"The Gothenburg Protocol – Projections, Expectations and Realities: Lessons from a National Review"

Blind Submission

Abstract

The Gothenburg Protocol entered into force on the 17th of May 2005, with 24 Parties ratifying the proposed emission ceilings for a range of transboundary pollutants. These ceilings were themselves formulated in 1999 using the RAINS integrated assessment model and a broad base of relevant forecasts and calibration data. In the intervening nine years, with the 2010 ceiling deadline approaching and a potential review for a new round of future emission ceilings, there is an opportunity to review the earlier work and consider the lessons for future processes. This paper considers the original projections and expectations associated with the Gothenburg Protocol emission ceilings for six countries and contrasts these against the current realities and contemporary short-term forecasts out to 2010. In this process, the paper derives a number of considerations and lessons to be considered for future agreements of this nature.

Keywords: Gothenburg, Protocol, Review, RAINS, Projections, Emissions

1. INTRODUCTION

The Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, better known as the Gothenburg Protocol (GP), signed in 1999, was developed within the framework of the UN Convention on Long Range Transboundary Air Pollution (CLRTAP). This Convention was adopted in 1979 and formed the first successful international agreement to take common legally binding actions against air pollution. Currently there are 51 parties to the Convention and the region covered extends from North America to Europe and Central Asia. The Convention is characterized by a strong interaction between scientists and policy makers. Monitoring of emissions, air quality and impacts is one part of the scientific activities under the Convention. Integrated assessment models (especially the RAINS[1]-model developed by IIASA[2]), play an important role in the negotiation of new protocols. These models enable the policy makers to develop effect-oriented protocols that reduce damage to ecosystems and human health in Europe in a cost-effective way. The use of emission projections for future decades is a crucial element for the modelling results. Expected growth rates of key emission drivers such as energy use and

---

[1] Regional Air Pollution Information and Simulation model

[2] International Institute for Applied Systems Analysis (www.iiasa.ac.at)

livestock, as well as the effectiveness of existing policies determine the gap between projected exposure and environmental protection targets, as well as the costs of additional policy measures. Within the CLRTAP-framework, such projections are based upon national expectations. The central questions for this *ex-post* analysis are; How accurate were the projections used for the Gothenburg Protocol, and what we can learn from the differences between projections and realizations?

1.1 Context

At present, eight protocols have been established within the Convention, to cover air pollutants like Sulphur, Nitrogen Oxides and Volatile Organic Compounds. The Gothenburg Protocol entered into force on 17 May 2005. For the first time, the Gothenburg Protocol addressed four pollutants simultaneously, introducing the innovative multi-pollutant multi-effect approach. The Protocol establishes national emission ceilings for Sulphur, Nitrogen Oxides, Ammonia and Volatile Organic Compounds and requires parties to the agreement to be in compliance with these ceilings by 2010. The 24 Parties, who have ratified the Gothenburg Protocol, are committed to fulfil these obligations by taking the necessary abatement measures. With the approaching of the target year and in accordance with the provisions of the Protocol, a review process has been completed in 2007, and a possible revision of the Gothenburg Protocol is envisaged within the next 2 years. This revision could lead to more stringent commitments for emission reductions as interim scientific research has recognized the persistency of significant risks for the environment, in particular, higher environmental risks related to eutrophication, and also increased risks to human health due to exposure of people to ozone and particulate matter (Maas et Amann, 2007).

This paper compares the assumptions made for the establishment of the GP emission ceilings in 1999 for six[3] Parties to the Protocol with corresponding contemporary reviews of national data, emissions and assumptions. The purpose of these efforts is to identify and understand the main causes of the variations in data and to thereby draw lessons that may be of use in the development of comparable future work.

1.2 Paper Outline

The following is an outline of the paper structure. The methodology section will be divided into two distinct elements.

[3] Spain, Portugal, Sweden, Italy, Ireland and the Netherlands

1. The first section of the methodology will present a basic overview of how the emission ceilings of the Gothenburg Protocol were calculated. This will focus on the RAINS integrated assessment model, the basic model mechanics and the key input parameters which were necessary to calibrate the model for use in this policy process.

2. The second section of the methodology will then set out the parameters evaluated under this paper for each of the six countries in the analysis. This will include a commentary on the calculation, estimation and sources of recent national data, and how these are compared against the 'older' values used in the original Gothenburg Protocol process of 1999. An additional element of this section will be a discussion of the analytical approach used on a case study of a change in the abatement efficiency of vehicle technologies considered by the model.

Following on from the methodology, the results section will present relevant results for each individual country across a number of headings. The issues discussed and identified for each country are broadly the same. However, in specific cases, different issues were identified and lessons learnt. The template for the results section is as follows:

- Growth ratios now versus original Gothenburg Protocol values
- The Gothenburg Protocol emission projections in contrast to recent projections
- Three Gothenburg Protocol indicators – emissions per capita, per billion € of GDP and per unit of energy – presented in contrast to indicator values based on more recent data.
- Impact of the change in efficacy for the vehicle 'Euro' standards

The conclusion section will then review these results and discuss their relevance to the current process and the lessons which are evident for future negotiations of similar protocols. Each country has a slightly varied focus on the process and different national circumstances have raised different issues. In this way the lessons presented are hoped to be of use to a broader section of the relevant community.

2. METHODOLOGY

There are two elements to this methodology discussion. Firstly, there is a summary of the process by which emission ceilings were calculated by the RAINS model for the Gothenburg protocol. This includes a broad discussion of the model parameters and submitted data followed by a synopsis of the mechanics of the basic model calculations. The purpose of this section is to give a sense of the significance of the various data and indicators to the ceiling setting process. The second section will then briefly identify the various national parameters and indicators which are examined under the results section. Additional detail is also provided here in relation to the Euro standard case study.

2.1 Gothenburg Protocol Emission Ceilings Calculation and RAINS

The RAINS model is described as an integrated assessment model (IAM). An IAM is a model or network of linked models and processes which employ a broad set of data to examine a complex interrelated issue. In the case of RAINS, the issue is transboundary air pollution and the associated effects. At the most basic level, RAINS[4] assists in estimating national emissions, where they travel, and the harm they cause. This information is constrained in an optimisation process with effect-orientated goals. The model then calculates least-cost solutions to the constraints relative to feasible abatement technology options in the countries evaluated. The necessary emission constraints are then translated into emission level ceilings for individual countries.

In practice, this process involves considerable data and calibration efforts. The types of data required are described in a simplified fashion in Figure 1. Broadly speaking, the key parameters are related to the range of polluting activities within sectors and the details of relevant abatement technologies. In all cases national forecasts are used, thus although some data may be historical, much of the input data to the modelling process is based upon expectations. In this way, the outcome of the modelling work and the efficacy and cost-effectiveness of the ceilings derived from this process are heavily dependent upon the quality and accuracy of the data used at the various stages of the process.

