, and derive an extension factor over the respectively relevant situation of 2007. This extension factor is then a multiplier to be applied to the emission reductions calculated for 2050 due to the respective measures, and establishes the additional reductions that can be performed when a larger fraction of livestock can undergo measures as there are less subsistence farms. In a similar manner, an extension factor was also derived assuming that there are no subsistence farms left, expressing a situation that may become relevant by the end of this century.

As a consequence of data availability, changes were introduced to EU27 (27 countries of the European Union as of 2007), and the Slovenian factors were applied to Croatia. Moreover, as this procedure will not allow addressing separately the GAINS differentiation between liquid and solid manure systems, changes introduced by this parameter had to be limited to replace, at the maximum, all still available shares of the respective activity for which a "no control" emission factor is used, in order to maintain system stability.

Cost change

The structure of GAINS allows to apply emission abatement technology to given activities. This technology is considered to be clearly defined, both in their potential to reduce emissions and in the costs involved in applying it. In consequence, any abatement measures will always have the same efficiency and the same costs at any time. There is no consideration of further development. Moreover, only technologies are suitable that can adequately be described at the time the model is operated. This includes abatement options that are under development, but makes it conceptually almost impossible to cover more speculative options that might develop in the more distant future.

In addressing a longer term vision, Winiwarter et al. (2014) discuss a handful of mitigation options in the agriculture sector which may, at immense costs, reduce emissions considerably beyond any currently discussed mitigation strategy. It is quite probable that none of these options will ever be applied. But these examples also make clear that a potential exists, that needs to be addressed especially when longer time periods are considered. Climate-related scenarios, for this reason, tend to use storylines to describe developments which take advantage of rather arbitrary improvement factors.

In order to more generally consider technological improvements, the concept of "technology learning" has been developed (McDonald and Schrattenholzer, 2001; Jamasb and Köhler, 2007 Foxon, 2010) and applied in the context of mitigation technology (Capros et al., 2013; Höglund-Isaksson et al, 2013). This concept relies on the assumption that, by implementing more devices, additional experience is gained which would allow for improvement. At a given emission threshold, available experience mostly refers to cost reductions due to such improvement only, and improvement clearly depends on the level of installations implemented already, no learning occurs just because time passes. Learning may also be triggered as an "autonomous development", which happens when there is an external cost aspect: CO_2 emissions are mostly related to energy consumption, here energy costs are an important trigger – reducing energy needs will save costs while mitigating CO_2.

While such concepts cannot be fully applied to air pollutants, we suggest an approach that can take care of a considerable junk of improvement. Without knowledge on future implementation, we will have to introduce annual improvements despite of limited theoretical foundation. But we apply improvements only to the most advanced technology in each sector-activity combination of GAINS, to make sure just the "forefront of technology" is covered. Moreover, in order to not limit learning to improve costs, the concept extends to reduce emissions per activity unit at a given rate. Costs are maintained constant, but as emissions reduce the costs per amount of reduced pollutant will automatically also go down. We estimate that, in each subsequent year, emissions of the most advanced options may decrease by 1%, with 99% remaining. After a period of 35 years (till 2050) emission factors would still be at 70.3% of their current value, and at the end of the century at 42.6%.

Resulting emission reductions are considerable, but – considering what may be possible as discussed by Winiwarter et al. (2014) – clearly plausible. As we cannot attribute the changes to a specific technology here, we instead refer to the result as an option "technological development" or *Tec_devel*.

Change of deposition pattern and substrate response change

The current framework does not yet address certain aspects that would have to be imported from the results of other components of the ECLAIRE project. Climate-induced change may affect also atmospheric transport and deposition of trace constituents, as a consequence of chemical reactions, sunlight, rainfall patterns etc. In GAINS, atmospheric deposition is an output based on multiple runs at different emission input of a chemical transport model (CTM), a regional air quality model, and source-receptor matrices developed from such exercises. Running CTM's from the results of different climate models indeed is possible, but with the expected small changes for 2050 differences in deposition patterns do not seem very relevant.

