National Data for Integrated Assessment Modelling under the Clean Air For Europe Programme

Environmental Research Centre Report

Prepared for the Environmental Protection Agency

by

Byrne Ó Cléirigh Limited in association with ICF Consulting

Authors:

Tom Cleary, Shane Malone, Sarah Dawson and Kim Keats Martinez

ENVIRONMENTAL PROTECTION AGENCY

An Ghníomhaireacht um Chaomhnú Comhshaoil
PO Box 3000, Johnstown Castle, Co. Wexford, Ireland

Telephone: +353 53 916 0600 Fax: +353 53 916 0699
E-mail: info@epa.ie Website: www.epa.ie

Lo Call 1890 33 55 99

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DISCLAIMER

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Details of Project Partners

Tom Cleary
Byrne Ó Cléirigh
30a Westland Square
Pearse Street
Dublin 2
Ireland

Telephone: + 353 1 6770733
E-mail: admin@boc.ie

Shane Malone
Byrne Ó Cléirigh
30a Westland Square
Pearse Street
Dublin 2
Ireland

Telephone: + 353 1 6770733
E-mail: admin@boc.ie

Sarah Dawson
Byrne Ó Cléirigh
30a Westland Square
Pearse Street
Dublin 2
Ireland

Telephone: + 353 1 6770733
E-mail: admin@boc.ie

Kim Keats Martinez
ICF International
Egmont House
25–31 Tavistock Place
London WC1H 9SU
United Kingdom

Tel: +44 20 73914700
E-mail: info@icfi.com

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1 Introduction

The Environmental Protection Agency (EPA), Sustainable Energy Ireland (SEI) and the Department of Environment Heritage and Local Government (DoEHLG) are all individually concerned with matters that affect emissions and pollutants. Whereas the remit of the EPA and the DoEHLG covers all emissions including pollutants with regional air quality implications such as NO_x, SO_2, VOCs, NH_3, SEI's remit is focussed more on energy consumption and greenhouse gas (GHG) emissions. There is nevertheless considerable overlap between the work of SEI in this area and that of the EPA and the DoEHLG, due to the fact that many of the activities which give rise to emissions of GHGs involve the use of energy and many activities in the economy emit regional or transboundary pollutants as well as GHGs.

At the European level, the Commission of the European Union has established the Clean Air for Europe (CAFE) programme with the aim of conducting a systematic and holistic review of all EU legislation related to air quality. As part of that programme, the EU has appointed an Austrian group, IIASA,[1] to produce an integrated assessment simulation model called RAINS – the Regional Air Pollution Information and Simulation Model. The purpose of RAINS is to provide a consistent framework for the analysis of reduction strategies for regional air pollutants. The output from RAINS is intended to assist the Commission and Member States to devise optimum abatement strategies for these pollutants. It is seen as important in Ireland's interest to ensure that the inputs and assumptions underlying the computations in RAINS correctly represent current and projected baseline emissions so that the scale of abatement needed is accurate. It is also important that realistic national cost curves for available abatement options are accurate.[2]

1. International Institute of Applied Systems Analysis.

It is the ultimate intention of the EPA and SEI to promote the investigation of major issues of environmental concern through the setting up of a Centre of Excellence under the aegis of the EPA. However, because of ongoing developments at EU level there was seen to be an urgent need for Ireland in the short term to conduct some preliminary investigations into these transboundary pollutants in advance of this centre being available.

Following a public tender process, Byrne Ó Cléirigh (BÓC), in association with ICF Consulting, were commissioned to undertake the current study in June 2004. The objective of this preliminary study, jointly sponsored by the EPA and SEI, is to examine the data in RAINS for Ireland in relation to future emissions. This is deemed to be important in the short term due to Ireland's need to comply with international obligations to limit emissions of the pollutants NO_x, SO_2, VOCs and NH_3 by 2010. Specifically, the study is aimed at checking the validity of the activity data[3] and results for Ireland as currently shown on the RAINS website to ensure that any decisions on abatement strategies suggested by the output from RAINS correctly reflect the current and future emissions in the absence of such strategies.

A key objective of this study is therefore to examine the data (activity levels and emissions factors) and assumptions underlying the RAINS modelling, and to inform the Irish Government whether, in the view of BÓC and ICF Consulting, the RAINS projections are reasonably correct or are over-optimistic or over-pessimistic compared with known trends and plans for the different sectors in the Irish economy.

2. It should be noted that the cost data were removed from the RAINS web site during the course of the project.
3. There is an unusual terminology used in RAINS which means that 'activity level' is in fact the level of fuel use expressed in petajoules.

2 The CAFE Programme

The CAFE Programme is a European Community measure set up to establish a long-term integrated strategy to tackle air pollution and to protect human health and the environment. It is based on the 6th Environmental Action Programme (EAP) and initiated in order to work towards a strategy on air quality.

The specific objectives of the CAFE programme are:

- to develop, collect and validate scientific information relating to the effects of ambient air pollution, emission inventories, air quality assessment, emission and air quality projections, cost-effectiveness studies and integrated assessment modelling, leading to the development and updating of air quality and deposition objectives and indicators and identification of the measures required to reduce emissions;
- to support the implementation and review the effectiveness of existing legislation, in particular the air quality framework[4] and daughter directives,[5] the decision on exchange of information, and the National Emission Ceilings Directive,[6] to contribute to the review of international protocols, and to develop new proposals as and when necessary;
- to ensure that the measures that will be needed to achieve air quality and deposition objectives cost-effectively are taken at the relevant level through the development of effective structural links with the relevant policy areas;
- to determine an overall, integrated strategy at regular intervals which defines appropriate air quality objectives for the future and cost-effective measures for meeting those objectives;
- to disseminate widely the technical and policy information arising from implementation of the programme.[7]

The primary focus of this report relates to the CAFE programme's first objective that encompasses the Integrated Assessment Model (IAM). The IAM used is the RAINS Model and was developed by the IIASA. RAINS is available for review and use on the Internet.

4. Ambient Air Quality Framework Directive (96/62/EC).
5. The first Daughter Directive (1999/30/EC) relates to limit values for NO_x, SO_2, Pb and PM_{10} in ambient air. The second Daughter Directive (2000/69/EC) relates to limit values for benzene and carbon monoxide in ambient air. The third Daughter Directive (2002/3/EC) relates to ozone and there is a proposed fourth Daughter Directive that will cover As, Cd, Ni, Hg and PAH.
6. National Emission Ceilings on NO_x, SO_2, VOCs and NH_3 (2001/81/EC).
7. *The Clean Air for Europe (CAFE) Programme: Towards a Thematic Strategy for Air Quality*, Communication from the Commission, COM(2001)245 final, Brussels, 04.05.2001.

3 Regional Air Pollution Information and Simulation Model (RAINS)

3.1 Overview

The EU appointed the IIASA research group in Austria to prepare an integrated assessment of emissions, impacts, abatement and economics of managing transboundary pollution with a view to optimising the strategy for meeting the national emission ceilings (NECs). The IIASA has developed the RAINS integrated model for this purpose which provides for the integrated assessment of emissions of nitrogen oxides (NO_x), sulphur dioxide (SO_2), volatile organic compounds (VOCs), ammonia (NH_3) and particulate matter (PM) from a wide range of sources in Europe. It attempts to provide a consistent framework for the analysis of emissions reduction strategies, focusing on acidification,[8] eutrophication[9] and the tropospheric ozone.[10]

3.2 Activities in RAINS

In the model, different fuel types are referred to as **Activities**. There are 23 activities listed in RAINS. The amount of fuel consumed is referred to as the 'Activity Level'. It is a measure of the amount of energy consumed. All the RAINS activities are listed in Appendix 1.

3.3 Sectors in RAINS

There are 110 modes of generating emissions in RAINS; these are described as **Sectors.** Some of these can be related directly to a fuel (activity) such as an existing pulverised fuel power plant (linked to hard coal, for example). In this study, the primary sectors for the SO_2/NO_x modules are:

- Transport;
- Power plants;
- Fuel production and conversion;
- Domestic;[11]
- Industrial;
- Non-energy use of fuels;
- Other.

The RAINS Model calls up different sector headings depending on the pollutant of concern. Hence, agriculture, which is not a primary sector for NO_x in RAINS, is a primary sector for NH_3. VOC and PM also have different primary sectors for those used for NO_x.

In RAINS, each of these sectors is broken down further; for example, the RAINS categorisation 'TRA_RD_LD4' is the 4-stroke, light-duty vehicle, road-transport sector. All the transport and power sectors categorised in RAINS are listed in Appendix 1.

3.4 Control Technologies in RAINS

Finally there is a list of over 94 **Control Technologies** in RAINS which may be applicable to a combination of an Activity and a Sector. The input data are thus extensive and in Section 6 we set out how we conducted this preliminary assessment of the RAINS Model for Ireland.

3.5 Modules in RAINS (Fig. 3.1)

RAINS comprises modules for:

- Emission Generation;
- Emission Control Options and Costs;
- Atmospheric Dispersion;
- Environmental Sensitivities.

The focus of this study is on the Emission Generation and Emission Control Options and Costs.

3.6 RAINS Web

The RAINS Web (Fig. 3.1) provides access to all the RAINS data underlying the recent development of the CAFE baseline scenario. Relevant data for sulphur dioxide, nitrogen oxides, ammonia, non-methane volatile

8. The formation of acid rain.
9. The overloading of nitrogen and phosphorous nutrients in an aquatic ecosystem.
10. Ozone is a reactive molecule formed by the interaction of sunlight with hydrocarbons and nitrogen oxides. It damages living tissue, forests and crops.
11. Includes residential, commercial, institutional and agriculture sectors.

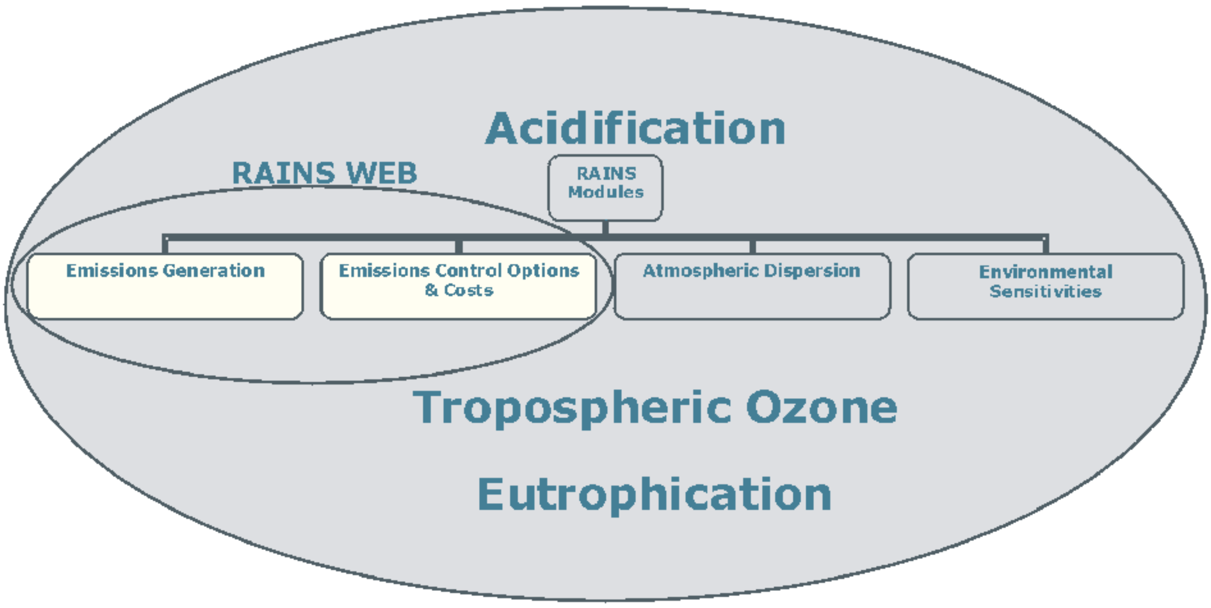

Figure 3.1. RAINS modules and RAINS Web.

organic compounds and particulate matter are included. For a given scenario, the model calculates the emissions of these pollutants and their abatement costs.

3.7 RAINS Forecasts

The RAINS emissions forecasts are based on the following equation:

$$E_i = \Sigma E_{i,j,k,m} = \Sigma(A_{i,j,k}) \times (ef_{i,j,k}) \times (1 - eff_m) \times (X_{i,j,k,m})$$

where: i, j, k and m represent country, sector, activity type, abatement technology; E_i is emissions in country; A is the activity level in a given sector, i.e. energy consumption in petajoules (PJ); ef is the 'Raw Gas' emissions factor (kt NO_x/PJ) before abatement; eff_m represents the reduction efficiency of the abatement technology, m; and X is the actual level of implementation of the abatement option under consideration (%).

Thus, the effective emissions factor (EEF) =

$$(ef_{i,j,k}) \times (1 - eff_m) \times (X_{i,j,k,m}).$$

The examples below illustrate how RAINS performs its calculations. The examples do not reflect the actual situation, as determined in this study, but rather how RAINS computed the NO_x emissions.

3.7.1 Example from RAINS of a coal-fired power plant in 2000

In the RAINS Model for the coal-fuelled power-plant sector, the activity level (A) for Ireland in the year 2000 was 60.27 PJ,[12] the emissions factor (ef) was 0.363 kt NO_x/PJ and according to RAINS there was no abatement technology installed.[13] Thus the emissions of NO_x currently computed by the RAINS Model for the year 2000 is:

$$E = (0.363 \times 60.27) = 38.934 \text{ kt } NO_x.$$

3.7.2 Example from RAINS of vehicle emissions in 2000

In the RAINS Model for petrol-fuelled cars complying with EURO I[14] standards, the activity level (A) for the year 2000 in Ireland was 64.148 PJ, the emissions factor (ef) was 0.75 kt NO_x/PJ, the reduction efficiency (eff_m) was 71% and the implementation rate[15] (X) was 26%. Thus the emissions of NO_x from this vintage of petrol car in Ireland were:

$$E = 64.148 \times 0.75 \times (1 - 0.71) \times 0.26 = 3.628 \text{ kt } NO_x.$$

RAINS completes this calculation for all the emissions sources and a total is reached.

12. Refer to Appendix 2 for current best estimate of the activity level in 2010.
13. The NERP shows that low NO_x burners are installed in Moneypoint.
14. EURO I was an emission standard for cars introduced in the EU in 1992 that limits car emissions to 8 g/kWh of NO_x and 0.36 g/kWh of PM. It was replaced by Euro II in 1995.
15. For vehicles, the implementation rate is the % of the vehicle population to which the abatement measure applies, in this case the % of petrol-fuelled cars built to EURO I standard.

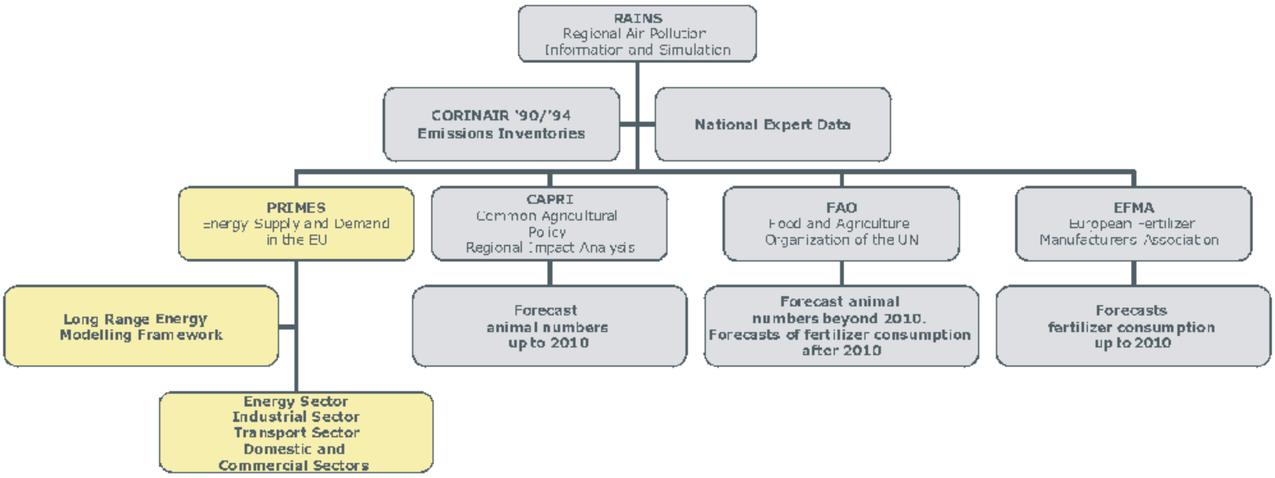

Figure 3.2. Breakdown of RAINS source data.

RAINS calculates emission forecasts using two scenarios:

1. Baseline Energy Scenario, which takes into account legislation and policies both in place and in the process of being implemented at the end of 2001 as developed with the PRIMES[16] Model; and

2. Climate Policy Scenario, which also takes into account a simulated EU-wide CO_2 emissions trading scheme.[17]

RAINS produces emissions based on both scenarios. A highly significant finding of our report is that there is virtually no difference in the activity levels, or abatement costs or emission levels between the two scenarios for 2010 in the RAINS results as of April 2004. The NO_x emissions in 2010 in the Baseline Energy Scenario are given by RAINS as 93.71 kt NO_x while under the Climate Change Scenario the emissions are 89.05 kt NO_x.

RAINS bases its forecasts on data from a number of sources. Figure 3.2 above gives a breakdown of the various sources. The PRIMES Model is the primary source of forecast information. The RAINS and PRIMES data can also be modified to take into account data supplied by national experts.

In Sections 7 and 8, we report on our preliminary assessment of the RAINS data, with a view to advising the EPA and SEI of the type of work programmes which would be required to ensure Ireland's interests are protected in the future by ensuring that RAINS (and because RAINS is inextricably linked to it, and PRIMES also) has the most accurate data possible on which to base projections for emissions and cost abatement strategies.

3.8 RAINS Abatement Options

Options and costs for controlling emissions of air pollutants are represented in RAINS by considering the characteristic technical and economic features of the most important emission reduction options and technologies. The cost evaluation is reportedly based on international operating experience of pollution control equipment, and extrapolated where applicable to the country-specific situation of application. The model only concentrates on presenting the direct emission control options. All indirect costs, such as effects on energy prices, trade balances, employment and the benefits induced by reducing damage to ecosystems or materials, are not included. The direct costs taken into account in relating the annual costs to the abated emissions are investments, fixed expenditures and variable operating costs. Ensuring that Irish cost curves used in RAINS are realistic is a potential area for future work.

16. PRIMES is a modelling system developed by the National Technical University of Athens that simulates a market equilibrium solution for energy supply and demand in the EU Member States. The model determines the equilibrium by finding the price of each energy form such that the quantity producers find the best supply to match the demand.
17. Assumes a permit price of €12 per tonne of CO_2 in 2010, rising to €16 per tonne in 2015 and €20 per tonne in 2020.

4 Sources of Pollutants

4.1 Nitrogen Oxides (NO_x)

Anthropogenic NO_x emissions originate mainly from combustion in stationary and mobile sources. Emissions of NO_x are a by-product of energy use in combustion and contribute significantly to acidification, eutrophication and the creation of tropospheric ozone. The two mechanisms that are the most important in the formation mechanisms for nitrogen oxides during the combustion of fossil fuels are:

1. Fuel-based NO_x, formed from the oxidation of fuel-bound nitrogen; and
2. Thermal NO_x, formed by the combination of atmospheric nitrogen and oxygen at high temperatures in the combustion process.

4.2 Sulphur Dioxide (SO_2)

Anthropogenic SO_2 emissions originate mainly from combustion in stationary and mobile sources. The level of SO_2 emissions primarily depends on the sulphur content of the fuel. SO_2 emissions are a major contributor to acid rain; when emitted to the atmosphere, they react with water vapour to produce sulphuric acid, which falls as acid rain.

4.3 Ammonia (NH_3)

NH_3 emissions originate mainly from the agricultural sector, in the form of animal manure, and to a lesser extent from fertiliser use, waste treatment and disposal, and from transport. NH_3 contributes to both acidification and eutrophication.

4.4 Volatile Organic Compounds (VOCs)

VOCs are organic chemicals that have a high vapour pressure and easily form vapours at normal temperature and pressure. They are produced by vehicle emissions, chemical manufacturing, the evaporation of automotive fuels, other petroleum-based products and chemical solvents. They are also naturally emitted by a number of plants and trees. VOCs combine with NO_x in the presence of UV light and heat to form tropospheric ozone. They are commonly divided into two categories – methane and non-methane. In the RAINS Model and the National Emissions Ceiling Directive, VOCs refer to the non-methane category only.

4.5 Particulate Matter (PM)

The emissions of PM in the RAINS Model are calculated for three different size classes:

1. The fine fraction ($PM_{2.5}$)
2. The coarse fraction (PM_{10}–$PM_{2.5}$)
3. Large particles (PM >10 mm).

When aggregated, these three fractions represent total suspended particles (TSP).

Airborne suspended particulate matter can be either primary or secondary in nature. Primary particles are emitted directly into the atmosphere by natural and/or anthropogenic processes with sources including fuel combustion in all sectors, construction sites, unpaved roads and stone crushing. Secondary particles are predominantly man-made in origin and are formed in the atmosphere from primary gaseous emissions. Examples include the formation of sulphates from sulphur dioxide emissions and nitrates from NO_x emissions from industry.[18]

18. Source: http://energyconcepts.tripod.com/energyconcepts/stack_emissions.htm

5 Ireland's Obligations

Ireland's obligations under a wide range of European legislation can be seen in Fig. 5.1. The motivation behind the Directives is the improvement of air quality to better the environment and human health. The Directives relate to control and limitations of various emissions on a national scale, local scale and from mobile and stationary sources. The idea behind CAFE was to gather all air quality policy within a single integrated programme.

The RAINS Model focuses on emissions of NO_x, SO_2, NH_3, VOCs and PM. With this in mind, the National Emissions Ceilings Directive (2001/81/EC) is of particular relevance to this study. The Directive sets upper limits for each Member State to the total emissions in 2010 of the four pollutants responsible for acidification, eutrophication and ground-level ozone, namely NO_x, SO_2, VOCs and NH_3. This Directive is discussed in further detail in the following section.

5.1 The National Emissions Ceilings (NEC) Directive

As noted above, this Directive of the European Parliament and of the Council on National Emission Ceilings for certain pollutants (NECs) sets upper limits for each Member State for the total emissions in 2010 of NO_x, SO_2, VOCs and NH_3. The Directive leaves it largely to the Member States to decide which measures to take in order to comply. Some of the other directives such as the Large Combustion Plant (LCP) Directive set limits for individual sources of emissions, thus aiding in the achievement of the national ceilings. The NECs for Ireland are shown in Table 5.1. To put these limits for 2010 in context, they are compared to the 1990 and the 2002 levels (EPA Emissions Inventory 2002).

From Table 5.1, the largest percentage reduction below the EPA Emissions Inventory 2002 to meet the NEC in 2010 is required for SO_2, at 56%. The largest reduction in

Figure 5.1. Air quality directives.

Table 5.1. Ireland's obligations under the National Emissions Ceilings Directive.

