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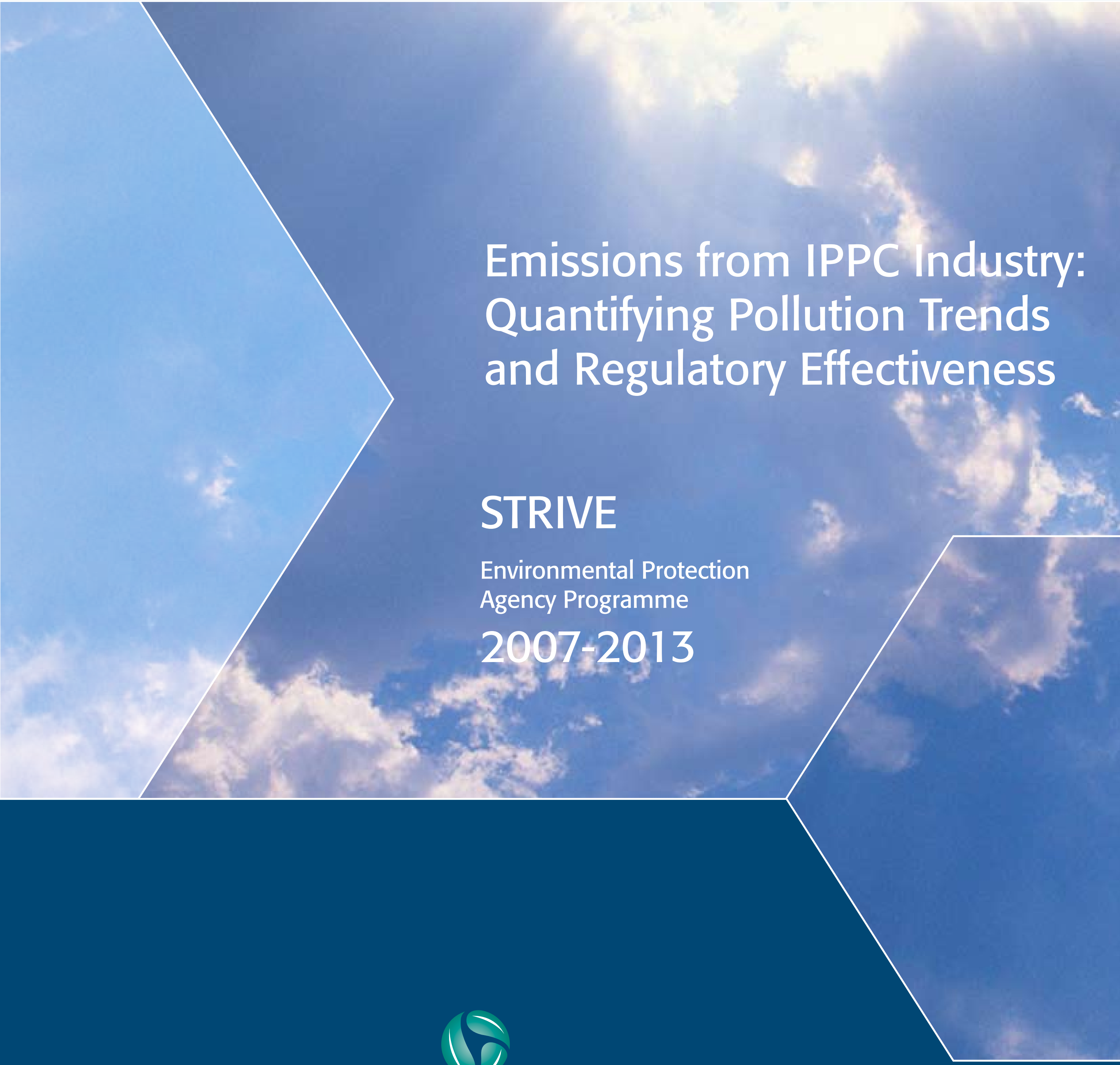

Emissions from IPPC Industry: Quantifying Pollution Trends and Regulatory Effectiveness

STRIVE

Environmental Protection
Agency Programme

2007-2013

SSTI
Strategy for Science, Technology and Innovation

Comhshaol, Oidhreacht agus Rialtas Áitiúil
Environment, Heritage and Local Government

Environmental Protection Agency

The Environmental Protection Agency (EPA) is a statutory body responsible for protecting the environment in Ireland. We regulate and police activities that might otherwise cause pollution. We ensure there is solid information on environmental trends so that necessary actions are taken. Our priorities are protecting the Irish environment and ensuring that development is sustainable.

The EPA is an independent public body established in July 1993 under the Environmental Protection Agency Act, 1992. Its sponsor in Government is the Department of the Environment, Heritage and Local Government.

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We license the following to ensure that their emissions do not endanger human health or harm the environment:

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- the contained use and controlled release of Genetically Modified Organisms (GMOs);
- large petrol storage facilities.
- Waste water discharges

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- Conducting over 2,000 audits and inspections of EPA licensed facilities every year.
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The work of the EPA is carried out across four offices:

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- Office of Environmental Enforcement
- Office of Environmental Assessment
- Office of Communications and Corporate Services

The EPA is assisted by an Advisory Committee of twelve members who meet several times a year to discuss issues of concern and offer advice to the Board.

Emissions from IPPC Industry: Quantifying Pollution Trends and Regulatory Effectiveness

Environmental Research Centre Report

Prepared for the Environmental Protection Agency

by

Trinity College Dublin

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Table of Contents

Executive Summary

1 Introduction

The 1996 EC Directive on Integrated Pollution Prevention and Control (IPPC) licensing (96/61/EC) integrated the regulation of emissions to air, water and land, and the management of wastes and noise, into single licences. Integration of impacts across different media and harmonisation across Member States were intended to ensure high environmental standards throughout the EU and avoid the shifting of environmental pressures to less-regulated media or countries. Although the IPPC Directive was only formally transposed into Irish law through the Protection of the Environment Act in 2003, a similar form of integrated licensing (Integrated Pollution Control, IPC) had been enforced since 1994 by Ireland's Environmental Protection Agency (EPA). Essentially, IPPC licence conditions specify minimum environmental performance standards, including emission limit values (ELVs) associated with application of best available techniques (BAT). Monitoring and reporting of emissions, waste export, resource consumption and local impacts are also required. This report presents the results of a 3-year research fellowship in which air and water emissions data reported by IPPC installations were collated and interpreted in terms of environmental performance, and used to infer the effectiveness of IPPC regulation.

2 Measurement of Environmental Performance

A major output from this study is the novel Environmental Emissions Index (EEI) model, devised to interpret the 20 major air and water emission parameters routinely reported in Annual Environmental Report (AER) summaries submitted by IPPC licensees. Life-cycle impact assessment (LCIA) characterisation, normalisation and weighting methodologies are used to aggregate reported emissions according to their contribution towards total pollution, in the context of six major environmental impact categories:

1. Acidification potential;
2. Aquatic toxicity potential;
3. Eutrophication potential;
4. Global warming potential;
5. Human toxicity potential; and
6. Tropospheric ozone formation potential.

Following characterisation based on appropriate published methodologies, pollution loadings for each impact category are normalised against total loading at either the Ireland or EU15[1] scale. Normalised impact category loadings are then aggregated based on weighting factors derived from distance–policy–target emission loading. Emissions data can thus be interpreted within the context of Ireland or the EU15 using the EEI. Individual emissions are represented within EEI profiles according to their contribution to overall pollution at the scale of normalisation. The EEI enables the comparison of overall pollution loading across installations, and over time.

The relative weighting factors applied to the six impact categories considered in the EEI model reflect current policy targets, but may deviate from best scientific understanding in terms of sustainable emission thresholds. The greatest uncertainties are the magnitudes of some national and EU water emission data for normalisation, toxicity characterisation factors, and weighting factors for toxicity impact categories. Sensitivity analysis performed on the EEI model in relation to Pharma (pharmaceutical manufacturing) sector emissions data indicated that the normalisation process ameliorates the impact of uncertain characterisation factors for all emissions except the aggregate non-methane volatile organic compounds (NMVOC) parameter (characterisation factors are applied to reported emissions and inventoried emissions against which reported emissions are

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[1] EU15 comprises the following 15 countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom.

normalised). Normalisation and weighting uncertainties are of greater importance for EEI outputs and composition. However, for individual Pharma installations, the single greatest potential source of uncertainty is the attribution of a single median toxicity factor to the reported aggregate NMVOC emission parameter. The mix of compounds, and associated toxicities, represented by this parameter could differ considerably across installations.

3 Installation-Level Benchmarking

Installation-level emissions and production data were aggregated for four major IPPC sectors:

1. Power Generation (Power Gen, IPPC activity code 1.1);
2. Food & Drink manufacture (Food & Drink, IPPC activity code 6.4);
3. Pharmaceutical manufacture (Pharma, IPPC activity code 4.5); and
4. (non-Pharma) Chemical manufacture (Chem, IPPC activity code 4.x).

The level of emissions reporting varied considerably across sectors, accounting for between 37% of estimated pollution loading from the Chem sector and almost 100% of estimated pollution loading from the Power Gen sector in 2007. Production data were less frequently reported than emissions data at the installation level, and only the Power Gen sector had sufficient emission and production data to comprehensively benchmark eco-efficiency across all installations. Conservative gap-filling techniques were employed, largely based on the application of emission factors to fuel use. However, substantial under-reporting of fugitive NMVOC emissions by Pharma and Chem installations will need to be addressed, and the potential for static eco-efficiency benchmarking across installations in these two sectors is restricted by the disparate range of chemicals they produce.

Confidentiality and comparability issues limit the potential to use installation-level production data to benchmark the eco-intensity of production across installations and over time. However, trends in absolute pollution were strongly correlated with trends in eco-intensity across Pharma installations, and may be used to evaluate the environmental performance of established installations. This is consistent with the stated goal of IPPC licensing – to achieve continuous pollution reductions at the installation level – and would place the onus on operators to provide some form of production data to justify pollution increases (e.g. for rapidly expanding, newly established operators). Accounting for indirect emissions associated with electricity use increased pollution loading by between 36% for the Chem sector and 106% for the Pharma sector; the activity boundaries used in environmental performance assessment require further consideration.

Reporting levels are improving across IPPC installations, and further anticipated improvements associated with new EU Pollutant Release and Transfer Register (PRTR) requirements should enable reasonably comprehensive quantification of pollution trends across most installations in the near future. In the meantime, aggregating and interpreting available emissions data using the EEI provides a simple, integrated, performance-oriented metric for operators and regulators. Despite data shortcomings, it is important to begin quantifying pollution trends at the installation level, using best available scientific methods, in order to inform efficient management, reporting and regulation, and foster greater environmental accountability.

4 Sectoral Pollution Trends

Trends in total pollution between 2001 and 2007 were estimated for the four IPPC sectors studied, based on aggregation of trends for installations that reported throughout this period and extrapolation to estimated total sectoral emissions. Between 2001 and 2007, annual pollution loadings were reduced by 21% for the Food & Drink sector, 24% for the Pharma sector, 39% for the Power Gen sector, and 83% for the Chem sector. Inflation-adjusted output indices from the Central Statistics Office (CSO) were used to estimate eco-intensity reductions of 38% for the Food & Drink sector, 42% for the Pharma sector, 45% for the Power Gen sector, and 87% for the Chem sector between 2001 and 2007. The Power Gen and Pharma trends were associated with the highest certainty. Large reductions for the Chem sector reflect the closure of high-emitting installations. Limited availability and comparability of material production data meant that it was impossible to derive material-based eco-efficiency trends for either the Food & Drink or Chem sector. Pollution loading trends for installations that reported throughout 2001 to 2007 differed somewhat from total sectoral trends, and equated to pollution reductions of 22%, 28%, 40% and 45% for installations in the Chem (n = 27), Food & Drink (n = 32), Pharma (n = 27) and Power Gen (n = 9) sectors, respectively. The confounding effect of changing installation numbers over time is removed from these trends, which may better reflect the effect of integrated licensing.

There were large reductions in sulphur oxide (SO_x) and nitrogen oxide (NO_x) pollution from all four sectors, largely reflecting a shift in fuel use from heavy fuel oil to light fuel oil and natural gas, and the installation of abatement technologies on large boilers. For the Chem and Pharma sectors, there was a substantial reduction in heavy metal pollution loadings to water (W-HMs), while for the Power Gen sector there were large reductions in carbon dioxide (CO_2) (by over 3 Mt/annum) and heavy metal pollution loadings to air (A-HMs) (by over 2 t/annum). This reflects a shift in electricity generation from coal, peat and oil power stations to combined-cycle gas power stations, and the installation of abatement technology to older stations. A 4.58 kt per annum reduction in ammonia (NH_3) emissions, caused by the cessation of fertiliser manufacturing in Ireland, dominated pollution reduction for the Chem sector.

Integrated licensing was not necessarily responsible for the observed pollution reductions. However, the emissions monitoring and reporting enforced through integrated licensing enabled these pollution trends to be quantified. Based on the results of the Pharma sector case study, it is highly likely that integrated licensing was also a major driver of observed pollution reductions across the Chem, Food & Drink and Power Gen sectors.

5 IPPC Effectiveness

Pollution loading from the Pharma sector was reconstructed back to 1995, based on partial emissions reporting and other data sources. This pollution loading was then extrapolated forward in a reference ‘no-improvement’ pollution scenario for the sector, assuming constant eco-intensity in relation to a material production index. Pollution avoidance was calculated relative to reference pollution, and the proportion of this avoidance attributable to integrated licensing (versus business as usual) was derived from questionnaire responses. Twenty Pharma environmental managers responded to an anonymous questionnaire circulated in March 2009.

Between 2001 and 2007, a 40% reduction in pollution translated into 45% avoidance for the 27 core Pharma installations that reported throughout this period. Reporting for a small number of installations indicated large reductions in SO_x, NMVOCs and W-HMs between 1995 and 2001. These reductions were corroborated by other data sources for non-reporting installations, and extrapolated up to the entire sector. Consequently, it was calculated that sectoral pollution loading was reduced by 59% between 1995 and 2007. Against an estimated material production increase of 70% during this period (partly attributable to new installations), pollution avoidance equated to 76%, i.e. actual pollution was 76% lower than reference, constant eco-intensity, pollution. This was dominated by avoidance of SO_x (97% lower), NMVOCs (71% lower), W-HMs (83% lower) and NO_x (76% lower). The Pharma sector pollution profile has changed considerably since 1995. Despite large decreases in other pollutants, CO_2 emissions increased by 32%. NMVOCs and CO_2 are now the sector’s biggest pollutants, and show no sign of decreasing.

Questionnaire responses indicated that integrated licensing was the most important driver of pollution avoidance, and was responsible for 50% of air pollution avoidance and 30% of water pollution avoidance. Consequently, between 1995 and 2007, it was estimated that integrated licensing reduced pollution by 35%, and individual emissions by between 8% (total phosphorus, TP) and 49% (SO_x) compared with reference, constant eco-intensity, emissions. There has been a considerable reduction in maximum allowable pollution, represented by ELVs in licence conditions, since the introduction of IPC licensing. Reported emissions were considerably below licensed limits for most Pharma installations (in contrast to other sectors). This may be a consequence of fluctuations in process operations and emissions associated with batch-production regimes at Pharma installations, but might also reflect pre-emptive emission reductions in anticipation of future ELV tightening by profitable and risk-averse Pharma operators. In addition to ELVs associated with BAT, it is likely that monitoring and reporting requirements incentivise, and identify opportunities for, continuous emission reductions.

6 IPPC Efficiency and Alternatives

Eight respondents to a detailed 2007 questionnaire indicated that IPPC compliance costs for Ireland's Pharma sector are relatively high, averaging €1.6 million per installation that responded. Most (63%) of compliance expenditure was on operation and maintenance of systems necessary for compliance, whilst 27% was on monitoring and reporting. Of total compliance expenditure, 20% was attributed to the control of air pollution, 30% to the control of water pollution, and 50% to the management of waste. Scaled up to the 27 core installations in proportion to pollution loading, aggregate compliance costs for the control of air and water pollution were estimated at €21.8 million per annum. Attributing external cost estimates to annual emission loadings avoided by integrated regulation indicated that licensing reduces the social cost of pharmaceutical manufacture by €49.0 million per annum, implying a basic benefit to cost ratio of 2.3. However, the net economic impact of integrated licensing on these installations may be lower than indicated by direct compliance costs. Questionnaire responses indicated that licence requirements drive innovation, and encourage licensees to identify production efficiencies. In terms of competitiveness, respondents suggested that licensing had a positive or neutral effect on competitiveness at the national and EU levels (through providing a more consistent regulatory environment), but a negative effect on global competitiveness.

Questionnaire respondents ranked voluntary regulation as the least important driver of emissions reductions within the Pharma sector. Results from this study were compared with those from a recent study[2] of the Chem sector in Padania, Northern Italy. That study found that direct environmental regulation (such as IPPC) had a greater influence on installations than economic and voluntary environmental regulation. Compared with economic and voluntary approaches to regulation, direct regulation has scope (range of pressures considered) and verifiability advantages. However, economic and voluntary instruments have a wider sphere of influence, and have a crucial role to play in cost-effectively reducing pollution from the overall economy, particularly for easily measured parameters (e.g. fuel use, CO_2). Integrated licensing appears to be the best approach to industrial regulation, but could be modified to focus more strongly on environmental outcomes.

7 Conclusions and Recommendations

The monitoring and reporting of emissions and energy use required under integrated licensing provided the large body of data that was used to quantify environmental performance trends in this study. This study focussed on those IPPC sectors with higher levels of reporting, but even amongst these sectors reporting by some installations, and for some parameters, remains poor. Reporting levels have improved significantly since 2001, and there appears to be considerable focus on this issue under new PRTR reporting requirements.

- **Recommendation 1:** The EPA should prioritise the enforcement of full environmental performance (emissions, waste, energy use) monitoring and reporting compliance by all IPPC installations. Validated estimation methods could be used where monitoring is impractical or too expensive.

In accordance with the EPA's risk-based approach to compliance assessment through inspection and reporting requirements, there may be merit to adopting separate compliance criteria for different sectors. This study is biased towards more compliant IPPC sectors (owing to the need for reporting data). For the Pharma and Power Gen sectors, in particular, large pollution avoidance has been achieved in the past decade, in part through implementation of BAT (e.g. waste

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[2] Iraldo, F., Testa, F., Del Borghi, M, Strazza, C., Oikonomou, V., Spijker, E., Patel, M. and Simone, C., 2009. *The Links between Environmental Regulation and Competitiveness in the Building and Construction Sector.* EMPIRE Project – Final Report – Policy Recommendations. CESISP, Genoa, Italy.

solvent incineration and abatement of acidifying gases). For installations and sectors that have installed the first generation of BAT, and established monitoring and reporting (and wider environmental management) systems, there may be scope to reduce prescriptiveness and move towards a more performance-oriented approach that aims to drive continuous improvement.

- **Recommendation 2:** For less compliant IPPC sectors, the regulatory focus should remain on full compliance with BAT standards.

- **Recommendation 3:** For BAT compliant sectors, enforcement of IPPC regulation should shift emphasis away from 'tick-box' compliance assessment towards a less prescriptive, performance-oriented approach. This could focus on a simple central requirement for continuous environmental performance improvement – for example based on 3-year pollution trends measured using metric(s) such as the EEI.

The boundaries of environmental-performance assessment used in regulation will need careful consideration. Accounting for substantial indirect pollution attributable to electricity use is straightforward, and would avoid any incentive to export energy generation off-site. However, licensees should not be allowed to depend solely on declining trends in the pollution intensity of off-site electricity generation to achieve their pollution reduction targets over the (3-year) compliance assessment period. Meanwhile, the expansion of life-cycle boundaries in industrial environmental performance assessment could encourage green procurement policies and effectively extend the sphere of influence of integrated licensing to non-licensed small- to medium-sized enterprises (SMEs).

- **Recommendation 4:** Environmental performance trends used for compliance assessment could be presented in two formats: direct performance only and overall performance (including indirect electricity emissions). Targets should be set for both, so that licensees cannot depend entirely on off-site performance improvements to achieve compliance.

Direct regulation through integrated licensing is probably the best approach to controlling pollution from large industrial installations, fulfilling objectives that voluntary regulation and economic instruments are unable to: enforcing minimum standards, tailoring requirements to the local environmental context, enforcing accurate monitoring and reporting of environmental performance (providing an essential evidence base for regulation). The traditional economic view of environmental regulation overlooks potential innovation and efficiency improvements stimulated by well-designed direct regulation such as IPPC, and thus overstates possible negative competitiveness impacts. Assessed in its entirety, IPPC licensing appears to be an economically efficient form of pollution control.

- **Recommendation 5:** In order to achieve the substantial pollution reductions integral to sustainable development, policy makers and regulators should not shy away from robust direct regulation.

Some IPPC installations are also included in the Emissions Trading Scheme (ETS) for CO_2. The ETS is regarded as the primary mechanism for controlling industrial CO_2 emissions within the EU, because it is capable of co-ordinating least-cost emission reductions across industrial installations. However, the environmental management plan (EMP) requirements of IPPC licensing can add value by requiring ETS participants to consider process-based CO_2 reduction options in the context of overall environmental performance improvements (i.e. considering implications for other emissions), and with reference to any significant off-site emission consequences (avoiding CO_2 outsourcing to non-ETS sectors, and potentially extending regulatory reach beyond large industrial installations).

- **Recommendation 6:** For IPPC installations included in the ETS, IPPC regulation should focus on developing EMPs that integrate CO_2 reductions with wider environmental performance improvements, and that consider indirect influence.

1 Introduction

1.1 Project Aims

This is the End of Project report for a 3-year fellowship entitled *Emissions to Air and Water* funded by the Environmental Protection Agency (EPA) under the Science, Technology, Research and Innovation for the Environment (STRIVE) programme. The primary objectives of this project, as outlined in the original proposal, were to:

1. Construct a database of emissions time series for installations and sectors, based on air and water emissions data reported to the EPA by installations licensed under the Integrated Pollution Prevention Control (IPPC) regime;
2. Develop and apply environmental performance indicators based on reported emissions data;
3. Model emission trends in relation to economic output, and isolate the effect of IPPC licensing compared with business as usual; and
4. Identify, using case studies, specific technologies and practices, in each sector, that reduce emissions.

Each of these objectives has been addressed throughout the project, though more emphasis has been placed on some than others. In particular, the objective to develop environmental performance indicators became a central component of this project, for reasons outlined in Section 2.1. This report summarises the main outputs of the study. More detail, particularly relating to the literature review, methodologies and discussion, is available in three published papers (Styles et al., 2009a,b,c), and should be available from at least one additional paper (Styles et al., submitted).

1.2 Background to IPPC Licensing

The 1996 EC Directive on Integrated Pollution Prevention and Control (IPPC) licensing (96/61/EC) integrated the regulation of emissions to air, water and land and the management of wastes and noise into single licences. Integration of impacts across different media and harmonisation across Member States were intended to ensure high environmental standards throughout the EU and avoid the shifting of environmental pressures to less-regulated media or countries. The IPPC Directive was formally transposed into Irish law through the Protection of the Environment Act, 2003. However, a number of EU Member States, including Finland, France, the Netherlands, Sweden and the United Kingdom, had implemented similar, though less comprehensive, forms of integrated licensing since the early 1990s. In Ireland, Integrated Pollution Control (IPC) licences had been issued since 1994, following the 1992 EPA Act. This Act consolidated the patchwork of environmental regulation and enforcement that previously existed, typical of EU Member States at that time (Silvo et al., 2002; Gray et al., 2007). Previously, industries were regulated by Ireland’s 33 local authorities through the issue of Single Media Licence (SML) discharge permits, in accordance with the Local Government (Water Pollution) Act, 1977 (amended 1990) and the Air Pollution Act, 1987.

1.3 Regulation through IPPC Licensing

The IPPC Directive defines the operations that require IPPC licences in relation to specific activities and their magnitude. In Ireland, over 700 activities are licensed across 12 sectors (EPA, 2006). Essentially, prospective operators intending to perform licensable activities are required to submit details of anticipated operations – including anticipated releases to land, air and water, energy use and waste generation, and a corresponding Environmental Impact Statement (EIS) – to the EPA as part of their licence application. The EPA then decides whether to issue a licence for the proposed installation, and sets out conditions for that licence. These conditions include minimum environmental performance standards, including emission limit values (ELVs), associated with application of best available techniques (BAT) – subject to acceptable local environmental impacts. The European IPPC Bureau in Seville publishes guidance documents outlining minimum environmental performance associated with BAT, and specific examples for each sector (http://eippcb.jrc.ec.europa.eu/). Through consultation with engineers, scientists, regulators, and industry representatives, sector-specific BAT ELVs are intended to balance the highest standards of environmental protection with affordability across the EU, and to guide, but not to prescribe, the adoption of cleaner technologies. Aside from mandatory ELVs, IPPC licences impose a number of additional conditions on operators, including requirements for accident management plans and spillage containment bunds. Of particular relevance to this project are requirements for the monitoring and reporting of emissions, and ongoing environmental performance targets set out in compulsory environmental management plans (EMPs). Licence conditions specify appropriate and enforceable methods for the monitoring of emissions considered significant from individual installations, and their reporting as mass annual loadings in Annual Environmental Reports (AERs). Historic (up to the Reporting Year 2006) emission summary sheets in AERs contain information on 28[1] emission parameters (Fig. 1.1) and form the basis of data collation in this study (Section 2.2). Larger IPPC installations, corresponding to particular activities and mass emission thresholds, are also required to report to the European Pollutant Emissions Register (EPER) – now the European Pollutant Release and Transfer Register (EPRTR). These registers include major industrial point source emissions across the EU (Pulles et al., 2007), and fulfil the transparency and public engagement objectives of the IPPC Directive through publication of installation-level emissions data on a dedicated website: http://eper.ec.europa.eu/.

1.4 Study Sectors

This study focussed on four diverse IPPC-regulated sectors:

1. Food & Drink manufacturing (Food & Drink);
2. Power Generation (Power Gen);
3. Pharmaceutical manufacturing (Pharma); and
4. (Non-pharmaceutical) chemical manufacturing (Chem).

Table 1.1 provides a summary of these four sectors. The Power Gen and Pharma sectors are tightly defined, whilst the Food & Drink and Chem sectors comprise a number of different activities. Initial study focussed on the Power Gen and Pharma sectors, for which detailed annual time series were constructed. Production data were obtained for these sectors, and a questionnaire survey circulated to Pharma installation operators as part of a case study assessing the effectiveness of IPPC licensing for this sector. Data collation for the Food & Drink and Chem sectors focussed on 3 years only: 2001, 2004 and 2007.