Different climate may also induce a different reaction of ecosystems. Species that constitute important elements of such ecosystems may find it difficult to adapt to altered humidity and temperatures. As is the case with farming, management strategies will in principle allow to adapt to such microclimatic differences caused by climate change. However, dynamics of such a change will not allow for a quick adaptation via species change, as that would require many years (in forests and semi-natural lands). Thus plants remaining at less-than-ideal growth sites may be more easily affected by air pollution than they otherwise would. Air pollution policy here needs to be regarded as an adaptation policy to climate change (Vincent Kint, pers. Info, August 2014). Attempts to quantify such effects, however, should be performed in accordance with the manner in which the quantification of ecosystems effects will be performed. With the development of novel thresholds to describe ecosystems damage high on the ECLAIRE agenda, assessing climate effects should take care of the same metric.

3. The GAINS system: implementing the above changes and first results

Implementing structural changes, as would be needed when considering the above, require considerable efforts in a complex model environment such as GAINS. For the purpose of this paper, such an implementation is not possible. Instead, effects can be approximated by using “add-on’s” to the GAINS model, i.e. parameterizations and external (ex-post) analyses of results. Such results will not exactly reflect a GAINS implementation, but will allow to study the system effects and to assess the importance of the respective contribution. Results shown below thus rather refer to responses of the “GAINS system” rather than the “GAINS model” alone. In practice, elements of the GAINS database (specifically, from the scenario “V5_ECLAIRE_CLE”) have been extracted and operations as indicated above implemented in a database setup externally.

Fig. 3 displays the result of a deposition calculation (scenario V5_ECLAIRE_CLE, year 2010 and 2050, total N deposition in eq per ha and year). Note that this result covers both changes in ammonia and in nitrate deposition, the improvements e.g. over large parts of Germany or Italy expected under current legislation conditions for 2050 reflect NO_x abatement rather than NH_3 reductions. Evaluation of this kind is currently not possible from the extension algorithms, only from the CLE[1] scenario implemented in GAINS.

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[1] CLE – for “current legislation” – expresses a scenario based on all currently implemented legislation, even if it becomes effective only in the future. In contrast, an “MFR” (for maximum feasible reduction) scenario covers all options for abatement that are implemented in the model.