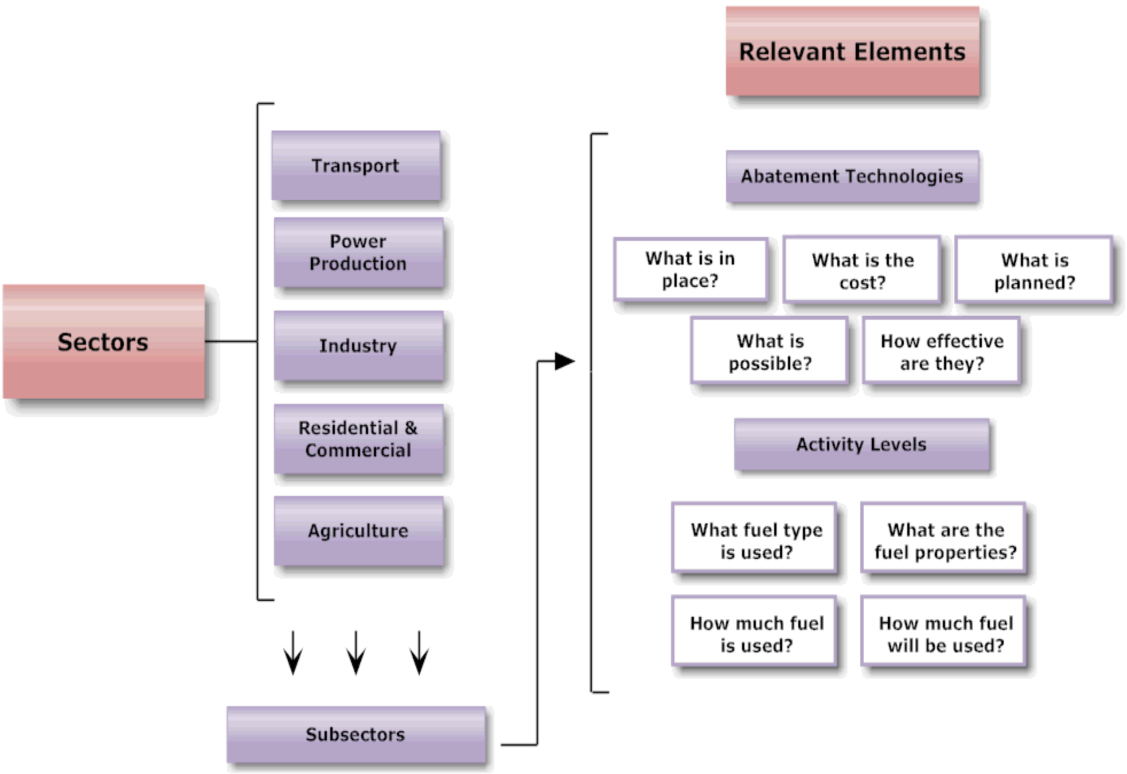
Inaccurate representation of expected future polluting activities or an expectation of significant abatement options becoming available can therefore have an obvious impact on the proposed ceilings and the capacity to comply. Although the optimisation process is not so straightforward,

---

[4] The full process includes external steps related to atmospheric dispersion modelling, grid transfer matrices and GAMS optimisation modelling. However, for the purpose of this paper the 'RAINS modelling process' is utilised as a catch-all.

generally, if a country were to overstate future emissions and/or understate future abatement capacity the ceiling would 'loosen' somewhat. Whilst the environmental objectives remain the driver of the model, the incidence of the burden to abate can shift on the basis of abatement potential, pollution sources and the cost-effectiveness of measures[5]. Thus, it is important for all Parties to the agreement to do their utmost to ensure the quality and accuracy of their data.

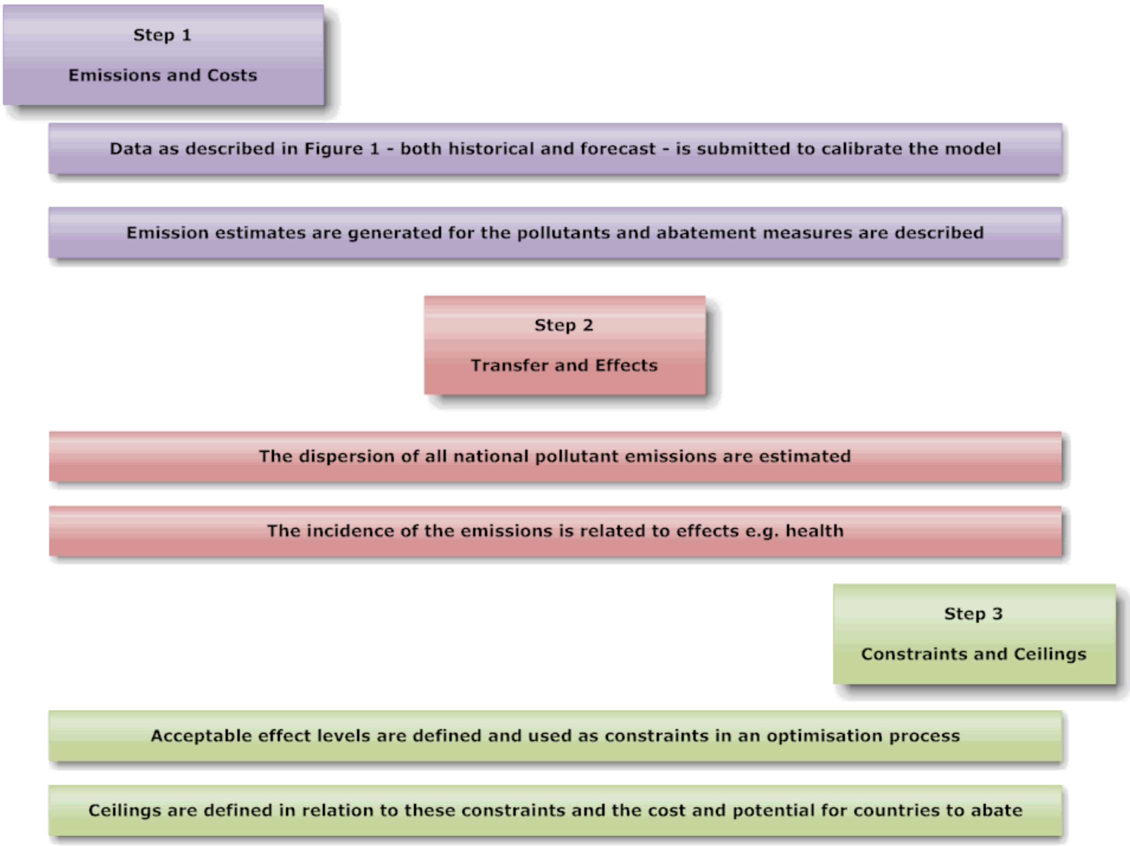
Figure 1: Rough Guide to RAINS Model Elements[6]



A simplified version of the ceiling setting process as handled by the RAINS model is presented in Figure 2. In these three steps, the importance of quality data and how data ultimately influence the emission ceilings are described.