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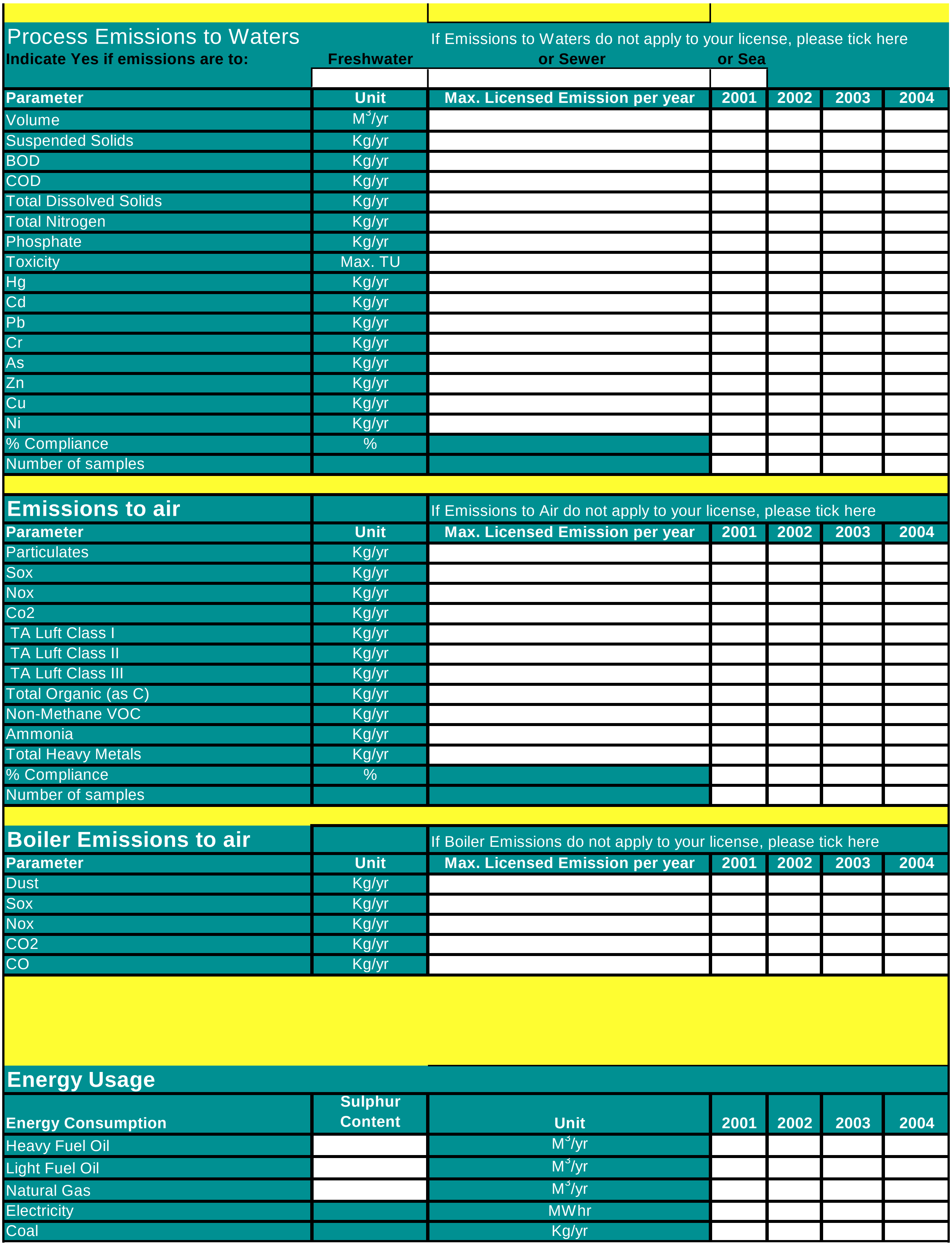
[1] Excluding repetition in ‘Boiler Emissions to air’, and considering ‘dust’ and ‘particulates’ as the same parameter.



Process Emissions to Waters

If Emissions to Waters do not apply to your license, please tick here

Indicate Yes if emissions are to:	Freshwater	or Sewer	or Sea

Parameter	Unit	Max. Licensed Emission per year	2001	2002	2003	2004
Volume	M^3/yr					
Suspended Solids	Kg/yr					
BOD	Kg/yr					
COD	Kg/yr					
Total Dissolved Solids	Kg/yr					
Total Nitrogen	Kg/yr					
Phosphate	Kg/yr					
Toxicity	Max. TU					
Hg	Kg/yr					
Cd	Kg/yr					
Pb	Kg/yr					
Cr	Kg/yr					
As	Kg/yr					
Zn	Kg/yr					
Cu	Kg/yr					
Ni	Kg/yr					
% Compliance	%					
Number of samples						

Emissions to air

If Emissions to Air do not apply to your license, please tick here

Parameter	Unit	Max. Licensed Emission per year	2001	2002	2003	2004
Particulates	Kg/yr					
Sox	Kg/yr					
Nox	Kg/yr					
Co2	Kg/yr					
TA Luft Class I	Kg/yr					
TA Luft Class II	Kg/yr					
TA Luft Class III	Kg/yr					
Total Organic (as C)	Kg/yr					
Non-Methane VOC	Kg/yr					
Ammonia	Kg/yr					
Total Heavy Metals	Kg/yr					
% Compliance	%					
Number of samples						

Boiler Emissions to air

If Boiler Emissions do not apply to your license, please tick here

Parameter	Unit	Max. Licensed Emission per year	2001	2002	2003	2004
Dust	Kg/yr					
Sox	Kg/yr					
Nox	Kg/yr					
CO2	Kg/yr					
CO	Kg/yr					

Energy Usage

Energy Consumption	Sulphur Content	Unit	2001	2002	2003	2004
Heavy Fuel Oil		M^3/yr				
Light Fuel Oil		M^3/yr				
Natural Gas		M^3/yr				
Electricity		MWhr				
Coal		Kg/yr				

Figure 1.1. A template of the Annual Environmental Report summary sheet (superseded in 2008) used to define the scope of emissions data collation and a source of much of the emissions and energy data used in this study.

Table 1.1. Descriptions of the four major sectors, and their sub-sectors, considered in this study, according to Environmental Protection Agency (EPA) activity schedules (and corresponding Integrated Pollution Prevention and Control (IPPC) activity codes where applicable).

Study sector	IPPC activity	EPA schedule	EPA schedule description
Power Gen	1.1	2.1	"*The production of energy in combustion plant the rated thermal input of which is equal to or greater than 50 MW other than any such plant which makes direct use of the products of combustion in a manufacturing process*"
Pharma	4.5	5.6	"*The manufacture of pesticides, pharmaceutical or veterinary products and their intermediates*"
Chem (non-pharma)	NA	5.1	"*The manufacture of chemicals in an integrated chemical installation*"
	4.1	5.2	"*The manufacture of olefins and their derivatives or of monomers and polymers, including styrene and vinyl chloride*"
	4.1	5.3	"*The manufacture, by way of chemical reaction processes, of organic or organo-metallic chemical products other than those specified at 5.2*"
	4.2	5.4	"*The manufacture of inorganic chemicals*"
	4.3	5.5	"*The manufacture of artificial fertilizers*"
			See Pharma sector definition (above) – treated separately
	4.1/4.2	5.7	"*The manufacture of paints, varnishes, resins, inks, dyes, pigments or elastomers where the production capacity exceeds 1,000 litres per week*"
	4.4	5.8	"*The formulation of pesticides*"
	4.2	5.9	"*The chemical manufacture of glues, bonding agents and adhesives*"
	4.2	5.10	"*The manufacture of vitamins involving the use of heavy metals*"
	NA	5.11	"*The storage, in quantities exceeding the values shown, of any one or more of the following chemicals (other than as part of any other activity) – methyl acrylate (20 tonnes); acrylonitrile (20 tonnes); toluene di-isocyanate (20 tonnes); anhydrous ammonia (100 tonnes); anhydrous hydrogen fluoride (1 tonne)*"
Food & Drink	6.4	7.1	"*The manufacture of vegetable and animal oils and fats where the capacity for processing raw materials exceeds 40 tonnes per day*"
	6.4	7.2	"*The manufacture of dairy products where the processing capacity exceeds 50 million gallons of milk equivalent per year*"
	6.4	7.3	"*Commercial brewing and distilling, and malting in installations where the production capacity exceeds 100,000 tonnes per year*"
	6.4	7.4	"*The slaughter of animals in installations where the daily capacity exceeds 1,500 units and where units have the following equivalents – 1 sheep = 1 unit, 1 pig = 2 units, 1 head of cattle = 5 units*"
	6.5	7.5	"*The manufacture of fish-meal and fish-oil*"
	6.4	7.6	"*The manufacture of sugar*"
	6.4	7.7	"*The rendering of animal by-products*"

2 The Environmental Emissions Index

2.1 Purpose

A primary aim of this study was to develop environmental performance indicators to interpret reported emissions data. Licensed installations report a diverse range of air and water emissions to the EPA in AERs. An example of two Pharma installations is used to illustrate the requirement for an integrated indicator of pollution (Table 2.1). Mass annual emissions reported by these two installations for 2004 and 2007 vary considerably across substances, between the installations, and over time. For Installation 1, annual emissions of total nitrogen (TN) and heavy metals (HMs) to water decreased substantially, whilst annual emissions of total phosphorus (TP) to water and non-methane volatile organic compounds (NMVOCs) to air increased substantially. In terms of total mass, annual water emissions decreased by 6.02 t, whilst annual air emissions increased by 1,412 t. For Installation 2, annual TP emissions to water and HM emissions to air increased, but all other emissions remained the same or decreased. In terms of total mass, annual water emissions decreased 2.75 t, and annual air emissions decreased by 25.01 t. In terms of assessing environmental performance, the central question is: How can we compare widely differing masses, and changes in those masses, across installations and over time? Intuitively, 1 kg of HM vapour/particulates released to the atmosphere has considerably greater environmental impact potential than 1 kg of CO_2 released to the atmosphere. Life-cycle assessment methodologies have been developed to answer this question in a scientific and systematic manner, according to environmental damage potential. This chapter summarises how life-cycle impact assessment (LCIA) methodologies were used to devise the Environmental Emissions Index (EEI) used in this study to quantify pollution. For a more detailed

Table 2.1. Mass annual emissions (kg/annum) reported for 2004 and 2007 by two Pharma installations, and percentage change for each emission over this period.

	Installation 1			Installation 2		
	2004	**2007**	**Change**	**2004**	**2007**	**Change**
Emissions to water						
Chemical oxygen demand	15 488	11 307	–27%	5 751	3 154	–45%
Total nitrogen	2 992	1 142	–62%	459	255	–44%
Total phosphorus	10	27	165%	107	158	48%
Heavy metals	6.5	2.7	–59%	6.9	6.1	–11%
Emissions to air						
Particulate matter	6.7	9	33%	91.5	21.2	–77%
Sulphur oxides				372	30	–92%
Nitrogen oxides	7 619	7 806	2%	12 708	12 127	–5%
Carbon dioxide	3.40E+06	4.80E+06	41%	4.40E+06	4.40E+06	0%
Volatile organic compounds	9.60E+03	2.10E+04	115%	1.40E+05	1.30E+05	–2%
Ammonia						
Total heavy metals				0.03	0.28	958%
Carbon monoxide	142	67	–53%	10	0	–100%

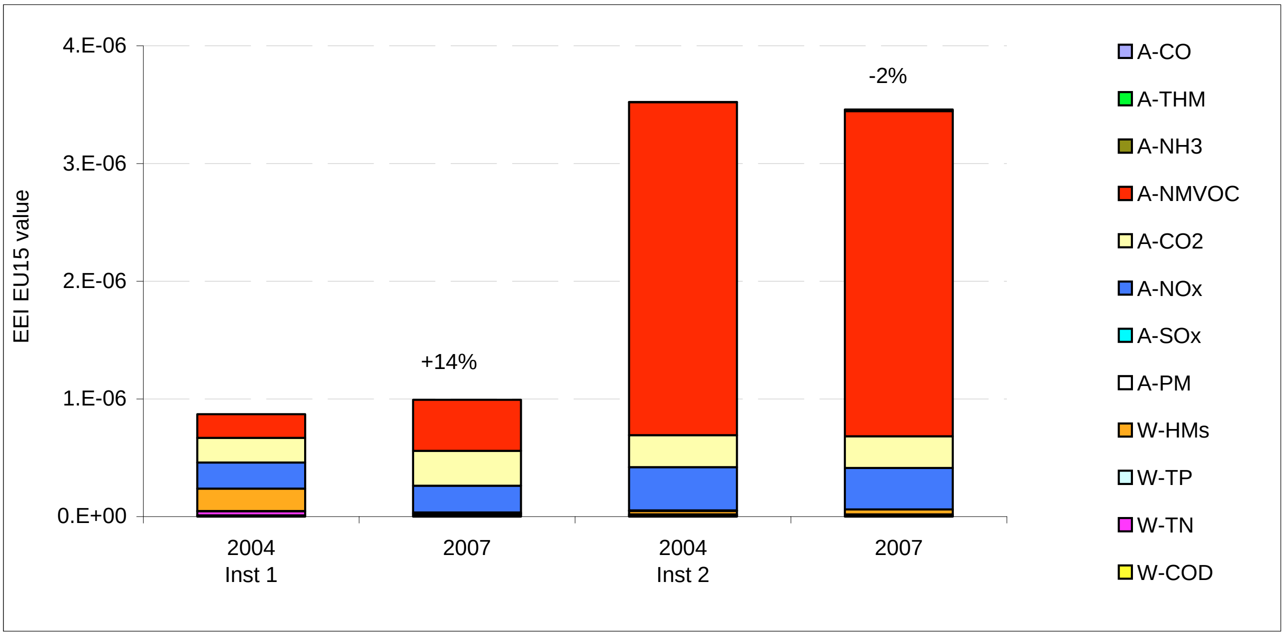


Figure 2.1. Environmental Emissions Index (EEI) profiles based on reported mass emissions for two Pharma installations (Inst 1 and Inst 2), as presented in Table 2.1.

methodological description, see Styles et al. (2009a). The purpose of the EEI is best illustrated through its translation of raw emissions data in Table 2.1 into comparable emissions profiles in Fig. 2.1 (the small, dimensionless values of the EEI are the consequence of normalisation at the EU15[2] scale, described in Section 2.3). Note how the relative contributions of individual emissions within the EEI profile (Fig. 2.1) differ substantially from relative mass annual loadings (Table 2.1). For example, 6.5 kg of HM loading to water account for 22% of total pollution loading from Installation 1 in 2004.

2.2 Input Data

Mass annual emissions data submitted annually in AERs provide the basis for this study. AER emission summaries focus on a suite of 28 parameters, 16 pertaining to water emissions and 12 pertaining to air emissions (Fig. 1.1, Table 2.2). These represent the minimum universal reporting requirement across all sectors, but other sectors have additional requirements on an ad-hoc basis. Mass emissions reporting became more standardised and widespread following the publication of an EPA guidance note in 2000 (EPA, 2000), but some installations had submitted mass annual emissions data under IPC licences since 1994. A new AER reporting procedure was introduced in 2008, compatible with new EPRTR reporting requirements covering 91 substance releases above specified threshold masses (EC, 2006b). For the purposes of this study, the EEI was specifically developed to aggregate emissions parameters contained in historic AER summaries.

Development of the EEI model itself required extensive data input, primarily in the form of characterisation factors (CFs), inventory data for normalisation, and policy targets to derive weighting factors (Section 2.3). The sources of characterisation and inventory data are summarised in Table 2.2. Normalisation and weighting data were collated for Ireland and the EU15 in order to develop and apply the EEI at two scales of context (national and EU). Air emissions are well reported in national and EU inventory and European Monitoring and Evaluation Programme (EMEP) reports (EEA, 2006; EPA, 2007; McGettigan et al., 2007; EMEP, 2008). Calculating mass loading inventories for freshwater and marine emissions was more challenging. For Ireland, the Convention for the

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[2] EU15 comprises the following 15 countries: Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden, United Kingdom.

Table 2.2. Mass-based characterisation factors (multiply by mass substance emitted) applied to Annual Environmental Report (AER)-reported emissions for relevant environmental impact categories, in some instances specific to freshwater (FW) or marine (M) receiving water compartments. The two columns on the right present inventory data sources used to derive normalisation totals.

	GWP	TOFP	AP	ODP	EP	ATP		HTP		Inventory data sources for normalisation	
	CO_2 eq.[1]	NMVOC eq.[2]	Acid eq.[2]	CFC-11 eq.	PO_4 eq.[3]	1,4-DCB eq.[3]		1,4-DCB eq.[3]		Ireland	EU15
Water compartment					FW & M	FW	M	FW	M		
Volume	–	–	–	–	–	–			–	–	–
Emissions to water											
Suspended solids	–	–	–	–	–	–			–	–	–
Biochemical oxygen demand	–	–	–	–	–	–			–	–	–
Chemical oxygen demand	–	–	–	–	0.022	–			–	–	–
Total dissolved solids	–	–	–	–	–	–			–	–	–
Total nitrogen	–	–	–	–	0.42	–			–	OSPAR Commission (2007)	Huijbregts et al. (2003)
Total phosphorus	–	–	–	–	3.06	–			–	OSPAR Commission (2007)	Huijbregts et al. (2003)
Toxicity	–	–	–	–	–	–			–	–	–
Mercury	–	–	–	–	–	6,349	45,861	101	117	OSPAR Commission (2007)	Huijbregts et al. (2003)
Cadmium	–	–	–	–	–	5,752	40,042	11	7	OSPAR Commission (2007)	Huijbregts et al. (2003)
Lead	–	–	–	–	–	32	258	5	7	OSPAR Commission (2007)	Huijbregts et al. (2003)
Chromium	–	–	–	–	–	24	187	1	1	OSPAR Commission (2007)	Huijbregts et al. (2003)
Arsenic	–	–	–	–	–	906	2,184	132	31	OSPAR Commission (2007)	Huijbregts et al. (2003)
Zinc	–	–	–	–	–	352	2,370	0.2	0.2	OSPAR Commission (2007)	Huijbregts et al. (2003)
Copper	–	–	–	–	–	4,746	25,361	0.4	0.3	OSPAR Commission (2007)	Huijbregts et al. (2003)
Nickel	–	–	–	–	–	14,254	30,370	43	8	OSPAR Commission (2007)	Huijbregts et al. (2003)

Table 2.2 ***contd.***

	GWP	TOFP	AP	ODP	EP	ATP	HTP	Inventory data sources for normalisation	
	CO_2 eq.[1]	NMVOC eq.[2]	Acid eq.[2]	CFC-11 eq.	PO_4 eq.[3]	1,4-DCB eq.[3]	1,4-DCB eq.[3]	**Ireland**	**EU15**
Emissions to air									
Particulates	–	–	–	–	–	–	0.82	EMEP (2008)	EMEP (2008)
Sulphur oxides	–		0.031	–	–	–	0.10	McGettigan et al. (2007)	EMEP (2008)
Nitrogen oxides	–	1.22	0.022	–	0.13	–	1.20	McGettigan et al. (2007)	EMEP (2008)
Carbon dioxide	1	–	–	–	–	–	–	McGettigan et al. (2007)	EEA (2006)
TA Luft Class I	–	–	–	–	–	–	–	–	–
TA Luft Class II	–	–	–	–	–	–	–	–	–
TA Luft Class III	–	–	–	–	–	–	–	–	–
Total organic carbon	–	–	–	–	–	–	–	–	–
Non-methane volatile organic compounds	–	1	–	–	–	0.071	8.67	McGettigan et al. (2007)	EMEP (2008)
Ammonia	–	–	0.059	–	0.35	–	–	McGettigan et al. (2007)	EMEP (2008)
Total heavy metals	–	–	–	–	–	8,618	33,921	EMEP (2008)	EMEP (2008)
Carbon monoxide	–	0.11	–	–	–	–	–	McGettigan et al. (2007)	EMEP (2008)
Methane[4]	23	0.014	–	–	–	–	–	McGettigan et al. (2007)	EEA (2006)

[1] IPCC (2001).

[2] de Leeuw (2002).

[3] Guinée et al. (2002).

[4] Methane not routinely reported by all sectors.

GWP, global warming potential; TOFP, tropospheric ozone formation potential; AP, acidification potential; ODP, ozone depletion potential; EP, eutrophication potential; ATP, aquatic toxicity potential; HTP, human toxicity potential; CO_2, carbon dioxide; NMVOC, non-methane volatile organic compound; CFC-11, trichlorofluoromethane; PO_4, phosphate; 1,4-DCB, 1,4-dichlorobenzene.

NB: values are not directly comparable among columns, but values within columns indicate relative importance of each substance to each impact category. In the absence of speciation information in AERs, it was assumed that all emissions of chromium were in the Cr^{3+}, rather than the highly toxic and rare Cr^{6+}, state.

Protection of the Marine Environment of the North-East Atlantic (OSPAR)-reported 2005 median riverine and direct discharges of nitrogen and HMs to coastal waters (OSPAR Commission, 2007) were taken to represent anthropogenic freshwater and marine loadings, respectively. To avoid double counting of air deposition of these substances (see Fig. 2.2), it was assumed that loading attributable to air deposition and natural sources was equal to freshwater-system retention. Based on information from a number of sources (Donnelly, 2001; McGarrigle and Donnelly, 2003; EEA, 2005), OSPAR-reported riverine discharges of phosphorus, measured after freshwater retention in lakes and sediments, were doubled to estimate total upstream anthropogenic loadings. For the EU15, 1995 freshwater and marine loading estimates for nutrients and HMs were taken from Huijbregts et al. (2003), reported in Guinée et al. (2007), and extrapolated to 2004 based on trends in OSPAR-reported emissions[3] (OSPAR Commission, 2006).

2.3 Methodological Overview

The sequence of EEI model development is detailed in Styles et al. (2009a), and summarised in Fig. 2.3. Key points are explained here. The Economics and Cross-Media Effects (ECME) guidance document for BAT assessment, published by the European Integrated Pollution Prevention and Control Bureau (EIPPCB) (EC, 2006a), provided the methodological framework used as a basis for EEI development. That document proposed seven environmental impact categories for the characterisation of air and water emissions from IPPC industry:

1. Acidification potential (AP);
2. Aquatic toxicity potential (ATP);
3. Eutrophication potential (EP);
4. Global warming potential (GWP);
5. Human toxicity potential (HTP);
6. Stratospheric ozone depletion potential (ODP); and

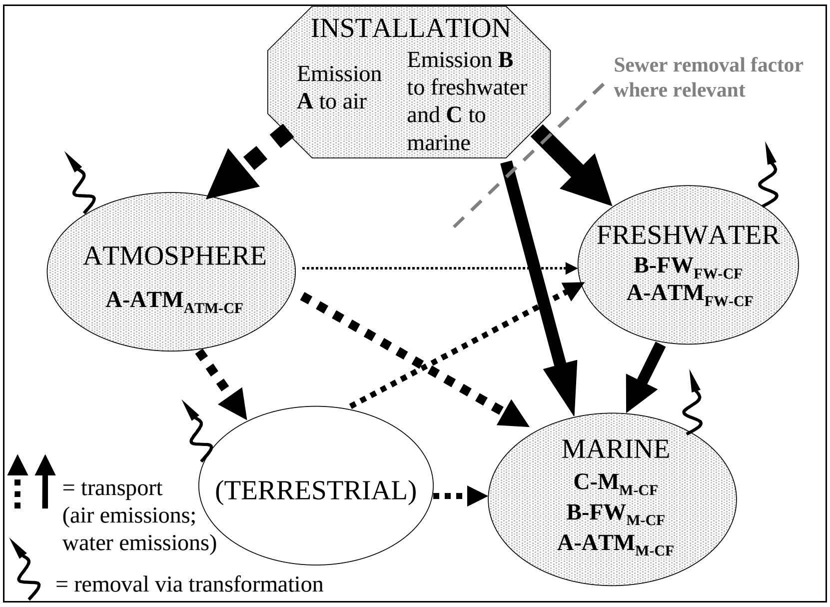

Figure 2.2. An overview of the multiple components of toxicity characterisation factors applied to emitted substances, according to transfer among environmental compartments, reflecting USES-LCA model considerations (Huijbregts et al., 2000a; Guinée et al., 2002). NB: The terrestrial compartment is indicated only as a major transport route considered in USES-LCA modelling, and is not explicitly considered in the aquatic toxicity potential and human toxicity potential impact categories applied in this study.

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[3] OSPAR only covers discharges into the north-east Atlantic, so could not be directly used to estimate total EU15 loading.

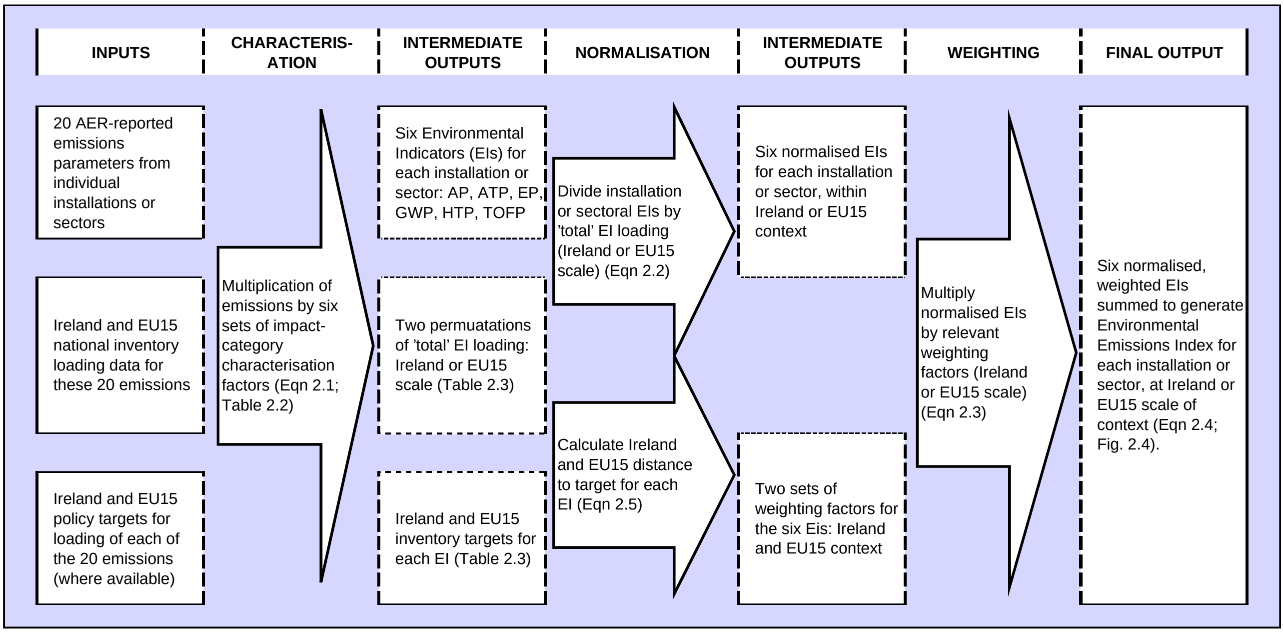

Figure 2.3. Flow chart of procedural steps, input data, and (intermediate) outputs for calculation of final distance-to-policy-target weighted Environmental Emissions Index. NB: European Pollutant Emission Register emission loading data were also used for normalisation, in place of inventory data, for comparison. AER, Annual Environmental Report.

7. Tropospheric ozone formation potential (TOFP)[4].

Of the 28 emission parameters listed in AER emission summaries, 20 were relevant to six of these impact categories (Table 2.2). No substances contributing to ODP were reported in AER emission summaries, so this impact category was omitted from the EEI. Table 2.2 summarises the CFs applied to AER mass annual loading data, and the published sources of the characterisation methodologies used (methodologies were chosen for appropriateness to reported parameters). Characterisation may be summarised thus:

$$EI_{1-6} = \Sigma(E_{i-n} \times CF_{i-n}) \qquad \text{Eqn 2.1}$$

where EI_{1-6} is the environmental indicator for each of the six impact categories, E_{i-n} is the range of reported emissions relevant to each impact category and CF_{i-n} is the impact-category-specific characterisation factors for those emissions. Note that transfer and fate modelling used to generate CFs (Huijbregts et al., 2000a) considered the transfer and impact of emissions across multiple environmental 'compartments' (Fig. 2.2). Water emissions were characterised according to whether they were released into freshwater or marine water, and directly or via a sewer, as indicated in AERs. A sewage treatment removal factor of 0.6 was applied in the latter case to account for reduced final loading to waterbodies (SEPA, 2002).

Characterisation translated reported emissions into loadings for each impact category, expressed as relevant characterisation units (e.g. CO_2 eq. for GWP, molar acid eq. for AP). Reported impact category loadings were then normalised against 'total' loadings:

$$nEI_{1-6} = (EI_i / EI_{tot}) \qquad \text{Eqn 2.2}$$

where nEI is the normalised EI, EI_i is the characterised emissions of interest (from installation or sector), and EI_{tot} is the characterised total emissions at context scale (Ireland, EU15 inventory data). National and EU15-scale total inventoried loadings for the 20 emission parameters reported in AERs were characterised to generate these 'total' environmental loadings for each impact category. Reported loadings

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[4] Referred to as photochemical ozone creation potential (POCP) in the ECME document.

were then divided by total environmental loadings in order to calculate normalised loadings for each impact category. Essentially, normalised loadings represent the relative contribution of reported emissions to six environmental pressures.

Normalised impact category loadings were then weighted and summed to generate the final EEI value:

$$wEI_{1–6} = nEI_{1–6} \times WF_{EI_{1–6}} \qquad \text{Eqn 2.3}$$

$$EEI = \Sigma(wEI_{1–6}) \qquad \text{Eqn 2.4}$$

where wEI is the weighted, normalised EI, and WF_{EI} is the weighting factor specific to each EI.

Policy-defined mass annual loading targets for each of the 20 emission parameters were characterised into the six impact categories (Table 2.3), and the distance between actual and target loadings for each impact category was used to calculate a weighting factor for each category:

$$WF_{EI_{1–6}} = (EI_{tot} – EI_{tar}) / EI_{tar} \qquad \text{Eqn 2.5}$$

where EI_{tar} is the characterised policy target emissions.