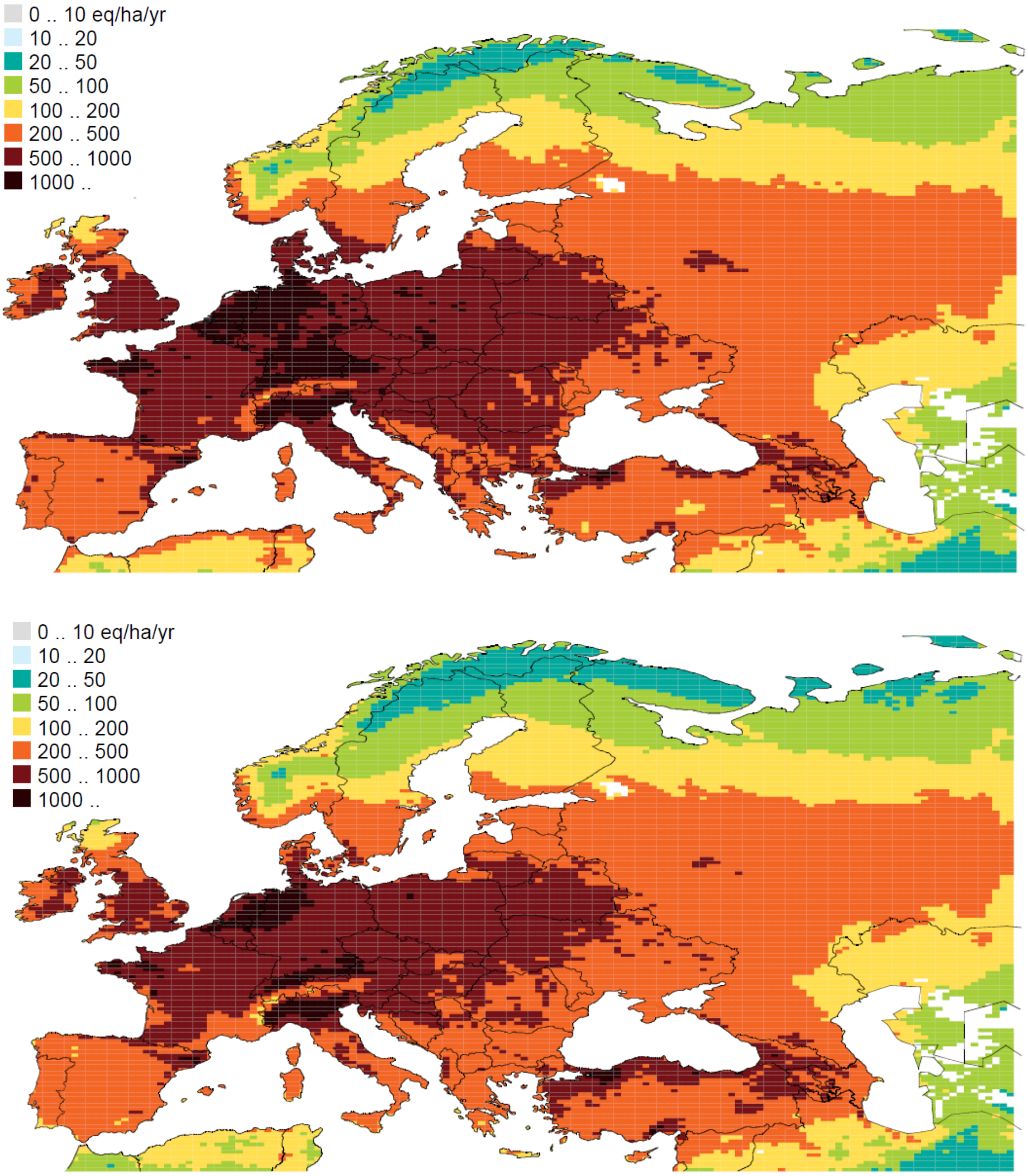

Fig. 3: GAINS total N deposition, in eq per ha and year, in 2010 (upper panel) and in 2050 (lower panel), current legislation

The “classical” set of scenarios (CLE for a base year, here 2010, and for a future year, together with an MFR scenario for this future year) is shown in Fig. 4 for 40 European countries. It becomes evident that, while expectations for the year 2050 diverge between countries (some increase, some decrease), a considerable potential of further reductions exist when applying the available measures. On a level of all 40 European countries, emissions of the MFR scenario in 2050 are only 62% of those of the CLE scenario. This analysis does not consider the climate-dependent factors developed in this paper.

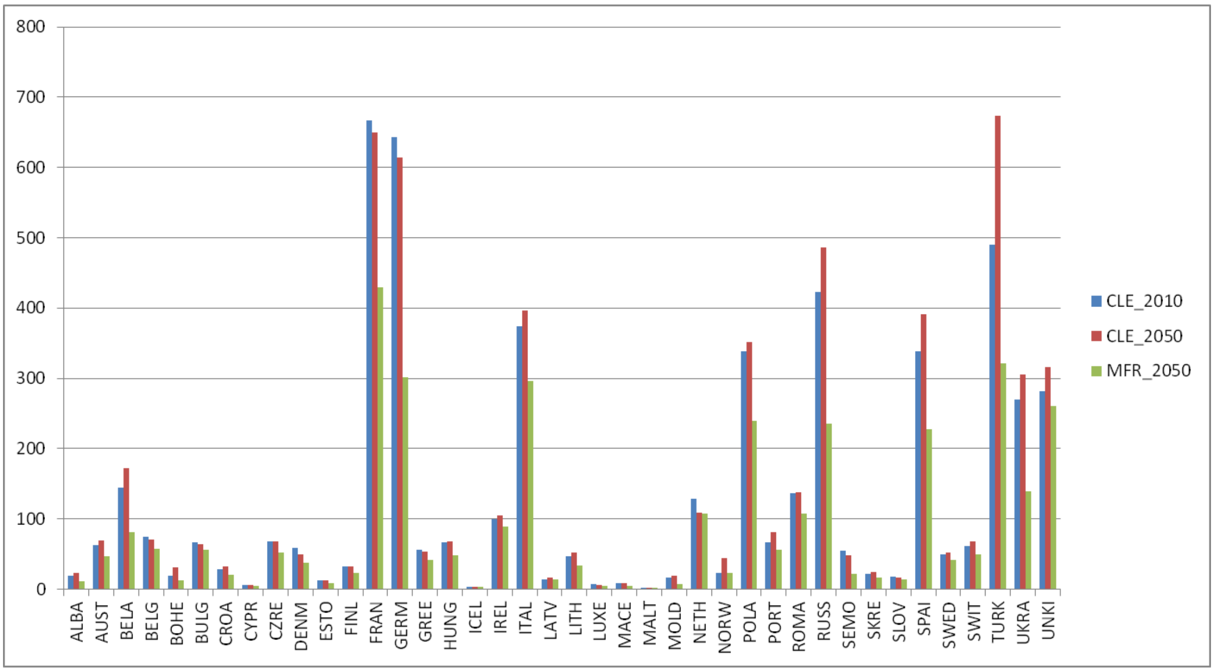

Fig. 4: Emissions without considering additional climate related effects: current legislation of historic data and for 2050 vs. maximum reduction scenario on 2050. All emission data are in kt NH_3.