[5] Certain additional constraints are imposed to ensure that all countries and their population benefit from the ceilings and the associated effects mitigation.
[6] Although under activity levels the reference is to fuel, in relation to the agriculture sector the 'activity' parameters are related to animal numbers and fertiliser use.

Figure 2: Rough guide to Gothenburg Protocol Ceiling Setting



2.2 National Parameters and the EURO Standard assessments

There are four headings for the indicators and results assessed in this paper. Generally each of the indicators is reviewed for each of the six countries; however, in certain cases some variation of results occurs as a result of data gaps or related challenges. The general approach of the results analysis is a comparison of the original 1999 GP data (Amann et al., 1999) used for setting the existing Gothenburg Protocol 2010 ceilings, with recent national data and forecasts. The indicators evaluated are described individually below.

Activity levels now versus original Gothenburg Protocol values

These results will present the proportional difference between the original forecast Gothenburg Protocol (GP) values for 2010 and the recent national data for 2005, and recent national forecasts for 2010. Essentially this looks at the original expectations for activity of key variables (e.g. energy use) as used in the GP work of 1999, and contrasts these values with recent national data for 2005, and more contemporary forecasts for 2010. The model input parameters include values for drivers such as national energy use or head of animals. These figures enable a direct comparison of original GP forecast growth values for 2010 with actual data for 2005, and the most recent national forecasts for 2010. Thus highlighting the changes that have occurred in reality (actual 2005 figures) and in national expectations (recent 2010 forecasts).

GP Emission ceilings versus most recent emission projections

This set of results will look at the original GP calculated 2010 emission ceilings against recent inventory emissions in 2005, and the most recent forecasts of emissions for 2010. Results for the GP data are again taken from official documentation of the time, and more recent national data has been provided from relevant national contacts and experts. It should be noted that current national forecasts and figures represent current legislation scenarios – i.e. the emissions under the current policies, measures and activity estimates.

GP indicators versus current and expected values

The next set of results present the values of three indicators for each of the pollutants from the original GP 2010 work against values from 1990, 2005 and recent forecasts for 2010. The three indicators are as follows:

- Kg of pollutant per capita
- Kg of pollutant per €Bn of GDP
- Kg of pollutant per Terajoule of energy

In each case the paper is presenting the value of this indicator based on the original GP data against more recent values of same. These data are used to highlight the progress or otherwise of the countries in relation to three major pollution drivers – population, economic activity and energy use[7].

Impact of Euro standard change

In order to evaluate existing emissions and future abatement potentials, the modelling process must assess the impact of both technical and non-technical measures. Emission calculations are therefore influenced by the abatement technologies which can be applied to a given activity (e.g.

[7] It is acknowledged that the kg of energy indicator is not especially relevant as a driver of ammonia emissions.

improved vehicle technologies for the mobile sector) and/or non-technical policy measures which may influence the absolute level of activity (e.g. a fuel tax to reduce vehicle usage).

Thus, whilst forecasts of energy usage and other parameters are obviously vital to emission estimation, the accurate representation of abatement measures and their efficacy are also essential in the process. Within the transport sector the principal abatement measures identified by the RAINS model for NOx emissions from the transport sector are the European emission standards (EURO standards) which regulate the maximum acceptable emissions to be allowed from the manufactured engines in a given period.

In the case of the Gothenburg protocol the ceilings were calculated originally in 1999 on the basis of certain assumed efficacy levels for vehicle emission standards into the future. Thus, the forecast emissions, and forecast abatement potentials, were determined in some part on the basis of specific emission abatement values (removal efficiencies) for each EURO standard. An issue has since arisen in this area, namely that the presumed efficacy levels for certain EURO standards ultimately fell below the expected values which had been used in the model in 1999 when setting the original ceilings.

The impact of this change in the removal efficiency of specific Euro standards has led to an increase in national NOx emissions as calculated under the updated model parameters. To put this plainly, 100 petajoules of transport activity for a given EURO standard technology under the model in 2007 has a higher level of NOx emissions than the same 100 petajoules run through the model as calibrated in 1999 for the setting of the GP ceilings. Thus, countries have higher emissions under the current model framework with less efficient abatement options. As the ceilings were fixed in 1999 under the original model framework this provides a significant constraint with respect to the recent emission updates.

The effect of this Euro standard change is quantified for each of the six countries. The emissions of current data under the old removal efficiency values, and current data under the new removal efficiency values have been quantified using an Excel™ simulated replication of the RAINS emission calculation process. National transport activity data, the penetration of the associated control measures, and updates of the actual removal efficiencies have all been obtained from historical model literature and existing reports to perform these Excel™ based computations.

The impact of the change varies as it is dependent upon the fleet/technology mix in a given country and the level of fuel used for each class of vehicle.

3. RESULTS

In this section results are presented for each of the six countries in the format described in the methodology section. However, each country will take a somewhat varied approach to the discussion and interpretation of results. It should be noted that for some countries data considerations meant that specific variables or indicators may not have been available and are therefore omitted. In the case of Italy a more discursive approach is taken to the assessment.

3.1 Results: Ireland

Growth ratios now versus original GP values

Ireland has experienced exceptional GDP growth from the 1990 base year of the Gothenburg Protocol to the present[8]. Even with a significant moderation of GDP growth to 3% per annum for the remaining years to 2010, the Irish economy will likely outperform all of the EU25 in terms of averaged GDP growth for the period 1990-2010. This growth is reflected in the indicators presented in Table 1.

These levels of growth have rendered prior forecasts of energy activity quite conservative, with particularly large increases in both the transport and construction sector activity levels. Although the construction sector has now slowed, the impact of these surges in activity have added pressure to emission ceiling targets – particularly in the case of NOx, where the increases in private transport and transport related to industry have grown substantially.

Table 1. Variation of actual national activity levels in 2005 and recent forecasts for 2010 against activity levels forecast in the 1999 GP work for 2010 – Ireland

Activity level	2005 vs. GP 2010	2010 vs. GP 2010
Energy (PJ)	-4.4%	10.9%
Cattle (Mheads)	-16.2%	-25.7%
Pigs (Mheads)	-22.7%	27.3%
Poultry (Mheads)	22%	4.5%
Fertiliser use (kt N)	-1.4%	-4.8%

[8] Irish GDP growth at current market prices for the period 1995-2006 averages at 11.4% GDP growth p.a.