	1990 (kt)	2002 (kt)	2010 ceiling (kt)	kt reduction vs. 2002	% reduction on 2002 to meet 2010 ceiling
NO_x	115	121	65	56	46
SO_2	178	96	42	54	56
NH_3	126	122.6[1]	116	6.6	6
VOC	197	77.65[2]	55	23	29

[1]Discussion Paper: Strategy to Reduce Emissions of Transboundary Air Pollution by 2010, DoEHLG.

[2]Sum of NMVOC from 'Sectoral report for energy' and 'Sectoral report for solvent and other product use', EPA Emissions Inventory 2002.

tonnage terms is required for NO_x, at 56 kt. Both of the ceilings placed on NO_x and SO_2 represent significant challenges for Ireland.

The quantity of NH_3 emissions is dominated by the emissions from the national cattle herd, representing some 64% of the emissions generated.[19] With the proposed introduction of CAP reform, the cattle numbers are forecast by FAPRI-Ireland to drop by approximately 11%,[20] thus contributing significantly to the achievement of the NEC for ammonia. The RAINS Model has not taken CAP reform into account. In contrast to the cattle numbers projected by FAPRI-Ireland, RAINS has predicted a rise in cattle numbers of 7%, leading to the situation as shown in Fig. 5.2. RAINS is forecasting a herd that will be 20% larger than forecast by FAPRI-Ireland with a consequent overstatement of the forecast emissions of NH_3 in 2010.

19. Source: RAINS breakdown of emissions 2000.
20. Source: *The Luxembourg CAP Reform Agreement: Analysis of the Impact on the EU and Irish Agriculture* FAPRI-Ireland Partnership.

The reduction in cattle numbers, together with other related CAP reforms and abatement options, should enable the attainment of the NEC for NH_3 without the requirement for further additional measures.

The fact that the emissions of SO_2 and VOC have been in decline since 1990 shows that some progress has been made in achieving the NECs, reducing by 46% and 60.5% respectively between 1990 and 2002. If these trends continue VOC emissions should achieve the ceiling in 2010. SO_2 however would be a cause for concern in the absence of measures such as the Flue Gas Desulphurisation at Moneypoint.

However, the main concern in examining these figures is the increase in NO_x emissions between 1990 and 2002. All other emissions have shown a marked decrease between 1990 and 2002. Thus the most challenging target for Ireland is likely to be in reducing NO_x emissions by 56 kt between 2002 and 2010.

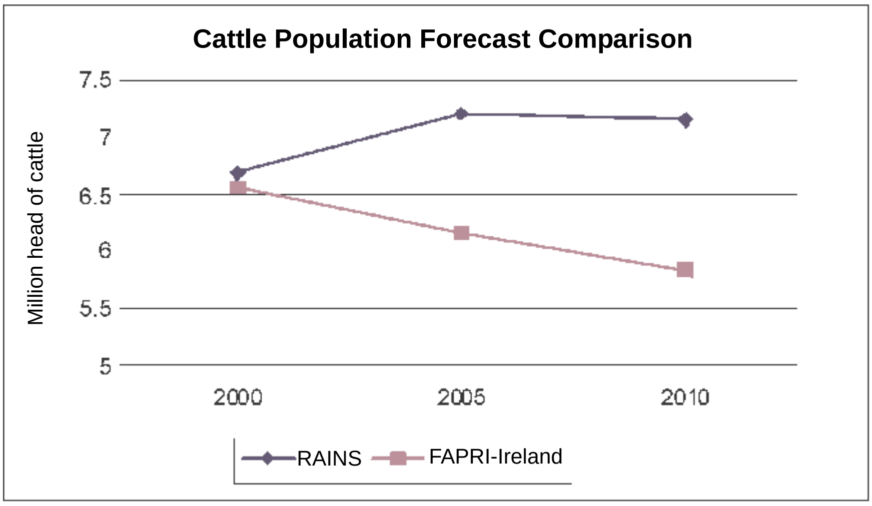

Figure 5.2. Forecast of national herd – impact of CAP reform on cattle numbers.

5.2 RAINS Forecast Emissions for Ireland

The RAINS Model is the IAM used for the CAFE programme and is also in use by the United Nations Economic Commission for Europe (UNECE) for the Gothenburg Protocol. Our examination of the April 2004 outputs from the model is central to this study. RAINS currently has two scenarios, as discussed in Section 3.7.2: the baseline scenario and the climate change scenario. The model forecasts emissions in 5-year intervals up to 2030 from the base year of 1990 as shown in Table 5.2. The key year for compliance with the NEC Directive is 2010. All RAINS forecasts will be referenced from the baseline scenario unless otherwise stated.

The predicted emissions resulting from the climate change scenario are shown in Table 5.3.

Based on the current RAINS input data for Ireland, the trends suggest that although NO_x and SO_2 are seen by the EPA, SEI and DoEHLG as the primary sources of concern currently, these two pollutants are also projected to undergo the most substantial future decreases. According to RAINS, only SO_2 will achieve its target under the NEC Directive.

Table 5.2. Current RAINS projections for Ireland as per baseline scenario.

	Year								
	1990	1995	2000	2005	2010	2015	2020	2025	2030
					kt/year				
NO_x	107.5	115.7	128.2	107.2	**93.7**	75.8	61.4	60.5	60.7
SO_2	144.0	137.8	133.2	75.9	33.8	26.7	20.2	18.8	17.7
NH_3	127.3	132.2	129.2	133.1	**131.0**	126.9	122.7	118.5	114.2
VOC	103.6	99.8	93.2	82.3	**72.2**	68.3	69.7	71.7	73.7
PM	58.6	37.4	34.6	36.4	32.8	30.9	30.6	31.1	31.4

Values in bold depict emissions which exceed National Emissions Ceiling.

Table 5.3. Current RAINS projections for Ireland as per the climate change scenario.

	Year				
	2000	2005	2010	2015	2020
			kt/year		
NO_x	128.3	107.1	**89.1**	72.5	59.2
SO_2	133.2	75.9	30.4	24.9	19.7
NH_3	129.2	133.1	**131**	126.9	122.7
VOC	93.2	82.3	**72**	68.1	69.5
PM[1]	35.5	37.3	33.3	31.4	31.1

[1]PM is not covered under the NEC Directive, but it is included in the RAINS Model.
Values in bold depict emissions which exceed National Emissions Ceiling.

6 Overall Approach

6.1 Study Emphasis

The emissions that are included in the RAINS Model span virtually the whole of Ireland's economy. Furthermore, there are five widely different pollutants involved, namely NO_x, SO_2, VOCs, NH_3 and PM. It is important to emphasise that the study is a preliminary one. Compared to the recent efforts expended by the DoEHLG, the EPA and a large number of external consultants engaged in the various studies of GHGs and the National Allocation Plan, the depth to which we could investigate the RAINS Model projections in this preliminary study is at a significantly lower level.

In relation to dividing the work effort between the different pollutants, it should also be recorded that there was particular emphasis placed in this study on NO_x. This reflects the terms of reference for the study. The view, re-emphasised during the initial discussions was that, of the five pollutants above, NO_x poses the most serious compliance challenge to Ireland. This is consistent with experience to date, which shows an increase in NO_x emissions between 1990 and 2002, while all other emissions which come under the NEC Directive have shown a marked decrease in emissions over the same time period.

6.2 Methodology

The study may be divided into a number of tasks, as follows:

- Comparison of historical emissions from RAINS for the year 2000 with most relevant data available for Ireland to identify any significant errors in RAINS historical data for Ireland;
- Comparison of emissions projections from RAINS for 2005 and 2010 with most relevant data available for Ireland, assuming 'business as usual' to identify any significant errors in RAINS projections;
- Identification of any additional abatement measures which could be applied to reduce emissions, together with costs where relevant.

6.2.1 Historical emissions

RAINS data are, in the main, derived from the PRIMES modelling system, a top–down EU approach which simulates a market equilibrium solution for energy supply and demand in the EU Member States. RAINS estimates of emissions for 2000 were compared with data from the EPA Emissions Inventory 2002 and BÓC estimates of 2002 emissions (based on the ESRI Medium Term Review, 2003). This allowed us to identify any underlying errors in the historical RAINS data for Ireland, either in terms of activity level or in the emission factors used.

6.2.2 Emission projection

Between September 2003 and February 2004, BÓC and ICF Consulting completed a study for the DoEHLG to inform the Government's decision on the allocation of GHG emission allowances under the EU Emissions Trading Scheme due to start in January 2005.[21] That report included a review of current and projected GHG emissions across all sectors.

Many of the activities which produce GHGs also result in emissions of transboundary pollutants which are the subject of the current study. Generally the same assumptions regarding historical and projected activity levels have been retained for the current study as for the work on GHGs unless otherwise stated in this report. The key assumptions relating to activity-level projections are summarised below.

6.2.2.1 Powergen sector assumptions

- In the GHG study for the DoEHLG, electricity demand was assumed to grow from 2003 to 2009 at an average annual rate of 3.4% in the absence of emissions trading and carbon taxes, in accordance with the rate recommended by the ESRI in November 2003. From 2009 onwards, electricity demand was assumed to grow at a reduced rate of 2.3%, again in accordance with ESRI recommendations. This growth forecast lies between the low and median growth forecasts from the *Generation Adequacy Report* (GAR) 2004–2010.

21. *Determining the Share of National Greenhouse Gas Emissions for Emissions Trading in Ireland*, Final Report, ICF Consulting in association with Byrne Ó Cléirigh.

- Following discussions between BÓC and the ESB in November 2004, we reviewed the ESB projections for total electricity demand in 2010 which is 31,842 GW/h. This closely corresponds to the GAR Median Demand Forecast projection for 2010 of 31,997 GW/h. These projections represent on average a 4.1% annual increase in the electricity demand between 2004 and 2010. The ESB has also provided projections for the fuel mix for power generation in 2005 and 2010 and we have used these values in this report.

- BÓC and ICF Consulting have reviewed the latest ESB projections for energy input (PJ) provided by the ESB for 2010 and the basis for them. We considered them to be valid for the purposes of this report.

- It was assumed in the ICF Consulting–BÓC report on GHGs that Moneypoint would continue to operate on coal at an 85% load factor. The latest ESB projections assume an 80% load factor for Moneypoint. We have used the ESB value for the purposes of this report.

- It is assumed that the three modern peat-burning plants – Edenderry Power and the new ESB peat stations at Lanesborough and Shannonbridge – will operate as base-load plants, since they have 15-year ‘take or pay’ fuel purchase contracts with Bord na Móna in place, back-to-back with 15-year power purchase agreements. The ESB projections also assume that these plants operate in this mode.

- We have assumed that biomass generation in 2005 will be provided by 35 MWe of Landfill Gas (LFG) generation, in accordance with the GAR 2004–2010. We have assumed an installed capacity of 90 MWe of biomass generation in 2010, in accordance with guidance from SEI. The 2005 emission factors for LFG in 2005 were assumed to be the same as the EPA 2002 value. The 2010 emissions factor was calculated based on LFG and peat emission factors. Emission factors for peat were used as an analogue, since a large proportion of the biomass is projected to be co-fired in the peat plants, and thus subjected to the same combustion conditions and abatement technology as peat.

- The ESB projections of energy consumption in the powergen sector have assumed 12.4% penetration of renewable energy by 2010 rather than the 13.2% target under the RES-E Directive.

- We have assumed that all measures identified in the National Emissions Reduction Plan (NERP) will be implemented by 2010, and we have incorporated them into the ‘base case’ projections. NERP reduction percentages have been applied to 2002 emission factors in order to estimate 2010 emission factors.

It should be noted that there are uncertainties in the projections of emissions from the powergen sector, for both RAINS and BÓC. There is a degree of uncertainty in forecasting:

1. the demand for electricity;

2. the fuel mix to meet the demand; and

3. the emissions factors in future years.

This is particularly so for forecasting the split between electricity generated from HFO and electricity from gas which depends on the relative costs of the fuels as well as on grid factors. The RAINS Model uses the forecasts of the PRIMES Model which bases its energy demand forecasts on economic factors and it is clear that the activity level for coal in RAINS will not reflect the situation in Ireland in 2010.

6.2.2.2 Transport

- Projections of demand for transport fuels are consistent with the projections in the Emissions Trading GHG study, and are based on ESRI Medium Term Review data. The ESRI model projects demand based on the stock of private cars only. It therefore does not allow a separate estimation of road-transport emissions for private cars, buses and heavy-duty vehicles. The model forecasts only total oil demand; the split between petrol and diesel is projected linearly on the basis of changes since 1990, with a 60% share for diesel being imposed.

- Again, consistent with the Emissions Trading GHG study, the ESRI Medium Term Review data were adjusted to take account of improved vehicle efficiency, VRT, taxes and car labelling, public transport and traffic management and freight measures designed to reduce activity levels in the sector.

- In the ESRI model, demand for fuel is derived as a function of the stock of cars and the fuel price differential relative to the UK. Therefore, the approach takes account of potential changes in cross-border fuel trade (fuel tourism). However, as the price differential is significantly affected by policy in the UK, a degree of uncertainty remains with these projections.

- The activity level for aviation in RAINS represents the total energy consumption for both international and domestic landing, take-off and cruising. The emissions estimate is made using an implied emissions factor to take into account that NEC Directive 2001/81/EC does not cover aircraft emissions beyond the landing and take-off cycle[22] and is not reported as part of national emissions. In contrast, the activity level for aviation from the Emissions Trading GHG study (undertaken in support of Ireland's Kyoto obligations) corresponds to **domestic** landings and take-offs (LTOs) only. For the purposes of this study, we have estimated the aviation activity level in accordance with 2001/81/EC to be the sum of the domestic LTOs plus the EPA 2002 values for international LTOs (increased at the same rate as BÓC domestic LTOs). The EPA 2002 emission factor for aviation has been applied to convert activity levels to emissions.

- For all other activities within the transport sector, we have applied the RAINS emission factors for the transport sector for 2005 and 2010. Therefore, emission reductions due to the European Auto-Oil programme, which has imposed progressively more stringent emissions standards for vehicles and fuels, are assumed to be included in the 'base case' scenario for the transport sector.

It should be noted that there are uncertainties in the projections of emissions from the transport sector, both with the RAINS and BÓC estimates. Potential shortcomings associated with the RAINS modelling approach for the transport sector are discussed in further detail in Appendix 4. In general, these observations also apply to the BÓC data.

6.2.2.3 Residential & commercial

- Projections for the residential & commercial sector are consistent with the projections in the Emissions Trading GHG study, and are based on the 'no policy change' scenario of the ESRI Medium Term Review, 2003. The trends in efficiencies and fuel switching seen over the past decade are projected to continue between now and 2010. The Government's policy of enhancing building standards is assumed to underlie the ESRI projections.

- EPA emission factors for 2002 have been applied to activity-level projections in order to estimate emissions levels.

6.2.2.4 Industrial

- With the exception of the cement sector, projections are based on the 'no policy change' scenario of the ESRI Medium Term Review, 2003. These projections vary slightly from those used in the Emissions Trading GHG study, which based emissions projections in the traded sector on a bottom–up analysis of projected emissions from the major industrial sites in the sector. ESRI projections for industrial fuel use were used in preference to the GHG study data since a breakdown by fuel type was not available for the latter data. In the context of total NO_x and SO_2 emission projections from all sectors in Ireland, differences in activity level between the two data sources are negligible.

- The ESRI projections do not take into account the recent opening of two new cement plants and the fact that these plants were still ramping up production in the period 2002 and 2003. As a result, the ESRI projections underestimated baseline activity levels in this sector and hence projections for 2005 and 2010. The projections used in this report are based on those agreed with the DoEHLG for the Emissions Trading GHG study.

- The BÓC projections from the GHG report for the industry sector have been modified to take account of the construction of a new gas-fired combined heat and power (CHP) plant at Aughinish Alumina, which will reduce the projected fuel oil consumption under the industrial sector. For this report emissions from the new CHP plant are included under the powergen-sector projections.

- For the industrial sector EPA emission factors for 2002 have been applied to activity-level projections in order to estimate emissions levels.

22. LTO – from NEC Directive 2001/81/EC, Landing and Take Off means a cycle represented by the following time in each mode: approach 4 min, taxi/ground 26 min, take-off 0.7 min and climb 2.2 min.

We have compared the emission estimates based on our projections with those from RAINS in order to identify any significant errors in the RAINS projections which have arisen due to incorrect assumptions regarding the specific situation in Ireland.

6.2.3 Identification of additional abatement measures

Where possible, additional abatement measures which are not already included in the ‘base case’ projections have been identified, together with costs where they are available. These are reported in Sections 7.3.3 and 7.5.4 and in Appendix 4.

7 NO_X

7.1 Overview

As described in Section 4.1, NO_X is a major contributor to acidification, eutrophication and the tropospheric ozone. Under the NEC Directive, Ireland has undertaken to limit emissions to 65 kt of NO_X by 2010. This represents a major challenge, since our current NO_X emissions are almost double this limit.

The following sections compare the RAINS historical data for Ireland in 2000 and the forecasted emissions for 2005 and 2010 with BÓC's independent assessments for 2002, 2005 and 2010. To fully understand the estimates of NO_X emissions, we have compared both the activity levels (mainly expressed as PJ of energy input) and the emission factors. Any discrepancy in either of these values will result in differences in the estimated NO_X emissions.

7.2 Sectoral Analysis

7.2.1 *Activity-level comparison*

Table 7.1 shows an overview of the sectoral energy consumption figures on which the calculations for NO_X emissions are based in RAINS and by BÓC for this study.

RAINS and BÓC historical activity levels for the years 2000 and 2002 are similar. The 5% difference in the level of activity may well be simply attributed to the fact that there is a 2-year difference in the estimates; it reflects the predicted increase in energy demand.

The trends in activity-level estimates for both RAINS and BÓC data show an increasing demand for energy over the period 2000–2010. This increase is consistent with the general forecast for increases in demand in both the power sector, the industrial and commercial sectors and in the transport sector as used in the ICF Consulting–BÓC GHG study for the DoEHLG in September 2003 to January 2004.

Although the sectoral activity levels are reasonably similar, the fuel mix within each sector has a very large bearing on the emissions generated. This will be discussed in further detail in the following sections. Discrepancies in the transport-sector projections for 2005 and 2010 are due in part to differences in the way that aviation fuel use is defined in the two different data sets. This is discussed in further detail in Section 7.3.

7.2.2 *Emission factor comparison*

The aggregated emission factors for each sector are presented in Table 7.2. These values represent the sector as a whole and provide a rough comparison between RAINS and BÓC data. They are broken down into their individual components in Appendix 3.

The overall sectoral emissions factors show good correlation. However, there are differences in the disaggregated emissions factors and they are discussed in the following sections. These values combined with the corresponding activity levels indicate that the general trends of both RAINS and BÓC forecasts should be similar in nature.

7.2.3 *NO_X emission comparison*

Figure 7.1 and Table 7.3 show a comparison between the NO_X emission forecasts of RAINS and BÓC for the years 2000/2002, 2005 and 2010. The EPA estimate of NO_X

Table 7.1. Comparison of energy input by sector.

Sector	2000/2002		2005		2010	
	RAINS 2000 PJ	BÓC 2002 PJ	RAINS PJ	BÓC PJ	RAINS PJ	BÓC PJ
Transport	172.50	176.63	208.10	186.45	230.61	200.86
Power	198.89	209.99	220.06	197.91	226.62	219.62
Residential & commercial	127.09	137.32	142.46	145.29	150.88	164.25
Industrial	54.61	62.11	66.59	63.66	79.72	63.08
Other	8.64	5.15	4.22	5.15	7.79	5.15
Total	**561.73**	**591.09**	**641.42**	**598.46**	**695.61**	**652.96**

Table 7.2. Comparison of emission factors for NO_x.

Sector	2000/2002		2005		2010	
	RAINS 2000 kt NO_x/PJ	EPA 2002 kt NO_x/PJ	RAINS kt NO_x/PJ	BÓC kt NO_x/PJ	RAINS kt NO_x/PJ	BÓC kt NO_x/PJ
Transport	0.40	0.37	0.30	0.37	0.23	0.29
Power	0.20	0.19	0.11	0.18	0.09	0.08
Domestic & commercial	0.06	0.06	0.07	0.06	0.06	0.06
Industrial[1]	0.11	0.19	0.09	0.22	0.09	0.23

[1]RAINS does not include the cement industry in the Industry Sector. It is categorised separately under process emissions with no fuel use associated with it. The RAINS emission factor for this activity is based on tonnes of cement rather than PJ.

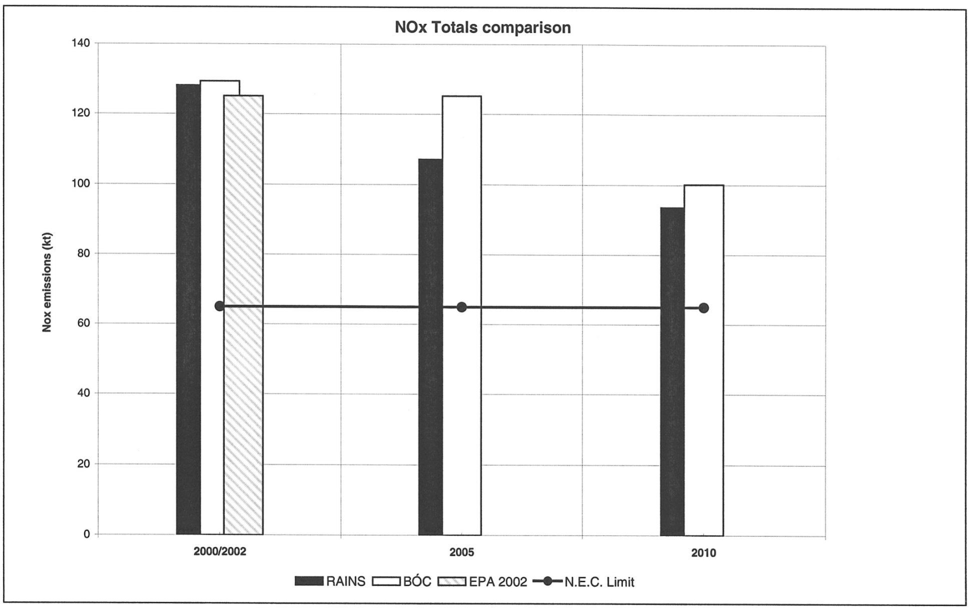

Figure 7.1. NO_x emissions comparison.

Table 7.3. NOx emissions comparison.

	2000/2002	2005	2010
RAINS (2000)	128.22	107.16	93.71
BÓC (2002)	129.00	127.13	99.51
EPA 2002	125.16	–	–
NEC limit	–	–	65.00

emissions for 2002 is also included for comparison purposes.

In 2000/2002, the emissions are all at a very similar level. However, when forecasting, the estimates have tended to diverge. The RAINS forecast shows a steady decline in the quantity of NO_x produced. The decline in NO_x emissions in BÓC data is also evident, but the rate of decline is slower than that in the RAINS forecast.

The decline in NO_x emissions can be attributed to two factors, as discussed in Section 3.7: (i) the level of sectoral activity, and (ii) the effective emissions factor. Since the overall activity levels are forecast to steadily increase over time, the decline in NO_x emissions is a reflection of abatement technology use and switches in fuel type.

7.2.3.1 Breakdown of NO_x emissions for 2000/2002

Figures 7.2 and 7.3 show the contribution of each fuel, by sector, to NO_x emissions for 2000/2002. Note that the process sector is represented by its own column in RAINS, while it is included in the industrial sector in the BÓC data. Both RAINS and BÓC data show similar trends.

From the figures, it is evident that the primary sources for NO_x emissions are:

- the transport sector, and
- the electricity generation sector.