Consideration of climate factors changes little for the 2050 CLE, which is consistent with the assumption that a 1°C change would not have huge impacts on ammonia emissions – especially when adaptation of management allows different timing of manure application. On the level of all 40 European countries included in the model, emissions are assumed to be merely 2% higher. The difference becomes much larger for MFR, at 7% lower emissions, due to the “learning” effects on the most advanced technologies.

Fig. 5 shows some more details of these climate-related impacts. CLE scenarios are shown in green-blue, MFR in red-orange. Clearly considerable increase, both due to additional emissions at higher temperature and due to additional activities, is seen for the end-of-the-century CLE projections which have been made available for the first time in a GAINS-like structure. Notably, increased reduction potential of MFR (again due to the technological improvement) may keep emission at a level comparable to 2050. The extent of control under CLE for end of the century will be almost identical to that of 2050, as current legislation will rather not impact on a change later than 2050. However, differences due to farm structures occur, as growing farm sizes will cause a larger share of animals to be available to undergo measures.

Again comparing for all 40 countries, CLE emissions at the turn of the century are 39% larger than in 2050, while comparing MFR emissions the increase is only 25%. However, at the end of the century MFR would be 30% lower than the 2050 CLE emissions. This indicates that action still can be introduced to resolve issues when they appear to become relevant on a later stage. Only, the important technology learning effect may be much smaller when developing and implementing new technologies is delayed into the far future.

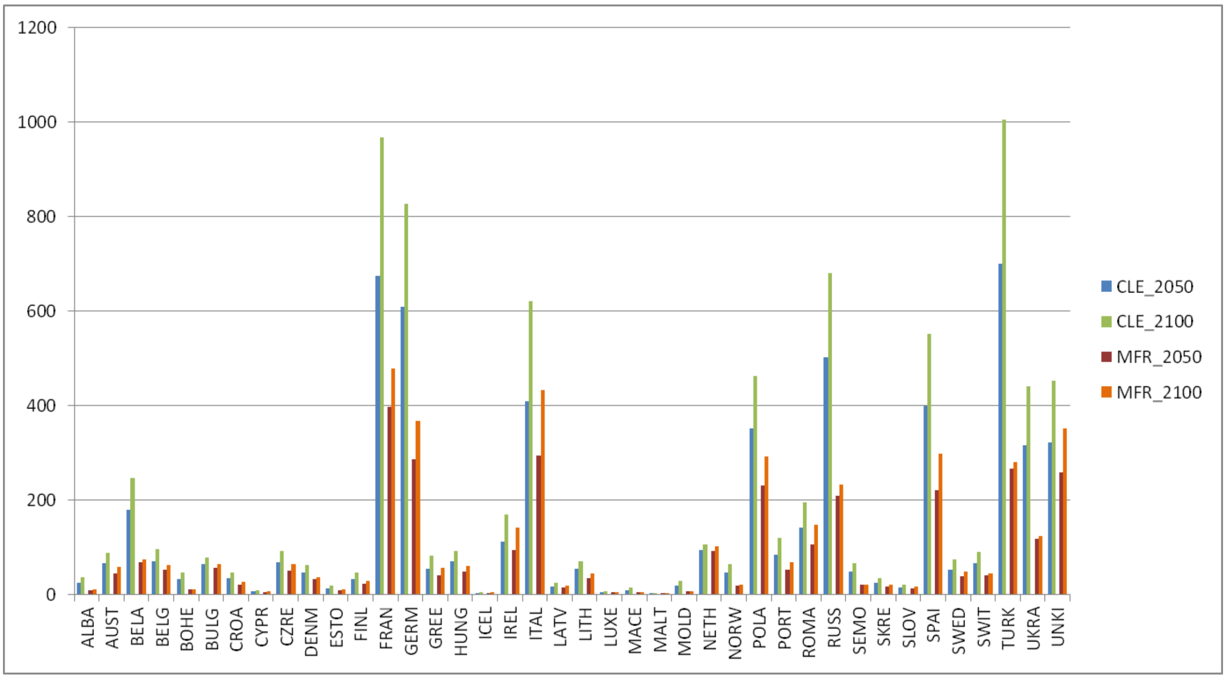

Fig. 5: Emissions including climate related effects: current legislation and maximum reduction scenarios for both 2050 and end of this century. All emission data are in kt NH_3.