In relation to agriculture, GP forecasts for cattle numbers are higher than recent forecasts, whilst pig and poultry numbers will exceed the original GP values. On aggregate, however, emissions from the agriculture sector are expected to be comparable with those originally forecast. Table 1 presents current values/forecasts relative to 2010 GP figures.

In terms of population, Ireland has experienced significant immigration over the period from 1990 to the present, and current mid-range estimates suggest a population of 4.4m persons by 2010. This is 23% higher than the estimate used within the GP work and is an additional emissions driver to contend with under the process.

GP emission projections vs. most recent projections

Table 2 shows that emissions are projected to decrease for all pollutants from current (2005) values to 2010 forecast values. However, on the basis of the current model projections, Irish NOx emissions will continue to present a significant challenge, with a forecast of 95kt of NOx in 2010 being some 30kt higher than the existing Irish NOx ceiling for 2010 under the GP.

Table 2. Comparison between current and expected emissions vs. GP ceilings – Ireland

Pollutant	GP ceiling	2005	2010
SO_2 (kt)	42	70	33
NOx (kt)	65	119	95
NMVOC (kt)	55	62	56
NH_3 (kt)	116	113	101

GP indicators vs. current and expected values

Table 3 shows that emissions per capita are falling sharply for all four pollutants within Ireland. In addition, per capita emissions are expected to be lower in 2010 than originally foreseen by original GP protocol work for all but NOx emissions.

Emissions per unit of activity show the same trend, with a strong downward movement in values for all pollutants between 1990 and 2010. Once again, in all cases but NOx, emissions per unit of energy used are expected to be lower in 2010 than original GP indicators suggested.

In terms of emissions related to GDP, the strong Irish economic growth for the period does not appear to have been pegged to emissions, with particularly significant reductions in emissions by GDP for all pollutants, and each pollutant improving significantly on the expected GP indicator value of emissions by GDP.

Table 3. Comparison between current and expected indicators vs. GP ceilings - Ireland

Indicator	GP-2010	1990	2005	2010
Kg SO_2 per capita	11.7	52.2	16.9	7.2
Kg SO_2 per B€	531	5033.1	435.9	167.2
Kg SO_2 per TJ	60.2	442.7	105.6	42.5
Kg NO_X per capita	18.2	35.5	28.6	21.5
Kg NO_X per B€	821.7	3419.7	737.4	481.3
Kg NO_X per TJ	93.1	300.8	178.5	122.3
Kg NMVOC per capita	15.4	30.5	14.9	12.7
Kg NMVOC per B€	695.3	2939.5	384.6	284.1
Kg NMVOC per TJ	78.8	258.6	93.1	72.2
Kg NH_3 per capita	32.4	31.4	27.1	23
Kg NH_3 per B€	1466.5	3030	698	515
Kg NH_3 per TJ	166.2	266.5	169	130.8

Impact of Euro standard change for Ireland

The evident strong coupling of Ireland's GDP growth with transport sector activity somewhat exacerbated the impact of the Euro standard change on national NOx emissions. The current RAINS model, with recent national data, estimates Irish NOx emissions from the road transport sector alone at 61.4kt. However, using the same data, but under the original GP assumptions of NOx removal efficiencies, Ireland's road transport NOx emissions have been calculated at 41.6kt.

Thus the change in the removal efficiency parameters for Ireland leads to an increase in the model estimated NOx emissions of almost 20kt. This represents approximately a 50% increase of NOx emissions attributed to the road transport sector and has obvious implications for compliance with the existing 65kt ceiling which was derived under the original Euro standard removal efficiency values.

3.2 Results: Spain

Growth ratios now versus original GP values

The estimated Spanish GDP growth, at constant prices, used for the Gothenburg Protocol was originally estimated at 67%. Current expectations place the value at closer to 86%, with a significant portion of this growth being attributable to an increase in construction based activities. The GDP share of gross rents, fuel and power have decreased from 19.2% of total GDP in 2000 to 16.2% with a corresponding increase in the construction share from 8.3% to 11.6%. This shift in GDP structure has resulted in notable emission level pressures given the association of the construction sector with heavy industry.

Related to this change in sectoral activities, both current and projected activity values are now higher than those originally forecast under GP work for all but fertilizer use. Table 4 shows that the current 2010 national energy use projections are some 28.5% higher than the original energy forecast used in the GP modelling work. Similarly, vehicle activity (including passenger cars, motorcycles, LDV and HDV) is now forecast to be 21.9 % greater than originally forecast under the GP work. For livestock, 2010 figures are 5.8%, 28.5% and 138.0% larger than the values considered in the Protocol. Moreover, the most recent figures (2005) are also higher than the original 2010 GP expectations.

Population is another important driver for emissions and the GP projected a population of 40.6 million people in Spain in 2010. However, official figures in 2006 put the Spanish population at 45.1 million people, some 11.2 % higher than originally forecast.

Table 4. Variation of actual national activity levels in 2005 and recent forecasts for 2010 against activity levels forecast in the 1999 GP work for 2010 - Spain

Activity level	2005 vs. GP	2010 vs. GP
Energy (PJ)	14.0%	28.5%
Vehicles (k veh)	7.4%	21.9%
Cattle (Mheads)	14.0%	5.8%
Pigs (Mheads)	24.4%	28.5%
Poultry (Mheads)	14.0%	138.0%
Fertiliser use (kt N)	-13.8%	-10.8%

GP emission projections vs. most recent

Table 5 highlights that although emissions are projected to decrease from current (2005) values to 2010, Spain will still face difficulties in reaching compliance with all but the SO_2 ceiling under current projections. The national baseline scenario estimates low SO_2 emissions for 2010 (46% lower than the ceiling) and a moderate exceedance of the 2010 NH_3 ceiling (6%). The current NOx and NMVOC forecasts for 2010 will however, breach the GP ceilings by 43% and 25% respectively.