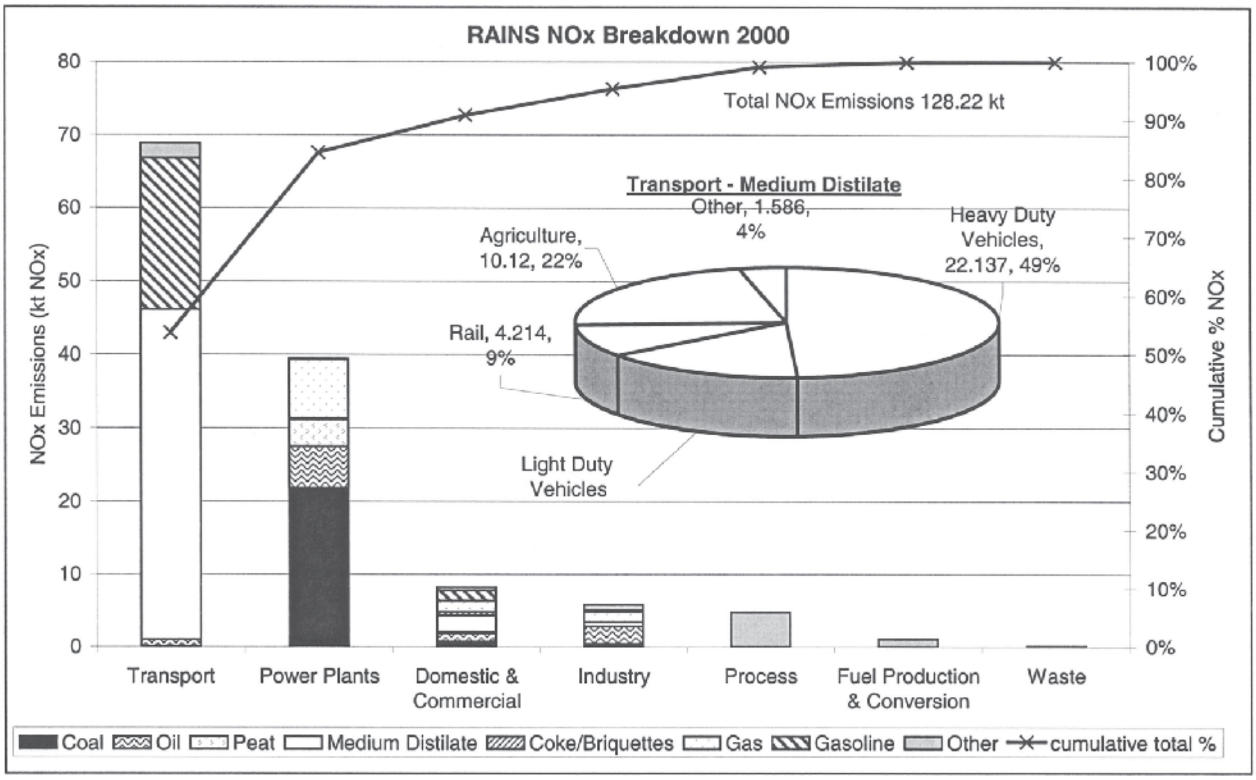

Figure 7.2. RAINS NO_x breakdown for 2000.

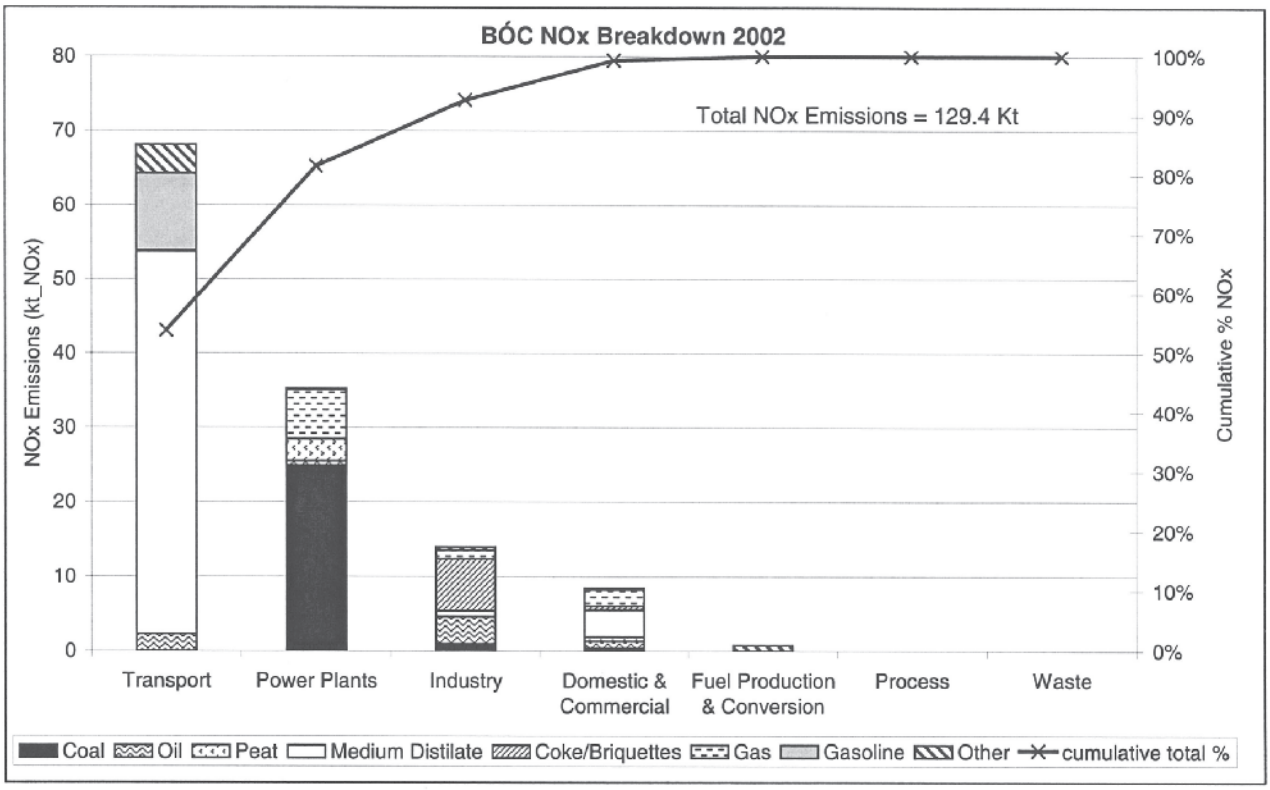

Figure 7.3. BÓC NO_x breakdown for 2002.

The single most significant source of NO_x emissions was emissions from medium distillate (diesel, gas oil and kerosene) in the transport sector. The pie chart in Fig. 7.2 shows a breakdown of the emissions from medium distillate (diesel) use in the transport sector. Heavy-duty vehicles (HDV) account for approximately 50% of the NO_x emissions from the transport sector, corresponding to 17% of the national NO_x emissions.

The relative importance of the source of emitters within the transport sector assumed by RAINS is consistent with that in the Oscar Faber report 1999.[23] No breakdown of medium distillate emissions into individual source categories within the transport sector is available for the data used in the ICF Consulting–BÓC GHG study.

7.2.3.2 Breakdown of NO_x emissions for 2005

Figures 7.4 and 7.5 show the contribution of each fuel, by sector, to NO_x emissions for 2005.

As for the historical data, both RAINS and BÓC projections show similar trends, with the primary sources for NO_x emissions forecast to be the transport sector and the electricity generation sector, with these two sectors accounting for approximately 80% of the national NO_x emissions in that year.

7.2.3.3 Breakdown of NO_x emissions for 2010

Figures 7.6 and 7.7 show the contribution of each fuel, by sector, to NO_x emissions for 2010. As for 2000/2002 and 2005 data, both RAINS and BÓC data show similar trends, with the primary sources for NO_x emissions forecast to be the transport sector and the electricity generation sector. However, BÓC estimated that in 2010 emissions of NO_x will be 6% higher than those of RAINS.

We discuss the contribution from these two sectors in further detail in the following sections.

7.3 Transport-Sector Analysis

7.3.1 Transport sector – 2000/2002

Of the total national NO_x emissions, 50–55% were attributable to the transport sector in the period 2000–2002.

23. *Study of the Environmental Impact of Irish Transport Growth and of Related Sustainable Policies and Measures, Volume 2, Technical Report*, Report produced by Oscar Faber Transportation in association with Ecotec, Goodbody and the ESRI for the Technical Assistance Programme Steering Committee within the operational Programme for Transport, Department of Public Enterprise, December 1999.

7.3.1.1 Activity levels and emission factors

Table 7.4 shows a comparison between RAINS and BÓC energy consumption estimates within the transport sector for this time period. The EPA's estimates for 2002 from the EPA Emissions Inventory 2002 have been included also.

From this table, it can be seen that the energy input by fuel type in the transport sector is broadly comparable with the RAINS values as a whole, with RAINS data showing slightly lower values than BÓC or EPA. This is likely to be due to the 2-year difference in the source data. The most significant difference lies in the medium distillate estimates, which comprise road diesel, rail diesel, agricultural diesel and other minor sources. The difference in the energy consumption values of aviation fuel are not significant – they are due to differences in the way the aviation fuel usage is defined in the different data sets and are compensated for by using different emission factors as previously discussed in Section 6.2.2.

Table 7.5 shows a comparison of RAINS and EPA emissions factors for 2000/2002.

The difference between the emissions factors for road petrol may reflect the 2-year lag in the EPA data, with the EPA emissions factor reflecting the EURO programme which is introducing progressively more stringent emission limits for new road vehicles. As noted above, the difference in the aviation fuel emission factors reflects the different data from the two sources, as discussed in Section 6.2.2.

7.3.1.2 NO_x emissions

By breaking down the transport emissions by fuel use, a direct comparison can be made between the RAINS emissions estimates and those of BÓC. The results are shown in Table 7.6. We have used the EPA emission factors for 2002 to convert the BÓC activity levels to NO_x emissions.

Both data sources show NO_x emissions from the transport sector to be dominated by emissions from medium distillates and from gasoline in the period 2000–2002, representing 93–96% of the total NO_x emissions from the sector. The primary source of the gasoline-related emissions in the transport sector is private car usage, while the primary source of medium distillate emissions in the transport sector is HDVs. BÓC data show a relatively

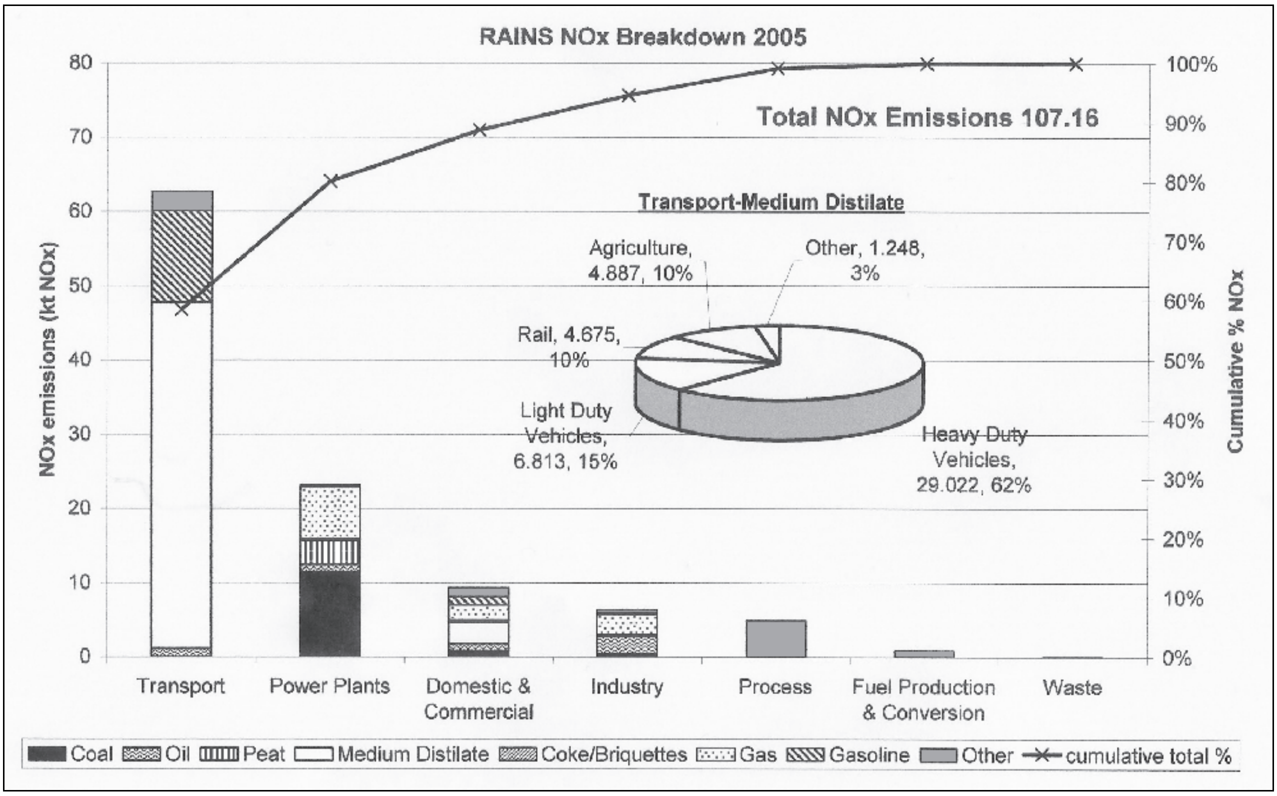

Figure 7.4. RAINS NO_x breakdown for 2005.

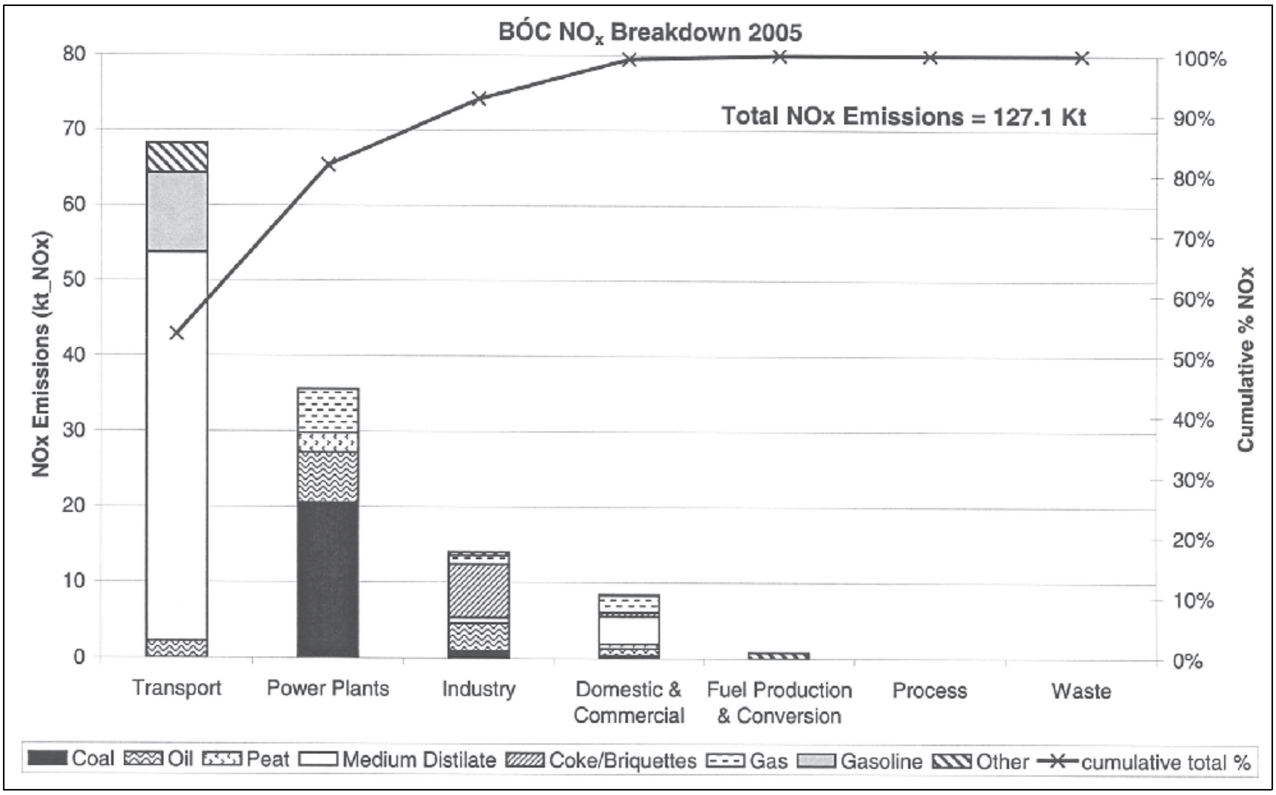

Figure 7.5. BÓC NO_x breakdown for 2005.

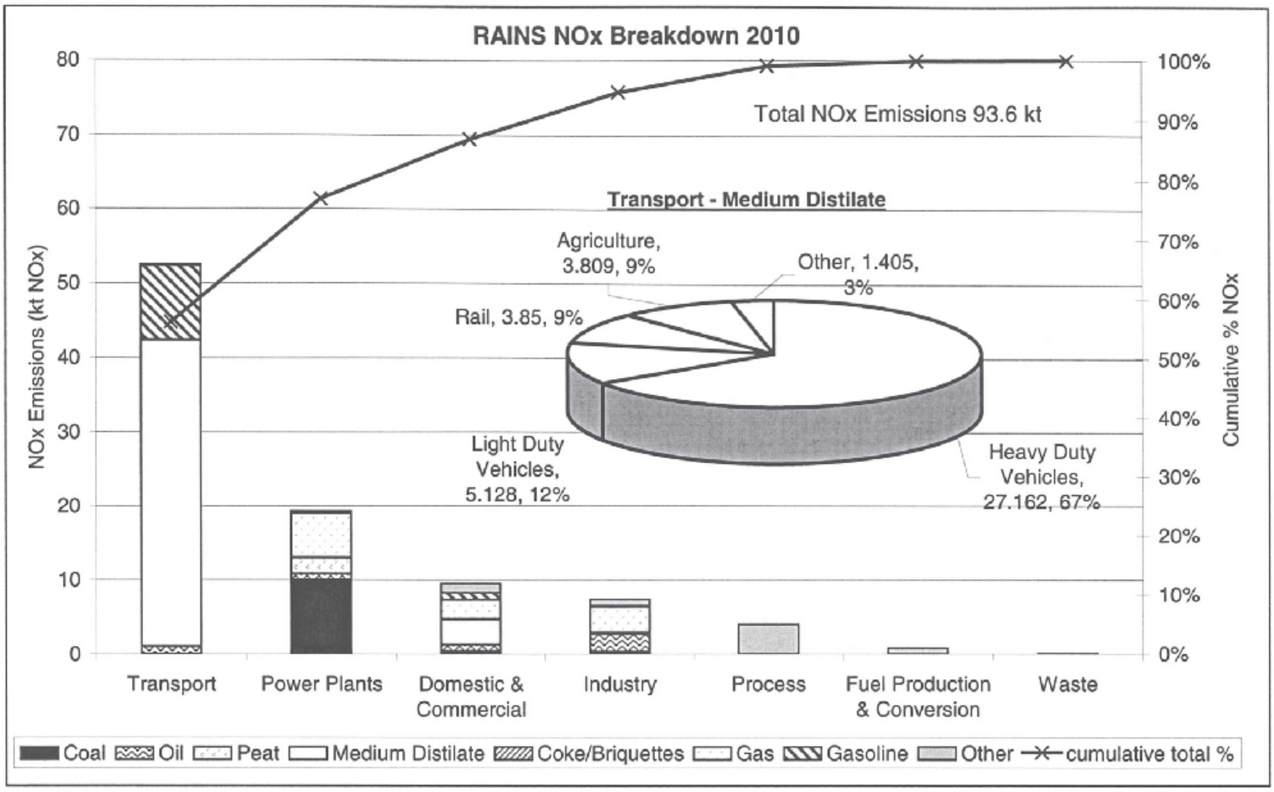

Figure 7.6. RAINS NO_x breakdown for 2010.

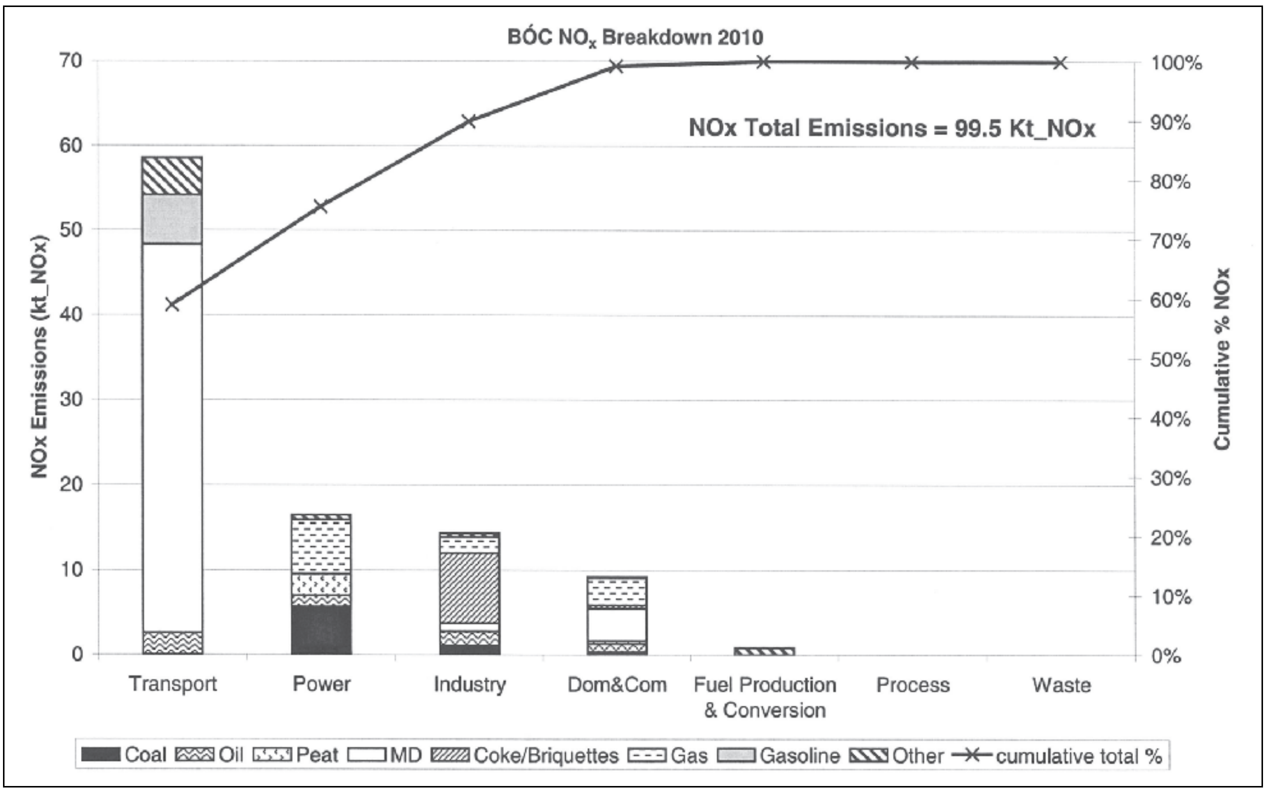

Figure 7.7. BÓC NO_x breakdown for 2010.