Looking at the countries individually, it is interesting to note that some countries exhibit variations of almost a factor 3 (Turkey, emissions at the end of the century) while other countries display almost no difference, even between CLE and MFR: that is most notably the case for Netherlands, a country renowned to have implemented a large share of the possible ammonia-related measures already. It is also interesting to note that, for Ireland, there is virtually no difference between CLE and MFR scenarios – indicating that the measures still available are relatively ineffective.

Further to the emissions, GAINS also allows to evaluate the costs of measures. This can also be extended to the assumptions and factors developed in this paper. In contrast to the emissions, most factors influencing costs due to climate change are constant. Results shown in Fig. 6, costs of MFR scenarios in addition to CLE, reflect the size of the agricultural sector in a given country at the one hand, and the magnitude of measures implemented on the other hand. Differences between the respective scenario sets are small. Even improving technology ("technology learning") is considered to alter emission factors only, but not costs of measures. Changing farm sizes will allows a larger share of animals being covered by measures (in 2050 and at the end of the century), and cause some differences, like also overall activity changes (as also assumed for the end of the century, with very similar factors applicable to all countries). So patterns look almost identical for all countries, except maybe for Romania where a quick changeover from subsistence farms is expected calling for additional abatement at the MFR scenarios.

More notice may be given Fig. 7, where the costs of abated emissions (€ per kg NH_3) are determined. Relying on emissions, the full set of multiplication factors becomes active again. Note that this dataset allows to directly compare countries, as specific emissions are independent of country size.

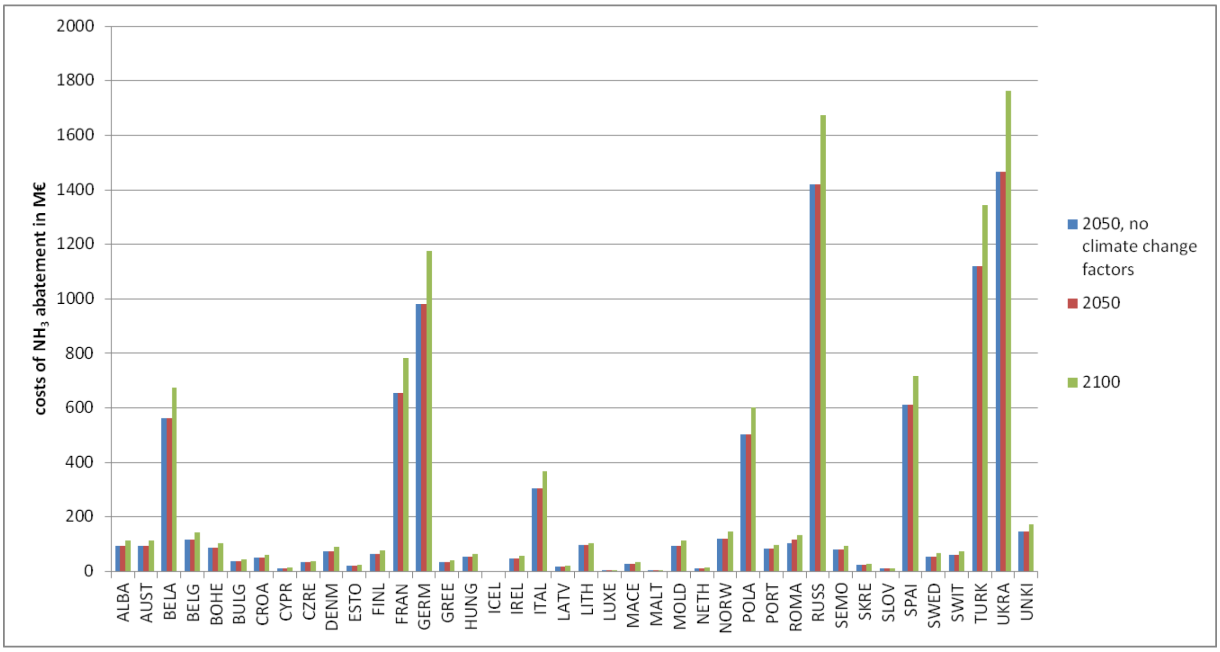

Fig. 6: Annual costs of NH_3 abatement (in M€) at a 4% social discount rate, increment of the respective MFR scenario over a CLE scenario.