Table 5. Comparison between current and expected emissions vs. GP ceilings – Spain

Pollutant	GP ceiling	2005	2010
SO_2	774	1215	420
NOx	847	1405	1209
NMVOC	669	1055	837
NH_3	353	398	373

Table 6. Comparison between current and expected indicators vs. GP ceilings – Spain

Indicator	GP-2010	1990	2005	2010
Kg SO_2 per capita	19	54	27	9
Kg SO_2 per B€	1226	5132	1764	604
Kg SO_2 per TJ	148	566	204	63
Kg NO_X per capita	21	30	31	27
Kg NO_X per B€	1342	2899	2040	1738
Kg NO_X per TJ	162	320	236	180
Kg NMVOC per capita	16	29	24	19
Kg NMVOC per B€	1060	2784	1532	1203
Kg NMVOC per TJ	128	307	177	125
Kg NH_3 per capita	9	9	9	8
Kg NH_3 per B€	559	828	578	536
Kg NH_3 per TJ	68	91	67	56

GP indicators vs. current and expected values

Emissions per capita are decreasing for each pollutant despite Spain becoming a highly developed country. Values presented in table 6 show a decline of 83% for SO_2, 11% for NOx, 36% for NMVOC and 4% for NH_3. In comparison with the values for the other 5 countries in this analysis for 2010 ceilings with GP drivers, Spain has the highest indicator for SO_2, the second highest for NO_X, the 4th for NMVOC and 3rd for NH_3.

In relation to emissions per unit of energy consumption (kg/TJ) future trends are very similar. A large decrease is projected for SO_2 (88%) with more moderate, but still notable reductions forecast for NO_X, NMVOC and NH_3 (40%, 57% and 35% respectively). Emissions related to GDP exhibit the same trend as those of emissions per unit of energy consumption.

Impact of Euro standard change for Spain

The impact of the vehicle Euro standard change on Spanish NO_X emissions has been estimated at 169.4kt or 20% of the 847kt national ceiling. Thus estimated NOx emissions using current activity data, but analysed under the original GP NOx removal efficiencies for transport, would be almost 170kt lower for Spain. On a sectoral level this represents a 38% increase in road transport emissions as a result of the change in the Euro standards. This has significant implications for the NOx ceiling that would have been delivered by the original 2010 GP work were the NOx removal efficiency parameters the same as those in use under the existing model framework.

3.3 Results: Netherlands

Growth ratios now versus original values used for the Gothenburg Protocol

Current population growth in The Netherlands does not differ significantly from the growth ratio used for the GP. For the GP immigration was underestimated by 300,000 persons (or 2% of the total population). Annual GDP-growth between 1990 and 2005 was 2.5% on average. This was much lower than the growth scenario used for the GP. From a selection of possible future scenarios the ‘high economic growth scenario’ (of 3.8% per year) was chosen as the basis for international negotiations (e.g. the Gothenburg Protocol as well as the Kyoto Protocol). The rationale for this ‘strategic’ approach was that international environmental obligations should be realized whilst at the same time respecting economic targets such as the standards of the European Monetary Union and the targets of the Lisbon Agenda.

As economic growth was ultimately lower than forecast one would expect that the Dutch obligations of the GP would be met easily, however, this is not the case. The first reason for the remaining challenge is that the energy efficiency of the economy improved far less than expected. In the scenario used for the GP, energy efficiency was expected to improve by 1.8% each year, whereas in reality energy efficiency between 1990 and 2005 improved by only 1.3% per year. The effect is that total energy use increased by 1.2% each year. For the GP a growth in energy use of 2% per year was expected. Moreover there was an unforeseen switch in the fuel mix after the liberalization of the electricity market. The expected trend towards more gas and renewable energy was replaced by the reintroduction of coal. In the transport sector the expected switch from road transport to rail and water did not materialize and the share of diesel in road traffic increased. Due to these differences with the original scenario additional measures had to be defined to meet the emission ceiling for Sulphur.

In the agricultural sector current estimates lead to 25 % more poultry and 25% less cattle than assumed for the GP. The cattle stock was reduced after the foot and mouth disease crisis. Although the scenario was wrong, the Netherlands will meet the national emission ceiling for ammonia.

Table 7. Variation of actual national activity levels in 2005 and recent forecasts for 2010 against activity levels forecast in the 1999 GP work for 2010 - Netherlands

Activity level	2005 vs. GP 2010	2010 vs. GP 2010
Energy (PJ)	-10.4%	4.7%
Cattle (Mheads)	-20.8%	-22.9%
Pigs (Mheads)	1%	0%
Poultry (Mheads)	19.4%	25.8%
Fertiliser use (kt N)	3%	2.1%

GP emission projections vs the most recent projections

According to the most recent projections (table 8) the Netherlands will have to implement additional policy measures in order to meet the national emission ceiling for Sulphur. The other ceilings will be met, partly thanks to the high economic growth scenario that was used as the basis for the negotiations.

Table 8. Comparison between current and expected emissions vs. GP ceilings - Netherlands

Pollutant	GP ceiling	2005	2010
SO_2 (kt)	50	66	53
NOx (kt)	266	348	262
NMVOC (kt)	191	171	159
NH_3 (kt)	128	133	125

GP indicators vs. current and expected values

There are two points to note from Table 9. The emission of SO_2 per PJ in 2010 is higher than expected during the preparation of the GP. This is due to the higher share of coal in energy use as mentioned before. The NO_x-emission per PJ in 2010 is higher due to the fact that the effectiveness of Euro-standards for vehicles appeared to be lower than expected.

Table 9. Comparison between current and expected indicators vs. GP ceilings – Netherlands

Indicator	GP-2010	1990	2005	2010
Kg SO_2 per capita	3.0	12.7	4.1	3.2
Kg SO_2 per B€	90.6	616.3	149.7	103.7
Kg SO_2 per TJ	13.5	67.9	19.9	15.0
Kg NO_X per capita	16.1	36.8	21.4	15.6
Kg NO_X per B€	482.2	1793.4	786.5	512.7
Kg NO_X per TJ	71.6	197.5	104.5	74.0
Kg NMVOC per capita	11.8	33.0	10.5	9.5
Kg NMVOC per B€	353.5	1605.6	385.1	311.2
Kg NMVOC per TJ	52.5	176.9	51.3	44.9
Kg NH_3 per capita	7.8	16.7	8.2	7.4
Kg NH_3 per B€	232.1	814.5	300.1	244.6
Kg NH_3 per TJ	34.5	89.7	40.0	35.3

Impact of the Euro standard change for the Netherlands

The decrease in the expected effectiveness of the Euro standards for vehicles and the effectiveness in reality was estimated at around 7% of the total national emissions of NOx. Nevertheless the Netherlands is expected to meet this national emission ceiling around 2010.

3.4 Results Sweden

Growth ratios now versus original GP values

As presented in Table 10, Sweden will both exceed and undershoot the original activity projections made in 1999 for the GP. GDP growth has been slightly stronger than predicted and is now foreseen to be higher in 2010 than predicted for the GP. Since the mid 1990's Sweden has had a higher GDP growth than the EU average.