There were no available mass annual loading targets for most ATP and HTP emissions, so weighting factors for these impact categories were taken as the mean of the four calculated weighting factors (Table 2.3). At the EU15 scale, these gap-filled weighting factors correspond well with the weighting factors derived elsewhere (Soares et al., 2006). In addition, the HTP weighting factor is consistent with the recently announced target to reduce ambient urban concentrations of $PM_{2.5}$[5] by 20% between 2010 and 2020 (European Parliament, 2008), in order to protect human health. Table 2.4 summarises the key features of the EEI.

2.4 Interpretation, Context and Uncertainties

Once the EEI model had been developed with normalisation and weighting data relevant to the national and EU15 scales of context, total sectoral emissions data reported by the Pharma sector in 2004 were inputted to assess the interpretive features of the model. Key input parameters and the scale of context considered were varied in order to test the sensitivity of

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[5] 5. Particulate matter less than 2.5 mm in diameter.

Table 2.3. National and EU15 inventoried emissions (kt/annum) (2004/2005 values) used for normalisation, policy target emissions, and derived weighting values for each of the environmental categories.

	GWP CO_2 eq.	TOFP NMVOC eq.	AP Acid eq.	EP PO_4 eq.	ATP 1,4-DCB eq.	HTP 1,4-DCB eq.
Total						
Ireland	60,385	240	11.5	135.4	3,401	2,874
EU 15	3,828,000	22,212	543	3,501	130,785	193,251
Target						
Ireland	48,308	165.5	9.6	100.0	NA	NA
EU 15	3,100,680	17,736	457	3,002	NA	NA
Weight						
Ireland	0.25	0.45	0.19	0.35	0.31^2	0.31^2
EU15	0.23	0.25	0.19	0.17	0.21^2	0.21^2

[1] Excludes N_2O, of the three major greenhouse gases.

[2] Average of other weighting factors.

GWP, global warming potential; TOFP, tropospheric ozone formation potential; AP, acidification potential; EP, eutrophication potential; ATP, aquatic toxicity potential; HTP, human toxicity potential; CO_2, carbon dioxide; NMVOC, non-methane volatile organic compound; PO_4, phosphate; 1,4-DCB, 1,4-dichlorobenzene; NA, not applicable because no recent mass emission targets.

Table 2.4. Summary features of the Environmental Emissions Index: the substances contributing to the six impact categories, the characterisation methods applied to these substances, and the impact category weighting factors based on EU15[1] distance-to-policy targets.

Impact category	Substances	Characterisation factor units	Source	Weight
Acidification potential	Sulphur oxides Nitrogen oxides Ammonia	Acid eq.	de Leeuw (2002)	0.19
Aquatic toxicity potential	A-Volatile organic compounds A-Total heavy metals W-Heavy metals	1,4-Dichlorobenzene eq.	Guinée et al. (2002)	0.21
Eutrophication potential	W-Total phosphorus W-Total nitrogen W-Chemical oxygen demand A-Ammonia A-Nitrogen oxides	Phosphate eq.	Guinée et al. (2002)	0.17
Global warming potential	A-Carbon dioxide A-Methane	Carbon dioxide eq.	IPCC (2001)	0.23
Human toxicity potential	A-Nitrogen oxides A-Sulphur oxides A-Particulate matter A-Volatile organic compounds A-Total heavy metals W-Heavy metals	1,4-Dichlorobenzene eq.	Guinée et al. (2002)	0.21
Tropospheric ozone formation potential	A-Volatile organic compounds A-Nitrogen oxides A-Methane A-Carbon monoxide	Volatile organic compound eq.	de Leeuw (2002)	0.25

A-, emissions to air; W-, emissions to water.

EEI outputs, in particular index values and emission profiles, to major assumptions and choice of context. Using current weighting factors, the maximum theoretical value for the EEI is 1.26 (the sum of the six weighting factors) – achieved if measured emissions equate to 100% of EU15 emissions loading. At the EU15 scale, the Pharma sector is responsible for 0.0047%[6] of the total emission loading to the environment across the six impact categories, following normalisation against values in Table 2.3. In summary, EEI values represent the relative contribution of emissions towards total environmental loading (for the 20 considered emissions) at the EU15 scale for each impact category, multiplied by distance-to-target weighting factors. Distance-to-target weighting means that the EEI represents 'excess' emissions loading for each impact category, and thus quantifies the contribution of reported emissions towards overall pollution. The scale of context reflects 'the big picture' in terms of environmental burdens, but may not represent local effects. For example, small loadings of nutrients or HMs to a confined waterbody with high residence times could lead to substantial localised ecological damage. Local effects are considered as part of the licence application/issue process, and during the determination of ELVs applicants must demonstrate negligible local environmental and health effects arising from the proposed activity.

The EEI integrates a number of data sources and methodologies. Data uncertainties (e.g. CFs, normalisation data, and weighting data) and methodological assumptions (e.g. number and definition of impact categories, scale of context, weighting method) are two major types of sources of potential EEI model variability relevant to comparisons across installations, and over time. Figure 2.4 presents

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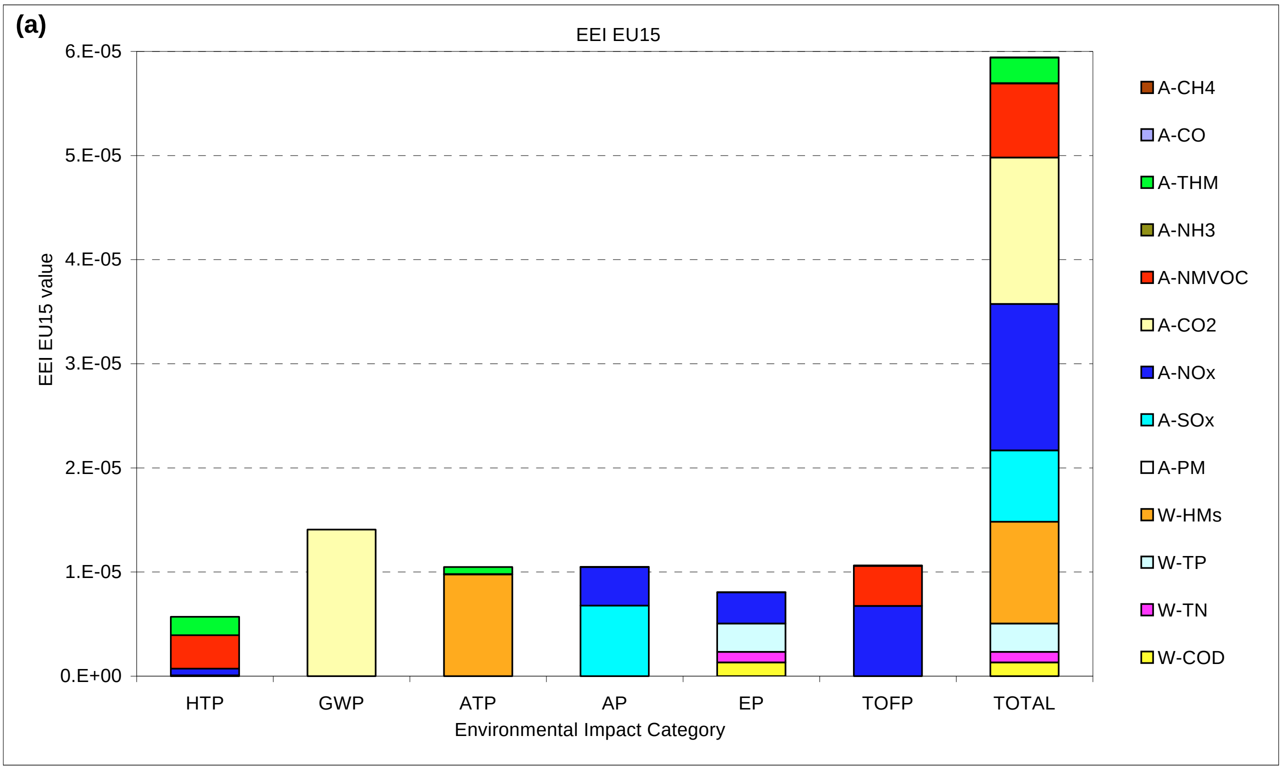
6. The value of the EEI EU15 for reported Pharma sector emissions (5.94×10^{-5}: Fig. 2.4) represents 0.0047% of 1.26.



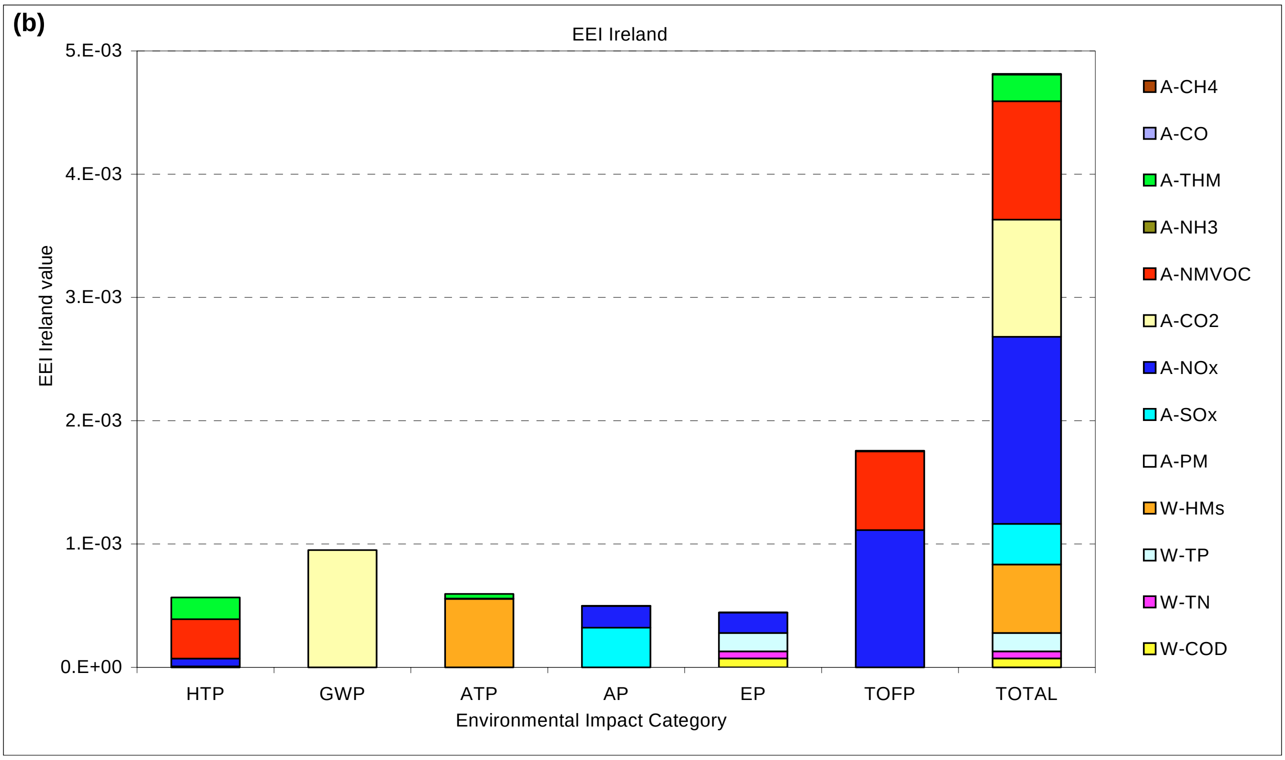


Figure 2.4. The contribution of emissions cumulatively reported by Pharma installations in 2004 towards each impact category, and the final Environmental Emissions Index (EEI) at (a) the EU15 and (b) Ireland scales of context, and (c) in the EU15 European Pollutant Emission Register (EPER) context. HTP, human toxicity potential; GWP, global warming potential; ATP, aquatic toxicity potential; AP, acidification potential; EP, eutrophication potential; TOFP, tropospheric ozone formation potential.

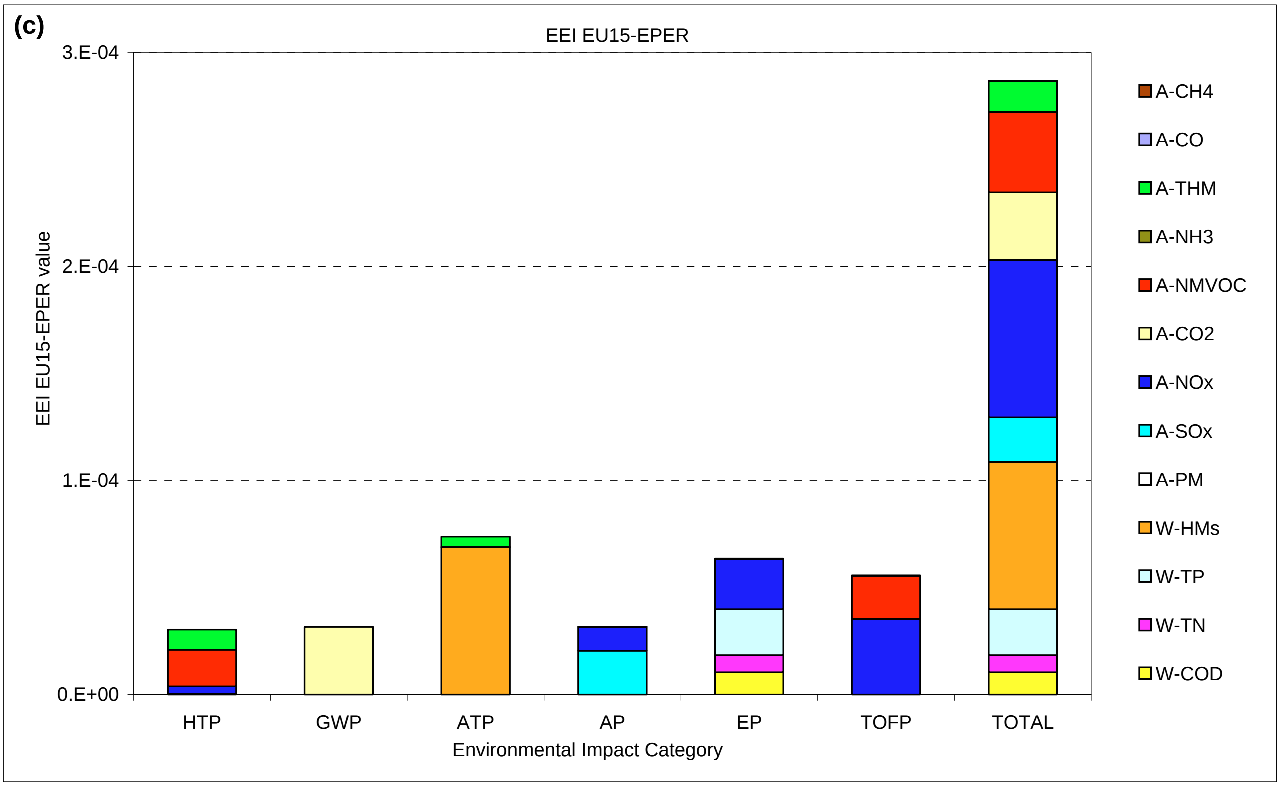


Figure 2.4 ***contd.***

EEI profiles at three scales of context: Ireland, EU15, and EU15 EPER-reported (industrial) emissions. The latter was included because the EPER database provides a convenient source of IPPC emissions data that could be used (as an alternative to national emission inventories) to normalise emissions from a particular installation or sector. Absolute EEI values are inversely proportional to total emissions loading at the scale of context. Hence, values are almost 100 times greater at the Ireland scale, and five times greater using EPER data for normalisation, compared with using inventory data for normalisation at the EU15 scale (Fig. 2.4).

Pollution comparisons across installations and over time will be sensitive to differences in EEI profiles (relative importance of individual emissions) associated with different scales of context. A higher weighting factor for TOFP at the Ireland scale compared with the EU15 scale (0.45 vs 0.25: Table 2.3) reflects high national emissions of nitrogen oxides (NO_X) relative to target (119 vs 65 kt/annum), and results in NMVOCs and NO_X receiving higher weighting at the Ireland than the EU15 scale (Fig. 2.4).

Meanwhile, despite higher weighting factors for EP and ATP at the Ireland scale (Table 2.3), Pharma-reported nutrient and HM emissions to water make a smaller contribution to the EEI at the Ireland scale owing to normalisation against high comparative loading of these substances in Ireland (a consequence of large diffuse agricultural emissions relative to population size). EPER data represent industrial emissions from large point sources. They include a high proportion of total CO_2 and sulphur oxides (SO_X) emissions, but a low proportion of total nutrient and HM emissions to water. Consequently, using EPER data instead of total inventory data to normalise emissions confers lower importance onto CO_2 and SO_X emissions, and higher importance onto the HM emissions to water (Fig. 2.4). Styles et al. (2009a) summarise that poor representation of diffuse, mobile and smaller point sources in EPER means that it provides an incomplete context for emissions normalisation that may distort EEI outputs. Also these authors propose application of the EEI at the EU15 scale of context, owing to the more conservative (less variable) weighting factors across impact categories, and wider applicability, compared with the Ireland scale EEI.

Varying NMVOC and THM CFs (for ATP and HTP), HM normalisation totals, and the ATP weighting factor, made relatively little difference to the overall value and composition of the EEI based on 2004 Pharma AER data (Table 2.5). Altering CFs by ±50% had the smallest effect, with a symmetrical response of ±2% for THM CF variation and ±3% for NMVOC CF variation. Meanwhile, EEI values were moderately sensitive to normalisation totals, varying by between 4% lower and 8% higher in response to a ±50% change in inventory loading estimates of HM emissions to water. Asymmetrical effects reflect interaction between changed emission and normalisation profiles (e.g. when HM loading to water decreases, HM loading to air increasingly influences ATP). Simple, indicative error propagation suggests that the combined EEI uncertainty attributable to the above input uncertainties is –11% and +15% (Table 2.5). The greatest single source of uncertainty is the toxicity of specific NMVOC emission profiles at the installation level. The EEI model assumes that the aggregate toxicity of all installations' NMVOC emissions is the same as the estimated aggregate toxicity of EU15 NMVOC emissions (as represented by the single median toxicity value in the EEI). If it is assumed, for indicative purposes, that NMVOC toxicity could range up to three times higher at the sectoral level, and up to 10 times higher at the installation level, then adjusted EEI values would be increased by up to 11% at the sectoral level and 49% at the installation level (Table 2.5). At the sectoral level, the upper bound of combined uncertainty would increase to +19% (data not shown). Meanwhile, the Canadian expert-panel weighting factors of Soares et al. (2006) would increase the importance of CO_2 emissions, and decrease the importance of NMVOC and NO_x emissions, relative to the standard EEI EU15 (Fig. 2.5). Other emissions remain of similar importance according to both EU15 and Soares weighting. Nonetheless, in terms of interpreting reported emissions data and quantifying pollution trends, these EEI model uncertainties proved to be of lesser importance than uncertainties surrounding data reporting (Section 4.3.2; Table 4.6).

2.5 Summary

The EEI uses LCIA characterisation, normalisation and weighting methodologies to aggregate reported

Table 2.5. Sensitivity of the Pharma sector Environmental Emissions Index EU15 (EEI EU15) value to potential uncertainty ranges in model parameters, expressed as estimated lower and upper confidence limits (CLs). High potential non-methane volatile organic compound (NMVOC) toxicity at the installation level is also assessed.

	Parameter	Uncertainty		EEI EU15 sensitivity	
		CL_{low}	CL_{high}	Low	High
Characterisation factors (CFs)	Total heavy metals CF	×0.5	×1.5	–2%	+2%
	NMVOC CF[a]	×0.5	×1.5	–3%	+3%
Normalisation data	A-Total heavy metals	×0.5	×1.5	–2%	+8%
	W-Heavy metals	×0.5	×1.5	–4%	+8%
Weighting	ATP weighting factor	×0.5	×1.5	–9%	+9%
Combined				**–11%**	**+15%**
Sectoral NMVOC toxicity	NMVOC CF[b]	×0.3	×3	–4%	+11%
Installation NMVOC toxicity	NMVOC CF[b]	×0.1	×10	–5%	+49%

A-, emissions to air; W-, emissions to water; aquatic toxicity potential.

[a] Aquatic toxicity potential (ATP) and human toxicity potential (HTP) CFs applied throughout model (i.e. including to normalisation and weighting data).

[b] ATP and HTP CFs varied only for sectoral emissions data to indicate possible deviation from average NMVOC toxicity at the sectoral and installation levels, respectively.

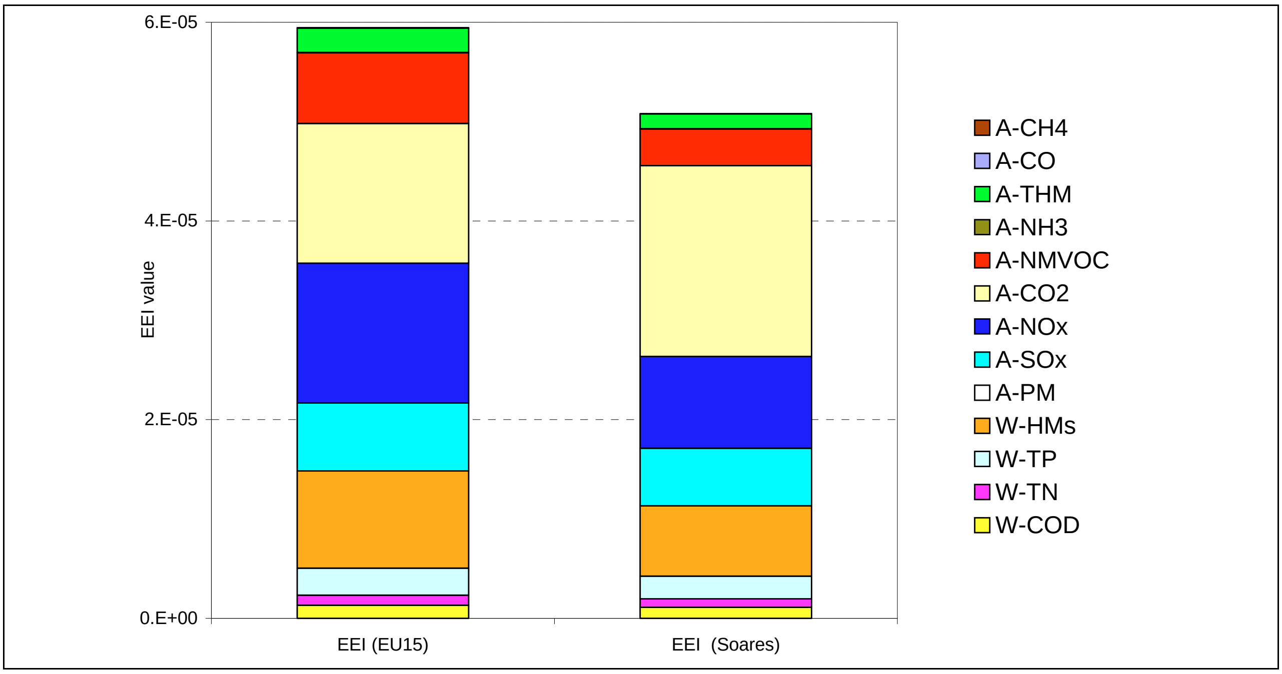


Figure 2.5. The effect of replacing EU15 weighting factors with Soares et al. (2006) weighting factors on the absolute Environmental Emissions Index (EEI) value (15% decrease) and substance profile.

emissions in the context of their contribution towards total pollution across six major environmental impact categories. It was developed specifically to enable comparison of overall pollution loading across installations, and over time, using mass annual loading data for 20 air and water emission parameters routinely reported in AER summaries submitted by IPPC-licensed installations. Specific emissions are essentially represented according to their contribution to overall pollution at the scale of normalisation, though this may not represent *local* pollution impacts.

The relative weighting of the six impact categories considered in the EEI reflects current policy targets, but may deviate from best scientific understanding in terms of sustainable emission thresholds. The greatest uncertainties were the magnitudes of some national and EU water emissions data for normalisation, toxicity characterisation factors, and weighting factors for toxicity impact categories. Application of the EEI to emissions reported by the Pharma sector indicated that the normalisation process ameliorated the impact of uncertain characterisation factors (except for NMVOCs). Normalisation and weighting uncertainties are of greater importance for EEI outputs and composition. However, the single greatest potential source of uncertainty at the installation level is the attribution of a single median toxicity factor to the aggregated NMVOC emission parameter reported by IPPC installations. The mix of compounds, and associated toxicities, represented by this parameter could differ considerably across installations.

A number of EEI model permutations were devised based on different scales of context (Ireland and EU15) and levels of reporting for normalisation data (inventory estimates of total emissions, and EPER reporting of large industrial point source emissions). Although associated with some uncertainty, environmental loadings calculated from total inventory estimates are more comprehensive and generate more meaningful EEI profiles. The authors consider the EU15 scale[7] to be the most appropriate for general application, owing to more conservative weighting assumptions and its wider applicability to installations across the EU15. The EEI is based on normalisation and weighting data that will require periodic updates, and could be extended to include additional parameters as reporting evolves. It should be regarded as an evolving tool.

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[7] Ideally the EU27 scale would be used in future, when sufficient normalisation and weighting data are available

3 Installation Benchmarking

3.1 Background and Aims

To date, most IPPC indicator development and enforcement assessment has focussed on compliance metrics, such as number of complaints or non-compliances (e.g. EPA, 2006; IMPEL, 2008). Enforcing basic procedural and operational compliance has proven to be effective at reducing pollution from licensed installations (Environment Agency, 2004; EEA, 2008; Mirasgedis et al., 2008; Styles et al., 2009c). To ensure continued progress in reducing pollution from IPPC installations, it will be necessary to shift compliance away from procedural and operational metrics and towards environmental performance metrics (Silvo et al., 2002; Blackmore and Yearsley, 2005). There is increasing recognition that mandatory reporting of environmental performance metrics incentivises continuous improvement, and also leads to the identification of 'win–win' efficiencies. Honkasalo et al. (2005) refer to concomitant substantial improvements in key performance indicators (KPIs) and economic efficiency at a large Swedish dairy farm in response to eco-efficiency assessment required under IPPC permit conditions. There remains a need to develop explicit assessment tools that fully encompass the broad scope of IPPC licensing, in order to:

1. Evaluate effective pollution control across installations;
2. Focus regulation on performance; and
3. Instil greater operator responsibility for pollution impacts.

There is a common perception among environmental managers within pharmaceutical manufacturing installations in Ireland that IPPC regulation is overly prescriptive (Styles et al., 2009c), which could result in economically suboptimal environmental improvements (Bréchet and Tulkens, 2009). Performance-based regulation offers the opportunity to build upon the rigour and comprehensiveness of current IPPC regulation, with less prescription. Such regulation would be consistent with the objective of Ireland's EPA to deliver outcome-oriented regulation (EPA, 2007), and the European Commission's emphasis on continuous environmental performance improvement across the IPPC industry – emphasised in a recent report entitled *Beyond Regulatory Compliance* (EC, 2007).

The broad scope of IPPC licensing both poses challenges and provides opportunities for performance-oriented regulation. It has resulted in the implementation of an extensive monitoring and reporting regime across industrial installations (which is becoming increasingly rigorous under EPRTR requirements) that could form the basis for objective and comprehensive environmental performance measurement. However, the range of parameters considered under IPPC licensing – including emissions to air, water and land, waste generation, energy use, and noise – poses challenges for the development of appropriate environmental performance indicators. Globally, reporting for and application of such indicators remain patchy (DEFRA, 2006), though there is an increasing focus on standardisation (http://www.globalreporting.org).

This chapter examines the potential and challenges for using the EEI as a tool to benchmark pollution loading across installations in four IPPC sectors. In particular, following the identification of substantial NMVOC under-reporting at the sectoral level in Chapter 4 and the need for considerable gap filling of emissions data to generate consistent sectoral time series, it is assessed whether emissions data reported by IPPC installations are sufficient to enable a shift towards less prescriptive but more rigorous environmental-performance-oriented regulation of industry. Specific aims of this chapter include:

1. Assessment of data availability for installation-level environmental performance benchmarking;
2. Quantification of absolute and production-normalised pollution loadings and trends at the

installation level across four IPPC sectors using the EEI;

3. Assessment of existing benchmarking opportunities possible using reported data; and

4. Identification of, and recommendations for, future benchmarking opportunities associated with new PRTR reporting requirements.