Table 7.4. Comparison of energy consumption for 2000/2002.

Fuel type	2000 RAINS PJ	2002 BÓC PJ	2002 EPA PJ
Gasoline	64.49	66.59	70.58
Medium distillate	82.06	93.98	92.22
Oil	1.60	1.75	0.78
LPG/gas	0.28	2.24	1.98
Aviation fuel	24.08	12.08[1]	11.28
Total	**172.51**	**176.63**	**176.84**

[1]This value comprises 10.7 PJ of international LTO, taken from the EPA Emissions Inventory 2002. The remaining amount is from domestic LTO.

Table 7.5. Comparison of emission factors for 2000/2002.

Fuel type	2000 RAINS kt NO_x/PJ	2002 EPA kt NO_x/PJ
Road petrol	0.32	0.22
Road diesel	0.43	0.40
Rail diesel	0.81	0.81
Agricultural machinery gas oil	1.15	1.15
Nav. fuel oil	1.20	0.98
Aviation fuel	0.08	0.28

higher contribution from the medium distillate compared to data from RAINS.

7.3.2 *Transport-sector projections*

The transport sector is forecast to account for 50–60% of the total national NO_x inventory in 2005, rising to 55–60% of the total national NO_x emissions by 2010, with the relative proportion of the emissions coming from medium distillate sources increasing relative to data for 2000/2002.

7.3.2.1 Activity levels and emission factors

Table 7.7 shows a comparison between RAINS and BÓC energy consumption estimates within the transport sector in 2005 and 2010.

As noted previously, there are differences in the way that the two different data sources define aviation fuel usage. Excluding aviation, the total transport activity levels for the two data sources are very similar. However, the BÓC data predict a higher percentage of diesel usage relative to gasoline when compared to the RAINS forecast. RAINS bases its energy consumption values on input from the PRIMES energy model which has taken account of fuel tourism, but how it has dealt with it in Ireland's case is unclear. Thus, one of the potential sources of discrepancy is the treatment of fuel tourism.

Table 7.8 shows the emissions factors for 2005 and 2010. In the absence of a comprehensive transport/fuel/ efficiency model for Ireland, we have used the RAINS emissions factors to convert the 2005 and 2010 BÓC activity levels to NO_x emissions.

As for 2000/2002 data, the difference in aviation fuel emission factor between RAINS and BÓC data is due to the differences in the way that activity in the sector is defined in the two different models. The reduction in emissions factors over the time period 2000–2010 demonstrates the impact of NO_x abatement technology penetration over time, manifesting itself in a reduction in emissions factors.

Table 7.6. NO_x emissions from the transport sector for 2000/2002.

Fuel type	2000 RAINS		2002 BÓC	
	kt NO_x	% NO_x from transport	kt NO_x	% NO_x from transport
Gasoline	20.72	30	14.47	21
Medium distillate	45.11	66	48.31	72
Oil	1.01	1	1.71	3
Other	2.05	3	3.01	4
Total	**68.9**	**100**	**67.6**	**100**

Table 7.7. Comparison of energy consumption for 2005 and 2010.

Fuel type	2005		2010	
	RAINS PJ	BÓC PJ	RAINS PJ	BÓC PJ
Gasoline	76.19	64.37	78.27	64.58
Medium distillate	99.09	103.88	112.62	115.56
Oil	1.99	1.91	2.26	2.18
LPG and gas	0.08	2.52	0.08	3.01
Aviation fuel	30.76	13.77	37.32	15.53
Total	**208.10**	**186.45**	**230.55**	**200.86**
Total excluding aviation	**177.34**	**172.68**	**193.23**	**185.33**

Table 7.8. Comparison of emissions factors for 2005 and 2010.

Fuel type	2005		2010	
	RAINS kt NO_x/PJ	BÓC kt NO_x/PJ	RAINS kt NO_x/PJ	BÓC kt NO_xx/PJ
Road petrol	0.16	0.16	0.09	0.09
Road diesel	0.40	0.40	0.31	0.31
Rail diesel	0.81	0.81	0.76	0.76
Ag. machinery gas oil	1.05	1.05	0.88	0.88
Nav. fuel oil	1.20	1.20	1.20	1.20
Aviation fuel	0.08	0.28	0.08	0.28

7.3.2.2 NO_x emissions

The NO_x emission forecasts for the transport sector for 2005 and 2010 are shown in Table 7.9. Since we have used the same transport emissions factors for both the RAINS and BÓC data for 2005 and 2010, the NO_x emission estimates will simply reflect any differences in activity levels between the RAINS and BÓC estimates.

For both RAINS and BÓC estimates, the transport sector is dominated by emissions from medium distillates. The discrepancy between the medium distillate and gasoline estimates lies in the difference between the activity levels, as shown in Table 7.7.

Considering the dominance of medium distillate emissions, any variation in the level of activity or emission factor will have a significant effect on the national emissions as well as on the transport-sector emissions. There is the potential with 10% swings in either activity level or emissions factor for emission forecasts to vary by up to 21% to –19%.

These combined extreme scenarios may seem somewhat unlikely given that medium distillates are made up of a number of sources, and for the scenario outlined to occur, all emissions factors and activity levels would have to decrease or increase by on average 10%. However, according to RAINS, approximately 67% of medium

Table 7.9. NO_x emissions from the transport sector for 2005 and 2010.

Fuel type	2005				2010			
	RAINS		BÓC		RAINS		BÓC	
	kt NO_x	% total	kt NO_x	% total	kt NO_x	% total	kt NO_x	% total
Gasoline	12.35	20	10.49	15	7.02	13	5.81	10
Medium distillate	46.65	74	51.45	76	41.31	79	45.68	78
Oil	1.10	2	2.29	3	1.09	2	2.61	4
Other	2.56	4	3.91	6	3.09	6	4.47	8
Total	**62.7**	**100**	**68.2**	**100**	**52.5**	**100**	**58.6**	**100**

distillate emissions are from heavy-duty vehicles. Given the uncertainty surrounding the forecasting of emissions factors, vehicle numbers and driving patterns, it may not be unreasonable that the emissions factor and/or activity level for heavy-duty vehicles be subject to an uncertainty of plus or minus 10%. Clearly the larger the source of emissions the more sensitive it is to small variations in either the activity level or the emissions factor.

To summarise:

- The transport sector is estimated to contribute 50–60% to the national NO_x inventory in the period 2000–2010.
- The dominant source of NO_x emissions within the transport sector is medium distillate, primarily from heavy duty vehicles.[24]
- Overall, RAINS and BÓC estimates for 2000/2002 activity levels and NO_x emissions are very similar.
- BÓC NO_x emission forecasts for 2005 and 2010 are some 10% higher than those from RAINS. This is primarily due to the higher percentage of diesel usage relative to gasoline in the BÓC data. However, as noted in Section 6.2.2 and in the ICF Consulting–BÓC GHG Report there are considerable uncertainties regarding transport-sector activity levels and emission-factor projections for both RAINS and BÓC data; it is likely that the 10% difference in projections lies within the bounds of uncertainty of the data.

7.3.3 Abatement options

The European Auto-Oil Programme was implemented with a view to developing progressively more stringent emissions standards for vehicles and fuels. Emission reductions arising as a result of this programme have already been factored into the RAINS emission factors for 2005 and 2010, and are therefore included in the RAINS baseline projections for NO_x emissions. In this report, we are using the same emission factors for the transport sector.

Considering the NEC for NO_x in 2010, even taking into account the predicted reductions in NO_x emissions per vehicle, the transport sector alone will nearly breach Ireland's national emission ceiling of 65 kt NO_x. In light of the fact that Ireland is a technology taker in the transport sector and has very little influence over the emissions generated by individual vehicles, it is unlikely that significant additional measures can be taken to influence the NO_x standards of vehicles ex factory.

However, there are policy options which the Government could consider to influence NO_x emissions from transport by influencing activity levels rather than emissions rates. Many of these options have been found in the USA to be equally or more cost-effective than the type of technological standards imposed by the Auto-Oil Programme. Potential policy options include:

- Promotion of telecommuting, proximate commuting or compressed work weeks;
- Car-pooling strategies including ride-share/ride-match/high-occupancy vehicle lanes;
- Congestion charging/fuel taxes/emission taxes;
- Public transport promotion;
- Tyre pressure/vehicle maintenance.

Further details regarding these potential policy options are included in Appendix 4.

7.3.4 Fuel tourism

The National Climate Change Strategy 2000 identifies a significant distortion in the trade for transport fuel due to Ireland having amongst the lowest prices for transport fuel in the EU. This results in a perverse incentive for heavy-duty vehicles engaged in international transport to bunker in Ireland prior to travelling elsewhere in the EU. These incentives did not exist in 1990.

There have been several attempts to determine the level of fuel tourism in Ireland. Table 7.10 is extracted from a report by Goodbody Economic Consultants published in September 2001, entitled *Emissions from Road Transport, 1990–2000*.

The table compares a number of different estimates regarding the cross-border fuel movement between ROI and Northern Ireland in 1998. The wide range of estimates clearly demonstrates the uncertainties and unknowns in quantifying the impact of fuel tourism on overall fuel sales in Ireland.

The emissions from fuels bought by 'fuel tourists' will be emitted outside Ireland but in neighbouring EU Member

24. Based on RAINS definition, any vehicle >3.5 tonnes.

Table 7.10. Estimates of fuel movement into Northern Ireland ('000 tonnes), 1998.

Source	Petrol	Diesel	Total
Inland Revenue UK			130 –135
Submission to House of Commons NI Affairs Committee			130–600
Goodbody Method 1: Comparison with ROI	107	307	414
Goodbody Method 2: Comparison with GB	239	233	472

States and so will represent emissions of transboundary pollutants. However, under the 1988 Sofia Protocol to reduce national NO_x emissions to 1987 levels by 1994, which Ireland ratified in 1994, Member States are permitted to adjust their national NO_x emission inventories to take account of the effects of fuel tourism when reporting compliance or non-compliance. This assumes that a scientifically valid method of assessing fuel tourism can be developed.

One potential avenue for quantifying the level of fuel tourism could include the use of National Car Test (NCT) and Commercial Vehicle Roadworthiness test results to develop a more reliable picture of actual vehicle usage profile in Ireland. These tests provide a means of collating data regarding the mileage travelled as a function of the Irish road vehicle fleet size and age profile. Combined with average data regarding vehicle fuel efficiencies in urban and rural settings, the data could be used as a mechanism to cross-check and quantify road vehicle fuel consumption by fuel type. Comparing the results with national annual fuel sales would therefore give an estimate of the degree of fuel tourism.

7.4 Powergen Sector Analysis

7.4.1 Powergen sector – 2000/2002

The powergen sector accounts for approximately 30% of the total NO_x emissions in the period 2000–2002. Unlike the transport sector where the NO_x emissions are from many diffuse sources, in the power sector there is one primary source of NO_x emissions, the Moneypoint coal-fired power plant. This power plant currently (2004) contributes approximately 58% of total NO_x from the power sector.

7.4.1.1 Activity levels and emission factors

Table 7.11 shows a comparison between RAINS, BÓC and EPA energy consumption estimates within the powergen sector for this time period.

As was noted for the transport sector, the energy consumption values of RAINS, BÓC and the EPA for this time period are broadly comparable. Although the greatest amount of energy is consumed by the gas-fired plants, gas-fired power stations are not the most significant source of NO_x emissions. This is due to the wide disparity in emission factors between the different fuels. Table 7.12 shows a comparison of RAINS and EPA emissions factors for the power-generation sector for 2000/2002.

From the table, it is clear that the coal-fired power plant has the most significant potential for emitting NO_x, with its emissions factor being significantly higher than any other.

7.4.1.2 NO_x emissions

The NO_x emissions from the power-generation sector for 2000/2002 are shown in Table 7.13. We have used the EPA emission factors for 2002 to convert the BÓC activity levels to NO_x emissions.

Table 7.11. Comparison of energy consumption for 2000/2002.

Fuel type	2000 RAINS PJ	2002 BÓC PJ	2002 EPA PJ
Coal	60.27	63.93	61.44
Oil	41.48	43.96	39.50
Gas	76.41	77.68	76.70
Peat	19.75	24.42	23.43
Biomass	0.98	0	0
Total	**198.89**	**209.99**	**201.87**

Table 7.12. Comparison of emission factors for the powergen sector for 2000/2002.

Fuel type	2000 RAINS kt NO_x/PJ	2002 EPA kt NO_x/PJ
Coal	0.36	0.36
Fuel oil	0.14	0.15
Natural gas	0.11	0.08
Peat	0.19	0.16
Biomass	0.1	0.1

As expected, given the energy consumption level for Moneypoint (Ireland's only coal-fired power plant) and the emission factor for coal, both data sources show the NO_x emissions from the power sector in this time period to be dominated by emissions from coal. We discuss the situation at Moneypoint in further detail in Section 7.4.3. The other emissions are split between emissions from gas-, oil- and peat-fired power plants.

7.4.2 Powergen-sector projections

The powergen sector is forecast to account for approximately 28% of total NO_x emissions in Ireland in 2005, falling to approximately 17% of total NO_x emissions in 2010. The decline in total contribution is, to a large degree, due to the installation of NO_x abatement technology, and to a lesser degree due to fuel switching to gas and to a high growth in transport emissions in spite of major improvements in the emissions per PJ energy consumption.

7.4.2.1 Activity levels and emission factors

Table 7.14 shows a comparison between RAINS and BÓC energy consumption estimates within the powergen sector in 2005 and 2010.

From the table, the overall energy consumption forecasts from the two different data sources are comparable for 2005 and 2010, but fuel mix shows considerable discrepancies. The RAINS figures are derived from the PRIMES Model which forecasts a European-wide increase in gas usage and corresponding declines in coal and oil. However, Ireland is unique with respect to coal-fired power generation as this country has only one coal-powered plant, Moneypoint, in operation. The power plant is important in maintaining Ireland's overall fuel diversity in power generation, and the plant is expected to operate as a base-load plant for the foreseeable future. Though the penetration of wind energy is expected to play an increasingly significant role in the fuel mix for power generation in the future, the take-up of renewables is unlikely to significantly affect the level of coal-fired generation by 2010. Moneypoint is further examined in Section 7.4.3.

Table 7.15 shows a comparison of RAINS and EPA emissions factors for the power-generation sector for 2005 and 2010.

There are significant differences in the emission factors between the two data sources for 2005, with RAINS forecasting significant reductions in emission factors over the 5-year period from 2000. The RAINS projections assume a large take-up of abatement technology in the power plants by 2005. The percentage difference in the

Table 7.13. NO_x emissions from the powergen sector for 2000/2002.

Fuel type	2000 RAINS		2002 BÓC	
	kt NO_x	% NO_x from powergen	kt NO_x	% NO_x from powergen
Coal	21.88	56	23.21	58
Heavy fuel oil	5.66	14	6.70	17
Medium distillate	0.11	0		
Gas	8.08	21	6.00	15
Peat	3.65	9	3.88	10
Biomass	0.07	0	0	0
Total	**39.47**	**100**	**39.79**	**100**

Table 7.14. Comparison of energy consumption for 2005 and 2010.

Fuel type	2005		2010	
	RAINS PJ	BÓC PJ	RAINS PJ	BÓC PJ
Coal	52.26	57.00	46.61	57.97
Oil	12.02	43.50	7.84	18.05
Gas	125.68	74.30	148.26	121.90
Peat	27.40	22.10	19.56	21.70
Biomass	3.31	1.01	4.35	5.03
Total	**220.67**	**197.91**	**226.62**	**219.62**

Table 7.15. Comparison of emission factors for the powergen sector for 2005 and 2010.

Fuel type	2005		2010	
	RAINS kt NO_x/PJ	BÓC kt NO_x/PJ	RAINS kt NO_x/PJ	BÓC kt NO_x/PJ
Coal	0.22	0.36	0.22	0.10
Fuel oil	0.10	0.15	0.10	0.07
Natural gas	0.06	0.08	0.04	0.06
Peat	0.12	0.12	0.11	0.12
Biomass	0.07	0.1	0.07	0.11

Table 7.16. RAINS forecast of % NO_x abatement technology installed.

Fuel type	% NO_x abatement technology installed per unit of energy input	
	2005	2010
Coal	80.0	80.0
Heavy fuel oil	55.0	55.0
Medium distillate	0.0	0.0
Gas	25.4	25.8
Peat	29.8	31.3
Biofuel	0.0	0.0

emission factors between RAINS and BÓC data for 2010 has decreased from those projected for 2005, suggesting that the timing of abatement technology introduction is incorrect in RAINS. There are some issues with forecasting emissions factors as the NO_x emission concentrations are a non-linear function of the plant load. BÓC has applied the projected NERP reductions to the EPA's 2002 emission factors to derive emissions factors for 2010.

RAINS data for 2000 assumes that no power plants have NO_x abatement technology installed. Table 7.16 shows the level of abatement that RAINS assumes (i.e. the percentage of generating plant in terms of energy input which will have some form of abatement technology fitted) will be installed by 2005 and 2010.

The RAINS assumption for coal-fired generation, that for every petajoule of coal energy consumed, 80% of the resulting NO_x emissions will be abated to some degree, is not applicable to a situation in which there is a single coal-fired power station as is the case in Ireland. Once Selective Catalytic Reduction (SCR) is installed at Moneypoint the percentage application will be 100%, not 80% as shown by RAINS.

RAINS assumes that a significant level of NO_x abatement technology will be installed by 2005. The reality in Ireland is that installation of new abatement technology will not have taken place at the scale assumed by RAINS up to 2005, resulting in higher emission factors for the BÓC data for 2005. Based on discussions held with the ESB, the profile of NO_x abatement technology installed by 2010 as a function of fuel types is expected to be significantly different from that assumed by RAINS, which will again result in different emission factors between RAINS and BÓC data. The most significant difference is for Moneypoint, which is discussed in further detail in Section 7.4.3.

7.4.2.2 NO_x emissions

The NO_x emission projections from the power-generation sector for 2005 and 2010 are shown in Table 7.17.

As expected, given the energy consumption level for Moneypoint (Ireland's only coal-fired power plant) and the emission factor for coal, both data sources show the NO_x emissions in 2002 and 2005 from the power sector to be dominated by emissions from coal. This dominance will be reduced according to the BÓC and ESB forecasts[25] by 2010. It should be noted that the strict application of the percentage reductions under NERP to the EPA's emission factors for 2002 shows a lower projected emission for 2010, as shown in Table 7.17, than those provided by the ESB in November 2004. The difference is 1.8 kt NO_x, with the ESB estimate being 18.3 kt.

The other emissions are split between emissions from gas-, oil- and peat-fired power plants with emissions from gas playing a more significant role as time goes on. This is due to the reduction in emissions from oil and coal plants and also the increasing level of gas-fired power generation.

25. Information supplied by ESB Power Generation – 16th November 2004.

Table 7.17. NO_x emissions from the power-generation sector for 2005 and 2010.

Fuel type	2005				2010			
	RAINS		BÓC		RAINS		BÓC	
	kt NO_x	% total	kt NO_x	% total	kt NO_x	% total	kt NO_x	% total
Coal	11.38	49	20.57	58	10.15	52	5.71	35
Heavy fuel oil	1.04	5	6.63	19	0.71	4	1.28	8
Medium distillate	0.16	1			0.14	1		
Gas	7.02	30	5.74	7	5.93	31	6.40	39
Peat	3.28	14	2.59	16	2.12	11	2.54	15
Other	0.22	1	0.1	0	0.29	1	0.46	3
Total	**23.1**	**100**	**35.63**	**100**	**19.34**	**100**	**16.48**	**100**

BÓC's projections for NO_x emissions from the power sector for 2005 are significantly higher than those from RAINS. As discussed previously, this is due to an incorrect assumption in RAINS regarding the timing of uptake of NO_x abatement technology within the power sector.

BÓC data forecasts lower NO_x emissions from the power sector in 2010 than RAINS. The difference is mainly due to RAINS assumptions regarding the type of abatement technology that will be installed at Moneypoint – the abatement technology which will actually be installed will have a higher NO_x removal efficiency than that assumed by RAINS. We discuss the situation at Moneypoint in further detail in Section 7.4.3.

To summarise:

- The powergen sector is estimated to constitute approximately 30% of the national NO_x inventory in the period 2000/2002, falling to approximately 17% by 2010, primarily due to the installation of NO_x abatement technology at Moneypoint.
- The dominant source of NO_x emissions within the powergen sector is the Moneypoint coal-fired power plant.
- Overall activity levels and NO_x emissions in both RAINS and BÓC estimates for 2000/2002 are very similar. However, there are discrepancies in the disaggregated activity levels and the NO_x abatement technologies installed, leading to different disaggregated NO_x emission forecasts.
- RAINS activity levels and NO_x emission forecasts for 2005 and 2010 incorporate a number of incorrect assumptions regarding fuel switching and the timing and abatement performance of NO_x reducing technologies. This results in RAINS underestimating the NO_x emissions in 2005 by some 35% (12.5 kt), and overestimating the NO_x projections in 2010 by approximately 17% (2.9 kt).

7.4.3 Moneypoint

Moneypoint power station, Co. Clare, represents the single largest emitter of NO_x in Ireland. Thus the coal-fired generation plant has a significant impact on national NO_x emissions, and assumptions regarding future activity levels, emission factors and the timing of NO_x abatement technology installation will have a significant impact on NO_x forecasts in the future.

Table 7.18 shows the activity levels and emission factors from RAINS and BÓC data for the years 2000/2002, 2005 and 2010.

RAINS assumes a decrease in the level of activity in Moneypoint of 2–3% each year, amounting to a 22.6% drop in output over the period 2000–2010. However, as noted above, Moneypoint plays an important role in maintaining Ireland's fuel diversity in power generation, and there are no plans of which we are aware to significantly reduce power output at Moneypoint over this time period. There is likely to be a small reduction in load factor at Moneypoint by 2010. This is because the ESB has indicated that there is a likelihood that the Moneypoint units will be backed-off at night-time due to the number of combined cycle gas turbine (CCGT) plants on the grid in 2010 and also due to the increased amount of wind energy supplied.

RAINS has assumed that the NO_x abatement over the time period 2000–2010 will be achieved by combustion modification – PHCCM technology under RAINS

Table 7.18. Comparison of assumptions regarding operation of Moneypoint.

	2000/2002		2005		2010	
	RAINS	BÓC	RAINS	BÓC	RAINS	BÓC
Energy input (PJ)	60.27	63.90	52.26	57.00	46.61	57.97
Emission factor (kt NO_x/PJ)	0.36	0.36	0.22	0.36	0.22	0.10
NO_x emissions (kt)	21.88	21.93	11.39	20.57	10.16	5.71
Abatement technology installed	None	Low NO_x burners	PHCCM[1]	Low NO_x burners	PHCCM	Low NO_x burners & SCR

[1]See Appendix 1 for the RAINS abbreviations.

terminology. The combustion modification may include any of the following:

- low NO_x burners;
- fuel injection;
- oxycombustion;
- fluidised bed combustion.

These combustion modifications achieve approximately 50% removal efficiency.

A programme is in planning to install selective catalytic reduction (SCR) at Moneypoint between 2005 and 2010. Therefore, while we would expect to see a decrease in emission factor over the time 2000–2010, the timing of investment assumed by RAINS is incorrect. The removal efficiency of SCR is expected to be approximately 72% – significantly higher than that of the abatement technology assumed by RAINS to be installed by 2010.