Energy use is expected to be approximately 6% lower than expected despite an earlier underestimation of non-road activity that can be explained by faster development towards stricter regulations and shorter "economical life" than anticipated in 1999. Road traffic was underestimated due to a number of shifts of reality from prior expectations. These shifts included:

1. More freight activity (59->45) [1990-2006]
2. More activity (106->28)
3. More light duty vehicle activity (10->6)
4. Higher proportion of diesel cars to petrol cars
5. A slower introduction of strict regulations, especially on heavy duty vehicles.

Table 10. Variation of actual national activity levels in 2005 and recent forecasts for 2010 against activity levels forecast in the 1999 GP work for 2010 - Sweden

Activity level	2005 vs. GP 2010	2010 vs. GP 2010
Energy (PJ)	-12,1%	-6,3%
Cattle (Mheads)	-10,8%	-18,9%
Pigs (Mheads)	-24,5%	-16,7%
Poultry (Mheads)	-46,3%	34,9%
Fertiliser use (kt N)	18,9%	11,5%

In the agricultural sector numbers of cattle and pigs have been, and are expected to remain, below the numbers originally forecast. This reduced agricultural activity is a primary contributor to Sweden being in compliance with the ammonia target for 2010. More poultry than earlier predicted is foreseen, however, this is unlikely to counter the influence of the other reduced animal number levels.

Population growth does not differ significantly from the ratio predicted for the GP. Recent population growth in Sweden is mainly due to immigration. In 2004 the total population passed 9 million and is predicted to pass 10 million 20 years from now.

GP emission projections vs. most recent

According to the most recent projections Sweden will meet the ceilings for Sulphur, NMVOC and ammonia without further measures. The projection however shows that Sweden will exceed the NOx ceiling (154kton) by approximately 6 kton[9]. A recent increase of the NOx charge on large scale combustion is expected to bring us closer to the target. Table 11 shows the most recent projections compared to the Gothenburg protocol ceilings.

Table 11. Comparison between current and expected emissions vs. GP ceilings - Sweden

Pollutant	GP ceiling	2005	2010
SO_2 (kt)	67	39	33
NOx (kt)	148	180	154
NMVOC (kt)	241	199	183
NH_3 (kt)	57	52	50

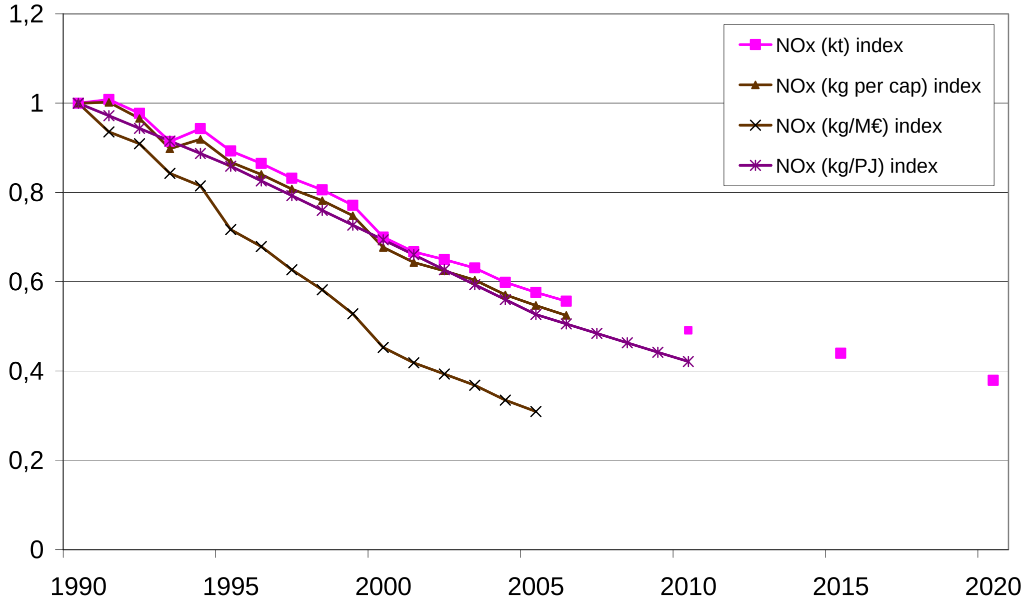
GP indicators vs. current and expected values

Table 3 below shows that for all pollutants, except NOx, all indicators show a clear downward trend. Per capita emissions as well as emissions per unit of activity and emissions related to GDP are for these three pollutants expected to be lower than those foreseen in the Gothenburg protocol.

[9] It should be noted that the optimised level for Sweden coincides with the today predicted emissions in 2010. Sweden proposed unilaterally to lower this figure.

Table 12 shows that for NOx both the per capita emissions and the emissions per unit of activity exceed the original GP estimates. The observed decrease in NOx emissions is mainly due to better technology in all sectors. However, the introduction of measures such as SCR (selective catalytic reduction) and SNCR (selective non-catalytic reduction) has not been as high as expected. Notably there is rapid growth in emissions from international transportation (shipping and aviation) which is not included in the Swedish figures.

Figure 3 NOx trend in Sweden relative to GP indicators



Impact of Euro standard change

The impact of the vehicle Euro standard change on Swedish NO_X emissions has been estimated at 19.7kt or 13% of the 148kt national ceiling for 2010. In other words, using current activity data analysed under the original GP NOx removal efficiencies of 1999 for transport, emissions would be almost 20kt lower than the same calculation under the updated NOx removal efficiencies of 2007. As Sweden is currently projecting a slight overshoot of the NOx ceiling in 2010 of 6kt, the impact of the euro standard could potentially be the difference between compliance or exceedance.

Table 12. Comparison between current and expected indicators vs. GP ceilings – Sweden

Indicator	GP-2010	1990	2005	2010
Kg SO_2 per capita	7,3	12,6	4,4	3,5
Kg SO_2 per B€	372	728,6	140,2	86,9
Kg SO_2 per TJ	26	52,1	17,4	13,7
Kg NO_X per capita	16,2	36,5	20	16,6
Kg NO_X per B€	821	2113,9	640	405,8
Kg NO_X per TJ	57,3	151,3	79,6	63,7
Kg NMVOC per capita	26,4	43,4	22,1	19,7
Kg NMVOC per B€	1337	2511,3	707,2	482,2
Kg NMVOC per TJ	93,4	179,7	88	75,7
Kg NH_3 per capita	6,25	6,3	5,8	5,4
Kg NH_3 per B€	316	362,6	186,1	131,7
Kg NH_3 per TJ	22,1	25,9	23,2	20,7

3.5 Results: Portugal

Growth ratios now versus original GP values

GDP growth in Portugal is expected to be higher than originally predicted under the GP work. However, general energy use was considerably overestimated in the original projections. Although transport activity is not listed in Table 13, road transport activity in Portugal has increased substantially since 1990. Although there are indications now that this trend is stabilizing to a more consistent level. The impact of the growth in transport has been less severe due to the majority of new cars being small size vehicles with a corresponding lower level of emissions.