3.2 Methodology

3.2.1 Compiling the emissions database

The emissions summary sheets of AERs constituted the major data source for emissions time series at the installation level, though it was often necessary to search other sections of AERs to retrieve required data. For the Pharma and Power Gen sectors, all available electronic and hard-copy (including archived) AERs were retrieved, and all emissions and energy data extracted. For the Food & Drink and Chem sectors, AER data retrieval was targeted at the years 2001, 2004 and 2007. Where necessary to fill obvious data gaps, relevant emissions data were taken from other sections of the AER, such as mass-balance reporting for selected substances[8], or company Environmental Statements. For the Pharma sector, mass-balance reporting more than doubled the NMVOC emission loading accounted for in AER emission summaries. Two significant supplementary data sources were (i) a database of 2004 emissions prepared for Ireland's EPER submission (including emissions below threshold reporting values) and (ii) a database of NO_x, SO_x and verified CO_2 emissions for installations, submitted to the EPA under LCPD and EU Emissions Trading Scheme (ETS) reporting requirements. Later AERs typically contained data for the previous 3 years, enabling consistency checks with data submitted in previous AERs. A degree of subjectivity was involved in resolving frequent discrepancies in order to produce consistent time series.

Generating consistent and complete time series also involved considerable gap filling based on interpolation and application of emission factors. Fuel-use data provided a basis for much gap filling of missing emissions data across the four sectors, through the application of installation-specific or standard emission factors (Table 3.1). Thistlethwaite et al. (2006) produced installation-specific HM and PM emission factors for application to power station fuel-use data. These were applied to gap fill emissions time series in the Power Gen sector. Where reported, water emissions contributed between 0.01% and 0.16% towards individual power station EEI values, so were excluded from further consideration in the context of

Table 3.1. Key characteristics and emission factors applied to fuel-use data reported in Annual Environmental Reports, used to fill gaps in emissions reporting.

Fuel	Density	Net calorific value		CO_2	SO_x	NO_x
	(t/m^3)	(MWh/t)	(MWh/m^3)		(kg/MWh)	
Natural gas	0.000717	15.11	0.0108	204.3	0	0.42
Light fuel oil	0.85	12.03	10.23	263.9	0.42	0.42
Heavy fuel oil	0.98	11.46	11.23	273.6	4.36	4.36
Coal	–	7.73	–	340.6	6.47	–
Peat	–	–	–	439.0	–	–
Propane	–	13.78	–	242.8	0	0.42
Tallow	–	11.46	–	0	0	0.44
Biogas	–	–	0.0065	0	0	0.42

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[8] Licence conditions require mass-balance accounting of pre-selected substances in particular years for some installations. This reporting provides a snapshot of particular substance emissions (including fugitive NMVOC emissions) sometimes not accounted for in AER summaries. New PRTR-compliant reporting requirements require specific reporting of fugitive emissions.

power stations. In summary, gap filling was based on four methods used in decreasing order of preference:

1. Use of alternative data sources where available and consistent (Environmental Statements, ETS and LCPD data);
2. Application of standard emission factors for relevant emissions (CO_2 and SO_2 from fuel use), or application of empirical, installation-specific emission factors (e.g. linear THM and PM to fuel-use ratios, non-linear NO_x to fuel-use ratios);
3. Interpolation from reported emissions for adjacent years; and
4. Static time series based on emissions reported for 1 or 2 years (this was performed for eight pharmaceutical installations that only reported NMVOCs to the 2004 EPER submission database).

Four emissions databases, one for each sector, were generated. Separate columns specify the installation identification, reporting year, receiving waters, direct or sewer discharge, and each of the AER emission, fuel-use and production parameters. Rows are grouped by installation, and ordered by year.

3.2.2 *Data availability and quality*

The quality of reporting was graded from A to E for each installation, for the years 2001, 2004 and 2007, according to the descriptions outlined in Table 3.2. Essentially, reporting at Grades A–C was sufficient for the generation of a complete EEI for the installation, but the certainty that all emissions were accurately represented decreases from high at Grade A to medium at Grade C (particularly with respect to NMVOC emissions). Reporting at Grade D enabled the construction of an estimated but incomplete EEI based mostly on emission factors from fuel use. Grade E reflects no emissions or fuel-use reporting.

For 2007, the reported pollution loading was compared with gap-filled pollution loading and estimated total pollution loading for operational installations in each sector. Gap-filled emissions time series were used to generate best estimates of installation-level pollution loading. Conservative estimates of total sectoral pollution loading were extrapolated from gap-filled emissions time series for installations that reported throughout 2001–2007, based on the ratio of reporting installations to known licensed, operational installations in each sector. At the sectoral level, it was possible to correct for considerable under-reporting of fugitive NMVOC emissions from the Pharma and Chem sectors (Chapter 4) using sectoral NMVOC emission inventories estimated by CTC (2005). Estimated sectoral pollution loadings were used to provide an indication of the overall completeness of reporting for each sector.

3.2.3 *Extended EEI*

On-site fuel use accounted for a large portion of reported emissions, and provided the main basis for emissions gap filling. Electricity use may substitute on-site fuel use, resulting in reduced direct emissions but increased indirect (electricity generation) emissions, and possibly increased life-cycle emissions for production at reporting installations. The benchmarking implications of including indirect emissions associated with the generation of consumed electricity in installation pollution loadings were

Table 3.2. Description of the grading system applied to emissions reporting by Integrated Pollution Prevention and Control (IPPC)-licensed installations, and the corresponding quality of Environmental Emissions Index (EEI) outputs.

Grade	Description	Output
A	Appears complete	Complete EEI, high certainty
B	Complete following minor or high-certainty gap filling	Complete EEI, high certainty
C	Complete following significant or low-certainty gap filling	(Complete) EEI, medium certainty
D	Incomplete, substantial gap filling required	Incomplete EEI, low certainty
E	No emissions reporting (some gap filling from fuel use)	No EEI

therefore assessed. Using data from the IPPC-licensed Power Gen sector, adjusted to account for alternative electricity generation in the final national electricity-supply mix based on Howley et al. (2008a)[9], the mass annual indirect emissions (PM, SO_x, NO_x, CO_2, THMs) attributable to reported electricity consumption at each Food & Drink, Pharma and Chem installation were quantified. Indirect emissions were included in a modified EEI (mEEI) for each installation, and their additional contributions were expressed relative to original EEI values. Values, and 2004–2007 trends, were compared for the EEI and mEEI in order to ascertain the effect of including indirect pollution on the performance ranking of installations.

3.3 Results

3.3.1 Data availability

For the Power Gen and Pharma sectors, emissions reporting was relatively complete in 2007, graded at ‘A’ or ‘B’ standard for the majority of installations, with all licensed and operating installations reporting at least some data (Table 3.3). Gap filling essentially enabled complete representation of Power Gen pollution loading (Fig. 3.1). Obvious under-reporting of NMVOC emissions was reflected in the 29% of Pharma installations with reporting classified as ‘C’ or ‘D’ standard, and resulted in a 32% deficit between cumulative installation-level gap-filled pollution loading and estimated sectoral pollution loading (Fig. 3.1). Just 39% of Food & Drink installations and 21% of Chem installations reported at ‘A’ or ‘B’ standard, whilst 47% of Chem installations reported small quantities of data (typically fuel use). Consequently, reported emissions from these two sectors accounted for just 53% and 37%, respectively, of estimated total pollution loading in 2007 (Fig. 3.1) – increasing to 81% and 43%, respectively, following gap filling. For the Food & Drink sector, NO_x, CO_2 and SO_x were the most under-reported emissions, whilst non-reported NMVOC emissions accounted for 26% of total estimated pollution loading from the Chem sector (Fig. 3.1). Overall, the level of reporting has improved considerably since 2001 (Table 3.3).

In 2007, the frequency of production reporting ranged from 26% of licensed installations for the Food & Drink and Chem sectors to 88% of licensed installations for the Power Gen sector (Table 3.3). With the exception of the Chem sector, the frequency of production reporting has increased since 2001. For the Power Gen sector, gap filling based on fuel use for two small power stations that didn’t report electricity generation in 2007 (and correction of erroneously high electricity-generation data from one power station) resulted in a

Table 3.3. Frequency of reported emissions and production data for the four sectors, expressed as a percentage of the number of licensed operating installations for the years 2001, 2004 and 2007. Emissions reporting is classified according to completeness (from A, complete reporting to E, no reporting).

		Power Generation			Pharmaceutical			Food & Drink			Chemical		
		2001	2004	2007	2001	2004	2007	2001	2004	2007	2001	2004	2007
Licensed (n)		14	17	16	32	37	35	57	59	57	53	51	47
Emissions reporting	**A**	0%	0%	38%	6%	22%	31%	5%	7%	14%	6%	6%	4%
	B	50%	76%	56%	28%	49%	40%	11%	24%	25%	11%	16%	17%
	C	21%	12%	6%	44%	16%	20%	28%	41%	44%	4%	8%	19%
	D	29%	12%	0%	16%	11%	9%	21%	20%	11%	53%	61%	47%
	E	0%	0%	0%	6%	3%	0%	35%	8%	7%	26%	10%	13%
Production data		57%	71%	88%	53%	54%	66%	16%	17%	26%	25%	24%	26%

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[9] Final electricity CO_2 intensities of 0.624 and 0.543 kg CO_2 eq./kWh in 2004 and 2007, respectively, in relation to aggregate IPPC Power Gen CO_2 intensities, were used to scale down all IPPC Power Gen sector emissions.

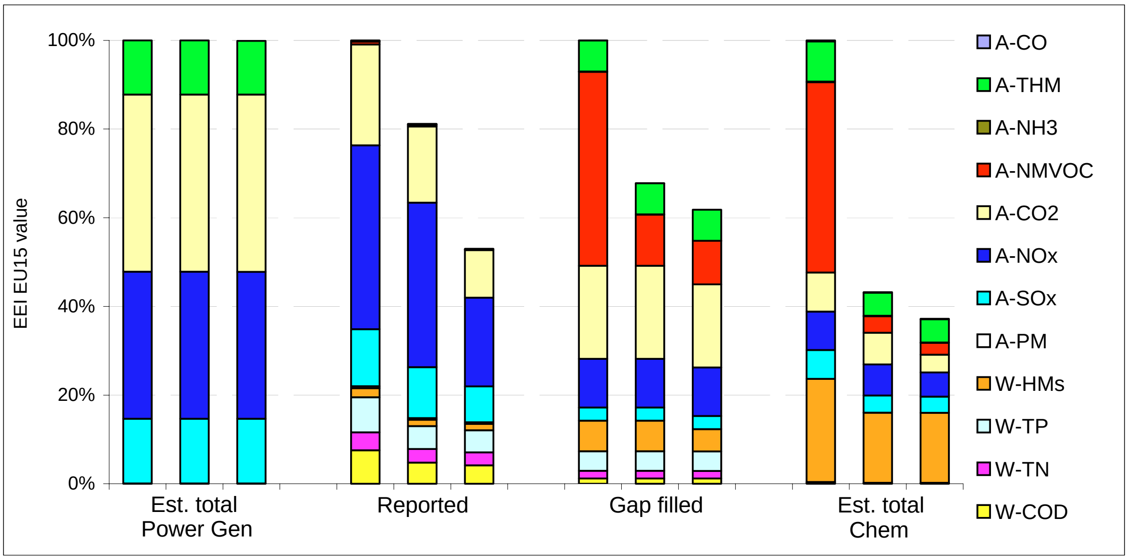


Figure 3.1. A comparison of 2007 cumulative gap-filled versus cumulative non-gap-filled reported emissions for the four sectors. NB: Whilst all major installations in the Power Gen and Pharma sectors were represented by reported data, 48 out of the 58 licensed and operating Food & Drink installations reported some data, and 38 out of the 47 licensed and operating Other Chemical installations reported some data. EEI, Environmental Emissions Index.

complete installation-level production time series. Meanwhile, production data from the Food & Drink sector are heterogeneous, including head of cattle, sheep or pigs slaughtered, tonnes of sugar, tonnes of milk powder and hectolitres of beer produced. Pharma production data are mostly expressed as tonnes active pharmaceutical ingredient (API), though in a few cases also as ‘batches’ and ‘million vials’, and it is not always clear that packaging is excluded from reported tonnages.

3.3.2 Pollution loading

Installation pollution loadings exhibited approximately log-normal distributions within the Power Gen and Pharma sectors, with distributions skewed towards one high value in the Power Gen sector and a small number of low values in the Pharma sector (Fig. 3.2). Pollution loading exhibited a bi-modal distribution across installations in the Food & Drink sector, and approached a normal distribution across installations in the Chem sector.

Cumulative pollution loadings from installations that reported through 2004–2007 declined substantially, by between 2.8% per annum for Chem installations and 9.1% per annum for power stations (Table 3.4). Pollution loadings exhibited declining trends for a majority of installations in the Power Gen and Food & Drink sectors, for 50% of Chem installations, and 44% of Pharma installations. Median pollution reductions were substantially smaller than cumulative pollution reductions for the Power Gen and Food & Drink sectors, whilst the median Pharma installation pollution trend was upwards (Table 3.4). Cumulative pollution loading trends were dominated by reductions from higher-emitting installations, countering pollution loading increases from lower-emitting installations. Production data are required to ascertain whether this difference in trends reflects production increases from smaller installations or risk-based regulatory focus on larger emitters.

3.3.3 Ecological-intensity benchmarking

A complete eco-efficiency comparison across installations was possible only for the Power Gen sector, owing to high levels of emissions reporting and comparable reported production outputs (GWh electricity exported to the grid). Aggregating major air emissions using the EEI indicates that unabated heavy metal emissions dominate the pollution loading from

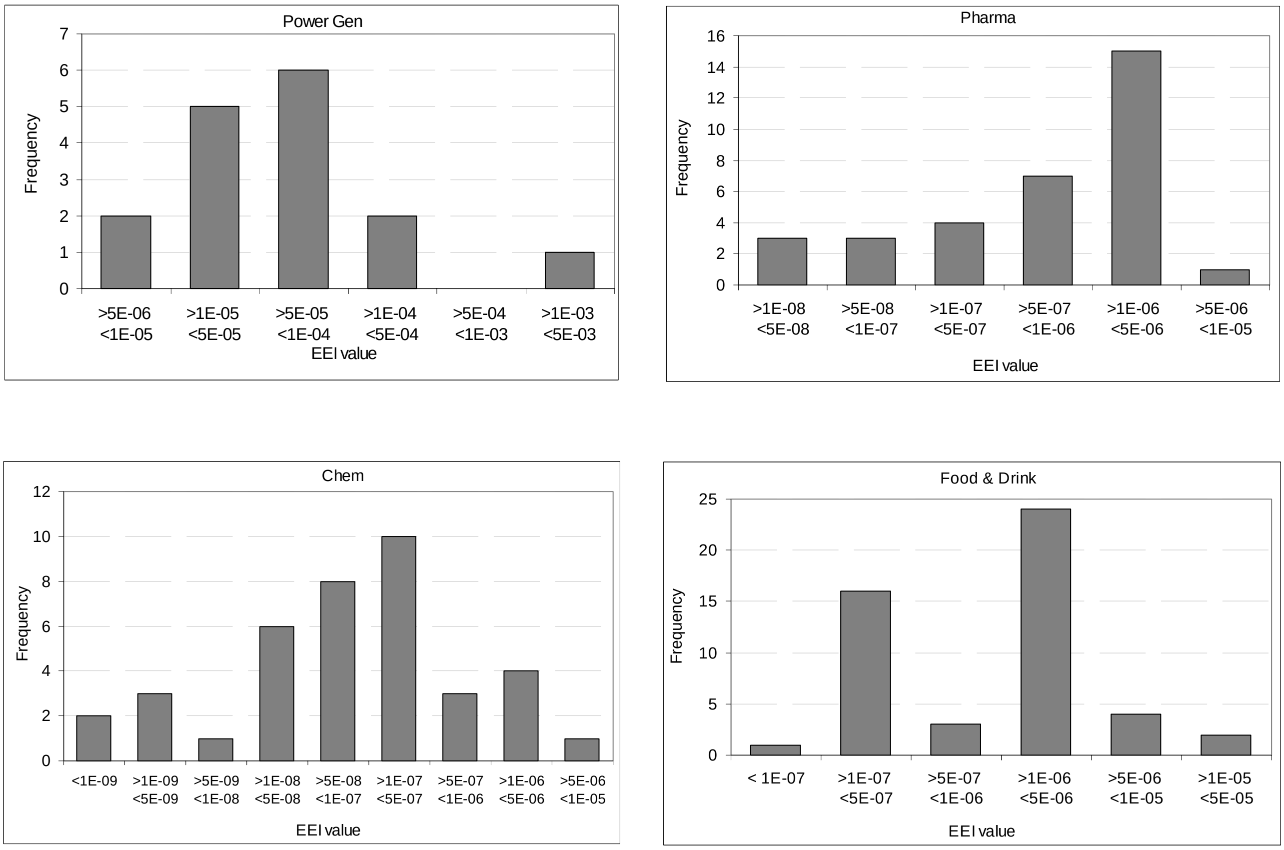


Figure 3.2. The distributions of pollution loading (Environmental Emissions Index (EEI) values) across all reporting installations in 2007 for the four studied sectors.

Table 3.4. Summary of pollution loading trends across installations between 2004 and 2007. The number of installations reporting pollution reductions and pollution increases are displayed for each sector, along with median installation trends and aggregate pollution trends.

Sector	No. of installations	Reduction	Increase	Pollution trends	
		n (%)		Median	Total
				%/annum	
Power Gen	12	8 (67%)	4 (33%)	–5.8%	–9.1%
Food & Drink	45	25 (56%)	20 (44%)	–2.0%	–7.0%
Pharma	32	14 (44%)	18 (56%)	+1.2%	–7.9%
Chem	34	17 (50%)	14 (41%)	–2.4%	–2.8%

power stations burning heavy fuel oil (Fig. 3.3). Large contributions of SO_X, NO_X and HMs to pollution loadings, relative to large CO_2 emissions, reflect: (i) the former emissions' contributions to multiple impacts (Table 2.4), and (ii) the relative contributions from these power stations towards total EU15 loadings for these emissions. Unabated pollution loading from an old, lower-efficiency heavy fuel oil power station is 13 times greater than pollution loading from a new, higher efficiency combined-cycle gas power station, per GWh electricity generated (Fig. 3.3). Fuel type and combustion/abatement technology are the dominant determinants of pollution. Trends in absolute pollution loading were not correlated with trends in production-normalised pollution loading across the power stations that reported throughout 2004–2007 (Fig. 3.4). Large

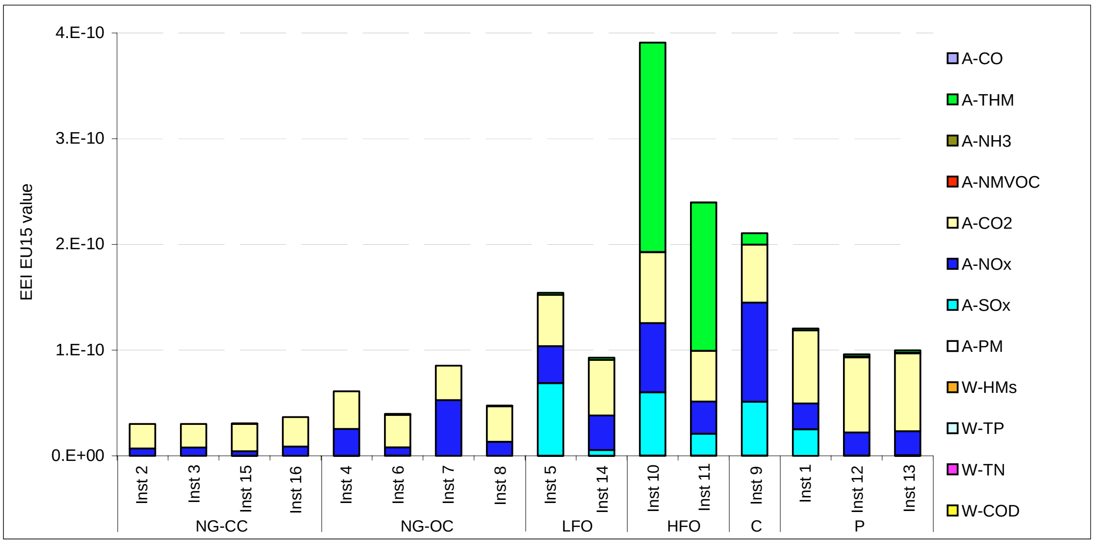


Figure 3.3. Pollution loading per GWh electricity generated across Integrated Pollution Prevention and Control (IPPC)-licensed power stations operating in 2007, grouped according to type (natural gas combined-cycle (NG-CC), natural gas open cycle (NG-OC), light fuel oil (LFO), heavy fuel oil (HFO), coal (C), peat (P)). EEI, Environmental Emissions Index.

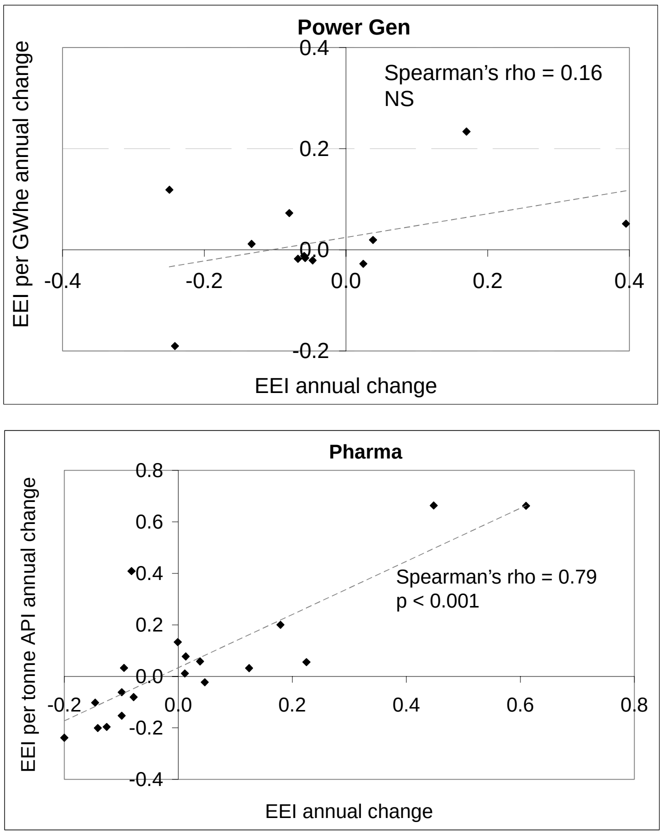


Figure 3.4. Relationships between annualised 2004–2007 trends in absolute and production-normalised pollution loading across installations in two sectors. Trends are expressed as average annual fractional change in pollution or eco-intensity for each installation. EEI, Environmental Emissions Index; API, active pharmaceutical ingredient.

reductions in pollution loading from these 12 power stations coincided with declining electricity outputs from them as new power stations came into operation – perhaps declining load factors (percentage of electricity-generating capacity utilised) for the older stations contributed to a decline in operating efficiency (and higher emissions per GWh generated).

There were sufficient data to calculate production-normalised pollution loadings for 21 Pharma installations in 2007 (Fig. 3.5). Pollution loadings per tonne of API produced varied by a factor of almost 2 million if the extreme lower and upper values are included, reflecting a wide range of reported mass API production – from 0.039 t at Installation 15 to 76,592 t at Installation 17 in 2007 (Fig. 3.5). The range in production-normalised pollution loading was reduced to a factor of 200 if these two extreme cases were removed, but still exceeded the range in absolute pollution loading (a factor of 68) for these 21 installations. There are some wide variations in the pollution profiles across installations. A large NMVOC emission profile for Installation 10 reflects full fugitive emission reporting, whilst a large heavy metal emission profile for Installation 12 coincides with the first year that this emission parameter was reported by that installation (and may reflect a reporting error). Incomplete reporting of fugitive NMVOC emissions, and wide variations in the types and quantities of APIs produced, limit the scope for benchmarking static eco-efficiency across Pharma installations. However, a strong correlation in the rankings of absolute and production-normalised 3-year pollution trends (Fig. 3.4) suggests that 3-year trends in absolute pollution loading could provide a reasonable benchmarking indicator for established installations within this sector.

Product outputs from Food & Drink installations range from animal carcasses, through fish, to cider. Slaughterhouses comprise the largest sub-sector, although the mix of animals slaughtered varies across installations. Consequently, and as a result of incomplete reporting by some installations and differences in the proportion of final energy supplied by electricity, pollution loadings per animal head vary considerably across installations (Fig. 3.6). For example, over 90% of reported energy use is in the form of electricity for Installation 6, resulting in a small proportion of direct pollution loading attributable to air emissions for this installation. Reporting levels at Installations 2 and 8 were poor, and the accuracy of low reported water emissions and fuel use (used to gap-fill air emissions) relative to production output at these two installations is questionable. The use of heavy fuel oil in this sector (e.g. two-thirds of

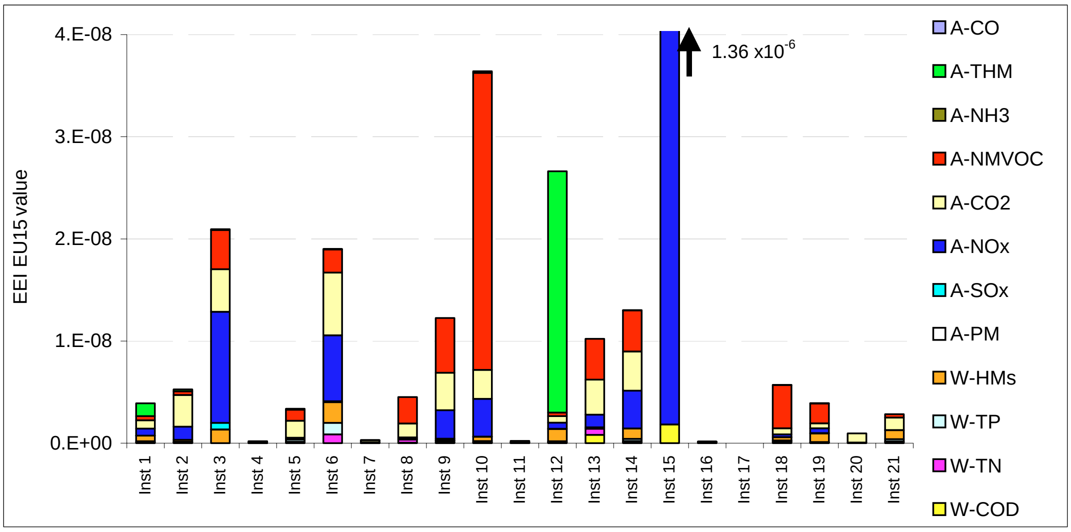


Figure 3.5. Pollution loading per tonne active pharmaceutical ingredient produced for the 21 Pharma installations that reported both emissions and production data in 2007. EEI, Environmental Emissions Index.

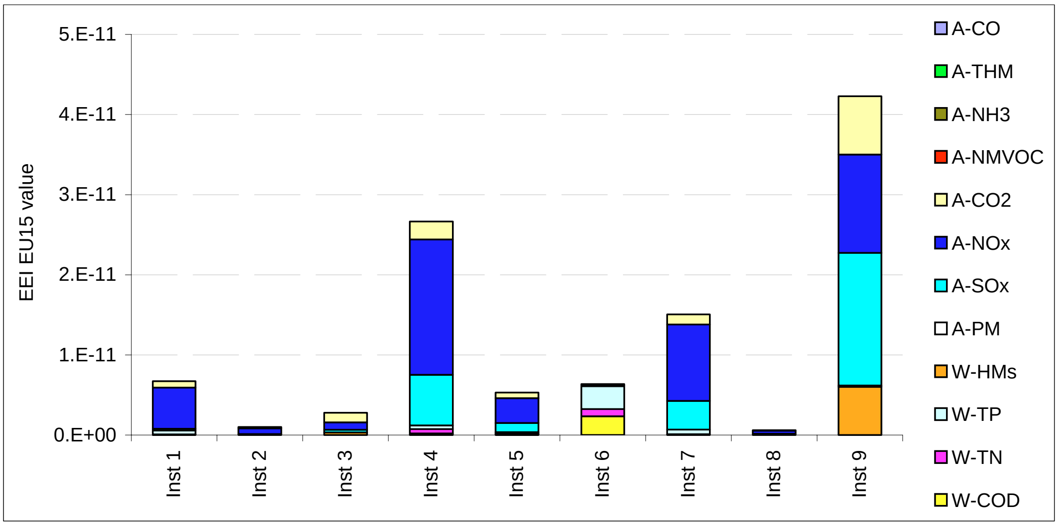


Figure 3.6. Pollution loading per animal head slaughtered for the nine slaughterhouses that reported both emissions and production data in 2007. EEI, Environmental Emissions Index.