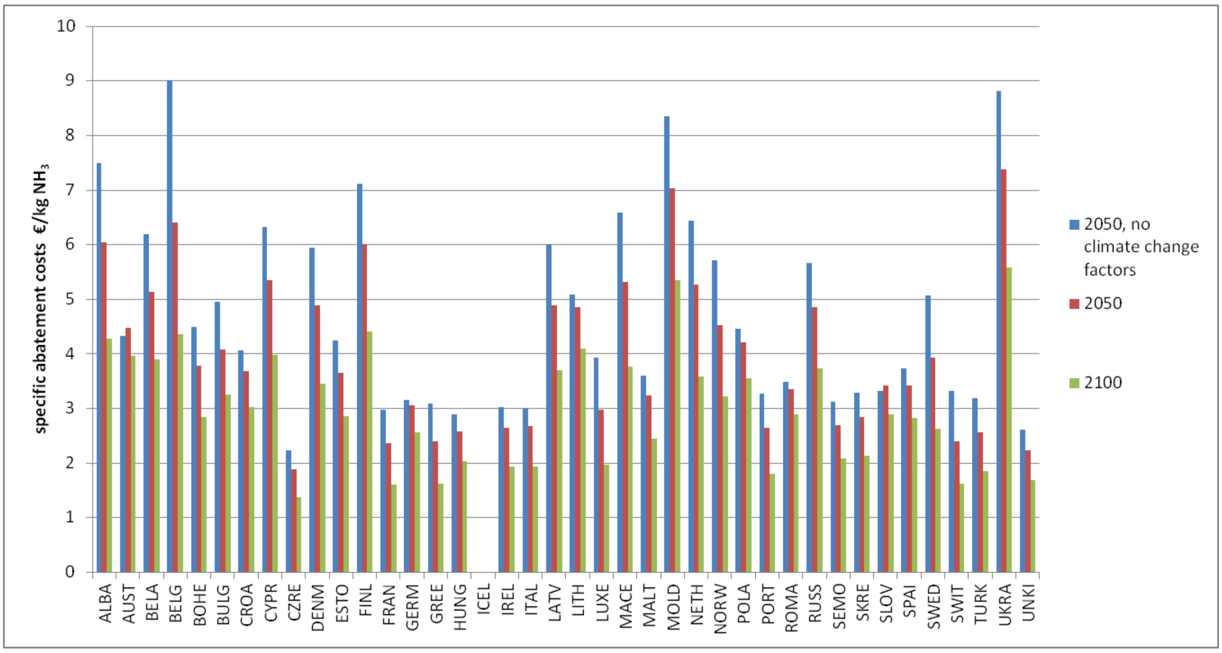

Fig. 7: Specific abatement costs of NH_3 abatement (only measures beyond CLE are considered). Costs are given in €/kg NH_3 abated

Specific costs presented in Fig. 7 are rather high, a consequence of including here also the most expensive measures available (MFR). Comparing individual countries, costs for non-EU countries, especially of Eastern Europe, seem higher. The most striking result, however, is that in almost all cases application of the climate-change related factors will decrease these specific costs. This is primarily a consequence of “technology learning”, which extends emission reduction of the most advanced, i.e. the most expensive abatement options, and thus decreases specific costs.

4. Outlook

A framework of including climate-change related factors and other considerations of long-term scenarios for GAINS has been established. This framework will require further development to

*) study sensitivity and assess uncertainty of the results provided

*) include novel metrics (thresholds) for ecosystem protection as far as developed within the ECLAIRE project

*) develop definitions for a policy scenario or scenarios which allow to achieve given policy targets at minimized costs instead of extending abatement to the maximum feasible level.

Definition of the policy scenario needs to be done in-line with the development of the cost-benefit analysis, another primary project output. These steps will provide guidance to shape air pollution policies under climate change conditions.

5. References

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