To conclude, RAINS and BÓC estimate similar NO_x emissions from Moneypoint for 2000/2002. RAINS data underestimate the NO_x emissions from the plant in 2005, due to an incorrect assumption that additional NO_x abatement technology will be installed at the plant by this year. RAINS also incorrectly assumes that the power output from the plant decreases over the time period 2000–2005; this results in a further decrease in NO_x emissions in the RAINS projection for 2005. RAINS overestimates the NO_x emissions from the plant for 2010, due to an incorrect assumption regarding the type of abatement technology that will be installed. The overall effect of this incorrect assumption is lessened somewhat by a second incorrect assumption by RAINS that the output from the plant will decrease by some 23% over the period 2000–2010.

7.4.4 Abatement options in the power sector

As noted above, the BÓC 'baseline' or 'business as usual' projections assume that all measures proposed in the NERP will be implemented. This results in a projected decrease in NO_x emissions from the power sector of approximately 50% in the period 2005 to 2010. The main contributor to the reduction in emissions is expected to be the installation of SCR abatement technology at the Moneypoint coal-fired power plant.

Since all emission reduction measures as identified under the NERP have already been incorporated in BÓC's base case projections for the sector for 2010, there seems limited scope for additional NO_x reductions to be achieved in this sector. RAINS has not taken all these reduction measures into account, resulting in a larger NO_x emission factor in 2010 and as a consequence a higher NO_x emission value compared to the estimates in this report. The difference for the power sector is approximately 5 kt NO_x.

7.5 Cement Sector Analysis

7.5.1 Introduction

Before examining the cement industry emissions, we note that there are differences in the reporting methods between RAINS, BÓC and ESBI data (supplied by the DoEHLG for this study), as follows:

- RAINS reports NO_x emissions from cement production as kt NO_x per Mt of cement produced. In order to avoid double counting, fuel consumption by the cement industry is subtracted from total industrial fuel use.
- BÓC reports NO_x emissions from cement production as kt NO_x per PJ of energy consumed in the process. From the EPA Emissions Inventory 2002, 100% of the petroleum coke and 58% of the coal used in the industrial sector is for the cement industry. (Note that

the coal-fired plants are the later ones and were not up to full output in 2002.) These figures have been used to derive the energy consumption figures for BÓC forecasts for the cement industry.

- The ESBI has reported emissions as kt NO_x per kt clinker.[26] This is similar to the RAINS method of reporting. Clinker constitutes approximately 95% of cement by weight for a typical Portland cement.[27]

7.5.2 *Activity levels and emission factors*

Table 7.19 compares cement production forecasts from three different data sources.

Table 7.19. Cement production comparison.

	Cement produced (Mt)		
	2000/2002	**2005**	**2010**
RAINS	2.4	2.5	2.5
BÓC	3.9	4.83	5.7
ESBI	–	–	3.9

From the table, there are very significant differences in the activity-level forecasts from the three different data sources, with BÓC data forecasting cement production levels over twice that of RAINS. BÓC projections are based on those from the ICF Consulting–BÓC study *Determining the share of National Greenhouse Gas Emissions for Emissions Trading in Ireland*, as outlined in Section 6.2.2.

The BÓC emission factor is based on the EPA Emissions Inventory 2002 and cement production in that year.

Table 7.20 shows the emission factors assumed for the various data sources under the 'business as usual' scenario. RAINS assumes that NO_x control on 50% of the plant will be introduced by 2010. BÓC and ESBI emission factors for the 'business as usual' scenario do not incorporate any assumptions regarding abatement technology in the cement sector.

From the table, there are significant differences between the emission factors from the different data sources. In particular, the ESBI emission factor seems to be very high

Table 7.20. Emission factor comparison.

	Emission factor (kt NO_x/Mt cement)		
	2000/2002	**2005**	**2010**
RAINS	1.75	1.75	1.4
BÓC	1.5	1.5	1.5
ESBI	–	–	2.6

when compared to the BÓC estimate, which was derived from the EPA Emissions Inventory 2002 data.

7.5.3 *NO_x emissions*

Table 7.21 compares the NO_x emissions from the cement industry from a number of different data sources. In comparison to the transport and powergen sectors, emissions from cement production of 5.7 kt NO_x in 2002 are relatively small. However, the potential reductions are significant and potentially economical, as discussed in Section 7.5.4.

There is a large difference in the projections from the various data sources, due to differences in both the projected activity levels and emission factors. However, based on the information, the RAINS data appear to be too low, due partly to a significant underestimate in the projected level in cement production in 2010, compounded by an assumption that some form of abatement technology will be applied to the plant by 2010.

7.5.4 *Abatement options*

According to an ESBI report[28] on NO_x reduction in Ireland, selective non-catalytic reduction (SNCR) technology can be installed with relative ease to dry process cyclone/pre-calciner kilns, at an estimated cost of €400/t NO_x abated. A reduction of 80–85% in NO_x emissions has been achieved in two Swedish kilns.

While emission reductions in the cement sector might seem relatively insignificant relative to the additional NO_x reductions which Ireland will need to achieve on top of 'business as usual' projections in order to meet our NEC limit for NO_x in 2010, the reported low cost of NO_x abatement in this sector as projected by the ESBI (if confirmed by site-specific analysis) suggests that installation of abatement technology could be worthwhile.

26. Marble-sized pieces of calcium silicate produced by the kiln. Gypsum and other constituents are added and mixed to produce cement.
27. Approximate amount of gypsum added to clinker to produce cement, http://matse1.mse.uiuc.edu/~tw/concrete/prin.html
28. Scope for cost-effectively reducing Ireland's reported NO_x emissions.

Table 7.21. NO_x emissions from the cement industry.

	2000/2002		2005		2010	
	kt NO_x	% total NO_x inventory	kt NO_x	% total NO_x inventory	kt NO_x	% total NO_x inventory
RAINS	4.2	3.7	4.3	4.6	3.45	3.7
BÓC	5.7	4.4	7	5.5	8.3	8.3
ESBI	–	–	–	–	10	9.1
EPA	6.2	5	–	–	–	–

8 SO_2

8.1 Overview

Sulphur dioxide is a significant contributor to acidification. It is emitted largely from the combustion process of stationary and mobile sources. Under the NEC Directive Ireland will be limited to emitting 42 kt SO_2 in 2010. The EPA Emissions Inventory 2002 puts the SO_2 emissions at 96 kt which is just over double the 2010 target. There are a number of measures planned to reduce this figure which apply primarily to the power-plant sector which currently produces over 60% of the SO_2 nationally.

8.2 Sectoral Analysis

8.2.1 Activity-level comparison

The overall sectoral energy consumption figures are shown in Table 7.1 and are discussed in Section 7.2.1. The sectoral energy consumption figures from RAINS and BÓC data are broadly comparable. However, as was the case for NO_x generation, the fuel mix within each sector has a very large bearing on the emissions generated. This will be discussed in further detail in the following sections, together with any significant differences in the individual sectoral activity levels.

While the transport sector represents the highest energy input of all the sectors, the sector is not a large emitter of SO_2, as the sulphur content of the fuels used in the transport sector, and hence the emission factors, are low in comparison to coal and heavy fuel oil, as used in the power, residential & commercial, and industrial sectors.

8.2.2 SO_2 emission comparison

Figure 8.1 and Table 8.1 show a comparison between the forecasts of RAINS, of BÓC and of the EPA for the years 2000/2002, 2005 and 2010. The RAINS forecast shows a decrease in the quantity of SO_2 produced in Ireland. In the same manner as discussed for NO_x emissions, the decrease may be attributed to two factors, the sectoral activity and the effective emissions factor. A large portion of the decrease is attributable to a reduction in emissions factors due to increasingly stringent requirements regarding the sulphur content of fuel. An uptake in the usage of gas will also result in a decrease in SO_2 emissions since SO_2 production is largely dependent on the sulphur content of the combustion fuel, and gas has a very low sulphur content.

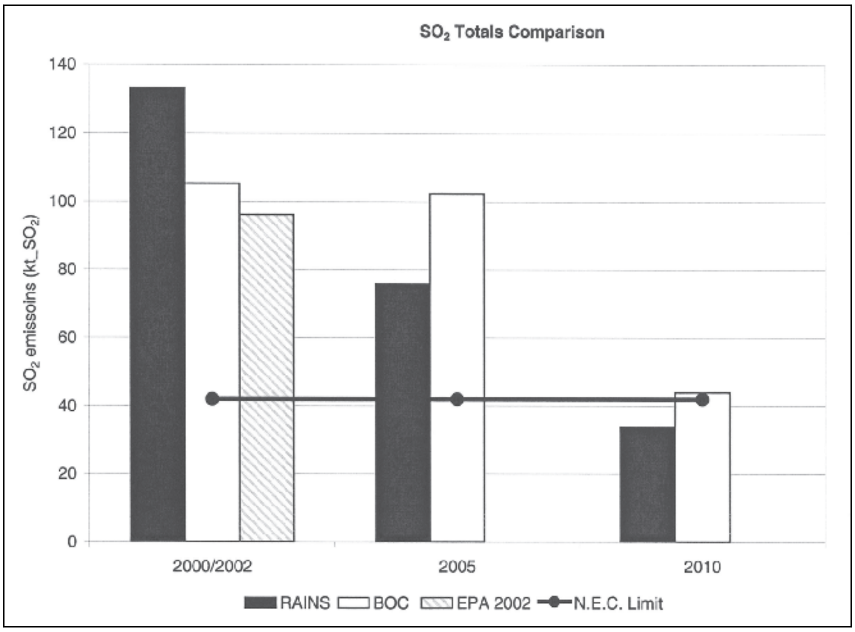

Figure 8.1. SO_2 emissions comparison.

Table 8.1. SO_2 emissions comparison.

	2000/2002	2005	2010
RAINS	133.2	75.9	33.8
BÓC	105.38	102.5	44
EPA 2002	96.2	–	–
NEC limit	–	–	42

From the table, RAINS appears to significantly overestimate total SO_2 emissions for the period 2000/2002. However, SO_2 emissions have been in sharp decline since 1990 levels of approximately 178 kt; therefore, the discrepancy is likely to be due at least in part to the 2-year difference in the reference year for the data. Differences in the EPA and BÓC estimates for 2002 are due to differences in the estimated fuel mix in both the powergen and industrial sectors.

RAINS appears to underestimate the SO_2 emissions in 2005 and 2010. Based on BÓC data estimates, Ireland's SO_2 emissions will be marginally above the NEC emission limit for SO_2 in 2010 based on 'business as usual'. Note that 'business as usual' assumes that flue gas desulphurisation (FGD) is fitted to Moneypoint before 2010.

8.2.2.1 Breakdown of SO_2 emissions for 2000/2002

Figures 8.2 and 8.3 show the contribution of each fuel, by sector, to SO_2 emissions for 2000/2002. Both RAINS and BÓC data show a similar sector profile. From the figures, the powergen sector is by far the largest contributor to SO_2 emissions. There is a discrepancy of approximately 25 kt in the overall SO_2 totals, with RAINS predicting higher levels than BÓC data.

The primary cause is the power sector discrepancy, contributing 15 kt, and to a lesser extent the domestic and commercial sector of 10 kt. Since the overall activity levels for this time period were comparable, the discrepancy lies in the emission factors. This is discussed in Section 8.3.1.

8.2.2.2 Breakdown of SO_2 emissions for 2005

Figures 8.4 and 8.5 show the contribution of each fuel, by sector, to SO_2 emissions for 2005. Again, both RAINS and BÓC data show a similar sector profile, with the powergen sector being the largest contributor to SO_2 emissions. BÓC data are predicting SO_2 emissions some 15 kt higher than the forecasts from RAINS. Differences in the forecasts for specific sectors are discussed in further detail in the following sections.

8.2.2.3 Breakdown of SO_2 emissions for 2010

The year 2010 is the compliance year for the NEC Directive. The NEC for SO_2 is 42 kt. SO_2 emissions have been in decline since 1990 levels of approximately 178 kt. The RAINS Model is forecasting compliance with the NEC in 2010; however, the BÓC estimate, which is 30% greater than the RAINS 2010 estimate, is forecasting an exceedance of the NEC by 2 kt SO_2.

Figures 8.6 and 8.7 show the contribution of each fuel, by sector, to SO_2 emissions forecast for 2010. The graphs show a dramatic reduction in the SO_2 emitted by the power sector from 2005 levels, of the order of 25–35 kt. The primary reason for the drop is the introduction of SO_2 abatement technology at Moneypoint coal-fired power plant. Both RAINS and BÓC forecasts assume that FGD will be installed between 2005 and 2010.

The graphs indicate that both residential & commercial and industrial sectors will be as significant emitters of SO_2 as the power sector in 2010. Thus, to ensure compliance with the NEC for SO_2, making what may now seem to be relatively insignificant reductions may prove valuable in the longer term.

Based on the data presented above, the most significant source of SO_2 emissions in Ireland is currently from the powergen sector. We discuss this sector in more detail in the following section, in particular the large reduction in SO_2 emissions from the sector which is predicted to occur between 2005 and 2010.

8.3 Powergen Sector Analysis

8.3.1 Power sector – 2000/2002

8.3.1.1 Activity level and emission forecast comparison

Table 7.11 shows a comparison between RAINS and BÓC energy consumption estimates within the powergen sector for this time period. As discussed in Section 7.4.1, the energy consumption values of RAINS and BÓC are broadly comparable.

Table 8.2 shows a comparison of RAINS and EPA emissions factors for the power-generation sector for 2000/2002. As noted previously, the main source of SO_2 is via the conversion of sulphur in fuel during the combustion process. The effective emission factor for gas-fired plant is zero, since gas contains negligible quantities of sulphur.

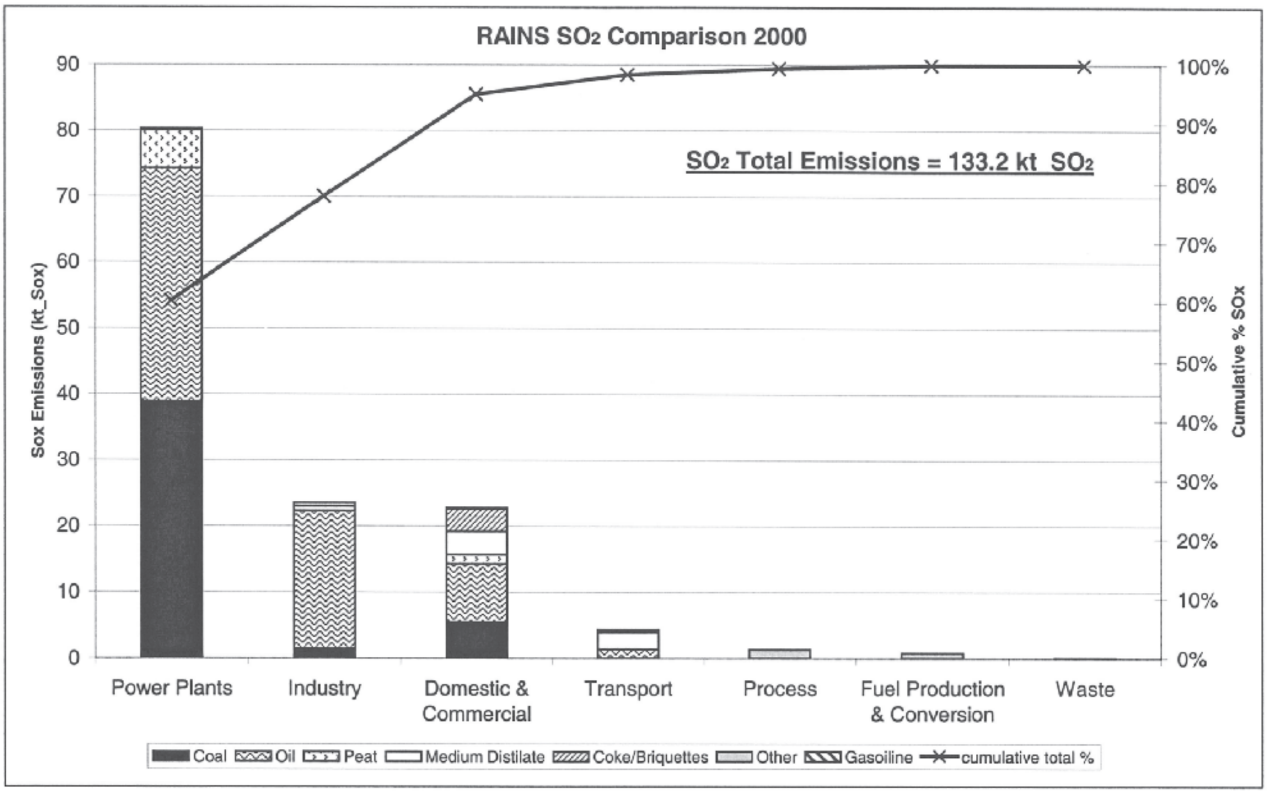

Figure 8.2. RAINS SO_2 breakdown for 2000.

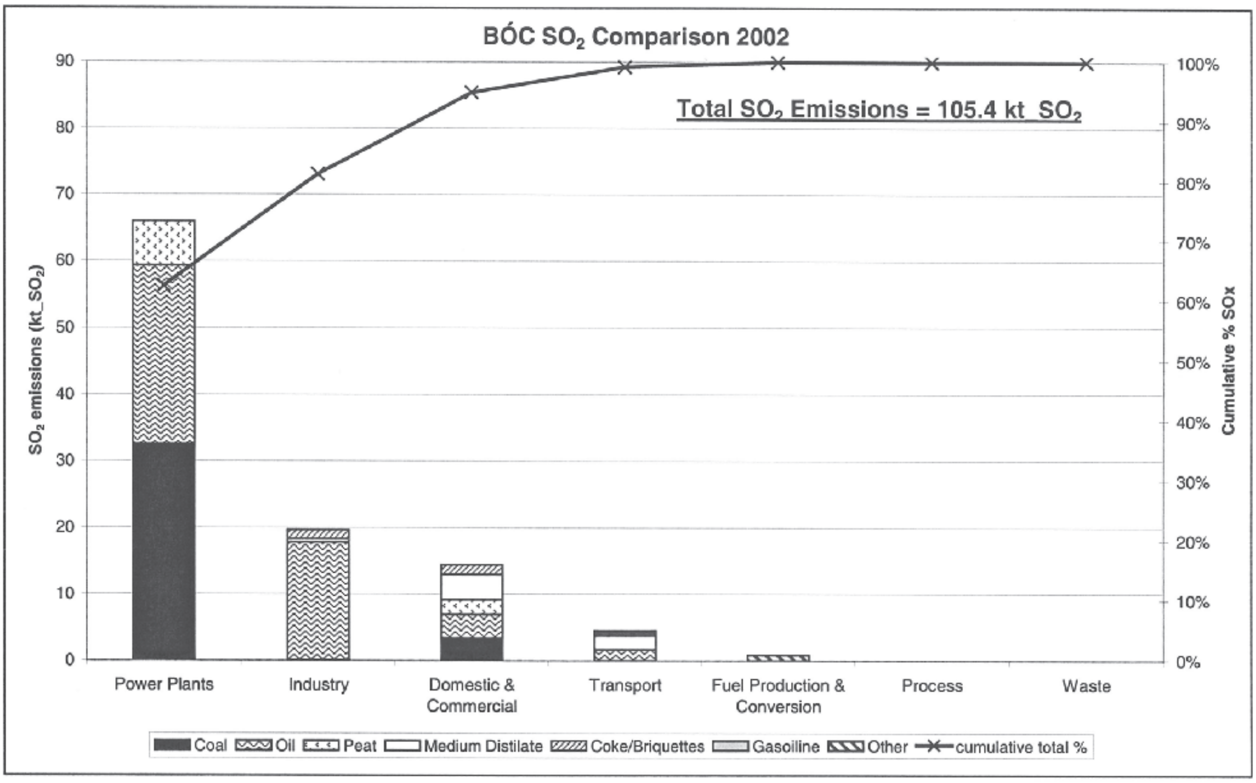

Figure 8.3. BÓC SO_2 breakdown for 2002.

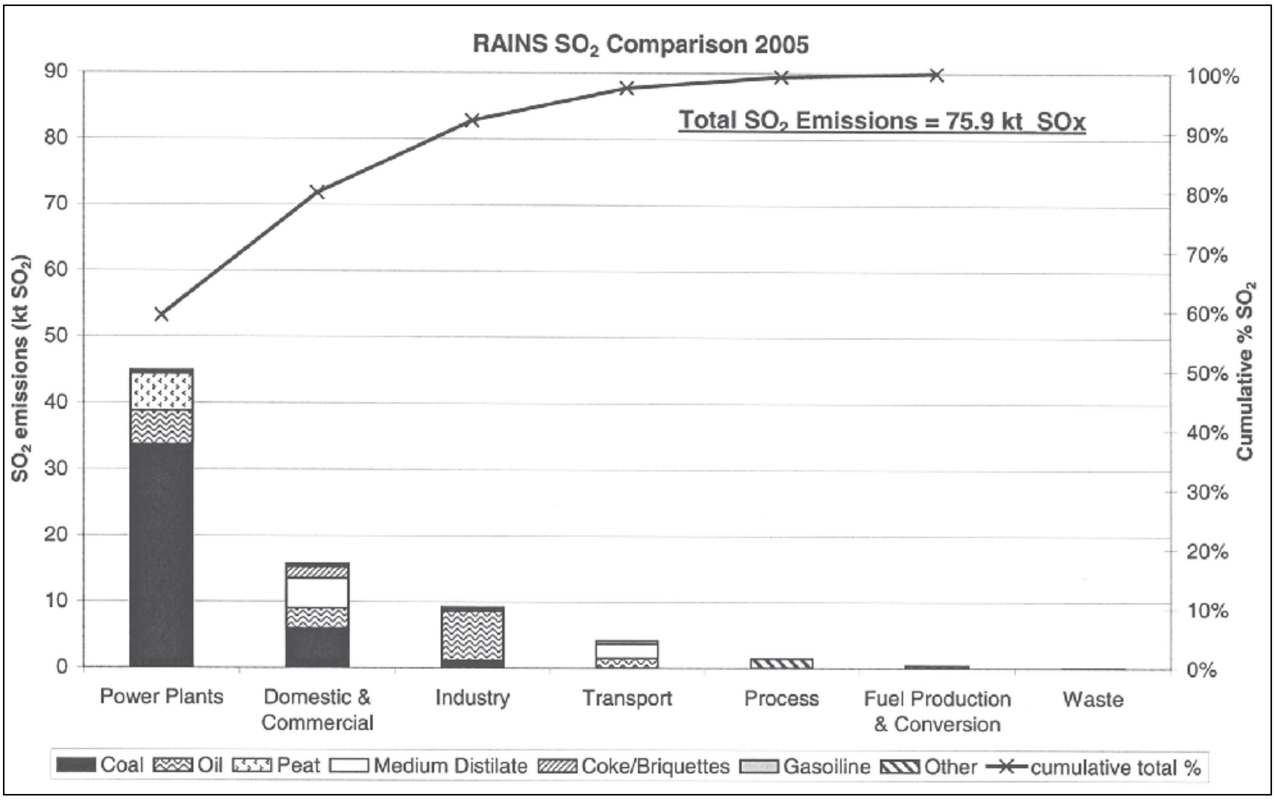

Figure 8.4. RAINS SO_2 breakdown for 2005.