Installation 4 final energy use) accounts for high NO_X and SO_X emissions relative to CO_2. Only five installations reported sufficient emission and production data throughout 2004–2007 to enable the comparison of 3-year trends. A disparate range of products, from tarmac to glue, prevents meaningful eco-efficiency benchmarking across Chem installations.

3.3.4 Scope and prospects for pollution benchmarking

On-site fuel combustion is a major pollution source for all four of the study sectors, and completely dominates the life-cycle pollution loading of electricity generation at power stations. However, electricity accounts for between 24% of final energy consumption in the Food & Drink sector and 39% of final energy consumption in the Pharma sector (Table 3.5). Accounting for the indirect 'outsourced' pollution associated with the generation of that electricity adds between 36% and 106% to the total pollution loading from these sectors, making energy use the dominant pollution source across all sectors. Significantly higher median additional pollution loadings in the Pharma and Chem sectors (Table 3.5) suggest that indirect emissions attributable to electricity consumption make a greater relative contribution to pollution loadings from lower-emitting installations in these two sectors. Nonetheless, installation rankings according to pollution loading remain very strongly correlated

Table 3.5. Summary of electricity use reported by installations in 2004 and 2007, the median and cumulative increase in installations' 2007 modified Environmental Emissions Index (mEEI) values attributable to inclusion of indirect electricity emissions, and the relationship between EEI and mEEI values and trends.

	Food & Drink	Pharma	Chem
Electricity used 2004 (% energy use) (GWh)	349 (20%)	618 (41%)	60 (23%)
Electricity used 2007 (% energy use) (GWh)	364 (24%)	486 (39%)	63 (31%)
Median % addition to 2007 EEI	39%	160%	83%
Cumulative % addition to 2007 EEI	42%	106%	36%
2007 EEI vs mEEI (rho)	0.97***	0.90***	0.80***
EEI vs mEEI change 2004–2007 (rho)	0.91***	0.85***	0.80***

***$p \leq 0.001$.

before and after inclusion of indirect pollution associated with electricity generation, with rho values ranging from 0.80 in the Chem sector to 0.97 in the Food & Drink sector (Table 3.5). Crucially, despite an increase in the proportion of final energy use provided by electricity in the Chem sector between 2004 and 2007, 3-year pollution trends also remain strongly correlated across installations before and after inclusion of indirect electricity emissions across all three sectors (Fig. 3.7; Table 3.5).

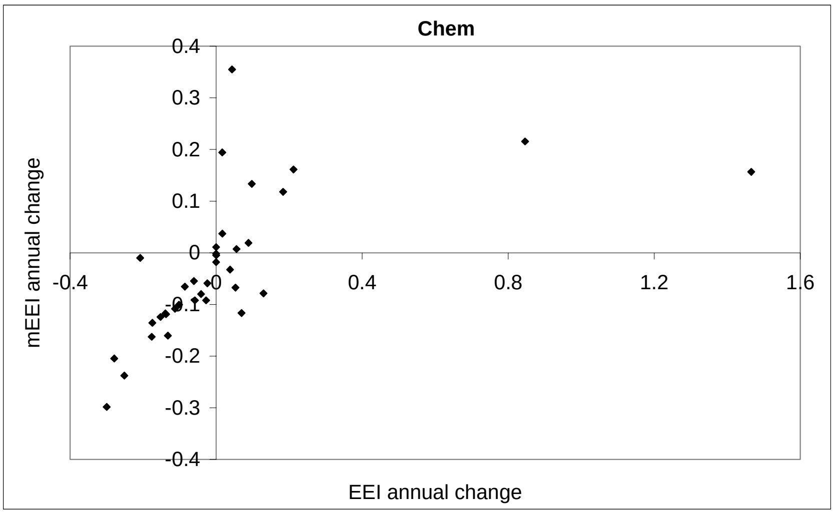
Use of reported emissions data for benchmarking purposes will necessitate greater scrutiny and verification of submitted data to ensure consistency across installations. Incorrect reporting of units was common. For example, the AER reporting summary requests that oil consumption is reported as m^3/annum, but data were also reported as litres and megawatt-hours (these mistakes were identifiable from inconsistencies with other years, or separate energy consumption data reported elsewhere in AERs). In addition to non- or obvious misreporting, a number of methodological inconsistencies were noted. The most significant issues included non-reporting of the fugitive component of NMVOC emissions by numerous installations, reporting of non-fossil fermentation and incineration CO_2 emissions by some installations, and reporting of vehicle (e.g. forklift truck) fuel use by some installations but not by others. New PRTR-compliant reporting formats adopted in 2008 clarify reporting requirements. For example, operators are explicitly required to include a separate estimate of fugitive emissions in the new reporting templates, which does appear to have increased the rate of fugitive NMVOC emission reporting in the Pharma sector.

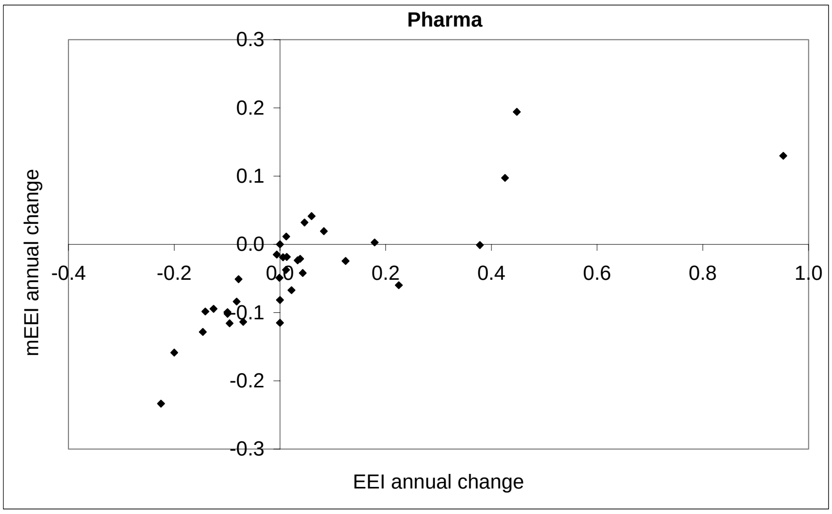
3.4 Discussion

The EEI is an example of the type of data aggregation and presentation that will be necessary to enable comprehensive and effective benchmarking for regulation. In particular, such aggregation should avoid the selective benchmarking of individual pollutants that could incentivise inefficient pollution substitution. Aggregation of major emissions using the EEI indicated surprisingly large differences in the pollution intensity of electricity generation and in pollution trends across power stations. These differences were considerably greater than differences in standard CO_2 intensity benchmarking documented in SEI reports (e.g. Howley et al., 2008a).

Apart from the limitations associated with the scope of direct emissions included in the EEI (Section 2.4), the major potential limitation of using the EEI to provide an estimate of aggregate pollution is the exclusion of major indirect impacts associated with operations. Accounting for emissions associated with the generation of consumed electricity more than doubled pollution loading attributable to Pharma production, but did not have a major effect on overall rankings of pollution loading, and pollution loading trends, across installations in the three relevant sectors. Electricity use is well reported across IPPC installations, and accounting for indirect pollution associated with its generation would more accurately represent energy-related pollution loading across licensed installations, and would capture one of the major pathways for pollution ‘outsourcing’ over time. However, full life-cycle assessment (LCA) accounting of all indirect pollution impacts associated with IPPC installations, including downstream final product consumption, may be too time and data intensive for routine annual benchmarking – in the short term at least. Instead, full LCA should be targeted at BAT assessment in the licence determination stage, as recommended by EC guidance documents (EC, 2006a), and also to provide comprehensive case-study assessments to guide the decisions of stakeholders, particularly plant operators, regulators and policy makers. Waste generation is a potentially important source of indirect emissions that is reported by IPPC installations, but industrial waste disposal makes a relatively small contribution towards national total pollution loading compared with electricity generation. Thus, expanding the scope of the EEI to include (difficult to quantify) indirect pollution associated with reported waste generation is a lower priority than including indirect electricity emissions for benchmarking purposes, in the first instance.

Current levels of production reporting are insufficient to enable comparative production-normalised pollution benchmarking across installations for most sectors, and confidentiality issues around production data mean that this is unlikely to change in the short term. Even when reported, production data may not be





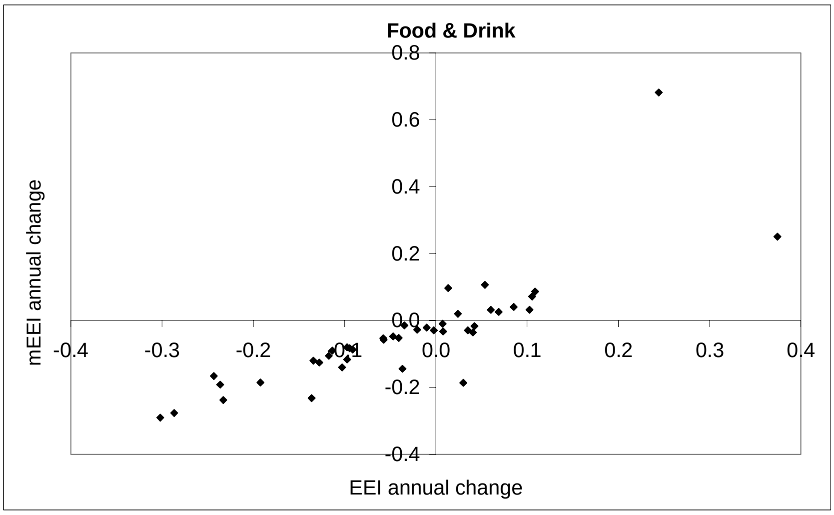


Figure 3.7. Relationships in three sectors between annualised 2004–2007 trends in direct pollution loading (Environmental Emissions Index, EEI) and direct plus indirect electricity generation pollution loading (modified EEI, mEEI) for three sectors. Trends are expressed as average annual fractional change in pollution loading for each installation. Correlation statistics are displayed in Table 3.5.

directly comparable across installations. Now that IPPC regulation is firmly established within the EU, there is an increasing focus on how to achieve its objective of encouraging continual environmental performance improvement (e.g. EC, 2007). Trends in absolute pollution loading offer a comprehensive benchmark for emissions performance that could assist measurement and compliance with this objective. As long as national and EU15 emissions remain above policy targets as used to weight EEI impact categories (yet alone above the considerably more stringent sustainability targets quantified by scientists), continued reductions in absolute pollution loading will be required. Thus, there is a rationale for holding all established installations accountable for trends in absolute pollution. There would then be an incentive for installations, particularly newly established installations, to volunteer production data (perhaps in index form) to justify any increases in pollution loading. Essentially, benchmarking pollution trends would increase the accountability of operators for pollution they cause, akin to their accountability for economic performance.

Obtaining complete, verifiable emissions data from licensed installations is challenging, as highlighted by the data completeness statistics presented here and in other studies (e.g. Saarinen, 2003a; Pulles et al., 2007). Despite being the most environmentally significant direct pollutant from the Pharma and Chem sectors, predominantly fugitive NMVOC emissions are inconsistently reported across installations, and substantially under-reported overall. Given that these emissions are estimated to have remained relatively constant between 2001 and 2007, against significant reductions in most other emissions (Styles et al., 2009b), fractional pollution reduction trends will be overestimated for installations that do not fully report fugitive NMVOC emissions. Thus, whilst it may be necessary to derive pollution trends from incomplete available emissions data for some installations, it would be important to account for none or suspected under-reported emissions when comparing trends across installations. In some cases, the underlying level of monitoring reasonably[10] required under licence conditions may restrict the quality of data available, especially for smaller installations. For example, annual loading of highly variable NO_x emissions can be particularly difficult to extrapolate from spot sampling (Pulles and Heslinga, 2004). Generating consistent time series from AER data required a considerable degree of screening, correction and gap filling (Styles et al., 2009b): numerous errors were detected and inevitably others remain undetected. A shift towards performance-oriented regulation will require greater enforcement emphasis on validation and verification of operator monitoring and reporting.

Energy consumption was well reported across installations, and provided the basis for much gap filling. It also represented the dominant source of pollution for all sectors when indirect electricity-generation emissions were accounted for, despite the wide range of non-energy-related emissions reported by the Pharma and Food & Drink sectors. In the first instance, where emissions reporting is poor, trends in total primary energy consumption could be used as a reasonable proxy for pollution trends. The primary energy required to generate consumed electricity would need to be added to the primary energy contained in fuel consumed on-site for each installation. However, where possible, it would be preferable to account for the direct and indirect emissions associated with energy use in a pollution metric such as the EEI in order to represent the considerable range of pollution loading attributable to different fuel types (e.g. Fig. 3.3). Increasing the frequency and quality of reported emissions data is central to this, but verifying emissions data from licensed installations would significantly increase the workload of EPA inspectors, requiring additional auditing of licensee monitoring and reporting systems. It may be possible to offset much of this additional workload by reducing the emphasis on existing compliance metrics, and also by introducing more stringent sanctions against licensees for incomplete or inaccurate reporting.

Rapidly declining pollution intensities for electricity generation in Ireland are forecast to continue with a rapid expansion in renewable electricity generation (Howley et al., 2008b). From an environmental

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[10] Balancing the financial cost of monitoring imposed upon the company against the potential impact of its emissions.

perspective, this may favour a shift towards electricity as an industrial energy source in the near future. However, in the short term, inclusion of indirect pollution associated with electricity generation in any performance metric could reduce the incentive for operators currently heavily dependent on electricity to actively implement on-site pollution reduction measures. Careful thought is required when defining LCA boundaries for benchmarking purposes to ensure that responsibilities for impacts are attributed equitably and effectively across production chains. Inevitably, the methodology used for any regulatory benchmarking will involve numerous assumptions, omissions, and weakness. The authors of this report believe that, despite likely difficulties, it is important to shift regulation towards a performance-oriented approach wherever possible. Measurement problems can only be fully identified and addressed, and effective methodologies will only emerge, once performance-oriented regulation is actually implemented. There is increasing evidence that innovation associated with the proactive environmental management likely to be stimulated by such regulation can improve not just environmental performance, but also economic efficiency and competitiveness at the installation level (Honkasalo et al., 2005; López-Gamero et al., 2009b). For example, energy savings driven by rigorous regulation now would reduce the exposure of industry to future energy price volatility. Engagement with stakeholders from an early stage should help to develop reliable benchmarking methods and improve acceptance.

3.5 Summary

Of the four sectors studied, only the Power Gen sector had sufficient emission and production data to comprehensively benchmark eco-efficiency across all installations. Gap filling can correct for under-reporting of emissions arising from on-site fuel use, but is not possible for other missing emissions data at the installation level. In particular, under-reporting of fugitive NMVOC emissions by Pharma and Chem installations needs to be addressed to enable accurate benchmarking.

Difficulties obtaining comparable production data limit the potential for installation-level eco-efficiency benchmarking. However, absolute pollution *trends* were strongly correlated with production-normalised pollution trends across Pharma installations, and may be used to evaluate environmental performance of established installations. This is consistent with the goal of IPPC licensing to achieve *continuous* pollution reductions at the installation level, and would place the onus on operators to provide some form of production data to justify pollution increases (e.g. for rapidly expanding newly established operators).

On-site fuel combustion is a major source of pollution loading from all sectors. Accounting for indirect emissions associated with the generation of electricity used on-site increases pollution loading by between 36% (Chem sector) and 106% (Pharma sector). This emphasises the importance of accounting for indirect life-cycle impacts associated with regulated operations. Although the inclusion of indirect electricity emissions had a stronger relative influence on pollution loading attributed to smaller installations, their inclusion did not have a major effect on the relative ranking of installations in terms of pollution trends. If performance benchmarking becomes established, there could be an incentive for installations to substitute on-site fuel use with electricity, resulting in higher pollution per unit energy used in the short term. Given the significance of electricity use in industrial operations, the routine reporting of its use, and the relative simplicity of attributing pollution loading to it, it is recommended that off-site electricity generation is accounted for in pollution benchmarking.

Reporting levels are improving across IPPC installations, and further anticipated improvements associated with new PRTR requirements should enable reasonably comprehensive quantification of pollution trends across most installations in the near future. In the meantime, aggregating available emissions data using the EEI provides a simple, integrated, performance-oriented metric for operators and regulators. Despite data shortcomings, it is important to begin quantifying pollution trends at the installation level, using best available scientific methods, in order to inform efficient management, reporting and regulation, and to foster greater environmental accountability.

4 Sectoral Trends

4.1 Background and Aims

Chapter 3 outlines the potential to interpret AER data at the installation level using the EEI. This chapter explores quantification of pollution trends at the sectoral level, based on aggregate installation-level data. Compared with the more usual 'top–down' accounting of sectoral emissions, the increasing quantity of disaggregated, site-specific emissions data made available under IPPC licensing requirements (and associated EPRTR reporting) are more likely to be based on continuous monitoring, or site- or technology-specific emission factors derived from periodic monitoring. They include substances not well captured by current national inventory reporting, and may fill gaps in emissions data for sectors considered to be minor in, or outside the scope of, various national inventories. Saarinen (2003b) notes that top–down emissions inventory data for Finnish industry ranged from 90% lower to several-fold higher compared with bottom–up monitoring data. However, the apparently higher resolution offered by bottom–up data may sometimes be associated with higher levels of uncertainty. Exceptional and fugitive emissions may be excluded, and even routine emissions may be poorly estimated in the absence of continuous monitoring (Saarinen, 2003a,b). Even when based on site-specific periodic monitoring, emission factors for some substances can deviate substantially from average annual loadings, especially for highly temporally variable emissions such as NO_x (Pulles and Heslinga, 2004). In Ireland, the procedures used to derive reported mass annual emissions data are specified in IPPC licence conditions. These procedures, and AERs themselves, are validated by EPA inspectors, though data are not fully verified.

In this chapter, installation-level air and water emissions time series are aggregated up to generate comprehensive bottom–up sectoral pollution trends. The aims of this chapter are to:

1. Use the EEI to generate consistent and comparable pollution time series for the four study sectors;
2. Assess the completeness and uncertainties associated with these pollution time series; and
3. Combine pollution and production data to calculate trends in ecological intensity across sectors.

4.2 Methodology

4.2.1 *Quantifying pollution trends*

In this section, installation-level emissions data are aggregated up to generate two types of sectoral-level emissions trends between 2001 and 2007:

1. Consistent emissions trends for installations that reported throughout the period; and
2. Estimated total sectoral emissions trends for licensed, operating installations.

The latter trends were based on simple extrapolation of the number of reporting installations relative to the number of licensed, operating installations. Extrapolations were made from either the core installations that reported throughout the period (good indicators of trends), or all reporting installations in any given year (good indicators of total emissions, and reflect installation closures), individually for each substance, and according to consistency checks.[11]

For the Pharma and Chem sectors, under-reporting of fugitive NMVOC emissions was corrected using sectoral NMVOC estimates up to the year 2004, from CTC (2005). For the Pharma sector, estimated NMVOC emissions remained relatively constant from 1998 to 2004, and so 2005–2007 emissions were held constant at 2004 levels. For the Chem sector, there was a 37% reduction in NMVOC emissions between 2001 and 2004 according to CTC (2005), and a further

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[11] For example, total reported emissions for some substances were higher than estimated from extrapolation of core installation emissions.

decrease of 20% was extrapolated between 2004 and 2007.

4.2.2 *Assessing uncertainties*

In Chapter 3, Table 3.3 and Fig. 3.1 provide an overview of the completeness of reporting for the four sectors. In this chapter, the sensitivity of EEI values to estimated ranges of reporting uncertainties for specific emissions is explored at the sectoral level. The most uncertain emissions making substantial contributions to overall pollution from each sector were selected. Based on monitoring intensities (e.g. NO_x reporting is predominantly based on continuous monitoring within the Power Gen sector and spot sampling within the Food & Drink sector), and reporting completeness, maximum and minimum sectoral loadings were estimated for these emissions (see Table 4.6). These loadings represent statistically unspecified confidence limits for the most uncertain emissions from each sector. The sensitivity of the EEI to reporting uncertainties was calculated in terms of percentage increase or decrease in response to these upper and lower bound loadings for each emission.

4.2.3 *Quantifying ecological intensity trends*

Ecological intensity is the ecological pressure associated with each unit of production, and in this report is defined as direct pollution (EEI) divided by material or economic output. The difficulties of obtaining quantitative material production data are outlined in Chapter 3, and it was possible to estimate material production time series for the Power Gen and Pharma sectors only. However, inflation-adjusted economic production value indices were available from the CSO (http://www.cso.ie) for NACE[12] code activities. These were used to derive Economic Production Indices (EPIs), expressed relative to 2001, for each sector (Table 4.1). The closest matching economic production index for the Power Gen sector was for NACE activity D35, which includes gas, steam and air-conditioning supply (Table 4.1). It also includes non-combustion electricity-generating sources, whose contribution to electricity generation increased significantly between 2001 and 2007 (Howley et al., 2008a). Therefore, the EPI derived from this index was adjusted (progressively reduced throughout the period) to reflect the declining contribution of IPPC combustion-based power stations towards total Irish electricity generation. Disaggregated economic output data were available for the diverse Food & Drink sector, enabling the calculation of EPIs for three major Food & Drink sub-sectors: Animal slaughter (‘Meat’), Dairy processing and Drink (a few installations involved with sugar-beet processing and fish

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[12] Nomenclature générale des activités économiques dans les Communautés Européennes (General Industrial Classification of Economic Activities in the European Communities).

Table 4.1. The NACE activity codes for which inflation-adjusted economic output indices were available from the Central Statistics Office (CSO), and corresponding Integrated Pollution Prevention and Control (IPPC) sub-sectors.

IPPC sector	**CSO production indices**	
	NACE[1]	**Description**
Food & Drink	C10, C11[2]	Manufacture of food products and beverages
Meat	C10.1	Processing and preserving of meat and production of meat products
Dairy	C10.2	Manufacture of dairy products
Drink	C11	Manufacture of beverages
Power Gen	D35	Electricity, gas, steam and air-conditioning supply
Pharma	C21	Manufacture of basic pharmaceutical products and pharmaceutical preparations
Chem	C20	Manufacture of chemicals and chemical products

[1] NACE, Nomenclature générale des activités économiques dans les Communautés Européennes (General Industrial Classification of Economic Activities in the European Communities).
[2] Aggregated in CSO production index.

processing were not included in these sub-sectors, but were included in total sectoral data). An estimated time series of total animal head slaughtered was extrapolated up for the Meat sub-sector based on reporting by six slaughterhouses. Ecological intensity trends were calculated by dividing EEI values by the EPI for each sector and each year of available data.

4.3 Results

4.3.1 *Sectoral pollution trends*

Total pollution from the Power Gen sector decreased continuously between 2001 and 2007, by 39% (Fig. 4.1a). Mass annual loading of SO_x and NO_x decreased by 48 and 17 kt (63% and 41%),

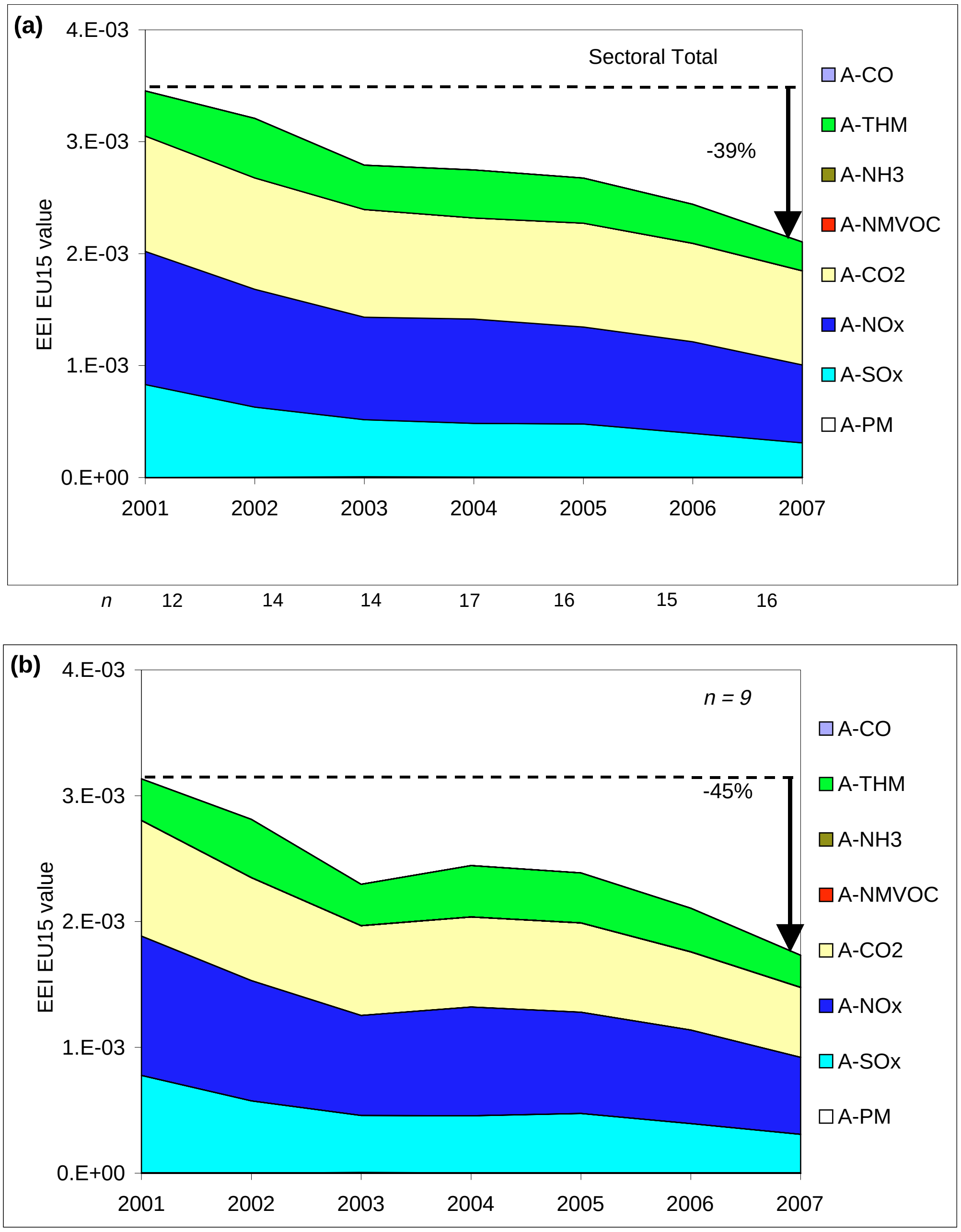


Figure 4.1. Overall pollution trend between 2001 and 2007 for (a) the entire Integrated Pollution Prevention and Control (IPPC)-licensed Power Gen sector, and (b) the nine major power stations that reported throughout the period. Number of installations operating in each year (n) is indicated in Fig. 4.1a. EEI, Environmental Emissions Index.

respectively (Table 4.2). Mass annual loadings of CO_2 decreased by 3.1. Mt (19%), and HMs by 2.2 t (30%). In 2007, the four dominant pollutants from the Power Gen sector were, in decreasing order of importance: CO_2, NO_x, SO_x, HMs. It is of note that large mass emissions of primary PM (1.8 kt, Table 4.2), representing 18% of primary PM emitted in Ireland, made a comparatively minor contribution towards overall pollution, according to the EEI. Primary PM emissions are characterised only for their contribution to HTP (Table 2.4), which is in turn dominated by NO_x and SO_x (partly through important secondary PM formation). The latter two emissions additionally contribute to AP, EP and TOFP. This example provides a useful insight into how the LCIA methodologies used in the EEI contextualise emissions according to overall environmental impact potential. Nine power stations were in operation throughout the period 2001–2007. Pollution loading from these installations declined by 45% over that period, though in a non-continuous trend (Fig. 4.1b).

Total pollution loading for the Pharma sector in 2007 equated to 3.4% of pollution loading from the Power Gen sector, and declined by 24% between 2001 and 2007, mostly during 2001–2002 and 2004–2005 (Fig. 4.2a). Based on CTC (2005), it was assumed that NMVOC emissions remained relatively constant over that time (Table 4.3), and represented the largest single pollutant according to the EEI (Fig. 4.2a). For the sector as a whole, net mass annual loading decreases ranged from 0.04 t for THM to 442 t for SO_x, and from 10% for TN to 70% for SO_x (Table 4.3). Mass annual loadings of TP and CO_2 increased by 8 and 51,726 t (39% and 27%), respectively. In 2007, the most important pollutants were, in declining order: NMVOCs, CO_2, NO_x, W-HMs, A-HMs, TP, SO_x, TN, COD. For the 27 installations that reported throughout 2001–2007, overall pollution was reduced by 40% (Fig. 4.2b). Total mass annual loading changes for these installations between 2001 and 2007 are presented in Table 5.3.