In the agricultural sector there was a change between cattle and pigs where investments were reduced but compensated by a higher number of poultry heads. The application of the Common Agriculture Policy (CAP) reform with an increased level of set-aside agricultural land has reduced fertiliser use in recent years and this is now tending towards a steady level which will be well below the original forecast of fertilizer use.

Population growth has a higher ratio than the predicted by the GP. Population growth in Portugal is mainly due to immigration but it will already stabilize until 2010.

Table 13. Variation of actual national activity levels in 2005 and recent forecasts for 2010 against activity levels forecast in the 1999 GP work for 2010 – Portugal

Activity level	2005 vs. GP	2010 vs. GP
Energy (PJ)	-42%	-38%
Cattle (Mheads)	-8%	-5%
Pigs (Mheads)	3%	-2%
Poultry (Mheads)	14%	7%
Fertiliser use (kt N)	-31%	-48%

GP emission projections vs. most recent

Portugal will meet the ceilings for all the pollutants even though the levels in 2005 are considerably higher than the ceilings. Emissions of SOx will be heavily reduced as a result of two large coal power plants that are being equipped with desulphurisation units. At the same time, fuel power plants are being decommissioned and natural gas is playing a more important role in electricity production in Portugal. With regard to NMVOC, a plan was designed to be implemented by the industrial sector in conjunction with the IPPC Directive.

NOx is primarily associated with road traffic and combustion in industry and a possible increase in traffic emissions will be offset by the installation of high efficiency low emission burners in power plants. The reduced agricultural land and consequent lower fertilizer use will be ensure far lower NH_3 emissions and compliance is expected. Table 14 shows the most recent projections compared to the Gothenburg protocol ceilings.

Table 14. Comparison between current and expected emissions vs. GP ceilings - Portugal

Pollutant	GP ceiling	2005	2010
SO_2 (kt)	170	217	133
NOx (kt)	260	251	241
NMVOC (kt)	202	280	194
NH_3 (kt)	108	71	69

GP indicators vs. current and expected values

Table 15 below shows that for all pollutants show a clear downward trend. For all pollutants per capita emissions as well as emissions per unit of energy activity and emissions related to GDP are expected to be lower than those foreseen in the Gothenburg protocol.

Table 15. Comparison between current and expected indicators vs. GP ceilings – Portugal

Indicator	GP-2010	1990	2005	2010
Kg SO_2 per capita	17.9	32.0	21.6	12.6
Kg SO_2 per B€	1308.7	3762.0	1721.6	943.7
Kg SO_2 per TJ	152.9	1483.6	663.6	376.8
Kg NO_X per capita	27.4	24.4	25.0	22.7
Kg NO_X per B€	2001.5	2869.1	1991.3	1710.1
Kg NO_X per TJ	233.8	1131.5	767.6	682.7
Kg NMVOC per capita	21.3	30.2	27.9	18.3
Kg NMVOC per B€	1555.0	3547.7	2221.4	1376.6
Kg NMVOC per TJ	181.7	1399.1	856.3	549.6
Kg NH_3 per capita	11.4	6.9	7.1	6.5
Kg NH_3 per B€	1555.0	3547.7	2221.4	1376.6
Kg NH_3 per TJ	181.7	1399.1	856.3	549.6

Impact of Euro standard change

The impact of the vehicle Euro standard change on Portuguese emissions of NO_X has been estimated at 32.7kt. This represents 13% of the 250kt national ceiling. Alternate factors including a higher rate of fleet renewal and increased petrol and diesel costs have however contributed to compensating for this change and as a result Portugal remains on course to comply with the current 2010 NOx ceiling.

Results – Italy

Table 16 presents the current emission estimates for 2010 in Italy alongside the emission ceilings for 2010. In all cases but NOx, Italy appears to be on course for compliance with the ceilings. However, in the Italian case, a more detailed and refined version of the RAINS model is available for analysis – RAINS-Italy. In analyses of the emissions for 2010 using the same activity data, RAINS-Italy in fact forecasts emissions to be somewhat closer to the GP ceilings. Specifically in the case of NH_3 (416 kt) and VOC (941 kt).

In the case of NOx however, the Italian Agency for New Technology Energy and the Environment (ENEA), have performed analyses of the 'Euro standard change' using the RAINS-Italy framework. Similar to the other assessments presented in this paper, their results show that applying the same calculation parameters (i.e. removal efficiencies), as were used for the determination of the ceilings in 1999, to existing activity data, would allow Italy to comply with the current 2010 GP ceiling.

However, despite this road traffic remains the principal Nox emission source and an associated problem has arisen. There has been a considerable shift towards diesel car as a result of the increased fuel efficiency and lower diesel prices of recent years in Italy. This has resulted in a significant deterioration of air quality as a result of the increased $PM_{2.5}$ emissions and their associated health impacts.

Table 16 National forecasts of emissions for 2010 versus the 2010 GP ceilings - Italy

Pollutant	Current 2010 Forecast	2010 GP Ceiling
SO_2 (kt)	340.3	500
NOx (kt)	1073.9	1000
NMVOC (kt)	395.1	419
NH_3 (kt)	869.7	1159

In relation to the pollutant levels, it should be noted that, especially for the pollutants coming from combustion, the emission projections are heavily dependent upon the structure of the underpinning energy scenario. In Italy National scenarios are developed using the Markal_Italy model, which is strongly influenced by fuel price growth and strategic choices taken at national level.

Looking at the changes in the national energy scenario characteristics over the past years, particularly between the development of the Gothenburg Protocol in 1999 and more recent years there have been some major changes which will have influenced the relevance of earlier emissions forecasts. As an example, fuel prices have dramatically increased and the structure of the energy scenario has changed toward an increased share of gas in power plants, an increased share of diesel cars with respect the petrol cars and a general increase in energy demand. In the case of the power plants, a strategic choice has been made regarding the installation of new generation combined cycle gas turbine plants. These factors have all influenced the accuracy of the original GP forecasts relative to more recent work, and highlight the ongoing evolution of national expectations.

Finally, in relation to ammonia and agriculture, the CAP reform and the IPPC Directive have had little effect in Italy in terms of NH_3 emissions. This is due to the persistent and extensive use of urea in agriculture and the small number of livestock farms which are subject to the IPPC Directive. In the case of the latter this is due to a national trend toward predominantly small livestock farms.

CONCLUSIONS AND LESSONS

The evidence to support Community action in relation to transboundary air pollution issues such as those covered by the Gothenburg Protocol is compelling. However, as with so many areas of environmental policy, progress requires a significant coordinated effort and the timescales involved are considerable. In the field of transboundary air pollution effective policy decisions require a level of prescience that integrated assessment models and associated research attempt to provide at the appropriate time.