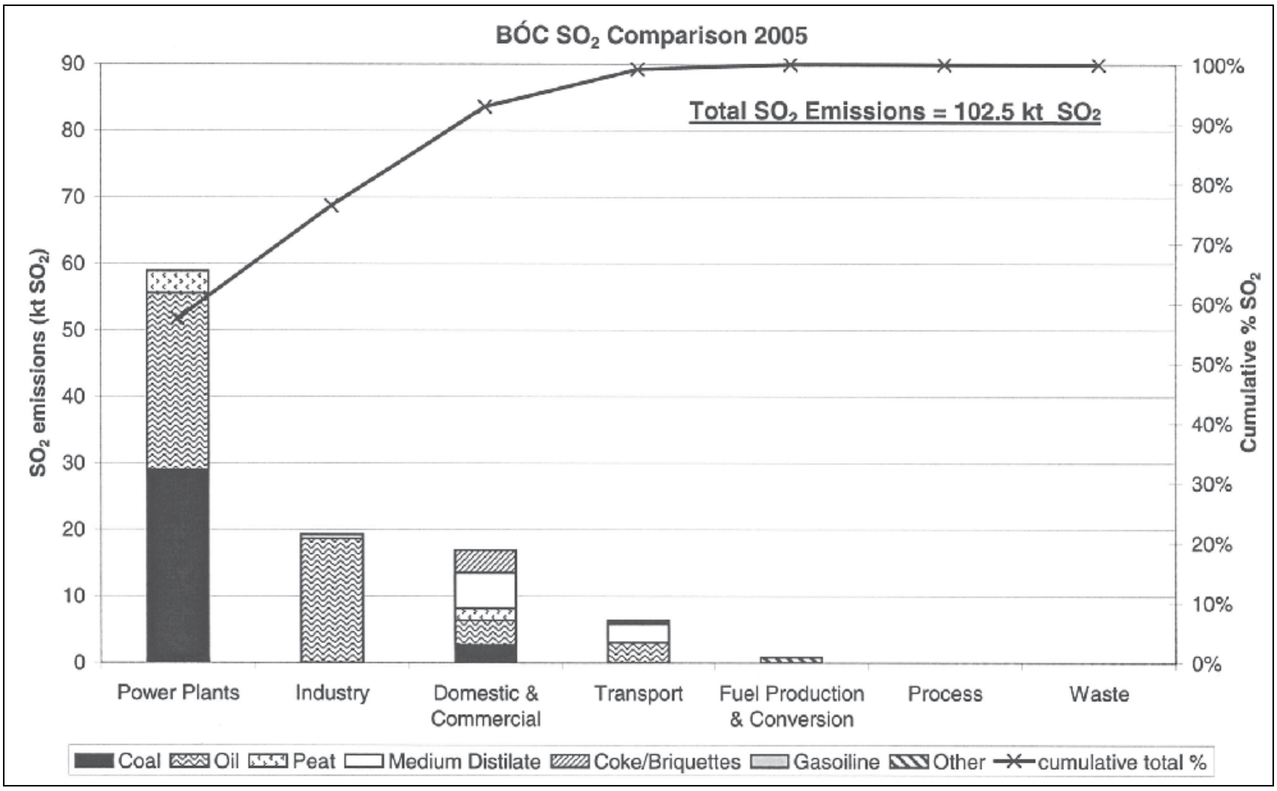

Figure 8.5. BÓC SO_2 breakdown for 2005.

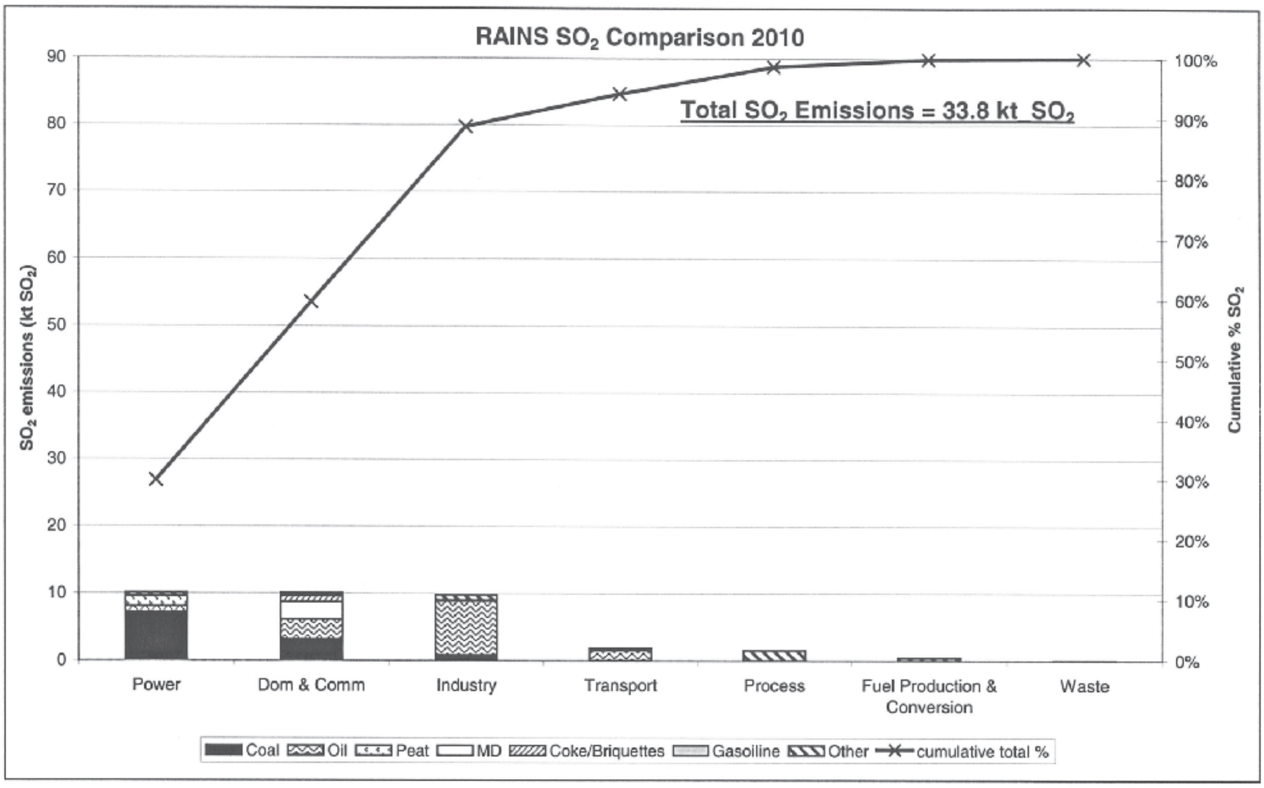

Figure 8.6. RAINS SO_2 breakdown for 2010.

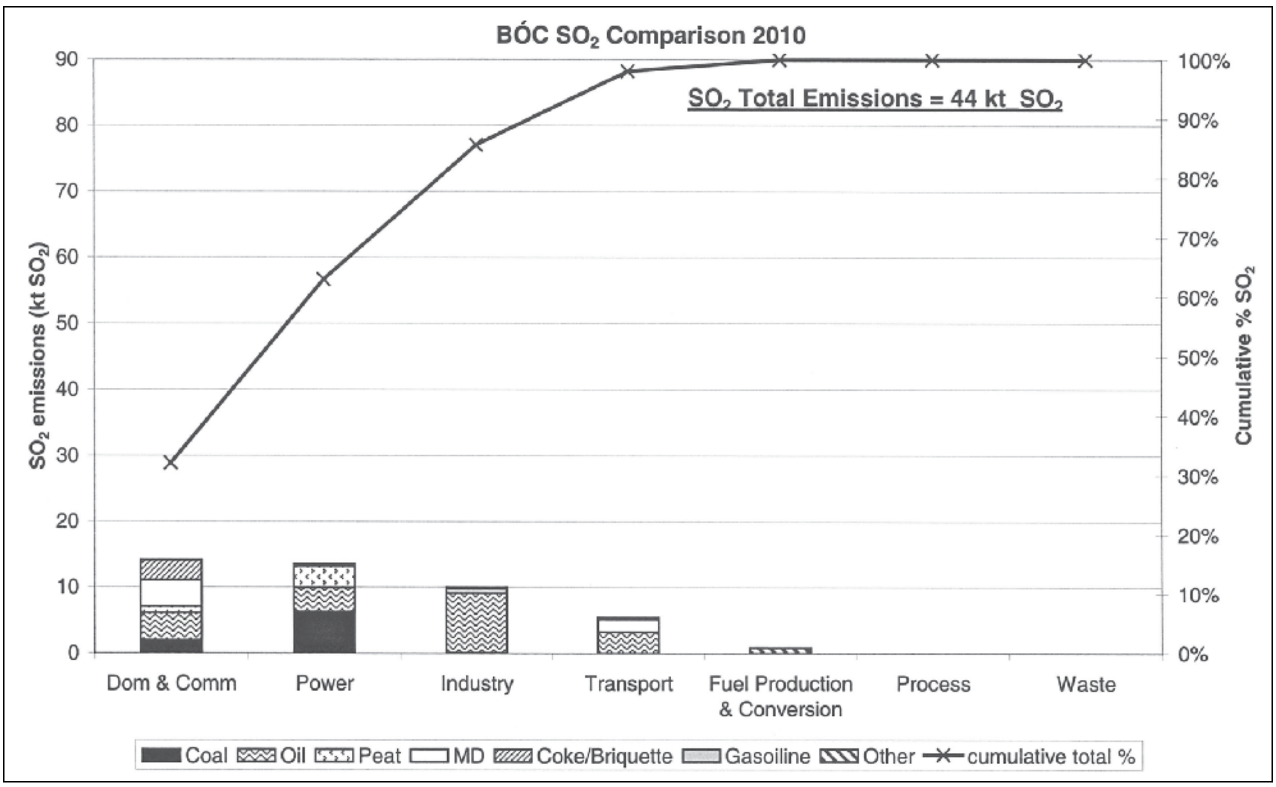

Figure 8.7. BÓC SO_2 breakdown for 2010.

Table 8.2. Comparison of SO_2 emission factors for the powergen sector for 2000/2002.

Fuel type	2000 RAINS kt SO_2/PJ	2002 EPA kt SO_2/PJ
Coal	0.65	0.51
Oil	0.85	0.61
Gas	0	0
Peat	0.29	0.27
Other	0.13	0

From the table it can be seen that there are significant differences between the RAINS and EPA emission factors for coal and oil. The EPA emission factors are taken from the EPA Emissions Inventory 2002.

The RAINS emission factors are based on three factors:

1. heat value of fuel (GJ/tonne);
2. sulphur content of fuel (%);
3. sulphur retention in ash (%/100).

The emissions factor is approximately equal to:

EEF = 2 × (sulphur content/heat value) (1 – sulphur retention).

Table 8.3 compares the properties of coal assumed by RAINS with typical properties of the coal burned at Moneypoint.

The heat value and the sulphur content have the largest bearing on the emissions factor as the sulphur retention value is very small. From the table it is clear that the properties of coal assumed by RAINS are quite different from those of the coal which is actually used for power generation at Moneypoint.

8.3.1.2 SO_2 emission

Table 8.4 compares SO_2 emissions from the powergen sector in 2000/2002 from two different data sources. The table clearly illustrates the dominance of coal- and oil-fired plants in the generation of SO_2 emissions, with 90–93% of the sector SO_x emissions arising from these sources. The difference in SO_x emission projections is due to the differences in the emission factors used by the two data sources, as discussed above.

8.3.2 Power-sector projections

Of the total SO_2 emissions, 57% are forecast to be attributable to the powergen sector in 2005. In 2010, the sector is forecast to generate approximately 31% of the total SO_2 emissions, representing a large reduction in the influence of the powergen sector on total emissions over the time period 2000 to 2010.

8.3.2.1 Activity levels and emission factors

Table 7.14 shows a comparison between RAINS and BÓC energy consumption estimates within the powergen sector for this time period. As discussed in Section 7.4.1, while the overall energy consumption forecasts from the two different data sources are comparable for 2005 and 2010, the fuel mix shows considerable discrepancies. This is mainly due to an incorrect assumption within the RAINS Model that generation from coal will decrease significantly over the period 2000–2010.

Table 8.3. Comparison of properties of coal used by RAINS with typical properties for Moneypoint coal.

Sector	Emissions factor (kt SO_2/PJ)	Sulphur content (%)	Net heat value (GJ/tonne)	Sulphur retention in ash (%/100)
RAINS	0.65	1	29.3	0.05
EPA Moneypoint	0.50	0.63	25.3	not available

Table 8.4. SO_2 emissions from the powergen sector for 2000/2002.

Fuel type	2000 RAINS		2002 BÓC	
	kt SO_2	% SO_2 from powergen	kt SO_2	% SO_2 from powergen
Coal	38.93	49	32.58	49
Heavy fuel oil	35.38	44	26.77	41
Medium distillate	0.07	0		
Peat	5.74	7	6.57	10
Other	**0.12**	**0**	**0**	**0**
Total	**80.13**	**100**	**65.9**	**100**

Table 8.5. SO_2 emission factors for the powergen sector for 2005 and 2010.

Fuel type	2005		2010	
	RAINS (kt SO_2/PJ)	BÓC (kt SO_2/PJ)	RAINS (kt SO_2/PJ)	BÓC (kt SO_2/PJ)
Coal	0.65	0.51	0.16	0.11
Oil	0.5	0.61	0.13	0.19
Gas	0	0	0	0
Peat	0.2	0.15	0.07	0.15
Other	0.12	0	0.11	0.08

Table 8.6. SO_2 emission forecasts from the powergen sector for 2005 and 2010.

Fuel type	2005				2010			
	RAINS		BÓC		RAINS		BÓC	
	kt SO_2	% total	kt SO_2	% total	kt SO_2	% total	kt SO_2	% total
Coal	33.76	75	29.05	49	7.23	72	6.32	47
Heavy fuel oil	5.06	11	26.54	45	0.9	9	3.58	26
Medium distillate	0.12	0			0.05	0		
Peat	5.57	12	3.33	6	1.44	14	3.28	24
Other	0.39	1	0	0	0.48	5	0.38	3
Total	**44.9**	**100**	**58.92**	**100**	**10.1**	**100**	**13.56**	**100**

The emission factor for coal-fired plants is predicted to fall dramatically between 2005 and 2010 for both data sources due to the installation of FGD at Moneypoint. These data are shown in Table 8.5. Both data sources predict comparable removal efficiencies: RAINS predicting a removal efficiency of 76% and BÓC estimating a removal efficiency of 78.7%.[29] The difference in the emission factors for 2010 between the two data sources is therefore due to the difference in emissions factor before the abatement technology is installed.

The emission factor for peat-fired generation is forecast to decrease between 2002 and 2005. This is due to two new peat-fired plants coming online in this time period. SO_2 reduction will be achieved by limestone injection at the new plants, allowing them to meet an SO_2 emission limit of 200 mg/Nm^3. This is significantly lower than the emission limit of 600 mg/Nm^3 as imposed at the existing peat-fired plant at Edenderry. The effect will be to reduce the average emission factor for peat-fired generation. However, based on the 'business as usual' scenario, it is not envisaged that peat-fired generation will achieve the very low emission factor forecast by RAINS in 2010.

Emission factors for oil in 2010 are in accordance with the projections from the NERP.

29. Value calculated from the NERP, also includes lesser effects of Load Factor Management.

8.3.2.2 SO_2 emission

Table 8.6 shows a comparison between RAINS and BÓC SO_2 emission estimates from the powergen sector for 2005 and 2010.

As noted above, the primary reason for the drop in SO_2 emissions in 2010 is the introduction of SO_2 abatement technology at Moneypoint.

To summarise:

- The powergen sector is estimated to contribute approximately 50% to national SO_2 emissions in 2000/2002. The contribution is forecast to fall to approximately 31% by 2010.
- RAINS and BÓC forecast quite different overall SO_2 emissions arising from the powergen sector for both 2005 and 2010.
- The RAINS Model correctly assumes that FGD will be installed at Moneypoint between 2005 and 2010. While the RAINS Model incorrectly assumes a decline in coal-fired generation, this is compensated for by the emission factor assumed by RAINS for coal-fired generation in 2010, which is higher than that which is expected to be achieved following installation of the FGD abatement plant at Moneypoint.

9 Conclusions

There are two issues to be addressed in this preliminary data validation study:

1. How do the most recent emissions in RAINS (for the year 2000) compare with the relevant estimates for Ireland?

2. How do the emissions projected in RAINS (for the years 2005 and 2010) compare with independent estimates by BÓC based on available data?

Since emissions are a product of two numbers (a) an activity level and (b) an emission factor per unit of activity, both these were examined by addressing the following:

- Are the trends in activity level projected in RAINS consistent with those underlying the work on emissions projections recently conducted for GHG emissions and in compliance with the Kyoto Protocol?

- Do the RAINS emission factors in 2000 match known emission factors from Ireland (EPA 2002 values)?

- Do the abatement measures and scenarios assumed by RAINS to be in place in Ireland in the future years reflect known plans in the different sectors in Ireland?

9.1 Activity Levels

Many of the activities involving emissions of NO_x and SO_2 are combustion activities. Hence, once the level of energy used or projected is established, the same 'activity' level provides the basis for the computation of NO_x and SO_2 emissions.

- We have cross-checked the activity levels used in RAINS in terms of PJ of energy for all emissions which are a function of energy consumption. We have checked the energy use in different sectors of the economy and found that there is reasonable agreement between RAINS 2000 values in different sectors and the most recent actual inventories computed by the EPA in 2002.

- The RAINS projections for both 2005 and 2010 understate the use of coal in power production compared to the projections of BÓC and the ESB. RAINS assumes a declining use of coal for power generation. In contrast, to BÓC's knowledge there is no plan to significantly reduce coal consumption at Moneypoint due to its importance in maintaining fuel diversity and security of supply in Ireland's generation portfolio.

- RAINS has understated the level of cement production in Ireland in 2010 and as a consequence understated the likely NO_x emissions in the cement sector.

- While RAINS overall projections for activity level in the transport sector are similar to the projections underlying the GHG study by ICF Consulting–BÓC, the RAINS projects a lower percentage usage of diesel relative to gasoline. However, as already reported to the Government in the ICF Consulting–BÓC GHG Report, there are considerable uncertainties regarding transport-sector activity levels for both data sources; it is likely that the difference in projections lies within the bounds of uncertainty of the data. In our view the uncertainty could potentially be as high as plus or minus 10%. This could place emissions from the transport sector in a range from 53 to 64 kt of NO_x per year from the transport sector in 2010.

9.2 Emission Factors

- There is good agreement between the emission factors used/inferred from the RAINS Model for 2000 and those inferred from the EPA Emissions Inventory 2002. However, it must be admitted that it is not possible at present to validate the emission factors for the transport sector for Ireland, since emissions from transport in particular are not measured This is in contrast to say the power sector where stack measurement is the norm.

- RAINS shows projected trends of reducing emission factors in the transport sector, as emission reduction and abatement technology come on stream as the vehicle fleet is continually modernised. We agree that this is a likely trend based on the Auto-Oil Programme.

- RAINS makes some incorrect assumptions regarding the timing and efficiency of NO_x abatement technology being introduced at Moneypoint coal-fired plant. This results in RAINS underestimating the NO_x emissions at Moneypoint in 2005 by some 9 kt NO_x, and overestimating the NO_x projections in 2010 by approximately 5 kt NO_x.

9.3 Compliance with Obligations

- Under the National Emission Ceiling Directive, Ireland's ceiling for NO_x in 2010 is 65 kt. RAINS forecasts that in 2010 Ireland's emissions of NO_x will be 93.7 kT.[30] BÓC forecasts that, based on a 'business as usual' scenario which incorporates plans under the National Emissions Reduction Plan, together with technology changes in the transport sector due to the European Auto-Oil Programme, NO_x emissions in 2010 will be 99.5 kt NO_x, i.e. exceeding the NEC for NO_x by some 34.5 kt.

- Ireland's ceiling for SO_2 in 2010 under the National Emission Ceiling Directive is 42 kt. RAINS forecasts that in 2010 Ireland's emissions of SO_2 will be 33.8 kt. However, BÓC's base case scenario forecasts that SO_2 emissions in 2010 will be 43.98 kt SO_2, i.e. 2 kt greater than the NEC for SO_2.

- The two factors which might influence the projections for NO_x and, to a much lesser extent, SO_x are (a) the uncertainty surrounding transport emissions and (b) the relative energy prices for oil and gas in 2010 which might change the merit order of oil- and gas-fired power plants with consequences for both NO_x and SOx emissions depending on the price relativities.

- Based on the projections for reduced activity levels in agriculture under CAP reform, Ireland should meet its NH_3 ceiling relatively easily without any additional measures to validate national data and abatement strategies.

- RAINS projects that VOC emissions are on a steady downward trend. However, the RAINS projections for 2010 show a significant gap in compliance compared with Ireland's obligations. Further work is needed in this area.

30. The latest version of RAINS is now projecting 99 kt NO_x for 2010 in Ireland.

9.4 Abatement Measures

- RAINS understates the NO_x emissions in 2005 because it factored in significant reductions in NO_x from coal-fired power stations by that year. In reality, the proposed introduction of SCR to reduce NO_x at Moneypoint will not be introduced until 2006 or thereafter. We understand that these NO_x reduction projects are more likely to come on stream in the period 2006 to 2008.

- BÓC base case/'business as usual' forecasts for 2005 and 2010 already incorporate all emission reduction plans for the powergen sector as outlined under the NERP. Therefore, it would appear that there is limited scope for additional emission reductions from this sector.

- Emission reductions from the transport sector due to the European Auto-Oil programme have been incorporated into BÓC's base case scenario projections for 2005 and 2010. There are policy options which the Government could consider to influence NO_x emissions by influencing activity levels rather than emissions factors over which Ireland as an importer of all vehicles has little control. Options include promotion of telecommuting, proximate commuting or compressed work weeks, car-pooling strategies including ride share/ride match/high-occupancy vehicle lanes, congestion charging/fuel taxes/emission taxes and public transport promotion.

- Although the cement sector represents a relatively small contribution to Ireland's NO_x emissions, the sector presents potential possibilities for economic reductions of NO_x emissions.

- RAINS computes abatement costs for a wide range of sectors. These predominantly relate to improvements which are inbuilt into the 'business as usual' projections presented in this report, such as improved vehicle performance. The costs provide little guidance on additional policy initiatives over 'business as usual'.

10 Recommendations

- The RAINS Model is reliant on accurate activity-level and emission-factor projections. While this report has highlighted a number of the discrepancies in the RAINS projections, there is still some uncertainty regarding the revised projections, particularly in the transport sector. Emission projections in this sector would benefit from a detailed transport model for the whole country with updated activity levels and emission factors, preferably based on actual vehicle-use data *inter alia* from national vehicle tests. It may be worth considering measurements of actual NO_x and fuel consumption on representative vehicles from the fleet under simulated Irish driving cycle conditions. In combination with mileage data collected via the NCT, this would provide a means of improving estimates of NO_x emissions from the transport sector in Ireland. The data would also reduce the uncertainty regarding the estimated level of fuel tourism in Ireland.