Emissions reporting was incomplete from the Food & Drink sector (Fig. 3.1; Table 3.3), and only 32 (out of 57) licensed installations reported throughout 2001–2007 (and even then, considerable gap filling was required to generate consistent emissions time series). The estimated sectoral pollution trend (Fig. 4.3a) is based on extrapolations from reported data, and therefore closely reflects the trend for the 32 continuously reporting installations (Fig. 4.3b). Total pollution from the sector equated to 6.9% of pollution loading from the Power Gen sector, and more than twice the pollution loading from the Pharma sector. Pollution loading declined by 21% between 2001 and 2007: 12% over the 2001–2004 period, and 10% over the 2004–2007 period (Fig. 4.3a). In 2007, the most important pollutants from the sector, were, in declining order: NO_x, CO_2, SO_x, TP, COD, TN, W-HMs.

Table 4.2. Total (gap filled) reported air emissions (t/annum) from the Power Gen sector between 2001 and 2007, and net change.

	Particulate matter	Sulphur oxides	Nitrogen oxides	Carbon dioxide	Volatile organic compounds	Ammonia	Total heavy metals	Carbon monoxide
2001	2,380	76,585	41,102	16,832,416	NA	NA	7.5	NA
2002	1,533	57,811	36,376	16,236,228	NA	NA	9.46	NA
2003	2,154	47,108	31,628	15,706,880	NA	NA	7.22	NA
2004	3,378	44,221	32,210	14,732,745	NA	NA	7.44	14
2005	2,837	43,756	29,956	15,132,522	NA	8	6.89	15
2006	1,577	36,228	28,262	14,335,389	NA	33.6	5.95	200
2007	1,818	28,324	24,060	13,706,141	41	26.21	5.29	1,640
Change	**–562**	**–48,261**	**–17,042**	**–3,126,275**	**NA**	**NA**	**–2.22**	**NA**
	–24%	–63%	–41%	–19%	NA	NA	–30%	NA

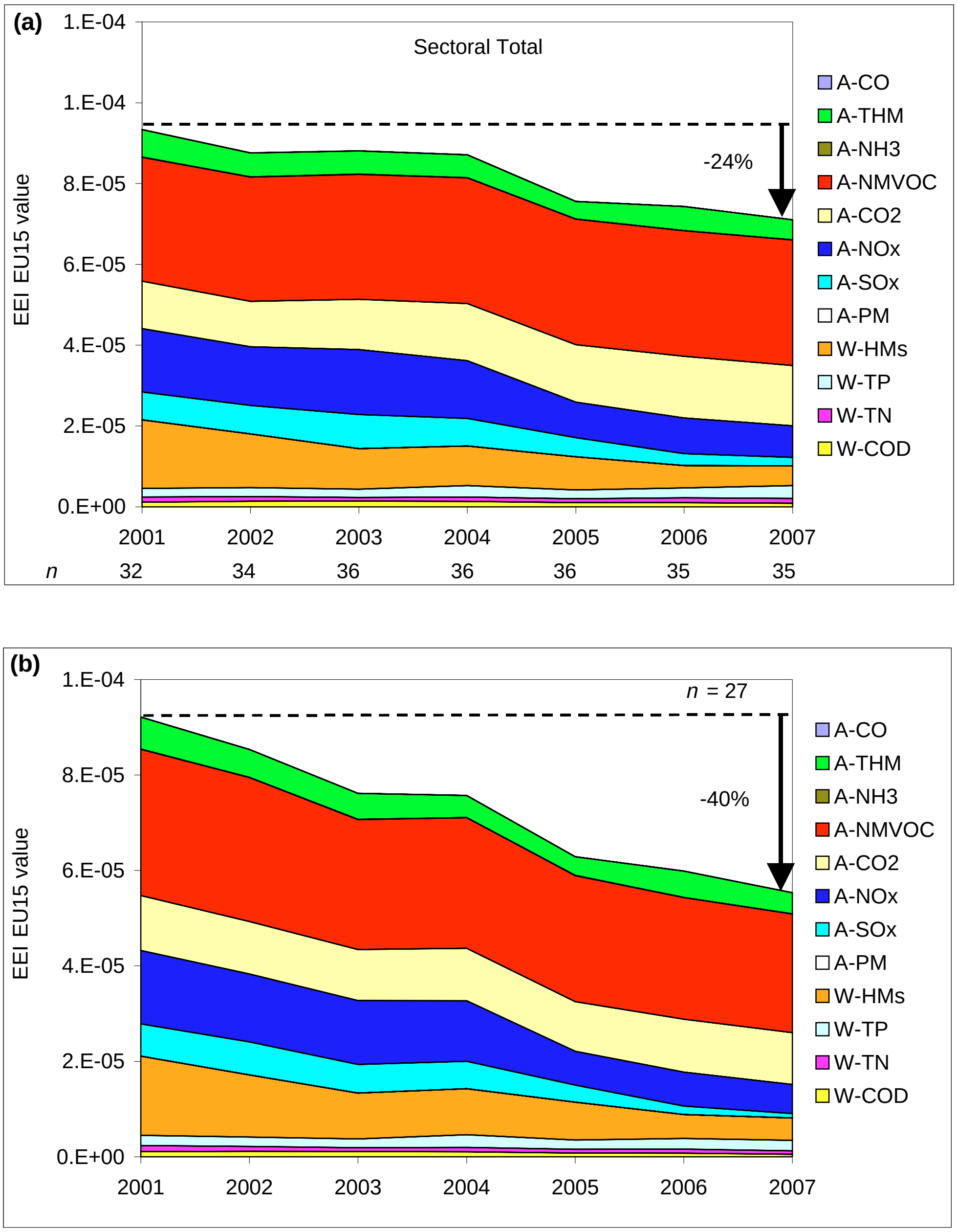


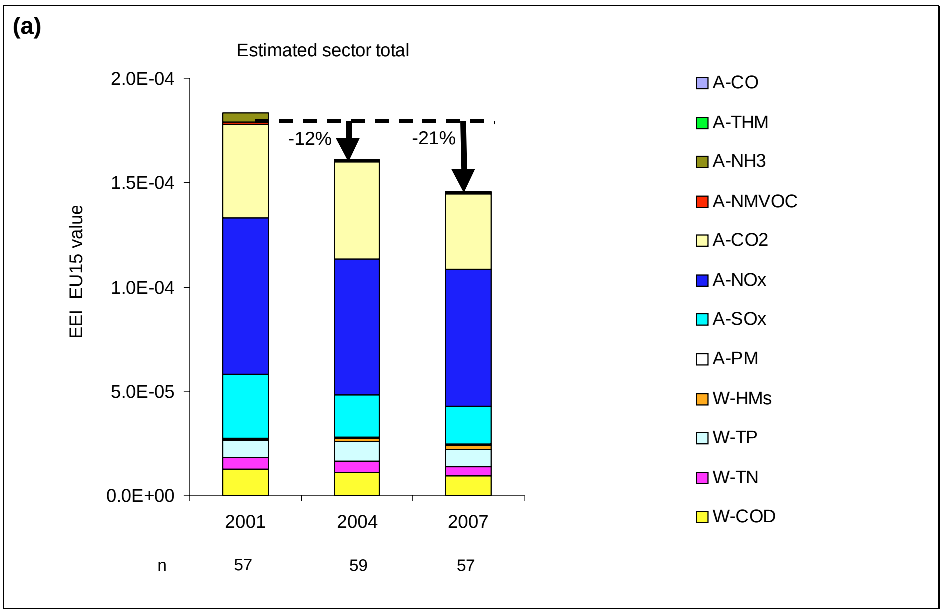
Figure 4.2. Overall pollution trend between 2001 and 2007 for (a) the entire Integrated Pollution Prevention and Control (IPPC)-licensed Pharma sector, and (b) the 27 major installations that reported throughout the period. Number of installations operating in each year (n) is indicated in Fig. 4.2a. EEI, Environmental Emissions Index.

Decreases in mass annual loadings ranged from 5 t for NMVOCs to 149 kt for CO_2, and from 5% for TN to 95% for NH_3 (Table 4.4). However, mass annual loadings of TP increased by 5 t (5%). There were large percentage increases in the comparatively unimportant (Fig. 4.3a) loadings of W-HMs and CO (probably attributable to improved levels of reporting).

Substantial gap filling was required to generate consistent emissions time series for the Chem sector (Fig. 3.1; Table 3.3), with only 27 (out of 47) licensed installations reporting throughout 2001–2007. As with the Food & Drink sector, the Chem sector pollution trend was estimated based on extrapolation of reported data, and estimated sectoral NMVOC emissions (CTC, 2005). Six Chem installations ceased operations between 2001 and 2007, including a

Table 4.3. Total (gap-filled) reported emissions from the Pharma sector between 2001 and 2007, and net change.

	n	Water emissions				Air emissions							
		Chemical oxygen demand	Total nitrogen	Total phosphorus	Heavy metals	Particulate matter	Sulphur oxides	Nitrogen oxides	Carbon dioxide	Non-methane volatile organic compounds	Ammonia	Total heavy metals	Carbon monoxide
2001	32	1,587	101	20	1.4	3.8	636	542	191,613	1,464	1.9	0.13	31
2002	34	1,801	86	19	1.2	1.7	650	502	182,976	1,472	1.5	0.12	45
2003	36	1,814	63	18	1.3	1.9	778	555	202,915	1,479	2.0	0.11	25
2004	36	1,748	79	24	1.0	1.5	631	494	230,869	1,486	0.8	0.11	28
2005	36	1,329	70	18	0.9	3.5	436	303	232,047	1,486	1.2	0.09	17
2006	35	1,390	88	20	0.6	1.4	271	305	248,978	1,486	1.3	0.12	19
2007	34	1,280	91	28	0.5	1.3	193	270	243,339	1,486	1.5	0.10	14
Change		**–307**	**–10**	**8**	**–0.9**	**–2.5**	**–442**	**–272**	**51,726**	**22**	**–0.4**	**–0.04**	**–17**
		–19%	–10%	39%	–65%	–66%	–70%	–50%	27%	1%	–23%	–27%	–54%



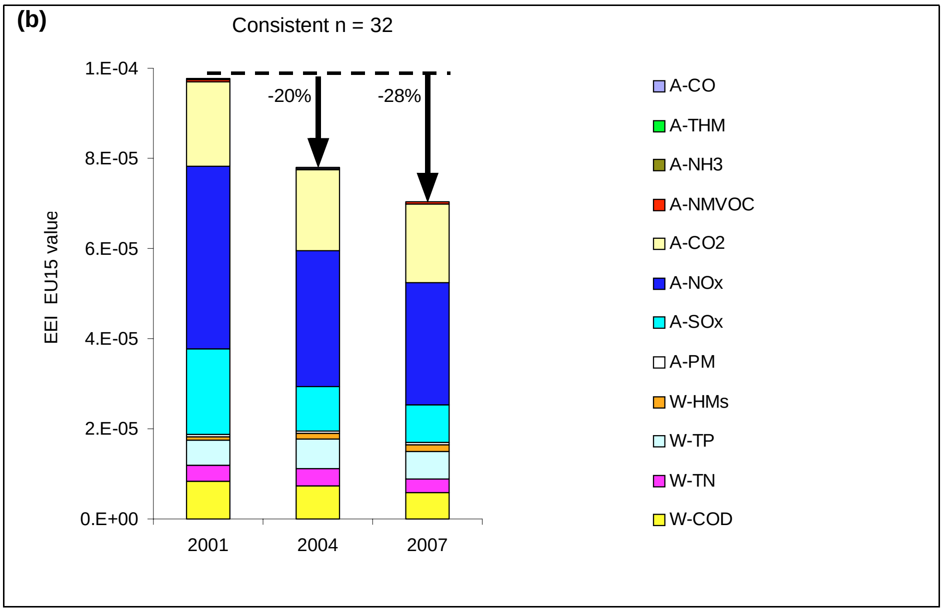


Figure 4.3. Overall pollution trend between 2001 and 2007 for (a) the entire Integrated Pollution Prevention and Control (IPPC)-licensed Food & Drink sector (estimated), and (b) the 32 major installations that reported throughout the period. Number of installations operating in each year (n) is indicated in Fig. 4.3a. EEI, Environmental Emissions Index.

fertiliser manufacturing plant whose reported release of 3.6 kt of NH_3 in 2001 dominated sectoral pollution (Fig. 4.4a). Consequently, total pollution loading for the sector declined by 83% between 2001 and 2007, mostly between 2001 and 2004. Mass annual loading reductions ranged from 2.4 t for W-HMs to 183 kt for CO_2, and from 10% for CO to 100% for NH_3 (Table 4.5). However, there were large relative increases in mass loadings of COD to water and HMs to air – the latter based on reporting from one installation only. In 2007, the most important pollutants from the Chem sector were, in declining order: NMVOCs, W-HMs, NO_x, CO_2, A-HMs, SO_x. Total pollution loading from the Chem sector in 2007 equated to 1.9% of pollution loading from the Power Gen sector and 55% of pollution loading from the

Table 4.4. Total (gap-filled) reported emissions from the Food & Drink sector between 2001 and 2007, and net change.

	n	Water emissions				Air emissions							
		Chemical oxygen demand	Total nitrogen	Total phosphorus	Heavy metals	Particulate matter	Sulphur oxides	Nitrogen oxides	Carbon dioxide	Volatile organic compounds	Ammonia	Total heavy metals	Carbon monoxide
2001	57	19,388	358	90	0.02	780	2,810	2,586	739,670	37	115	NA	14
2004	59	16,643	437	99	0.03	526	1,882	2,246	763,697	22	18	NA	107
2007	57	14,199	339	95	0.05	503	1,673	2,262	590,254	32	6	NA	154
Change		**–5,189**	**–19**	**5**	**0.03**	**–277**	**–1,136**	**–324**	**–149,415**	**–5**	**–109**	**NA**	**139**
		–27%	–5%	5%	155%	–36%	–40%	–13%	–20%	–13%	–95%	NA	963%

Table 4.5. Total (gap-filled) reported emissions from the Chem sector between 2001 and 2007, and net change.

	n	Water emissions				Air emissions							
		Chemical oxygen demand	Total nitrogen	Total phosphorus	Heavy metals	Particulate matter	Sulphur oxides	Nitrogen oxides	Carbon dioxide	Volatile organic compounds	Ammonia	Total heavy metals	Carbon monoxide
2001	53	722	860	52	5.1	19	471	391	239,230	1,600	4,576	0.018	76
2004	51	409	208	11	2.9	6.5	779	359	205,800	1,000	1.4	0.016	76
2007	47	2,424	6	0.7	2.7	7.3	233	117	56,095	800	1.3	0.070	68
Change		**1,703**	**–853**	**–52**	**–2.4**	**–12**	**–238**	**–274**	**–183,135**	**–800**	**–4,575**	**0.052**	**–7.3**
		236%	–99%	–99%	–47%	–62%	–50%	–70%	–77%	–50%	–100%	298%	–10%

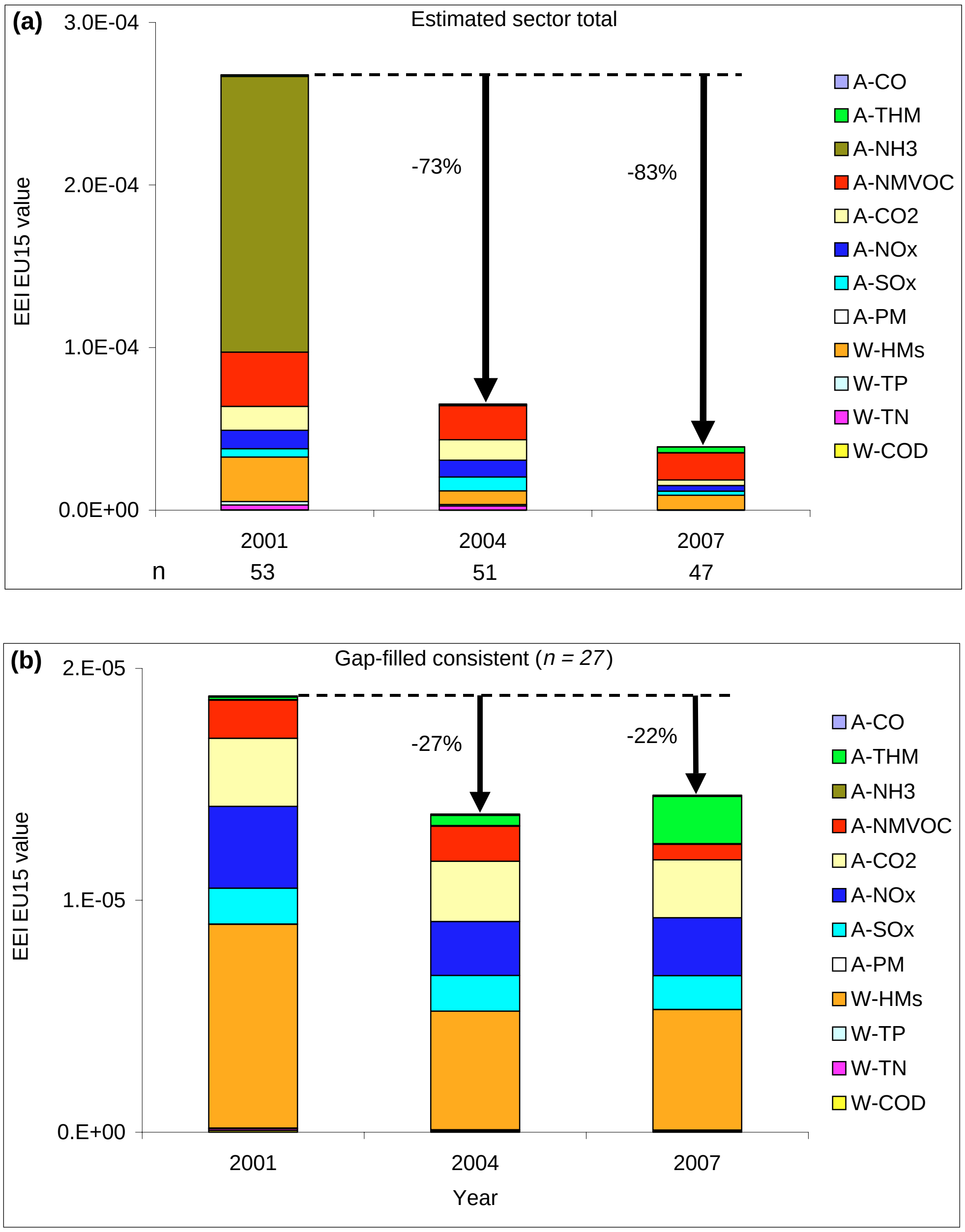


Figure 4.4. Overall pollution trend between 2001 and 2007 for (a) the entire Integrated Pollution Prevention and Control (IPPC)-licensed (non-Pharma) Chem sector (estimated), and (b) the 27 major installations that reported throughout the period. Number of installations operating in each year (n) is indicated in Fig. 4.4a. EEI, Environmental Emissions Index.

Pharma sector. For the 27 installations that reported throughout 2001–2007, there was a net decline of 22% in pollution loading (Fig. 4.4b), after accounting for an increase in pollution between 2004 and 2007 associated with increased HM emissions to air reported by one installation (Table 4.5). The level of reporting for the Chem sector was poor and, in conjunction with the closure of a number of major installations, this resulted in considerable uncertainty surrounding the estimated sectoral pollution trend.

4.3.2 Reporting uncertainties

High levels of monitoring and reporting, combined with the estimation of non-reported emissions from comprehensive fuel-use data, mean that pollution from the Power Gen sector is quantified with a high level of certainty. Continuous monitoring of NO_x in many power stations, and more continuous operating conditions than smaller industrial boilers, suggest a low level of uncertainty around reported NO_x emissions (Table 4.6). Heavy metal emissions may vary with the fuel supply and abatement efficiency, but a change of ±50% would alter EEI values by just ±6% (Table 4.6). Total pollution loading from the Power Gen sector is thus quantified within a range of ±9%. Despite potentially significant uncertainty associated with some of the major pollutants from the Pharma sector (notably NMVOCs, NO_x and W-HMs), overall uncertainty associated with pollution loading at the sectoral level is a modest ±23% – primarily attributable uncertainty in mass loading of NMVOCs (Table 4.6). For these two sectors, sectoral-level uncertainty is considerably below installation-level uncertainty (e.g. Table 2.5), owing to the 'evening out' of multiple uncertainties. Also for the Pharma sector, estimated sectoral NMVOC emissions (CTC, 2005) were used to correct for under-reporting of NMVOCs at the installation level. Lower levels of reporting result in higher uncertainties associated with pollution loading in the Food & Drink and Chem sectors. Uncertain NO_x loading is the dominant source of uncertainty for the Food & Drink sector, while NMVOCs and W-HMs are the major sources of uncertainty for Chem sector pollution loading (Table 4.6). For the latter two sectors, considerable numbers of installations with little or no reporting make assessment of reporting completeness and uncertainty difficult. Assessing the influence of incomplete and uncertain reporting on trends is also difficult. In Styles et al. (2009b), reporting uncertainties, rather than EEI model assumptions, were found to dominate uncertainty in both absolute pollution loading and trends for the Pharma and Power

Table 4.6. Overview of the most uncertain emission quantities, and the potential influence of this uncertainty on Environmental Emissions Index values for each sector, expressed as estimated low and high confidence limits (CLs).

Activity	Scale	Emissions	Uncertainty		EEI sensitivity	
			CL_{low}	CL_{high}	Low	High
Power Gen	Sector	A-Nitrous oxides	×0.8	×1.2	–7%	+7%
	Sector	A-Total heavy metals	×0.5	×1.5	–6%	+6%
	Sector	**Combined**			**–9%**	**+9%**
Food & Drink	Sector	A-Nitrous oxides	×0.3	×2.0	–30%	+42%
	Sector	W-Total phosphorus	×0.5	×2.0	–4%	+8%
	Sector	**Combined**			**–30%**	**+43%**
Pharma	Sector	A-Non-methane volatile organic compounds	×0.5	×1.5	–22%	+22%
	Sector	A-Nitrous oxides	×0.5	×1.5	–6%	+6%
	Sector	W-Heavy metals	×0.5	×1.5	–3%	+3%
	Sector	**Combined**			**–23%**	**+23%**
Chem	Sector	A-Non-methane volatile organic compounds	×0.5	×1.5	–22%	+22%
	Sector	A-Nitrous oxides	×0.3	×2.0	–6%	+9%
	Sector	A-Total heavy metals	×0.5	×3.0	–5%	+9%
	Sector	W-Heavy metals	×0.3	×2.0	–16%	+23%
	Sector	**Combined**			**–28%**	**+34%**

A-, emissions to air; W-, emissions to water.

Gen sectors. Trends were not particularly sensitive to systematic errors (e.g. consistent under-reporting of NMVOCs), but it is difficult to assess their sensitivity to potential random variations (e.g. over-reporting some years, under-reporting other years).

4.3.3 *Ecological intensity trends*

Material production data were not widely available for installations across all sectors (Table 3.3). There were sufficient installation-level production data to derive total material production time series for the Power Gen and Pharma sectors only. For the Food & Drink sector, it was possible to derive a total material production time series for the Meat sub-sector only. There were some divergences between trends in material and economic outputs for those sectors (Table 4.7). Inflation-adjusted economic output increases were greater than material production increases for the Power Gen and Pharma sectors, and the EPI increased despite a small decrease in electricity generated by the Power Gen sector. Meanwhile, despite an estimated 22% increase in the number of animals slaughtered, the EPI for the Meat sub-sector increased by just 4% between 2001 and 2007.

Electricity output and EPI remained relatively constant from the IPPC Power Gen sector (Table 4.7), though decreased substantially (42%) from the nine power stations that reported throughout 2001–2007 (data not shown). There were considerable changes in the sector during this period, including the replacement of two old peat power stations with new, more efficient peat power stations, and the commissioning of four new combined-cycle gas power stations. For the sector as a whole, the ecological intensity of electricity generation decreased by 38% between 2001 and 2007, and the ecological intensity of economic output decreased by 45% (Fig. 4.5). The 32% increase in EPI and 24% decrease in direct pollution from the Pharma sector between 2001 and 2007 contributed to a decline of 42% in the ecological intensity of economic output from this sector (Fig. 4.5). Based on the 27% estimated increase in physical production, the ecological intensity of each tonne of API produced declined by 40%.

The EPI for the Chem sector increased by 12% between 2001 and 2007 (Table 4.7), despite the closure of a number of large, high-polluting installations (Fig. 4.4a). The ecological intensity of

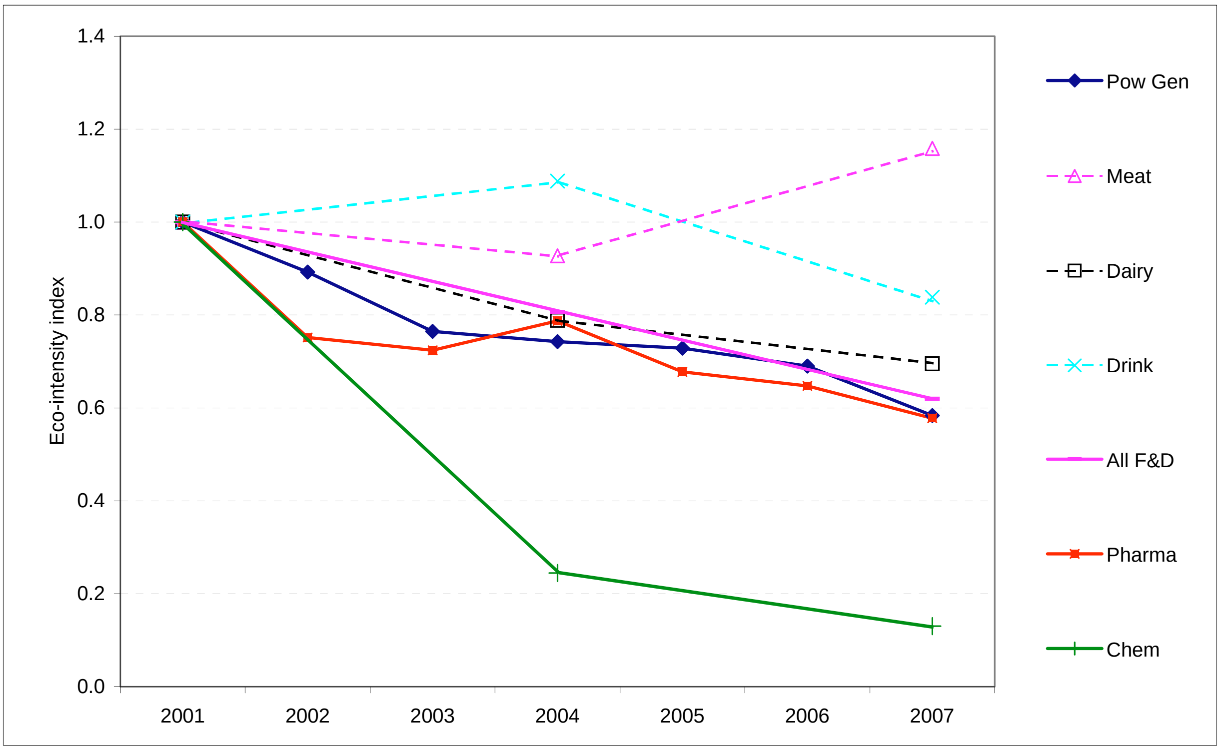


Figure 4.5. Eco-intensity trends for the four Integrated Pollution Prevention and Control sectors studied (and three Food & Drink sub-sectors).

Table 4.7. Material production data and economic output indices for the study sectors.

	Food & Drink							Power Gen		Pharma		Chem
	Meat		Dairy		Drink		All					
	Head[1]	EPI	t[1]	EPI	Hectolitres[1]	EPI	EPI	GWhe	EPI[2]	t API[1]	EPI	EPI
2001	7,158,088	100	NA	100	NA	100	100	22,124	100	24,052	100	100
2002	–	–	–	–	–	–	104	21,934	104	24,518	125	108
2003	–	–	–	–	–	–	109	22,304	106	28,701	130	108
2004	7,400,700	102	NA	90	NA	96	115	22,072	107	29,620	119	100
2005	–	–	–	–	–	–	117	21,954	106	29,931	119	88
2006	–	–	–	–	–	–	118	22,073	102	26,114	123	99
2007	8,707,628	104	777,968	102	11,434,247	129	121	21,737	104	30,456	132	112
Change	22%	4%	NA	2%	NA	29%	21%	–2%	4%	27%	32%	12%

[1] Estimated, based on extrapolation of available installation-level data.