In the lead up to the 1999 Gothenburg Protocol, considerable work was undertaken to estimate the emission paths and abatement potentials of Parties out to 2010. These data were then processed under various effects constraints to deliver cost effective ‘emission ceilings’ that should deliver on the Protocol’s objectives.

Almost ten years on, hindsight provides an opportunity to evaluate the process, its accuracy and efficacy and ultimately to learn for future agreements. This has been the principal objective of this piece and the lessons are of value to future agreements. The main issues and associated lessons are as follows:

Issue

Trends in the growth of activity levels are in many cases underestimated: population growth, economic growth and especially mobility growth and the associated use of fossil fuels. This presents many countries with a considerable challenge with regard to compliance with the emission ceilings that were originally based upon far more conservative projections.

Lesson

The lesson is that if activity projections are based on a conservative projection, ‘reserve’ measures should be formulated in case the projections prove to be higher. An alternative is to base abatement policies on the assumption that countries will meet the Lisbon growth targets, as well as ‘targets’ in the field of energy security. This might lead to an ‘overshoot’ in policy. The choice between the risk of not meeting the ceiling or doing ‘too much’ for the environment is of course a political one.

Issue

Optimistic assumptions in relation to the effectiveness and timing of policy measures can provide significant problems in relation to compliance. As an example, the Euro standard issue evaluated as part of this paper has been shown to have had a considerable and varied impact on Parties to the GP agreement.

Lesson

The lesson is to evaluate policy progress nationally on a year-to-year basis and compare this progress with the time-path leading to meeting the emission ceilings in the target year. In addition, where measures are revised and major challenges arise, care should be taken to ensure that the cost-effectiveness and ambitions of the process remain on target.

Issue

Indicators comparison between countries show great differences between national values when negotiating the GP. For instance, NOx emissions per capita for 2010 under GP vary from 27.4 to 16.1 kg per capita. Regarding SO_2, emissions per energy consumption are in the range of 152.9 to 13 kg/TJ. These differences highlight a problem between equity and environmental improvement per country.

Lesson

The lesson is to include indicators comparisons between countries when negotiating future emission ceilings as the Post-Kyoto work is currently doing.

Ultimately the nature of the environmental challenges we face require pre-emptive action. In order to determine an appropriate and effective course, there must be assumptions made for the future and such assumptions entail a degree of uncertainty. Models serve an important role in this process, but are entirely dependent upon the quality of the data. As a result there should be ongoing structured efforts to improve the quality of the modelling data, and a commitment to take account of updates and improvements as efforts to meet environmental objectives progress.

Great expectations with poor forecasts are not likely to deliver the desired realities.

BIBLIOGRAPHY

Amann, M., Bertok, I., Cofala, J., Gyarfas,. F., Heyes, C., Klimont, Z., Schöpp, W., 1999. Integrated Assessment Modelling for the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone in Europe. Lucht & Energie 132.

Bernow, S., Duckworth, M., 1998. An evaluation of integrated climate protection policies for the US. Energy Policy 26, 357-374.

Böhringer, C., 2000. Cooling down hot air: a global CGE analysis of post-Kyoto carbon abatement strategies. Energy Policy 28, 779-789.

Cofala, J., Syri, S., 1998. Nitrogen oxides emissions, abatement technologies and related costs for Europe in the RAINS model database. IIASA Interim Report.

Freedman, M., Jaggi, B., 2002. Evaluation of the first phase of sulphur dioxide and nitrogen oxides provisions of the 1990 Clean Air Act: A plant-based approach. Environmental Management 29, 437-450.

Gellera,H., Harrington, P., Rosenfeld, A.H., Tanishima, S., Unander, F., 2006. Polices for increasing energy efficiency: Thirty years of experience in OECD countries. Energy Policy 34, 556-573.

Johnson, K.C., 2007. California's greenhouse gas law, Assembly Bill 1493: Deficiencies, alternatives, and implications for regulatory climate policy. Energy Policy 35, 362-372.

Kelly, J.A, 2006 'An overview of the RAINS model' Environmental Research Centre (ERC) Report #4, Environmental Protection Agency, Dublin, Ireland.

Kelly, J.A., 2007. 'A Disproportionate Challenge? A retrospective assessment of the factors underpinning the 2010 national ceiling for oxides of nitrogen under the NECD', forthcoming Environmental Research Centre (ERC) report, Environmental Protection Agency, Dublin, Ireland.

Lipp, J., 2007. Lessons for effective renewable electricity policy from Denmark, Germany and the United Kingdom. Energy Policy 35, 5481-5495.

Lumbreras, J., Borge, R., Andres, J.M., Rodriguez, E. A model to calculate consistent atmospheric emission projections. Application to Spain. Submitted to Atmospheric Environment.

Maas, R. and Amann, M., 2007. Review of the Gothenburg Protocol. Report of the Task Force on Integrated Assessment Modelling and the Centre for Integrated Assessment Modelling, MNP/IIASA.

Nakano, K., Aoki, R., Yagita, H., Narita, N., 2007. Evaluating the reduction in green house gas emissions achieved by the implementation of the household appliance recycling in Japan. International journal of life cycle assessment 12, 289-298.

Urge-Vorsatz, D., Koeppel, S., Mirasgedis, S., 2007. Appraisal of policy instruments for reducing buildings' CO2 emissions. Building research and information 35, 458-477.

Voorhees A.S., Araki S., Sakai R., Sato, H., 2000. An ex post cost-benefit analysis of the nitrogen dioxide air pollution control program in Tokyo. Journal of the Air & Waste Management Association 50, 391-410

GLOSSARY

Organisations and Abbreviations	
GAINS	Greenhouse Gas-Air Pollution Interactions and Synergies
GDP	Gross Domestic Product
GP	Gothenburg Protocol
GP 2010	Generally refers to the values used or produced in the work for setting the original 2010 ceilings of the Gothenburg Protocol in 1999
IIASA	International Institute for Applied Systems Analysis
Kt	Kilo ton
NEC/D	National Emissions Ceiling/s Directive
NECPI	National Emissions Ceilings and Policy Instruments group
NH_3	Ammonia
NMVOC	Non Methane Volatile Organic Compound
NOx	Nitrogen Oxide
PJ	Petajoule
PM	Particulate Matter
PRIMES	Equilibrium Energy Model for EU
RAINS	Regional Air Pollution Information and Simulation
SO_2	Sulphur Dioxide
TREMOVE	Transport Policy Assessment Model
TFIAM	Task Force on Integrated Assessment Modelling
TFEIP	Task Force on Emission Inventory and Projections
TJ	Terajoule