- The RAINS Model bases its energy consumption values for the powergen sector on the forecasts of the PRIMES Model. The PRIMES Model predicts future fuel prices and forecasts energy demand accordingly. It does not appear to take cognisance of other factors that contribute to fuel mix, for example the location of oil plants on the grid and the fuel use in the dual powered plants. In addition, the calculation of emission factors is a complex issue, particularly in the case of NO_x, as the emission concentrations vary with the plant load. It may be worth considering providing RAINS, and PRIMES with the ESB's projections for energy demand, planned abatement technology installation dates and forecasts of emissions factors. This may go some way in reconciling the forecasts of RAINS and BÓC for the powergen sector. The provision of co-ordinated information to agencies responsible for running the RAINS and PRIMES Models appears to be a requirement, as does an ongoing consultation process in Ireland with the key sectors involved.

- The rapidly changing projections in the RAINS Model across many sectors, even during the course of this study, emphasises the level of uncertainty surrounding the data in many sectors, suggesting that there is a need for co-ordinated actions to ensure that the agencies responsible for RAINS and PRIMES are updated on a regular basis by a suitable agency/agencies in Ireland.

- The RAINS cost data were taken 'offline' for updating purposes during the compilation of this report, but it is expected to be accessible again on the RAINS website in the near future. An ongoing process of validation of the national emissions and reduction cost data for Ireland should be designed when the RAINS cost data become available again, with a view to planning the most cost-effective strategy to achieve compliance with the NEC, in particular for NO_x.

Appendix 1 Abbreviations Used in RAINS Web Model

Activities

Abbreviation	Description
BC1	Brown coal/lignite, high grade
BC2	Brown coal/lignite, low grade
HC1	Hard coal, high quality
HC2	Hard coal, medium quality
HC3	Hard coal, low quality
DC	Derived coal (coke, briquettes)
OS1	Other solid – low S (biomass, waste, wood)
OS2	Other solid – high S (incl. high S waste)
HF	Heavy fuel oil
MD	Medium distillates (diesel, light fuel oil)
GSL	Gasoline
LPG	Liquefied petroleum gas
MTH	Methanol
ETH	Ethanol
H2	Hydrogen
GAS	Natural gas (incl. other gases)
LFL	Leaded gasoline
REN	Renewable (solar, wind, small hydro)
HYD	Hydro
NUC	Nuclear
ELE	Electricity
HT	Heat (steam, hot water)
NOF	No fuel use

Sectors

Abbreviation		**Description**
CONV_COMB		Fuel production and conversion: Combustion
	CON_COMB1	Fuel production and conversion: Combustion, grate firing
	CON_COMB2	Fuel production and conversion: Combustion, fluidised bed
	CON_COMB3	Fuel production and conversion: Combustion, pulverised
	CON_COMB	Fuel production and conversion: Combustion
CON_LOSS		Losses during transmission and distribution of final product
DOMEST		Residential & Commercial: Combustion
	DOM	Combustion in residential/commercial sector (liquid fuels)
	DOM_FPLACE	Residential & Commercial: Fireplaces
	DOM_STOVE	Residential & Commercial: Stoves
	DOM_SHB_M	Residential & Commercial: Single house boilers (<50 kW) – manual
	DOM_SHB_A	Residential & Commercial: Single house boilers (<50 kW) – automatic
	DOM_MB_M	Residential & Commercial: Medium boilers (<1 MW) – manual
	DOM_MB_A	Residential & Commercial: Medium boilers (<50 MW) – automatic
IN		Industry
IND_BO		Industry: Combustion in boilers
	IN_BO1	Industry: Combustion in boilers, grate firing
	IN_BO2	Industry: Combustion in boilers, fluidised bed
	IN_BO3	Industry: Combustion in boilers, pulverised
	IN_BO	Industry: Combustion in boilers
IND_OC		Industry: Other combustion
	IN_OC1	Industry: Other combustion, grate firing
	IN_OC2	Industry: Other combustion, fluidised bed
	IN_OC3	Industry: Other combustion, pulverised
	IN_OC	Industry: Other combustion
PP		Power plants: Combustion
	PP_EX_OTH1	Power plants & district heat plants: Existing other, grate firing
	PP_EX_OTH2	Power plants & district heat plants: Existing other, fluidised bed
	PP_EX_OTH3	Power plants & district heat plants: Existing other, pulverised
	PP_EX_OTH	Power plants & district heat plants: Existing other
	PP_EX_WB	Power plants & district heat plants: Existing wet bottom
	PP_NEW1	Power plants & district heat plants: New, grate firing
	PP_NEW2	Power plants & district heat plants: New, fluidised bed
	PP_NEW3	Power plants & district heat plants: New, pulverised
	PP_NEW	Power plants & district heat plants: New
	PP_TOTAL	Power plants & district heat plants (total)
TRA_ROAD		Road transport
	TRA_RD_HD	Heavy-duty trucks and buses (exhaust)
	TRA_RD_LD2	Motorcycles: 2-stroke; mopeds (also cars) (exhaust)
	TRA_RD_M4	Motorcycles: 4-stroke (exhaust)
	TRA_RD	Light-duty vehicles: Cars, motorcycles (electric, renewable)
	TRA_RD_LD4	Light-duty vehicles: 4-stroke (excl. GDI) (exhaust)
	TRA_RDXLD4	Light-duty vehicles: Gasoline direct injection (GDI) (exhaust)
	LEAD_GASOL	Heavy- and light-duty vehicles: Leaded gasoline (exhaust)

Sectors *contd.*

Abbreviation		Description
TRA_OTHER		Other transport: Off-road, heating (stationary combustion)
	TRA_OT	Other transport: Heating (stationary combustion)
	TRA_OT_LD2	Other transport: Off-road, 2-stroke (exhaust)
	TRA_OT_CNS	Other transport: Construction machinery (exhaust)
	TRA_OT_AGR	Other transport: Agriculture (exhaust)
	TRA_OT_RAI	Other transport: Rail (exhaust)
	TRA_OT_INW	Other transport: Inland waterways (exhaust)
	TRA_OT_AIR	Other transport: Air traffic (LTO)
	TRA_OT_LB	Other transport: Other off-road; 4-stroke (military, households, etc.)
TRA_OTS		Transport: National sea shipping
	TRA_OTS_M	Other transport: Ships, medium vessels (exhaust)
	TRA_OTS_L	Other transport: Ships, large vessels (exhaust)
TRT_RD_HD		Heavy-duty trucks and buses (tyre wear)
TRT_RD_LD2		Motorcycles: 2-stroke; mopeds (also cars) (tyre wear)
TRT_RD_M4		Motorcycles: 4-stroke (tyre wear)
TRT_RD_LD4		Light-duty vehicles: 4-stroke (excl. GDI) (tyre wear)
TRT_RDXLD4		Light-duty vehicles: Gasoline direct injection (GDI) (tyre wear)
TRB_RD_HD		Heavy-duty trucks and buses (brake wear)
TRB_RD_LD2		Motorcycles: 2-stroke; mopeds (also cars) (brake wear)
TRB_RD_M4		Motorcycles: 4-stroke (brake wear)
TRB_RD_LD4		Light-duty vehicles: 4-stroke (excl. GDI) (brake wear)
TRB_RDXLD4		Light-duty vehicles: Gasoline direct injection (GDI) (brake wear)
TRB_OT_RAI		Other transport: Rail (non-exhaust)
TRD_RD_HD		Heavy-duty trucks and buses (abrasion)
TRD_RD_LD2		Motorcycles: 2-stroke; mopeds (also cars) (abrasion)
TRD_RD_M4		Motorcycles: 4-stroke (abrasion)
TRD_RD_LD4		Light-duty vehicles: 4-stroke (excl. GDI) (abrasion)
TRD_RDXLD4		Light-duty vehicles: Gasoline direct injection (GDI) (abrasion)
PR_PIGI		Industrial processes: Pig iron, blast furnace
PR_PIGI_F		Industrial processes: Pig iron, blast furnace (fugitive)
PR_COKE		Industrial processes: Coke oven
PR_PELL		Industrial processes: Agglomeration plant – pellets
PR_SINT		Industrial processes: Agglomeration plant – sinter
PR_SINT_F		Industrial processes: Agglomeration plant – sinter (fugitive)
PR_HEARTH		Industrial processes: Open hearth furnace
PR_BAOX		Industrial processes: Basic oxygen furnace
PR_EARC		Industrial processes: Electric arc furnace
PR_CAST		Industrial processes: Cast iron (grey iron foundries)
PR_CAST_F		Industrial processes: Cast iron (grey iron foundries) (fugitive)
PR_ALPRIM		Industrial processes: Aluminium production – primary
PR_ALSEC		Industrial processes: Aluminium production – secondary
PR_OT_NFME		Industrial processes: Other non-ferrous metals production – primary and secondary
PR_BRIQ		Industrial processes: Briquettes production
PR_CEM		Industrial processes: Cement production
PR_LIME		Industrial processes: Lime production
PR_CBLACK		Industrial processes: Carbon black production
PR_OTHER		Industrial processes: Production of glass fibre, gypsum, PVC, other
PR_REF		Industrial processes: Petroleum refineries
PR_GLASS		Industrial processes: Glass production (flat, blown, container glass)
PR_FERT		Industrial processes: Fertiliser production
PR_SMIND_F		Industrial processes: Small industrial and business facilities – fugitive

Sectors *contd.*

Abbreviation		Description
MINE	Mining	
	MINE_BC	Mining: Brown coal
	MINE_HC	Mining: Hard coal
	MINE_OTH	Mining: Bauxite, copper, iron ore, zinc ore, manganese ore, other
WASTE_FLR		Waste: Flaring in gas and oil industry
WASTE_AGR		Waste: Agricultural waste burning
WASTE_RES		Waste: Open burning of residential waste
STORE	Storage and handling	
	STH_COAL	Storage and handling: Coal
	STH_FEORE	Storage and handling: Iron ore
	STH_NPK	Storage and handling: N, P, K fertilisers
	STH_OTH_IN	Storage and handling: Other industrial products (cement, bauxite, coke)
	STH_AGR	Storage and handling: Agricultural products (crops)
AGR_POULT		Agriculture: Livestock – poultry
AGR_PIG		Agriculture: Livestock – pigs
AGR_COWS		Agriculture: Livestock – dairy cattle
AGR_BEEF		Agriculture: Livestock – other cattle
AGR_OTANI		Agriculture: Livestock – other animals (sheep, horses)
AGR_ARABLE		Agriculture: Ploughing, tilling, harvesting
AGR_OTHER		Agriculture: Other (activity as emissions in kt)
CONSTRUCT		Construction activities
RES_BBQ		Residential: Meat frying, food preparation, BBQ
RES_CIGAR		Residential: Cigarette smoking
RES_FIREW		Residential: Fireworks
OTHER		Other (activity given as emissions in kt)
NONEN		Non-energy use of fuels

Control technologies.

Abbreviation	Description
NOC	No control
NSC	Stock not suitable for control
ESP1	Electrostatic precipitator: 1 field – power plants
ESP2	Electrostatic precipitator: 2 fields – power plants
ESP3P	Electrostatic precipitator: more than 2 fields – power plants
FF	Fabric filters – power plants
CYC	Cyclone – power plants
WSCRB	Wet scrubber – power plants
IN_ESP1	Electrostatic precipitator: 1 field – industrial combustion
IN_ESP2	Electrostatic precipitator: 2 fields – industrial combustion
IN_ESP3P	Electrostatic precipitator: more than 2 fields – industrial combustion
IN_FF	Fabric filters – industrial combustion
IN_CYC	Cyclone – industrial combustion
IN_WSCRB	Wet scrubber – industrial combustion
PR_ESP1	Electrostatic precipitator: 1 field – industrial processes
PR_ESP2	Electrostatic precipitator: 2 fields – industrial processes
PR_ESP3P	Electrostatic precipitator: more than 2 fields – industrial processes
PR_WESP	Wet electrostatic precipitator: industrial processes
PR_FF	Fabric filters – industrial processes
PR_CYC	Cyclone – industrial processes
PR_WSCRB	Wet scrubber – industrial processes
GHIND	Good housekeeping: industrial oil boilers
PRF_GP1	Good practice: industrial processes – stage 1 (fugitive)
PRF_GP2	Good practice: industrial processes – stage 2 (fugitive)
FP_CAT	Fireplaces, catalytic insert
FP_ENC	Fireplaces, non-catalytic insert
WOOD1	New domestic stoves (wood): non-catalytic
WOOD2	New domestic stoves (wood): catalytic
COAL1	New domestic stoves (coal): stage 1
COAL2	New domestic stoves (coal): stage 2
NB_COAL	New domestic boilers: (coal)
MB_PELL	New medium (automatic) size boilers: (wood chips, pellets)
MB_PLBAG	New medium boilers: (wood chips, pellets) with end-of-pipe abatement
MB_CYC	Cyclone for medium boilers in domestic sectors
MB_BAG	Bag house for medium (automatic) boilers in domestic sector
GHDOM	Good housekeeping: domestic oil boilers
MDEUI	EURO I – 1992/94, diesel light-duty and passenger cars
MDEUII	EURO II – 1996, diesel light-duty and passenger cars
MDEUIII	EURO III – 2000, diesel light-duty and passenger cars
MDEUIV	EURO IV – 2005, diesel light-duty and passenger cars
MDEUV	EURO V – diesel light-duty and passenger cars, post-2005, stage 1
MDEUVI	EURO VI – diesel light-duty and passenger cars, post-2005, stage 2
CAGEUI	Construction and Agriculture Off-road – 1998, as EURO I for HDV
CAGEUII	Construction and Agriculture Off-road – 2000/02, as EURO II for HDV
CAGEUIII	Construction and Agriculture Off-road – as EURO III for HDV
CAGEUIV	Construction and Agriculture Off-road – as EURO IV for HDV
CAGEUV	Construction and Agriculture Off-road – as EURO V for HDV
CAGEUVI	Construction and Agriculture Off-road – as EURO VI for HDV

Control technologies *contd.*

Abbreviation	Description
TIWEUI	Rail and Inland Waterways Off-road – 1998, as EURO I for HDV
TIWEUII	Rail and Inland Waterways Off-road – 2000/02, as EURO II for HDV
TIWEUIII	Rail and Inland Waterways Off-road – as EURO III for HDV
TIWEUIV	Rail and Inland Waterways Off-road – as EURO IV for HDV
TIWEUV	Rail and Inland Waterways Off-road – as EURO V for HDV
TIWEUVI	Rail and Inland Waterways Off-road – as EURO VI for HDV
HDEUI	EURO I – 1992, heavy-duty diesel vehicles
HDEUII	EURO II – 1996, heavy-duty diesel vehicles
HDEUIII	EURO III – 2000, heavy-duty diesel vehicles
HDEUIV	EURO IV – 2005, heavy-duty diesel vehicles
HDEUV	EURO V – 2008, heavy-duty diesel vehicles
HDEUVI	EURO VI, heavy-duty diesel vehicles, post-2008
LFGDIII	EURO III, gasoline direct injection engines
LFGDIV	EURO IV, gasoline direct injection engines
LFGDV	EURO V, gasoline direct injection engines
LFGDVI	EURO VI, gasoline direct injection engines
LFEUI	EURO I, light-duty, spark ignition engines: 4-stroke, not DI
LFEUII	EURO II, light-duty, spark ignition engines: 4-stroke, not DI
LFEUIII	EURO III, light-duty, spark ignition engines: 4-stroke, not DI
LFEUIV	EURO IV, light-duty, spark ignition engines: 4-stroke, not DI
LFEUV	EURO V, light-duty, spark ignition engines: 4-stroke, not DI
LFEUVI	EURO VI, light-duty, spark ignition engines: 4-stroke, not DI
MMO2I	Motorcycles and mopeds 2-stroke, stage 1
MMO2II	Motorcycles and mopeds 2-stroke, stage 2
MMO2III	Motorcycles and mopeds 2-stroke, stage 3
MOT4I	Motorcycles 4-stroke, stage 1
MOT4II	Motorcycles 4-stroke, stage 2
MOT4III	Motorcycles 4-stroke, stage 3
HDSEI	Heavy-duty, spark ignition engines, stage 1
HDSEII	Heavy-duty, spark ignition engines, stage 2
HDSEIII	Heavy-duty, spark ignition engines, stage 3
STMCM	Combustion modification: ships (medium vessels)
STLHCM	Combustion modification: ships (large vessels – fuel oil)
STLMCM	Combustion modification: ships (large vessels – diesel)
STH_GP	Good practice: storage and handling
FEED_MOD	Feed modification (all livestock)
HAY_SIL	Hay-silage for cattle
FREE	Free range poultry
ALTER	Low-till farming, alternative cereal harvesting
AGR1	A generic option for 'other animals' – good practice
FLR_GP	Good practice in oil and gas industry – flaring
BAN	Ban on open burning of agricultural or residential waste
MINE_GP	Good practice in mining industry
SPRAY	Spraying water at construction places
FILTER	Filters in households (kitchen)
RESP1	Generic, e.g. street washing

Appendix 2 RAINS & BÓC Activity Levels for 2000/2002, 2005 and 2010

Activity levels – RAINS data for Ireland.

	2000 PJ	2005 PJ	2010 PJ
Fuel combustion and conversion			
CON_COMB-GAS-NOC-[PJ]	2.822	2.829	2.945
CON_COMB-HF-IOGCM-[PJ]	2.08	0.2086	0.3258
CON_COMB-HF-NOC-[PJ]		0.8344	0.7602
CON_COMB-LPG-NOC-[PJ]	0.138	0.139	0.144
CON_COMB-MD-NOC-[PJ]	0.338	0.17	0.176
Subtotal	**5.378**	**4.181**	**4.351**
Residential and commercial			
DOM-BC1-NOC-[PJ]	4.632		
DOM-DC-NOC-[PJ]	7.52	3.929	1.973
DOM-GAS-NOC-[PJ]	30.577	40.644	51.528
DOM-GSL-NOC-[PJ]	23.259	19.768	16.407
DOM-HC1-NOC-[PJ]	9.568	10.415	5.635
DOM-HF-NOC-[PJ]	9.168	7.846	7.488
DOM-LPG-NOC-[PJ]	3.541	3.566	3.457
DOM-MD-NOC-[PJ]	36.972	47.676	54.95
DOM-OS1-NOC-[PJ]	1.855	8.615	9.439
Subtotal	**127.092**	**142.459**	**150.877**
Industry			
IN_BO-GAS-NOC-[PJ]	9.77	8.3	5.86
IN_BO-HC1-ISFCM-[PJ]	0.1748	0.152	0.2679
IN_BO-HC1-NOC-[PJ]	0.7452	0.248	0.2021
IN_BO-HF-IOGCM-[PJ]	0.627	0.58	0.435
IN_BO-HF-NOC-[PJ]	5.643	2.32	1.015
IN_BO-MD-NOC-[PJ]	1.14	0.62	0.94
IN_BO-OS1-NOC-[PJ]	1.92	0.77	2.36
IN_BO-OS2-NOC-[PJ]	2.11	1.06	3.38
IN_OC-GAS-NOC-[PJ]	10.397	31.759	43.297
IN_OC-GSL-NOC-[PJ]	3.611	2.723	2.207
IN_OC-HC1-ISFCM-[PJ]	0.2223	0.67526	1.16736
IN_OC-HC1-NOC-[PJ]	0.9477	1.10174	0.88064
IN_OC-HF-IOGCM-[PJ]	0.861	2.4312	4.374
IN_OC-HF-NOC-[PJ]	7.749	9.7248	10.206
IN_OC-LPG-NOC-[PJ]	2.576	1.433	1.098
IN_OC-MD-NOC-[PJ]	6.071	2.69	2.024
IN_OC-OS1-NOC-[PJ]	0.041	0.001	0.001
Subtotal	**54.606**	**66.589**	**79.715**

Activity levels – RAINS data for Ireland *contd.*

	2000 PJ	2005 PJ	2010 PJ
Power plants			
PP_EX_OTH-BC1-NOC-[PJ]	19.75	14.025	8.505
PP_EX_OTH-BC1-PBCCM-[PJ]		4.675	2.835
PP_EX_OTH-GAS-NOC-[PJ]	48.22	24.11	14.435
PP_EX_OTH-GAS-POGCM-[PJ]		24.11	14.435
PP_EX_OTH-HC1-NOC-[PJ]	60.27	10.452	9.322
PP_EX_OTH-HC1-PHCCM-[PJ]		41.808	37.288
PP_EX_OTH-HF-NOC-[PJ]	24.71	4.5315	3.096
PP_EX_OTH-HF-POGCM-[PJ]		5.5385	3.784
PP_EX_OTH-MD-NOC-[PJ]	0.76	0.96	0.96
PP_EX_OTH-OS2-NOC-[PJ]	0.02	0.02	0.02
PP_NEW-BC1-NOC-[PJ]		5.22	4.932
PP_NEW-BC1-PBCSCR-[PJ]		3.48	3.288
PP_NEW-GAS-NOC-[PJ]	28.19	69.714	95.512
PP_NEW-GAS-POGSCR-[PJ]		7.746	23.878
PP_NEW-HF-NOC-[PJ]	16.77		
PP_NEW-MD-NOC-[PJ]		0.36	0.08
PP_NEW-OS1-NOC-[PJ]	0.41	1.63	2.31
PP_NEW-OS2-NOC-[PJ]	0.55	1.68	2.02
Subtotal	**199.65**	**220.06**	**226.7**
Process			
PR_CEM-NOF-NOC-[Mt]	2.402	2.454	1.234
PR_CEM-NOF-PRNOX1-[Mt]			1.234
PR_LIME-NOF-NOC-[Mt]	0.139	0.142	0.143
PR_NIAC-NOF-PRNOX3-[Mt]	0.238	0.243	0.249
PR_REF-NOF-NOC-[Mt]	3.221	3.246	1.6985
PR_REF-NOF-PRNOX1-[Mt]			1.6985
Subtotal	**6**	**6.085**	**6.257**
Transport			
TRA_OTS_L-HF-NOC-[PJ]	0.84	0.917	0.909
TRA_OTS_M-MD-NOC-[PJ]		0.05	0.15
TRA_OT_AGR-MD-CAGEUI-[PJ]	0.0883	0.4639	0.4347
TRA_OT_AGR-MD-CAGEUII-[PJ]		0.4639	0.4347
TRA_OT_AGR-MD-CAGEUIII-[PJ]			0.95634
TRA_OT_AGR-MD-NOC-[PJ]	8.7417	3.7112	2.52126
TRA_OT_AIR-GSL-NOC-[PJ]	24.076	30.755	37.323
TRA_OT_CNS-MD-CAGEUI-[PJ]	0.0666	0.0346	0.0243
TRA_OT_CNS-MD-CAGEUII-[PJ]		0.03979	0.0297
TRA_OT_CNS-MD-CAGEUIII-[PJ]			0.0459
TRA_OT_CNS-MD-NOC-[PJ]	0.6734	0.09861	0.0351
TRA_OT_INW-MD-NOC-[PJ]	0.761	1.026	1.001663
TRA_OT_INW-MD-TIWEUI-[PJ]			0.200337
TRA_OT_LD2-GSL-MMO2I-[PJ]		0.004	0.0144
TRA_OT_LD2-GSL-MMO2II-[PJ]			0.0144
TRA_OT_LD2-GSL-NOC-[PJ]	0.04	0.046	0.0312

Activity levels – RAINS data for Ireland *contd*.