[2] NACE code D35: includes gas, steam and air-conditioning supply.

EPI, Economic Performance Indicator; API, active pharmaceutical ingredient.

economic output from this sector declined by 76% between 2001 and 2004, and 87% between 2001 and 2007 (Fig. 4.5), reflecting in particular the cessation of highly polluting fertiliser manufacturing in Ireland in 2002 (Fig. 4.4a). The EPI for the entire Food & Drink sector increased by 21% between 2001 and 2007, though this varied across sub-sectors from a 2% increase for the Dairy EPI to a 29% increase for the Drink API (Table 4.7). The ecological intensity of economic output increased by 16% for the Meat sub-sector, but declined by 30% for the Dairy sub-sector and 16% for the Drink sub-sector (Fig. 4.5). The ecological intensity of economic output for the sector as a whole declined by 38%, in part reflecting the closure of high ecological intensity sugar-processing installations.

4.4 Discussion

The EEI was used in this study only to quantify direct pollution associated with air and water emissions. This direct pollution represents less than 50% of life-cycle pollution associated with production from the Pharma, Chem, and Food & Drink sectors. Strictly speaking, the gate-to-gate scope of emissions quantification is more consistent with value-added measures of output, rather than the measures of total material and economic output used here. Eco-efficiency trends derived from any such value-added metrics could differ from the observed trends, but would require more detailed economic data. Furthermore, the CSO production indices are not entirely compatible with IPPC pollution trends, owing to the incompatibility between IPPC and NACE activity classifications, the CSO NACE aggregation level, and representation of small (non-IPPC) installations in CSO data. For the Chem sector, particularly large pollution reductions were attributable to the 'outsourcing' of polluting, low-value output activities (e.g. fertiliser manufacture) to other countries, and thus do not reflect global sustainability benefits. Nonetheless, despite such limitations associated with the available data, this study has produced a uniquely comprehensive assessment of pollution and eco-efficiency trends across four contrasting IPPC sectors. In particular, the application of LCIA methodologies to fully characterise and aggregate major emissions into a single pollution index enabled the presentation of uniquely comprehensive, and scientifically robust, aggregate eco-efficiency trends.

There have been significant reductions in overall direct pollution from all four IPPC sectors, over the 2001–2007 period – irrespective of whether pollution trends are derived only from installations that reported throughout the period, or extrapolations of total reported data. Following gap filling, emissions time series for the Power Gen and Pharma sectors are complete and relatively certain. However, a considerable degree of uncertainty is associated with estimated sectoral emissions extrapolated up from incomplete reporting for the Chem and Food & Drink sectors. Across all sectors, large reductions in NO_X and SO_X were major components of pollution reductions, reflecting a shift in fuel use towards natural gas and lower sulphur fuel oil, improved combustion control, and the installation of abatement technology in power stations and some Pharma installations. For the Pharma sector in particular, a large overall pollution reduction masks a stabilisation or increase in emissions of some pollutants – notably NMVOCs and CO_2. The pollution profile of regulated sectors thus appears to be shifting, and the focus of managers and regulators needs to shift towards the residual pollutants in order to tackle remaining environmental problems, and maintain progress in reducing overall pollution. Although the relative influence of integrated licensing on pollution trends was only identified for the Pharma sector (Chapter 5), it is highly probable that integrated licensing made a significant contribution to observed pollution reductions across the other three sectors. Crucially, the quantification of pollution trends was only possible owing to monitoring and reporting enforced through licensing. This is a crucial step towards sustainable production, as emphasised in Chapters 3 and 6.

4.5 Summary

The frequency of emissions reporting is generally high in the Power Gen and Pharma sectors, but somewhat lower in the Food & Drink and Chem sectors, and it is clear that fugitive NMVOC emissions in particular are not well reported. Incomplete reporting, and monitoring limitations for temporally variable emissions such as NO_X, resulted in considerable uncertainty around sectoral pollution trends derived from aggregation of bottom–up installation data (particularly for the Chem and Food & Drink sectors). Nonetheless, when combined with alternative data sources (e.g. national NMVOC inventory; CTC, 2005), the derived trends are probably the most comprehensive currently available.

There were substantial pollution reductions from the four studied sectors between 2001 and 2007. Annual pollution loadings were reduced by 21% for the Food & Drink sector, 24% for the Pharma sector, 39% for the Power Gen sector, and 83% for the Chem sector. The particularly large pollution reduction from the Chem sector reflects the closure of high-emitting installations. Most notably, a 4.58 kt/annum reduction in NH_3 emission was caused by the cessation of fertiliser manufacturing in Ireland, representing pollution outsourcing on a national scale. Meanwhile, operations in new installations have somewhat countered the large reduction in pollution from long-term operational Pharma installations. In terms of assessing regulatory effectiveness, it is more instructive to look at pollution trends from a constant number of long-term operational installations, or pollution intensity of production for entire sectors. Absolute pollution loading trends for installations that reported throughout 2001–2007 differed somewhat from total sectoral trends, and indicated pollution reductions of 22%, 28%, 40% and 45% for installations in the Chem (n = 27), Food & Drink (n = 32), Pharma (n = 27) and Power Gen (n = 9) sectors, respectively.

SO_x and NO_x emissions were reduced substantially across all four sectors, reflecting a general shift in fuel use from heavy fuel oil to light fuel oil and natural gas, and the installation of abatement technologies on large boilers. For example, SO_x emissions were reduced by 1,136 and 48,261 t/annum in the Food & Drink and Power Gen sectors, respectively. For the Chem and Pharma sectors, there was a substantial reduction in HM pollution loading to water, while for the Power Gen sector there were large reductions in CO_2 (>3 Mt/annum) and HM (>2 t/annum) pollution loadings to air. Part of the reduction in the pollution intensity for the Power Gen sector overall is attributable to an increasing portion of electricity coming from newer, combined-cycle gas power stations with lower emissions than traditional coal, oil and peat stations.

As documented in Chapter 3, there are limited material production data for three of the sectors. Eco-efficiency trends were instead calculated based on inflation-adjusted output indices from the CSO, based on NACE codes that corresponded approximately with IPPC sectors. The eco-intensity of production was estimated to have declined by 38% for the Food & Drink sector, 42% for the Pharma sector, 45% for the Power Gen sector, and 87% for the Chem sector, between 2001 and 2007. These sectoral economic eco-efficiency trends deviated somewhat from material eco-intensity trends derived for those installations for which material production data were available (although not directly comparable). Although the substantial absolute and production-normalised sectoral pollution reductions presented in this chapter cannot be attributed to IPPC licensing with any certainty, the enforcement of annual emissions reporting under IPPC licensing was fundamental to quantifying these trends. Given the findings of Chapter 5, it is highly probable that IPPC licensing has contributed significantly to these pollution reductions.

5 Effectiveness of IPPC Licensing

5.1 Background and Aims

Although environmental regulation is based upon a large number of EU directives and national legislation, IPPC licensing is the primary mechanism through which these regulations are implemented and enforced for large industrial installations. ELVs determined according to BAT are a central tenet of IPPC licensing, representing minimum compliance criteria, but may not be the main drivers of environmental performance improvement. As outlined in Section 1.3, IPPC licensing aims to encourage continuous environmental performance improvement through environmental reporting and EMPs. The broad scope of IPPC licensing presents challenges in terms of assessing its effectiveness. For example, it is possible that most of the pollution reductions quantified in Section 4.3.1 are attributable to 'business-as-usual' (BAU) and non-regulatory drivers of environmental performance improvement. Such drivers include technological advancements, cost-saving efficiencies, voluntary agreements, and corporate social responsibility (CSR). The Pharma sector participates in voluntary reporting and 'self-regulation' through Pharmachemical Ireland.

Some recent studies have assessed the theoretical influence of BAT implementation on emissions from large installations based on EPER data (EEA, 2008; Mirasgedis et al., 2008; Karavanas et al., 2009). Other studies have assessed the theoretical influence of IPPC licensing broadly but not quantitatively (Honkasalo et al., 2005; López-Gamero et al., 2009a). There is little published quantitative literature on the effectiveness of IPPC licensing for installations and sectors that largely fall below EPER reporting thresholds. Gray et al. (2007) refer to a 25% reduction in waste disposal between 1998 and 2002 by operators holding integrated licences. In Ireland, Clinch and Kerins (2002) refer to undisclosed pre- and post-IPC emissions data that indicate significant reductions in emissions of particulates, NMVOCs and ammonia to air following the introduction of IPC licensing. They reported that emissions of COD, nitrogen and phosphorus to water also declined substantially, but emissions of SO_x and NO_x to air showed little change. Even where quantitative data are available, it can be difficult to interpret diverging trends for different emissions in terms of overall pollution.

Empirical quantification of pollution prevention attributable to integrated licensing over time requires (i) information on reference pollution trends, and (ii) information on the contribution of integrated licensing to any reduction relative to reference pollution. Hossain et al. (2008) highlight difficulties associated with assessing pollution prevention in relation to activity boundaries and the comparison of multiple criteria. Empirical quantification is often restricted by data availability, and studies quantifying IPPC pollution prevention have tended to take a modelling approach, usually based on the assumption that full BAT implementation will be the sole driver of emissions reduction associated with IPPC licensing (EEA, 2008; Mirasgedis et al., 2008). These modelling approaches provide useful information, but have two major limitations:

1. It can be difficult to define the reference technology, which may converge with BAT over time under BAU trajectories (EC, 2006a); and
2. Other potentially important IPPC drivers of pollution prevention, such as EMPs and emissions reporting (Cunningham, 2000; Silvo et al., 2002), are neglected.

The implementation of IPC licensing in Ireland since 1994 for the Pharma sector, and good levels of reporting from this sector, present the opportunity for a quantitative study on the effectiveness of integrated licensing.

In this chapter, the pollution trend for the Pharma sector is extended back to 1995, and an extended ecological-intensity trend is generated as per Section 4.3.3; questionnaire survey data are then used to determine the fraction of air and water pollution avoidance attributable to integrated licensing. Figure 5.1 summarises the main input data and outputs, in

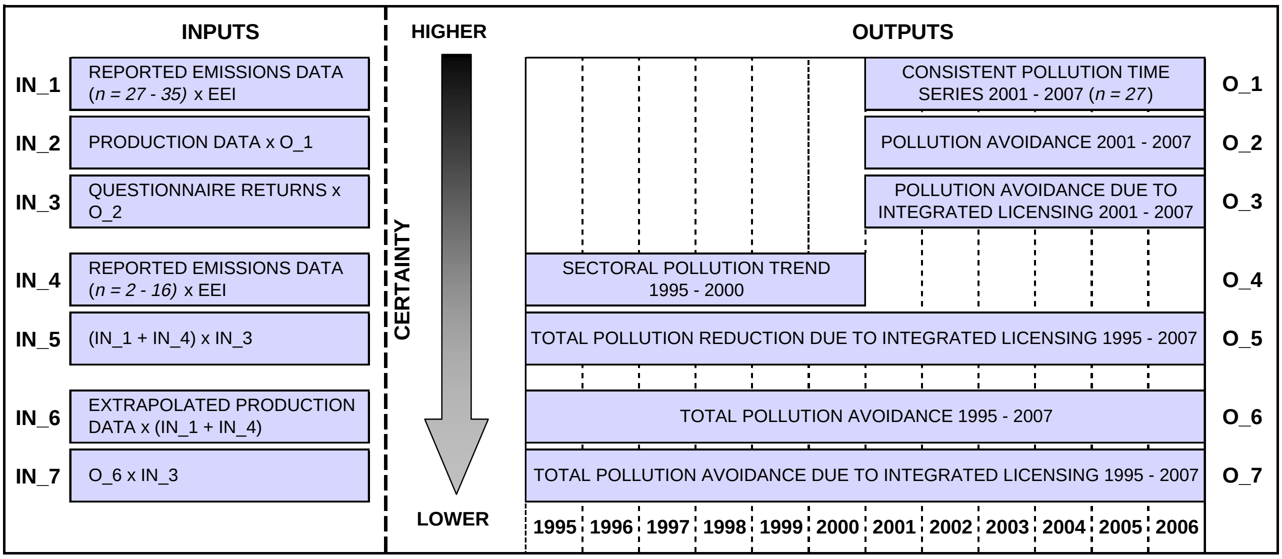


Figure 5.1. Summary of input data, process steps and associated specific outputs used to estimate total pollution avoidance attributable to integrated licensing. The input data and process steps are ordered according to the associated level of relative certainty. EEI, Environmental Emissions Index.

relation to their level of certainty. The major process steps involved are:

1. Interpretation of reported emissions data, using the EEI to quantify pollution trends for the sector between 2001 and 2007;
2. Extrapolation of sectoral emissions back to 1995, based on available data, licence information, and expert judgement;
3. Construction of 'no-improvement' emission trends, based on forward extrapolation of 1995 emissions in relation to production trends;
4. Apportionment of air and water emissions reduction between BAU and integrated licensing influence, according to questionnaire responses; and
5. Examination of ELVs and regulatory/voluntary reporting requirements as potential drivers of emissions reduction.

5.2 Methodology

5.2.1 *Extrapolating pollution trends*

1995 is taken as the reference year for IPC implementation across the sector, as most installations were issued their first IPC licence in that year. An extended version of the Pharma sector emissions time series presented in Section 4.3.1 is used. To extend the sectoral pollution trend back prior to 2001, installations' EEI trends were extrapolated back to the year of their first licence according to the median EEI change during reporting years. From this gap-filled database, the proportion of total sectoral pollution represented by reporting installations could be estimated, and the percentage additional pollution attributable to 'new' installations (licensed after 1996) could be calculated. The frequency of reporting declines substantially prior to 2001: 50% of estimated sectoral emissions were reported in 2000. Five installations representing 19% of sectoral pollution reported in 1998, and two installations representing 10% of sectoral pollution reported in 1996. As a best estimate of the change in each of the reported emissions for the entire sector between 1995 and 2001, the average annual change in each emission for the latter two installations between 1996 and 2001 was extrapolated back from 2001 sectoral emission quantities. For PM and THM emissions to air (not completely reported by the two installations), the annualised trend from the five installations reporting between 1998 and 2001 was applied. Excluding inventory-estimated sectoral NMVOC emissions (see below), the aggregate 1996 EEI value calculated this way corresponded with the aggregate 1996 EEI value calculated from extrapolation of individual installations' EEI values according to median reported changes.[13] For the two reporting installations, reported NMVOC emissions halved between 1996 and 2001. Extrapolating this trend up to sectoral NMVOC emissions implied substantial pollution reduction between 1995 and 2001. This trend corresponded with NMVOC emissions reduction estimated from the introduction of solvent incineration in a number of installations after 1995[14], and was corroborated by EPA inspectors. It is thus regarded as a plausible minimum estimate of NMVOC reduction over this time.

5.2.2 *Quantifying product output and emission avoidance*

Step 2 in this chapter involves the estimation of total pollution avoidance, relative to a hypothetical reference 'no-improvement' scenario. This reference scenario is based on the assumption that, in the absence of new technologies and improved efficiencies and management practices, emissions would have increased in direct proportion to production output between 1995 and 2007. Consistent material production volume data were available for 12 installations (representing 47% of the 2007 sectoral EEI) between 1998 and 2007. This chapter refers to three production indices expressed in relation to 2007 (Fig. 5.2). Index 1 is derived from the standard CSO inflation-adjusted production output index for NACE C21 (Table 4.1). Index 2 is a material production index

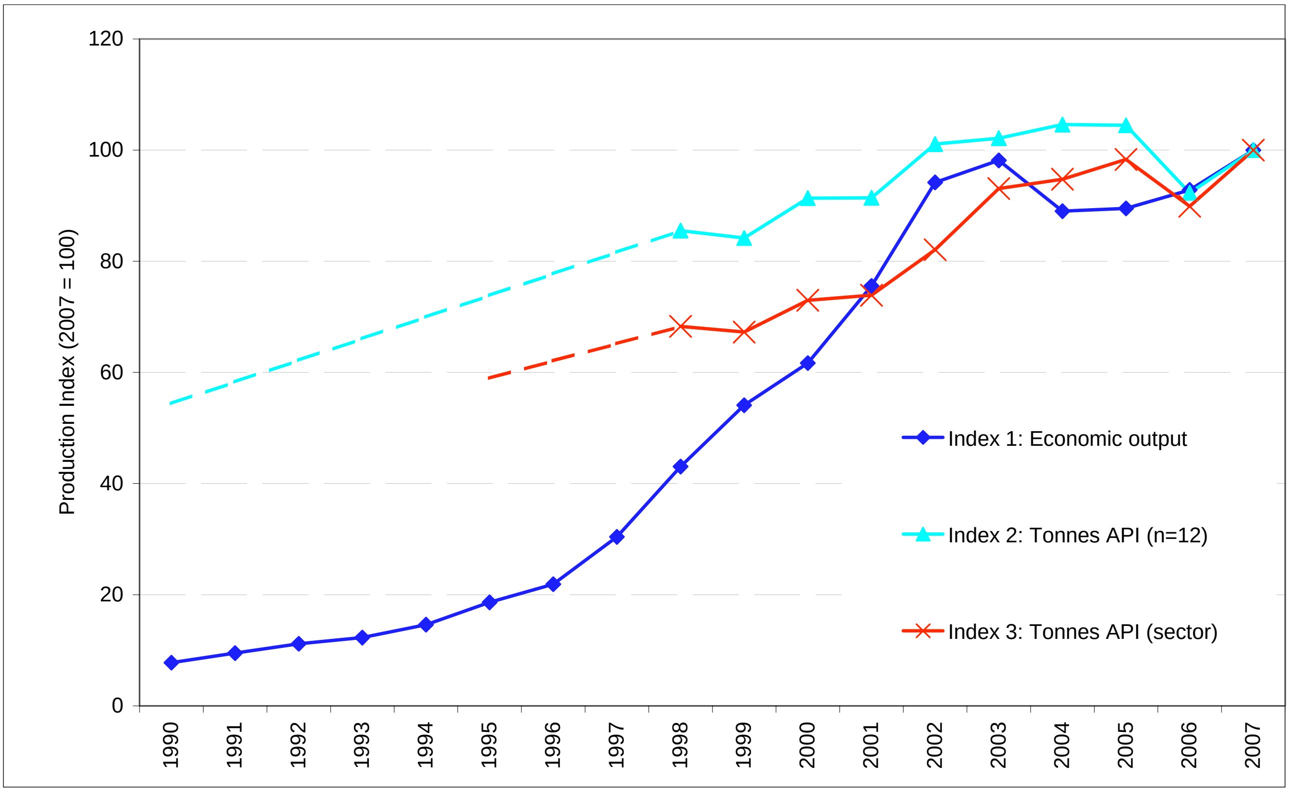


Figure 5.2. Production indices for the pharmaceutical sector between 1990 and 2007, based on: (i) economic output data (Index 1); (ii) reported tonnage of active pharmaceutical ingredient produced between 1998 and 2007 for 12 installations (Index 2); and (iii) estimated trend in tonnage produced for the entire sector (Index 3). API, active pharmaceutical ingredient.

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[13] The latter method estimates the change in sectoral EEI value, but not in EEI composition (i.e. provides no information on individual emission trends).

[14] Non-AER data provided by Installation 7 (Table 5.2) indicates a 480 t (>99%) reduction in annual NMVOC emissions following installation of a solvent incinerator. In total, five installations, representing over three times Installation 7's 2001 EEI, installed incinerators or thermal oxidisers between 1996 and 2001. From the above data, the resulting NMVOC reduction was estimated at 1,577 t, similar to the 1,486 t sectoral reduction calculated from the trend for the two early-reporting installations (Fig. 5.5).

representing a constant number of installations, against which emission or ELV trends for a constant number of installations can be normalised. Index 3 is a sectoral material production index, against which sectoral emission trends can be normalised. For Index 2, as a conservative best estimate and with reference to the economic output trend, the 1998–2007 index based on reported production data is extrapolated back to 1990 based on the 1998–2002 mean trend (Fig. 5.2). For Index 3, the cumulative additional production of 'new' installations that began operations after 1995 (most notably after 2002) is conservatively assumed to be in direct proportion to the cumulative contribution these installations make to the sectoral EEI in each year. Index 2 is used to estimate reference 'no-improvement' emissions for the 27 installations reporting between 2001 and 2007, whilst Index 3 is used to estimate reference 'no-improvement' emissions for the entire sector.

5.2.3 *Identifying drivers of emissions reduction*

In March 2009, a questionnaire survey was sent to the environmental managers of all Pharma installations, following consultation with industry representatives. Twenty responses were received (a response rate of 56% for the 36 operational installations). Respondents were first asked to rank the relative importance of six major potential drivers of emissions reduction (Table 5.1). Then, they were asked: "*Overall, for any reduction or prevention of emissions to the atmosphere that has been achieved at your installation, please estimate the extent to which EPA regulation (integrated licensing) was responsible?*'. The same question was asked for water emissions, and the respondents were asked to tick one of five options (0–20%, 21–40%, etc.). The median estimated licensing contributions contained in questionnaire responses were applied to apportion air and water emission avoidance between BAU and licensing influence. Meanwhile, the scope and completeness of voluntary reporting in Responsible Care Reports (RCRs) (an alternative potential driver of environmental performance improvement) were compared against AER reporting.

Pre-IPC (SML) ELV data were obtained from the original licence applications of eight installations selected by EPA inspectors to represent a range of compliance behaviour (Table 5.2). To indicate any step-change in ELVs associated with the transition from SML to IPC licensing, the last SML ELVs (in Air Pollution licences and Water Pollution licences) were compared with the earliest IPC ELVs. Similarly, the evolution of ELVs throughout integrated regulation was summarised by comparing ELVs from the first IPC licences with ELVs from the most recent IPPC licences. For each installation, the EEI comparison was restricted to those emissions for which ELVs were stipulated in both earlier and later licences. Where ELVs were introduced for additional emissions in later licences, these emissions were listed (Table 5.2).

Quantitative comparison of ELVs required transformation of concentration limits into mass annual emissions. Maximum allowable concentrations were

Table 5.1. Summary of questionnaire responses ranking the relative importance of six potential drivers of emission avoidance (n = 20).

Factor	Rank	
	Mean	Median
EPA regulation (IPC and IPPC licensing)	2.1	2.0
Corporate social and environmental policy	2.5	2.0
Improved technology and technical knowledge	3.7	3.5
Cost-saving efficiencies	3.7	4.0
Voluntary guidelines for sector	4.6	4.5
Environmental Management System accreditation	4.6	5.0

EPA, Environmental Protection Agency; IPC, Integrated Pollution Control; IPPC, Integrated Pollution Prevention Control.

Table 5.2. Summary comparisons of late Single Media Licensing (SML) and early Integrated Pollution Control (IPC) emission limit values (ELVs), and early IPC and most recent Integrated Pollution Prevention and Control (IPPC) ELVs. Percentage changes in Environmental Emissions Index (EEI) values applied to earlier and later ELVs are presented. These changes are also calculated for 1995 production-normalised ELVs (eco-efficiency changes). Where later licences cover additional emissions these are listed (New ELVs), but excluded from comparisons.

	SML:IPC EEI comparison					IPC:IPPC EEI comparison				
	Years	**Substance ELVs**	**ELV change**	**Eco-efficiency change**	**New ELVs**	**Years**	**Substance ELVs**	**ELV change**	**Eco-efficiency change**	**New ELVs**
Inst. 1	1995:1995	W-HMs, COD, TN, TP, PM, SO$_x$, NO$_x$, NMVOC, NH$_3$, CO	–7%	–7%	No	1995:2007	W-HMs, COD, TN, TP, PM, NH$_3$, SO$_x$, NO$_x$, NMVOC, CO	46%	8%	No
Inst. 2	1990:1995	TP, PM, SO$_x$, NMVOC, NH$_3$	–3%	–28%	W-HMs, TN, NO$_x$, CO	1995:2007	W-HMs, NO$_x$, NMVOC, CO	2%	–25%	No
Inst. 3	1994:1994	W-HMs, COD, TN, TP, PM, SO$_x$, NO$_x$, NMVOC, NH$_3$, CO	–42%	–42%	No	1995:2007	W-HMs, COD, TN, TP, PM, SO$_x$, NO$_x$, NMVOC, NH$_3$, CO	19%	–13%	No
Inst. 4	1992:1995	W-HMs, COD, TN,	31%	10%	TP, SO$_x$, NO$_x$, NH3, THMs, CO	1995:2005	W-HMs, COD, TN, TP, SO$_x$, NO$_x$, NMVOC, NH$_3$, THMs, CO	–65%	–75%	No
Inst. 5	1992:1996	W-HMs, COD, PM, SO$_x$, NMVOC	–45%	–56%	TN, TP, NH$_3$	1996:2008	W-HMs, COD, TN, TP, PM, SO$_x$, NH$_3$,	233%	159%	NO$_x$
Inst. 6	1990:1996	COD, PM, SO$_x$, NMVOC, NH$_3$	–21%	–45%	W-HMs, TN, TP	1996:2008	W-HMs, COD, TN, TP, PM, SO$_x$, NMVOC	–4%	–25%	No
Inst. 7	1989:1996	COD, TP, PM, SO$_x$, NMVOC	–19%	–43%	NO$_x$, CO	1996:2006	COD, TP, PM, SO$_x$, NO$_x$, NMVOC, CO	–52%	–59%	W-HMs, THMs
Inst. 8	1993:1996	W-HMs, COD, TN, TP, PM, SO$_x$, NO$_x$, NMVOC, NH$_3$, CO	73%	47%	No	1996:2005	W-HMs, COD, TN, TP, PM, NO$_x$, NMVOC, NH$_3$	–54%	–66%	No
Total			**2%**	**–12%**				**–28%**	**–47%**	

W-HMs, heavy metal emissions to water; COD, chemical oxygen demand; TN, total nitrogen; TP, total phosphorus; PM, particulate matter; SO$_x$, sulphur oxides; NO$_x$, nitrogen oxides; NMVOC, non-methane volatile organic compounds; NH$_3$, ammonia; CO, carbon monoxide; THMs, total heavy metals.

multiplied by maximum allowable flow rates over the stated duration of operations throughout the year, for each emission point (up to 20 per installation in early licenses), and then summed per installation. The consequent mass ELVs may overestimate the annual loading limits envisaged by regulators, as exhaust/ effluent emissions need to be maintained somewhat below ELV concentration and flow limits to ensure continuous compliance. Index 2 was used to estimate the magnitude of upward pressure on emissions exerted by production increases between successive licences, and to calculate the associated change in eco-efficiency represented by successive ELVs. This involved the assumption that each installation followed a production trend similar to that extrapolated for the 12 installations that reported material production data.

5.3 Results

5.3.1 Emissions reduction and avoidance

The relationships between trends in reported pollution, extrapolated pollution, hypothetical 'no-improvement' pollution (based on production extrapolation), pollution reduction, and pollution avoidance are summarised in Fig. 5.3. There was a 40% reduction in annual pollution loading for the 27 installations that consistently reported between 2001 and 2007 (Fig. 5.4). All emissions were reduced, by between 6% for CO_2 and 87% for SO_x (Table 5.3). After considering a 9% increase in production between 2001 and 2007 (Fig. 5.2), avoided pollution equated to 45% of hypothetical 'no-improvement' pollution (Fig. 5.4). Eighty-seven per cent of this avoidance was attributable to reductions in four major emissions: W-HMs, NO_x, NMVOCs and SO_x. Annual mass avoidance for each of these emissions was calculated at 0.9, 373, 404, and 598 t/annum, respectively (Table 5.3). Large avoided emissions of COD (985 t/annum) had a small effect on overall pollution, whilst large percentage reductions in CO and PM had negligible impact on overall pollution as measured by the EEI (Table 5.3; Fig. 5.4). It is notable that, for NMVOCs and CO_2, large mass emission reductions translated into small percentage reductions (Table 5.3), causing CO_2 to move from the fourth to the second most important pollutant from these installations between 2001 and 2007 (Fig. 5.4). For the sector as a whole (see Fig. 4.2a), emissions of NMVOCs remained constant, whilst CO_2 and TP emissions increased by 27% and 39%, respectively. After accounting for an estimated production increase of 35% between 2001 and 2007 for the sector as a whole (Fig. 5.2), annual pollution avoidance between 2001 and 2007 equated to 44% of hypothetical 2007 pollution, and there was avoidance for all emissions except TP (CO_2 decreased by just 3%) (data not shown).