	2000 PJ	2005 PJ	2010 PJ
Transport *contd*			
TRA_RD_LD4-ETH-LFEUI-[PJ]		0.002765	0.00045
TRA_RD_LD4-ETH-LFEUII-[PJ]		0.008111	0.005506
TRA_RD_LD4-ETH-LFEUIII-[PJ]		0.006969	0.006614
TRA_RD_LD4-ETH-LFEUIV-[PJ]		0.001155	0.007336
TRA_RD_LD4-ETH-NOC-[PJ]			0.000094
TRA_RD_LD4-GAS-LFEUIII-[PJ]		0.035	0.0099
TRA_RD_LD4-GAS-LFEUIV-[PJ]			0.0231
TRA_RD_LD4-GSL-LFEUI-[PJ]	16.67848	11.02875	1.75095
TRA_RD_LD4-GSL-LFEUII-[PJ]	30.14956	32.35859	21.42385
TRA_RD_LD4-GSL-LFEUIII-[PJ]		27.80307	25.73507
TRA_RD_LD4-GSL-LFEUIV-[PJ]			28.54438
TRA_RD_LD4-GSL-NOC-[PJ]	17.31996	4.608579	0.365754
TRA_RD_LD4-H2-NOC-[PJ]		0.015	0.019
TRA_RD_LD4-LPG-LFEUI-[PJ]	0.041777	0.036812	0.00576
TRA_RD_LD4-LPG-LFEUII-[PJ]	0.078356	0.108006	0.070477
TRA_RD_LD4-LPG-LFEUIII-[PJ]		0.0928	0.084659
TRA_RD_LD4-LPG-LFEUIV-[PJ]			0.093901
TRA_RD_LD4-LPG-NOC-[PJ]	0.057868	0.015382	0.001203
TRA_RD_LD4-MD-MDEUI-[PJ]	15.98308	10.57511	2.028101
TRA_RD_LD4-MD-MDEUII-[PJ]	8.178	9.3585	9.220032
TRA_RD_LD4-MD-MDEUIII-[PJ]		13.1019	13.3679
TRA_RD_LD4-MD-MDEUIV-[PJ]			13.3679
TRA_RD_LD4-MD-NOC-[PJ]	8.550917	4.398495	0.210067
TRA_RD_LD4-MTH-LFEUI-[PJ]		0.004656	0.000743
TRA_RD_LD4-MTH-LFEUII-[PJ]		0.013661	0.009085
TRA_RD_LD4-MTH-LFEUIII-[PJ]		0.011738	0.010913
TRA_RD_LD4-MTH-LFEUIV-[PJ]		0.001946	0.012104
TRA_RD_LD4-MTH-NOC-[PJ]			0.000155
TRA_RD_M4-GSL-MOT4I-[PJ]	0.01863	0.09108	0.0306
TRA_RD_M4-GSL-MOT4II-[PJ]		0.04554	0.16524
TRA_RD_M4-GSL-MOT4III-[PJ]			0.11016
TRA_RD_M4-GSL-NOC-[PJ]	0.18837	0.11638	
Subtotal	**172.503**	**208.666**	**231.182**
Waste			
WASTE_RES-NOF-NOC-[Mt]	0.038	0.038	0.038
TOTAL	**559.229**	**641.955**	**692.825**

Activity levels – BÓC estimates.

	2002 PJ	2005 PJ	2010 PJ
Household			
Coal	10.62	8.46	6.25
Petcoke	1.26	1.26	1.26
Gas oil	10.47	10.47	10.47
Kero	32.50	34.00	33.54
Gas	21.80	27.59	43.92
Peat	7.50	5.98	3.25
Briq	4.31	4.11	2.99
Renewables	1.77	1.69	1.57
Subtotal	**90.23**	**93.55**	**103.25**
Industry			
Coal	1.80	2.06	2.30
Petcoke	7.08	8.81	10.40
Fuel oil	21.92	22.99	17.06
Gas oil	4.36	5.12	7.56
Kero	5.09	3.71	2.09
Gas	17.18	16.40	19.12
Renewables	4.56	4.56	4.56
Subtotal	**62.01**	**63.66**	**63.08**
Commercial			
Fuel oil	7.19	7.59	8.36
Gas oil	25.77	27.88	31.97
Gas	13.95	16.10	20.51
Briq	0.18	0.17	0.16
Subtotal	**47.09**	**51.74**	**61.00**
Agriculture			
Oil	11.41	10.78	10.03
Transport			
Petrol	66.59	64.37	64.58
Diesel	76.86	86.04	96.88
LPG	0.22	0.22	0.22
Rail	5.71	7.06	8.65
Navigation	1.75	1.91	2.18
Aviation	12.08	13.77	15.53
Gas	2.02	2.31	2.79
Subtotal	**165.22**	**175.67**	**190.83**
Electricity			
Coal	63.93	57	57.97
Fuel oil	43.96	43.5	17.66
Gas	77.68	74.3	121.9
Peat	24.42	22.1	21.74
Renewables	0.00	1.01	5.03
Subtotal	**209.99**	**196.9**	**219.65**
Refinery			
Gas	3.71	3.71	3.71
Fuel oil	1.06	1.06	1.06
Gas oil	0.21	0.21	0.21
LPG	0.17	0.17	0.17
Subtotal	**5.15**	**5.15**	**5.15**
TOTAL	**591.09**	**585.96**	**671.8**

Appendix 3 RAINS & BÓC Emission Factors for 2000/2002, 2005 and 2010

Emission factors for NO_x.

Source	2000 RAINS kt NO_x/PJ	2002 EPA kt NO_x/PJ	2005 RAINS kt NO_x/PJ	2005 BÓC kt NO_x/PJ	2010 RAINS kt NO_x/PJ	2010 BÓC kt NO_x/PJ
Public electricity						
Peat	0.19	0.16	0.12	0.12	0.11	0.12
Coal	0.36	0.36	0.22	0.36	0.22	0.10
Fuel oil	0.14	0.15	0.10	0.15	0.10	0.07
Natural gas	0.11	0.08	0.06	0.08	0.04	0.05
Biomass	0.07	0.10	0.07	0.10	0.07	0.11
Refinery						
Gas	0.07	0.14	0.07	0.14	0.07	0.14
Fuel oil	0.17	0.25	0.15	0.25	0.09	0.25
Gas oil	0.08	0.10	0.08	0.10	0.08	0.10
LPG	0.07	0.10	0.07	0.10	0.07	0.10
Residential						
Peat	0.05	0.10	gone	0.10		0.10
Briq	0.07	0.10	0.07	0.10	0.07	0.10
Coal	0.08	0.05	0.08	0.05	0.08	0.05
Petcoke	0.07	0.10	0.07	0.10	0.07	0.10
Gas oil	0.06	0.05	0.06	0.05	0.06	0.05
Kero		0.05		0.05		0.05
Natural gas	0.05	0.05	0.05	0.05	0.05	0.05
LPG	0.06	0.05	0.06	0.05	0.06	0.05
Biomass	0.11	0.10	0.11	0.10	0.11	0.10
Commercial						
Peat	0.05	0.10	gone	0.10		0.10
Briq	0.07	0.10	0.07	0.10	0.07	0.10
Coal	0.08	0.05	0.08	0.05	0.08	0.05
Gas oil	0.06	0.05	0.06	0.05	0.06	0.05
Kero		0.05		0.05		0.05
Fuel oil	0.12	0.12	0.12	0.12	0.12	0.12
Natural gas	0.05	0.05	0.05	0.05	0.05	0.05
LPG	0.06	0.05	0.06	0.05	0.06	0.05
Biomass	0.11	0.10	0.11	0.10	0.11	0.10

Emission factors for NO_x *contd*.

Source	2000 RAINS kt NO_x/PJ	2002 EPA kt NO_x/PJ	2005 RAINS kt NO_x/PJ	2005 BÓC kt NO_x/PJ	2010 RAINS kt NO_x/PJ	2010 BÓC kt NO_x/PJ
Industry						
Coal	0.24	0.50	0.20	0.50	0.17	0.50
Cement petcoke		0.50		0.80		0.80
Cement petcoke		0.94				
Cement coal		0.50		0.50		0.50
Gas oil	0.08	0.10	0.08	0.10	0.08	0.10
Kerosene		0.10		0.10		0.10
Fuel oil	0.16	0.14	0.15		0.15	
Aughinish boilers		0.20		0.16		0.09
Aughinish calcin		0.08				
Nat gas	0.07	0.10	0.07	0.10	0.07	0.10
LPG		0.10		0.10		0.10
Biomass	0.13	0.10	0.13	0.10	0.13	0.10
Road transport						
Petrol	0.32	0.22	0.16	0.16	0.09	0.09
Diesel	0.43	0.40	0.40	0.40	0.31	0.31
LPG	0.44	0.06	0.11	0.11	0.07	0.07
Other mobile						
Rail diesel	0.81	0.81	0.81	0.81	0.76	0.76
Ag machinery gas oil	1.15	1.15	1.05	1.05	0.88	0.88
Nav fuel oil	1.20	0.98	1.20	1.20	1.20	1.20
Nav gas oil		0.98				
Domestic LTO	0.08	0.23	0.08	0.23	0.08	0.23
International LTO		0.28		0.28		0.28

Emission factors for SO_2.

Source	2000	2002	2005		2010	
	RAINS kt SO_x/PJ	EPA kt SO_x/PJ	RAINS kt SO_x/PJ	BÓC kt SO_x/PJ	RAINS kt SO_x/PJ	BÓC kt SO_x/PJ
Public electricity						
Peat	0.29	0.27	0.20	0.15	0.07	0.15
Coal	0.65	0.51	0.65	0.51	0.16	0.11
Fuel oil	0.85	0.61	0.50	0.61	0.13	0.19
Gas oil	0.09	0.00	0.09	0.00	0.05	0.00
Biomass inc. LFG		0.00		0.00		0.08
Refinery						
Fuel oil	0.30	0.79	0.30	0.79	0.30	0.79
Gas oil	0.09	0.07	0.09	0.07	0.05	0.07
Residential						
Peat	0.30	0.30	–	0.30	–	0.30
Briq	0.46	0.28	0.46	0.28	0.46	0.28
Coal	0.57	0.32	0.57	0.32	0.57	0.32
Petcoke	0.46	1.74	0.46	1.74	0.46	1.74
Gas oil	0.09	0.07	0.09	0.07	0.05	0.07
Kero	–	0.03		0.03		0.03
Biomass	0.04	0.00	0.04	0.00	0.04	
Commercial						
Peat	0.30	0.30	–	0.30		0.30
Briq	0.46	0.28	0.46	0.28	0.46	0.28
Coal	0.57	0.32	0.57	0.32	0.57	0.32
Gas oil	0.09	0.07	0.09	0.07	0.05	0.07
Kero	–	0.03	–	0.03		0.03
Fuel oil	0.96	0.49	0.38	0.49	0.38	0.49
Comm. biomass	0.04	0.00	0.04	0.00	0.04	
Industry						
Coal	0.72	0.02	0.54	0.02	0.35	0.02
Cement petcoke		0.02		0.02		0.02
Cement coal	0.72	0.02	0.54	0.02	0.35	0.02
Gas oil	0.09	0.07	0.09	0.07	0.05	0.07
Kerosene	–	0.03		0.03		0.03
Fuel oil	1.40	0.49	0.50		0.50	
Aughinish boilers		1.00	1.00	0.81		0.53
Aughinish calcin		0.55	0.55			
Natural gas	–	0.00		0.00		
LPG	–	0.00		0.00		
Biomass	0.04	0.00	0.04	0.00	0.04	
Road transport						
Petrol	0.00	0.01	0.00	0.00	0.00	0.00
Diesel	0.02	0.00	0.02	0.02	0.00	0.02
Other mobile						
Rail diesel	–	0.07		0.00		0.00
Ag machinery gas oil	0.09	0.06	0.02	0.09	0.00	0.00
Nav fuel oil	1.69	0.97	1.61	1.61	1.48	1.48
Nav gas oil		0.07	0.24		0.24	0.24
Air LTO	0.01	0.02	0.01	0.02	0.01	0.02

Appendix 4 Transport Sector: Potential Modelling Concerns with RAINS – Policy Options for Limiting Emissions (ICF Consulting)

Potential Modelling and Other Concerns with RAINS

The following observations are drawn from a brief review of the RAINS Model and especially the recent NO_x modelling activity for Ireland. It is based on a review of the online documentation for RAINS–EUROPE from the International Institute for Applied Systems Analysis (IIASA) website as well as an examination of the NO_x calculations made using RAINS. Comments can be divided into three elements:

1. Potential difficulties in assumption factors included within the applied version of RAINS;
2. Potential shortcomings with the RAINS modelling approach;
3. Issues and abatement options outside the area of emissions modelling.

These three elements are discussed in turn below. Comments are based on familiarity with other mobile source emissions models, experience preparing other emission inventories, and expertise in development of mobile source emission reduction strategies using a broad range of strategies. Although most of this knowledge has been developed in a North American and developing country context, the outside perspective provided by these is helpful in shedding light on potential issues with this European implementation of RAINS.

Assumptions and Emissions Factors within the Applied Version of RAINS

RAINS classifies all vehicles according to the emission standard applicable to them at their time of manufacture. The emission rates used reflect expected average in-use emissions for vehicles of the standard in effect for that vintage, and 'vintaging' is accounted for in the model such that any vehicles produced, for example, to EURO II standards, remain in this class until they are retired or scrapped (i.e. there is no retrofitting). However, this means that vehicle ageing **within** a standard is not reflected. For example, the model year 1999 vehicles produced at a EURO II standard have identical NO_x emission rates (82% abatement) in 2000, in 2005, and in 2010. One would generally expect that vehicle emission rates will increase with age. For example, MOBILE 5 for light-duty gasoline vehicles shows base NO_x zero mile vehicles with an emission rate of 0.178 g/mile, rising to 0.593 g/mile at 50,000 miles and 1.568 g/mile at 100,000 miles. While the RAINS approach presumably uses an average emissions factor that accounts for the mileage and vintage distribution of the fleet, such an approach introduces uncertainties through understating emissions reduction effectiveness for newer models and overstating it for older models.

RAINS does not appear to explicitly account for fuel quality or characteristics within fuel types. Fuel characteristics such as sulphur content and oxygenates are well known to affect emissions rates. In fact, in the United States alone there are at least 15 different regulatory standards for gasoline in order to meet the particular emissions abatement requirements of different areas. Decreasing evaporative characteristics (Reid Vapour Pressure) can benefit VOCs greatly (€500/tonne), but is relatively costly for NO_x alone (€15,000/tonne). Reformulated or low sulphur diesel can help reduce NO_x from heavy-duty vehicles at a cost as low as €5,000/tonne. Some of the emission standards covered in RAINS can only be achieved simultaneously with improved fuel characteristics, and thus fuel quality may be implicit in RAINS for new standards. However, these fuel quality shifts appear to be unrealistically ignored with regard to their effect on existing vehicles of previous standards.

RAINS does not explicitly address vehicle drive cycles, which may significantly affect NO_x emission rates. NO_x emissions vary substantially with vehicle speed, with rates rapidly increasing at higher and at very low speeds. Speed correction factors used in other emissions models estimate a 17–41% increase in g/mile in very congested conditions (speeds of 10 kmph/6 mph or less), a 30%

increase at 55 mph, and a 60% increase at 65 mph, all relative to g/mile at 20 mph. While RAINS presumably has included a standard European drive cycle in developing its emission rates, this cycle may not bear a strong resemblance to driving conditions and behaviour in Ireland.

RAINS appears to address only a limited number of vehicle and engine characteristics beyond emission control technologies. Other engine characteristics (related to engine loads, etc., and consequentially to emissions rates) are largely not covered. This leads to uncertainties regarding actual in-use emissions rates in some categories (e.g. uncontrolled agricultural equipment) compared to the standard Europe-wide emissions rate used by RAINS.

Potential Shortcomings with the RAINS Modelling Approach

The emissions rates in RAINS appear to be based on grams of pollutant per petajoule of energy consumed. One possible source of uncertainty is whether primary emission rates were calculated based on vehicle kilometres travelled, or on a fuel consumption basis. This can lead to uncertainties due to conversion factors due to variance in fuel content within fuel types, as well as to conversion uncertainties due to uncertainties regarding actual in-use fuel consumption rates.

These uncertainties regarding emissions rates expressed per unit of energy are exacerbated by the likelihood that the energy accounts used to allocate activities across the vehicle types are themselves a conversion of primary data. Fuel consumption data are generally collected on a volumetric basis (as that is the basis for taxation). Allocation across vehicle types is then generally conducted by estimates based on a combination of fleet statistics, models of vehicle kilometres travelled and estimates of fuel consumption rates, and vehicle registrations. Allocation by vintage (and thus emission control technology) is then made by estimated annual distance travelled by model year, generally based on partial data from vehicle registrations. As previously mentioned, the energy content for a given volume of a fuel type also has some variance. The multiple conversions and estimates required to allocate energy use by vehicle type and vintage, and then to apply energy-based emission rates thus leads to multiple sources of uncertainty.

For goods vehicles, the forecasts of activity levels by vehicle type and vintage are even more problematic. Because Ireland is significantly served by heavy goods vehicles from other countries, data on vehicle vintage and control technology are even more problematic. Lack of vehicle registration and information on distance travelled makes this allocation even more problematic. It is then further exacerbated by 'fuel tourism' due to Ireland's relatively low fuel prices. Lastly, the easy substitution between foreign and domestic vehicles, and in some cases even across freight modes, means that forecasts to allocate future activity are particularly sensitive and uncertain.

The vintaging process is described in the RAINS documentation as representing a simple ageing and retirement of the fleet, with the introduction of new vehicles and corresponding turnover the mechanism for the proliferation of newer emission control technologies. This approach makes it problematic to show the effects of abatement strategies such as voluntary or mandatory retrofit of devices (or entire engines) and of inspection and maintenance (I&M) programmes. Either of these may be difficult to incorporate into the RAINS vintaging procedure and their effects may not adequately correspond with the standards used as the basis of abatement options in RAINS (e.g. certain retrofit devices may focus on a single pollutant). This difficulty can be resolved with a more complex but flexible vintaging system. One example moving in the appropriate direction may be found in *The Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2002*.[1]

Fuel consumption rates are exogenous to the RAINS Model and form an important part of the basis for the allocation of emissions. This is appropriate with an exclusively technological model such as RAINS that reflects little change in the marginal **operating** cost of vehicles. However, this approach precludes the accurate inclusion of additional abatement measures that may have a monetary or non-monetary effect associated with them. Descriptions of some of these measures are provided below.

1. See Annex 3.2
http://yosemite.epa.gov/oar/globalwarming.nsf/content/ResourceCenterPublicationsGHGEmissionsUSEmissionsInventory2004.html

Issues Outside the Area of Emissions Modelling

Perhaps the most important area of potential concern with the RAINS–Europe Model implementation being used is the limitations of its scope. The model is limited to homogenous (fleet-wide) emission rate standards based on technological innovations. One shortcoming (and strength, as well) of this approach is that it usually is reduced simply to the concept of pollutant grams per unit of energy, fuel, or distance travelled.

However, transport is not an end unto itself. Rather, it is what economists call a 'derived demand', meaning that its utility is in obtaining other goals (the underlying trip purpose) rather than having utility in itself. The distinction can be illustrated with the concept of vehicle occupancy – one personal car with four occupants can in some cases provide the same transport as four cars each with one person. It is in the movement of the four people, and not the cars, from which benefits and utility are derived. But emission standards do not account for factors such as passenger distance travelled, tonne-miles carried, or similar measures. While the emissions standard approach used is the most practical, it should be recognised that environmental progress can also be made through means addressing activity levels as well as emission rates. In effect, abatement measures can be implemented that reduce aggregate tonnes of pollutant even while they may not affect emissions per vehicle or per unit of fuel.

Many of these abatement options have been found to be sometimes equally or more cost-effective than the type of technological standards addressed in RAINS. However, these abatement options are often **less** cost-efficient in addressing local air pollution emissions. The specifics of their implementation and the context in which they are carried out dramatically affect their cost-efficiency, making general comparisons of abatement options of very little value.[2] One last consideration is that many of the policy abatement options not covered in RAINS also have significant co-benefits (and sometimes dis-benefits or equity impacts).[3] A short enumeration of additional measures not included in RAINS follows:

- I&M programmes: Ireland has implemented a biannual I&M programme on vehicles four years or older. These programmes can significantly reduce mileage/age-based emission rate deterioration, and have often proven to be cost-effective. Cost-effectiveness as low as €2,000/tonne have been identified, although in the range of €3,000 to €8,000 is more common.

- Telecommute, proximate commute, compressed work week: these measures all reduce commute to work trips, although there is some evidence that individuals may take more discretionary trips under these policies, thus offsetting some or all of the emission abatement. Cost-effectiveness can run from near zero (announcing a policy), to fairly low (€variable; outreach and awareness campaigns), to very expensive (€100,000+/tonne; setting up regional telework centres).

- Ride share/ride match/high-occupancy vehicle (HOV) lanes: various car-pooling strategies can be effective in some situations in reducing vehicle travel and emissions, but vary considerably in their costs and effectiveness. Simple promotional programmes with employer support can be implemented relatively inexpensively. Implementing HOV lanes can be under €10,000/tonne for re-striping, signage and enforcement, to well over €1,000,000/tonne to build physically separated lanes. Substantial potential co-benefits and distributional impacts mean that development of these abatement options must be context sensitive and well planned.

- Congestion charging/fuel taxes/emission taxes: these abatement options effectively pay for themselves from a public finance point of view, although obviously there are significant distributional issues to consider. The costs for these are thus privately borne and theoretically can be set at whatever level is desired.

- Public transport promotion (increased service, bus lanes, rail infrastructure): these measures can reduce pollutants by encouraging mode shifts and improving the flow of buses. Typically, only tax policies encouraging employer-based public transport passes

2. Further, quantifying their costs and benefits is itself problematic, as it is much more difficult to measure behaviour and control for economic and transport conditions than it is to measure emissions on a laboratory dynamometer.

3. For example, many of the abatement measures will also reduce greenhouse gases. However, increasing bus lanes may decrease emissions and improve average travel times for all, but many drivers may be somewhat inconvenienced while bus riders receive a significant benefit.

approach cost-effectiveness benchmarks, although there are significant co-benefits. While expansion of public transport systems has many benefits and reduces pollutants, it is not at all cost-effective as a stand-alone emission abatement measure, with such projects typically running above €1,000,000/tonne.

- Tyre pressure/vehicle maintenance: maintaining proper tyre pressure and other good vehicle maintenance practices can have measurable benefits for fuel consumption and emissions at minimal costs. Because these practices typically pay for themselves in driver fuel consumption savings, the potential cost is usually limited to an outreach campaign. Total cost and effectiveness vary with the level of effort, and absolute savings are small but cost-efficient.

- Episodic controls/ozone action days: these measures are focused on improving air quality on days with high expected levels of pollution, and may include many of the above measures and/or others on a short-term basis. Other measures typically include voluntarily refilling petrol tanks after nightfall and restraints on lawn mowing and personal vehicle usage. It typically costs two to three times as much per tonne to implement measures on this basis, but while not cost-efficient for reducing annual emission inventories, the benefits to health and air quality are highly leveraged.

A variety of other abatement options have been implemented in regions with air quality concerns around the world. Many of these programmes involve various forms of technical assistance, outreach, and/or voluntary programmes. Because of the partial correlation with fuel consumption savings, many measures are relatively cost-effective once fuel savings are taken into account. However, user awareness, the availability of capital or funding, technical capacity, and institutional barriers all make implementation a challenge.

With proper planning, evaluation, and policy development, Ireland should be able to develop a NO_x abatement strategy somewhat more effective and cost-efficient than that demonstrated by RAINS.