Based on limited reporting from installations between 1995 and 2001, COD and CO_2 were the only emissions to increase from the sector over this period, by 37% and 4%, respectively (Fig. 5.5). Overall pollution was reduced by 45% from the sector over this period, almost entirely accounted for by large reductions in SO_x (83%), W-HMs (32%) and NMVOCs (50%) (Fig. 5.5). In total, between 1995 and 2007, pollution was reduced by 59% (Fig. 5.6), despite COD and CO_2 emissions increasing by 6% and 32%, respectively (Table 5.4). Reductions for other emissions ranged from 0.04 t/annum and 27% for A-THMs, to 3,627 t/annum and 95% for SO_x. Emissions of NMVOCs decreased by 50%. After accounting for an estimated production increase of 70% over this period, aggregate avoided emissions equated to 76% of hypothetical sectoral emissions (Fig. 5.6). Avoidance ranged from 22% for CO_2 to 97% for SO_x (Table 5.4). The most environmentally significant reductions in annual mass emissions were for SO_x (6,286 t/annum), NMVOCs (3,559 t/annum), NO_x (846 t/annum), and W-HMs (2.8 t/annum).

5.3.2 Licensing influence on emissions

Questionnaire returns ranked integrated licensing just ahead of corporate social and environmental policy as the most important driver of emission reductions (Table 5.1). There was considerable variation across questionnaire respondents in the estimated contribution of integrated licensing towards emission avoidance. For air emission avoidance, the median estimated contribution of integrated licensing was 50%, while for water emission avoidance the median estimated contribution was 30% (mean values were 52% and 42%, respectively). The mean and median recall period for the 20 respondents was 2001–2008. Based on these estimates, integrated licensing resulted in pollution avoidance of 20% for the 27 installations that reported between 2001 and 2007, in

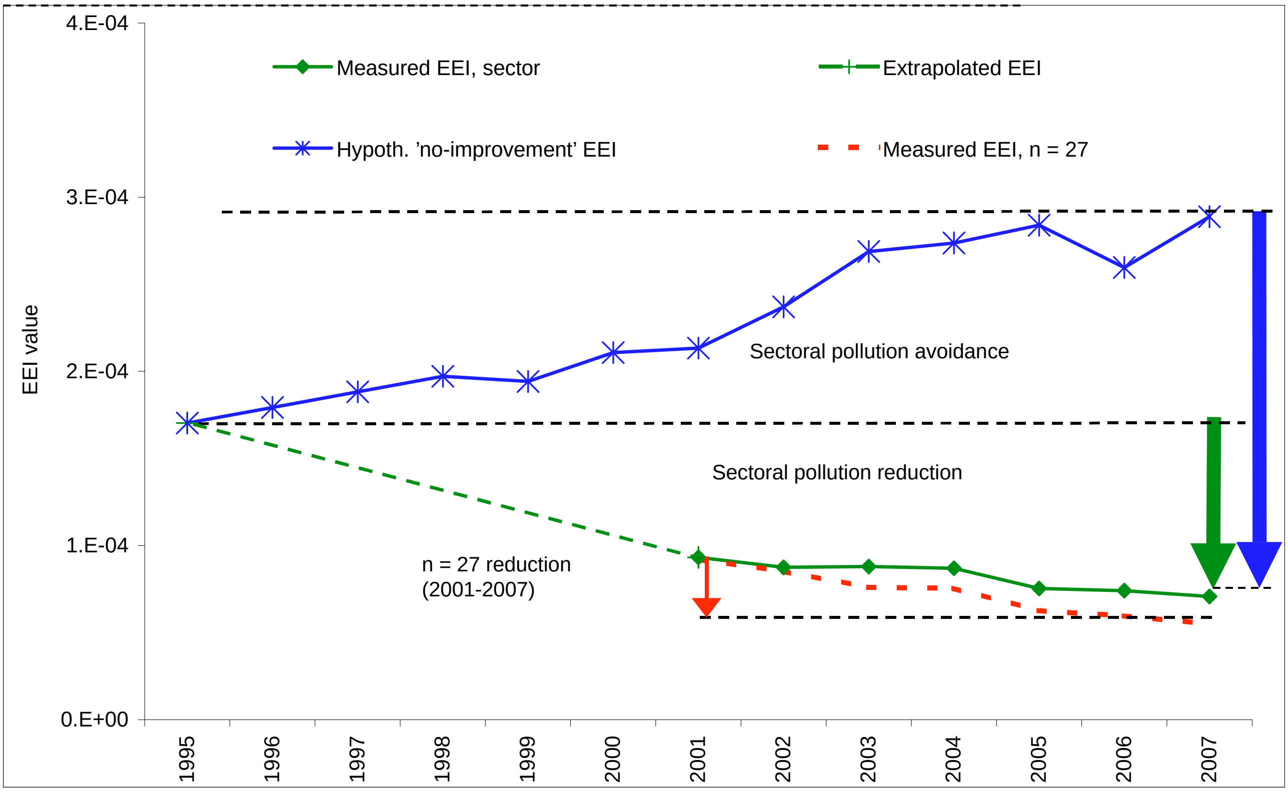

Figure 5.3. Overview of reported Environmental Emissions Index (EEI) time series for 27 continuously reporting installations and the entire sector between 2001 and 2007. The sectoral EEI was extrapolated back from 2001 to 1995 based on available reported data, then extrapolated forward from 1995 to 2007 in a hypothetical 'no-improvement' trend based on Index 2 (Fig. 5.2).

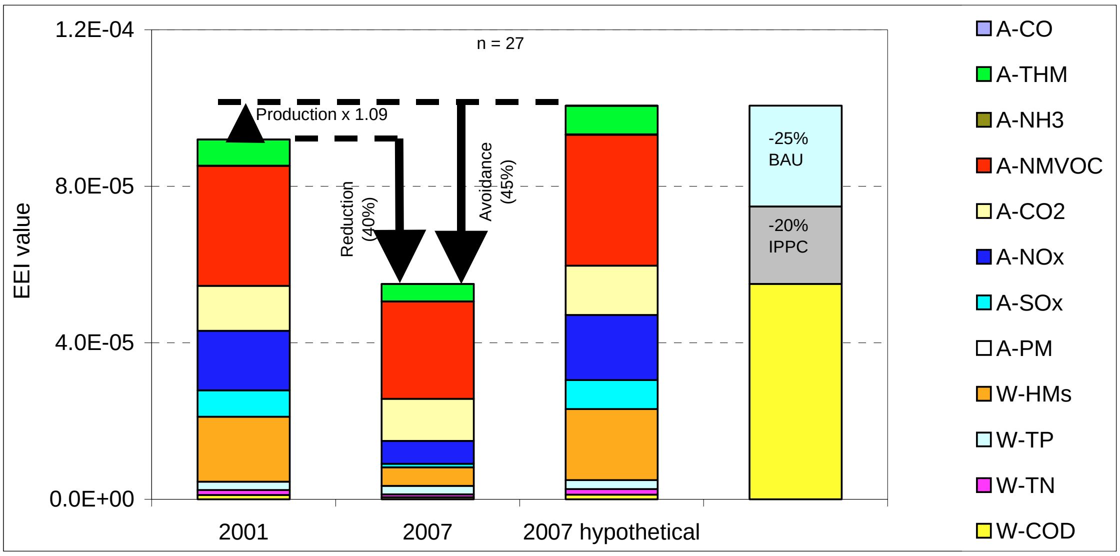

Figure 5.4. Pollution reduction and avoidance between 2001 and 2007 for the 27 installations that reported data throughout this period, based on a production-adjusted (Index 2) estimate of hypothetical 'no-improvement' 2007 emissions. Percentage avoidances attributable to business-as-usual (BAU) improvements and Integrated Pollution Prevention Control (IPPC) licensing are displayed, based on questionnaire data. EEI, Environmental Emissions Index.

Table 5.3. Total emissions (t/annum) in 2001 and 2007 (and percentage reductions), and avoidances relative to hypothetical 'no-improvement' emissions, for 27 major pharmaceutical installations. Also displayed are emission avoidances attributable to Integrated Pollution Prevention Control (IPPC) licensing.

Emission	2001	2007		Avoidance		IPPC effect	
	t/annum	t/annum	%	t/annum	%	t/annum	%
W-Chemical oxygen demand	1,616	783	–52%	–985	–56%	–295	–17%
W-Total nitrogen	99	50	–49%	–58	–54%	–17	–16%
W-Total phosphorus	20	17	–13%	–4.5	–21%	–1.4	–6%
W-Heavy metals	1.3	0.6	–58%	–0.9	–62%	–0.27	–19%
A-Particulate matter	3.7	1.2	–66%	–2.8	–69%	–1.40	–35%
A-Sulphur oxides	623	83	–87%	–598	–88%	–299	–44%
A-Nitrogen oxides	526	202	–62%	–373	–65%	–187	–32%
A-Carbon dioxide	187,781	175,717	–6%	–29,674	–14%	–14,837	–7%
A-Non-methane volatile organic compounds	1,457	1,189	–18%	–404	–25%	–202.21	–13%
A-Ammonia	1.8	1.3	–27%	–0.7	–33%	–0.34	–17%
A-Total heavy metals	0.13	0.09	–34%	–0.06	–39%	–0.03	–20%
A-Carbon monoxide	30	10	–67%	–23	–70%	–12	–35%

A-, emissions to air; W-, emissions to water.

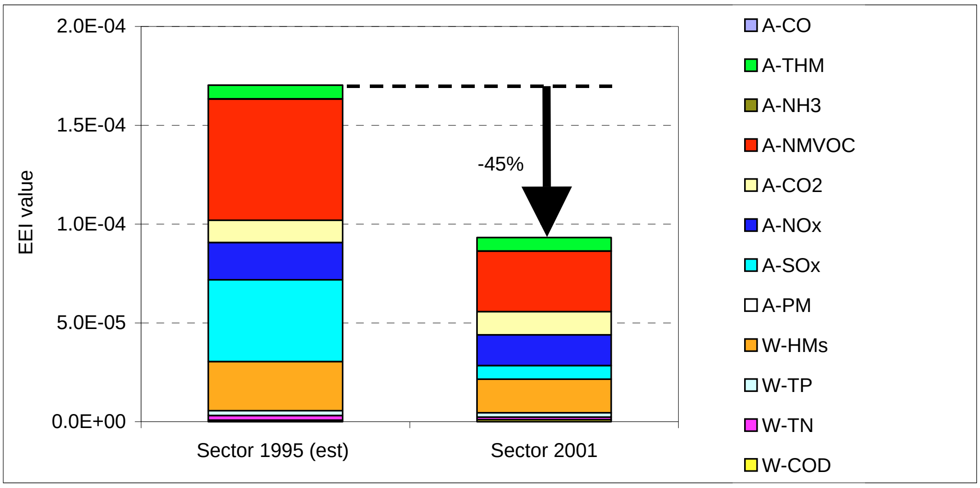

Figure 5.5. Estimated 1995 sectoral Environmental Emissions Index (EEI), extrapolated for each emission according to annualised emission trends for two installations that reported since 1996, and five installations that reported since 1998.

addition to BAU avoidance of 25% (Fig. 5.4). It was inferred that integrated licensing resulted in specific emission avoidance ranging from 6% for TP to 44% for SO_x (Table 5.3). The most environmentally important emission avoidances attributed to integrated licensing between 2001 and 2007 were those of NO_x (–32%), NMVOCs (–13%), W-HMs (–19%) and SO_x (–44%) (Fig. 5.4; Table 5.3). It was inferred that integrated licensing reduced CO_2 emissions by 7%. Applying questionnaire responses to sectoral emissions

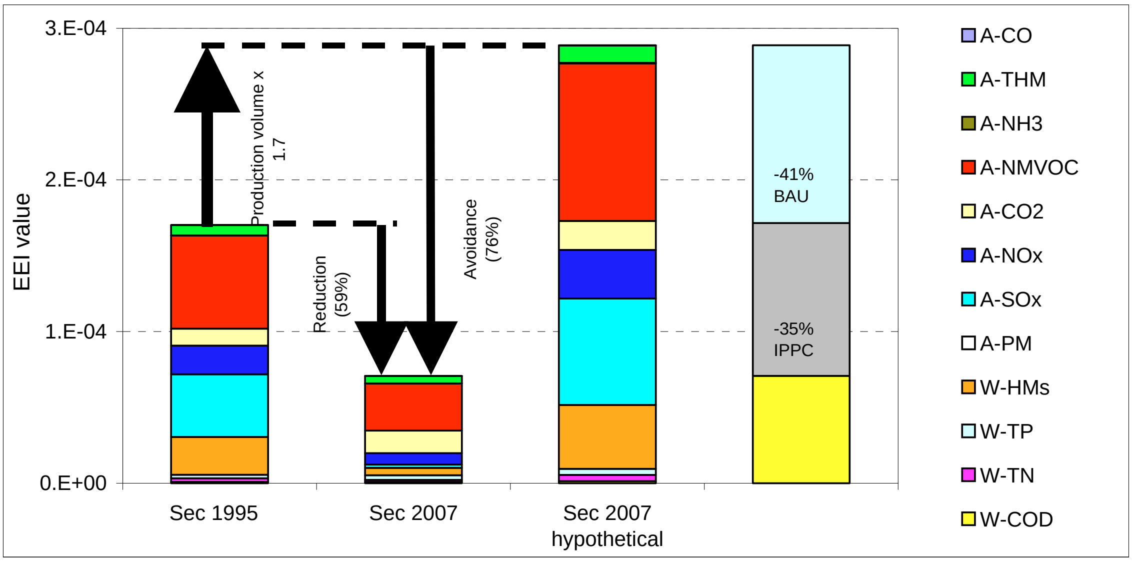

Figure 5.6. Total pollution reduction and avoidance achieved by the sector, based on estimated 1995 emissions and a production-adjusted (Index 3) estimate of hypothetical 'no-improvement' 2007 emissions. Percentage avoidances attributable to business-as-usual (BAU) improvements and Integrated Pollution Prevention Control (IPPC) licensing are displayed, based on questionnaire data. EEI, Environmental Emissions Index.

Table 5.4. Total emission reductions (t/annum) relative to 1995 emissions, and avoidances relative to hypothetical 'no-improvement' emissions (Fig. 5.3), for the entire pharmaceutical sector. Also displayed are emission avoidances attributable to integrated licensing.

Emission	Reduction		Avoidance		IPPC effect	
	t/annum	%	t/annum	%	t/annum	%
W-Chemical oxygen demand	69	6%	–774	–38%	–232	–11%
W-Total nitrogen	–93	–50%	–221	–71%	–66	–21%
W-Total phosphorus	6.1	27%	–9.5	–25%	–2.9	–8%
W-Heavy metals	–1.4	–71%	–2.8	–83%	–0.8	–25%
A-Particulate matter	–2.8	–68%	–5.6	–81%	–2.8	–41%
A-Sulphur oxides	–3 627	–95%	–6 286	–97%	–3 143	–49%
A-Nitrogen oxides	–392	–60%	–846	–76%	–423	–38%
A-Carbon dioxide	58 995	32%	–68 630	–22%	–34 315	–11%
A-Non-methane volatile organic compounds	–1 489	–50%	–3 559	–71%	–1 780	–35%
A-Ammonia	–3.1	–68%	–6.2	–81%	–3.1	–41%
A-Total heavy metals	–0.04	–27%	–0.13	–57%	–0.06	–29%
A-Carbon monoxide	–34	–68%	–68	–81%	–34	–41%

A-, emissions to air; W-, emissions to water.

changes extrapolated back to 1995 implied that integrated licensing was responsible for pollution avoidance of 35%, in addition to BAU avoidance of 41% (Fig. 5.6). Specific emission avoidances inferred to be attributed to integrated licensing ranged from 8% for TP to 49% for SO_X (Table 5.4). The most environmentally important emission avoidances attributed to integrated licensing between 1995 and 2007 were those of SO_X (–49%), NMVOCs (–35%), NO_X (–38%), and W-HMs (–25%) (Fig. 5.6; Table 5.4).

5.3.3 *Specific drivers of pollution avoidance*

Maximum allowable emissions under the first IPC licences ranged from 45% lower to 73% higher than mass emissions allowed under preceding SML licences, although cumulatively for the eight licence case-study installations they were similar (Table 5.2; Fig. 5.7). Adjusted according to production (Index 2), there was a 12% decrease in cumulative emissions allowed in the first IPC licences compared with the last SML licences (Table 5.2; Fig. 5.7). Across the eight installations, IPC ELVs covered between two and six additional emissions compared with SML ELVs (Table 5.2). These additional emissions were included in subsequent IPC and IPPC ELV comparisons. For individual installations, IPPC ELVs ranged from 65% lower to 233% higher than initial IPC ELVs (large changes reflect the 9- to 12-year intervening period, during which amended IPC licences were issued for most installations). Cumulatively for the eight installations, allowable emissions were reduced by 28% over the period of integrated licensing (Table 5.2; Fig. 5.7). This equated to a decrease of 47% in production-adjusted allowable emissions, dominated by a reduction in cumulative allowable heavy metal emissions to water (Fig. 5.7). Cumulative allowable TP emissions to water were also substantially lower in IPPC compared with IPC licences. A few insights gleaned during data collation are not fully conveyed in the ELV snapshots presented. For example, Installation 7's 1996 IPC licence stipulated that allowable NMVOC emissions be reduced from 350 to 0.56 tonnes per annum once a new incinerator was operational, and at the latest by 1998 (reflected in the

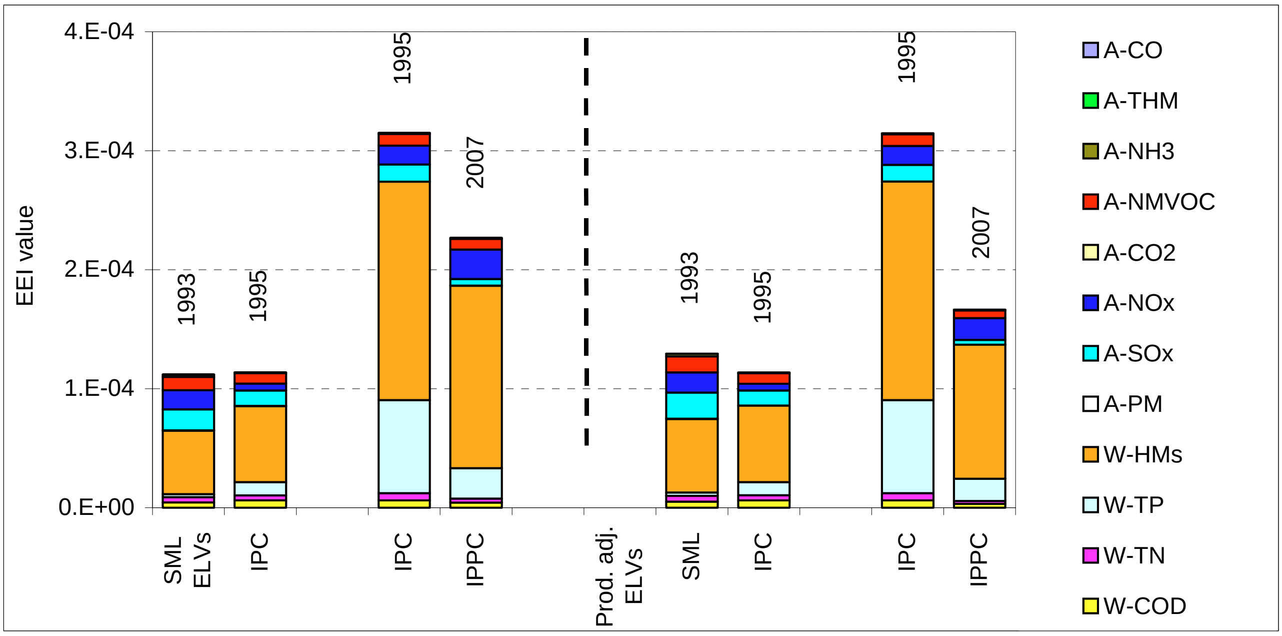

Figure 5.7. Emission limit values (ELVs) specified under Single Media Licences (SMLs), under the first Integrated Pollution Control (IPC) licences, and under the latest Integrated Pollution Prevention and Control (IPPC) licences, expressed as totals for the eight relevant installations, and aggregated using the Environmental Emissions Index (EEI) (left). Values were also normalised against 1995-indexed production (right). For each installation, comparisons are restricted to ELVs specified in the two sets of licences being compared. Average year of issue for the different types of licence specified above bars.

ELV decrease between 1996 and 2006 for Installation 7: Table 5.2). In some cases, increased IPC ELVs were the consequence of ELV recalculations associated with the consolidation of stack monitoring points.[15] Cumulatively for the eight licence case-study installations, reported mass emissions in 2006 represented less than 8% of theoretical maximum allowable emissions. This fraction varied from 1% for CO through 2% for W-HMs and 15% for NO_x, to 28% for SO_x.

Questionnaire respondents ranked voluntary reporting fifth out of six major possible drivers of environmental performance improvement (Table 5.1). Reporting in AERs under integrated licensing appears to be considerably more comprehensive than voluntary reporting in RCRs (Table 5.5). The cumulative EEI for the 34 Pharma installations that reported in 2006 was 60% higher than the cumulative EEI for the 45 pharmachemical (34 Pharma, plus 11 other chemical) installations that contributed information to RCRs. RCRs under-represented emissions of COD, SO_2 and NMVOCs, and excluded environmentally important emissions such as W-HMs and NO_x. Comments submitted in questionnaire returns affirmed the perceived importance of integrated licensing in terms of driving emissions reduction, but a few common complaints were expressed. Six respondents complained that licence conditions were excessively prescriptive, with three respondents claiming that the time taken to receive approval for process changes was harming competitiveness. Five respondents believed that rigid interpretation of BAT by the EPA was actually preventing (perceived) best environmental options being adopted. Meanwhile, two respondents referred to process changes (e.g. fewer batch runs) specifically made to reduce emissions in response to integrated licensing – examples of pollution prevention through process modification.

5.4 Discussion

This chapter quantifies the change in direct pollution from the Pharma sector, associated with changes in on-site emissions, within the scope of the EEI. Numerous emissions outside the scope of the EEI, and other impacts such as waste export and electricity consumption, are not accounted for. Changes in these impacts may or may not have been similar to changes in direct pollution quantified by the EEI. However, there

Table 5.5. Comparison of total reporting under licensing conditions (Annual Environmental Reports, AERs) and voluntary reporting (Responsible Care Reports, RCRs), for 2006. AER data represent 34 installations in IPPC Sector 4.5, whilst RCR data represent these same installations plus an additional 11 installations involved with chemical manufacture.

Emission	RCRs	AERs
Chemical oxygen demand	500	1,390
Total nitrogen	62	88
Total phosphorus	18	20
Sulphur dioxide	165	271
Carbon dioxide	359,000	248,978
Non-methane volatile organic compounds (NMVOCs)[1]	105	333
No. of installations	45	34
No. of emissions	6	20
Environmental Emissions Index	2.9E-05	4.7E-05*

[1] Excludes total estimated sectoral NMVOC emissions.

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[15] For some emission points and substances, the maximum concentration limit from component emission points was applied to the total flow from the new consolidated emission point.

is no evidence that direct pollution is being 'outsourced' from the Pharma sector. For example, electricity use is a major source of indirect emissions (Chapter 3), but increased by just 1% between 2001 and 2007 for the 27 core installations (and the life-cycle pollution associated with generation of that electricity decreased significantly: Fig. 4.1a). In addition, the introduction of solvent incineration at a number of installations since 1995 (previously exported as waste) is likely to have increased the proportion of pollution accounted for within 'gate-to-gate' reporting boundaries.

To some extent, the final years of SML licensing anticipated IPC licensing, particularly with respect to the principle of BATNEEC[16]. Therefore, environmental regulation now embodied in IPPC licensing exerted influence for a significant period prior to 1995. The pollution reduction associated with such regulation may thus be greater than indicated in this study. Similarly, the average recall period of questionnaire respondents does not represent the earlier (1995–2001) period of study. Assuming that integrated licensing had the same proportionate influence on pollution avoidance during its initial implementation may underestimate the effect of compliance with initial IPC licence conditions (in particular the documented installation of new incinerators and thermal oxidisers). The material production index also represents a conservative indication of upward pressure on emissions associated with production, given a recent shift towards higher-value, lower-volume products within the Pharma sector (IBEC, 2007).

Although reporting was patchy prior to 2001, the early pollution trend was corroborated by other data sources and the experience of EPA inspectors. In particular, an estimated halving of NMVOC emissions between 1995 and 2001 corresponded to the installation of new incinerators and thermal oxidisers over this period, and NMVOC emission reductions across the IPC industry reported by Clinch and Kerins (2002). Additionally, extrapolated 1995 SO_x emissions would imply that approximately 50% of the fuel consumed on-site was heavy fuel oil (max. 3% sulphur) in 1995. Large SO_x emission reductions are consistent with (incomplete) reported fuel-use data showing a shift towards light fuel oil and natural gas, and correspond with early IPC licence conditions requiring the fitting of acid-gas scrubbers and use of low-sulphur fuel oil. In terms of environmental protection, it is important to note that all but three emissions decreased substantially in absolute terms between 1995 and 2007, but two of the three that increased (CO_2 and TP) are of increasing environmental concern.

ELVs represent the minimum standard of emissions compliance required from individual installations. Using the EEI to aggregate calculated mass-emission ELVs into an index of maximum allowable pollution suggested that the transition from SML to IPC licensing was an evolutionary one, and not associated with an immediate reduction in total allowable pollution. Most large pharmaceutical installations were under the remit of Cork County Council prior to 1995 – the local authority at the vanguard of SML regulation in Ireland. Installation 7 is one of two installations in Table 5.2 located outside of Cork, and has experienced the largest overall decline in allowable pollution following the introduction of integrated licensing. The introduction of integrated licensing standardised regulation across the 33 local authorities, and extended control to a wider range of emissions. It also prepared for more stringent ELVs (especially when normalised against production growth) in later licences, with early licence conditions setting target dates for BATNEEC implementation and specific emission reductions. The consolidation of emission points required in early IPC licences facilitated comprehensive emission monitoring, although standardised mass emissions reporting only became widespread following publication of a formal guidance document in 2000 (EPA, 2000).

At first glance, the wide disparity between mass ELVs and mass emissions suggests that BAT-derived ELVs are not key drivers of emissions control within the Pharma sector. However, batch production of pharmaceutical products means that mass annual emissions are unlikely to approach continuous worst-case operating conditions over a year, as assumed in the calculation of annual mass ELVs. Operators in this well-established and profitable sector may also take a long-term and risk-averse perspective, future-proofing

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[16] Best available technology not entailing excessive cost.

all process investments against anticipated ELV tightening (the first generation of BAT-derived ELVs is lenient according to Honkasalo et al., 2005). Comments made in questionnaire returns suggested that ELVs were important, and one respondent specifically referred to compliance with anticipated future ELVs. Nonetheless, given the stated importance of integrated licensing in reducing emissions, the extent of the disparity between ELVs and actual emissions suggests that other aspects of integrated licensing play a role in driving emission reductions. Previous studies have indicated that reporting and public disclosure of emissions data is a strong driver of environmental performance improvement (Silvo et al., 2002). This study was possible only because of the emissions reporting required by integrated licensing. It is clear that such reporting is considerably more comprehensive and disaggregated (installation-specific) than voluntary reporting from Ireland's Pharma sector (although a number of installations do independently publish detailed environmental statements). Cunningham (2000) emphasised the importance of the monitoring and reporting process, and the requirement for EMPs, in driving earlier environmental performance improvements for Ireland's pharmaceutical industry. There is evidence from questionnaire respondents and EPA inspectors that EMP targets have resulted in the consideration of environmental impacts during process design, resulting in genuine pollution prevention. Further discussion on the results presented in this chapter can be found in Styles et al. (2009c).

5.5 Summary

For the 27 core Pharma installations that reported between 2001 and 2007, an aggregate pollution reduction of 40% over this period translated into pollution avoidance of 45%, after accounting for a 9% concurrent increase in production. Accounting for new entrants, a 24% decrease in sectoral pollution between 2001 and 2007 translated into pollution avoidance of 44%, accounting for a 35% increase in sectoral production – despite increases in emissions of TP and CO_2. Reported emissions data between 1995 and 2001 were considerably less comprehensive, but extrapolated sectoral emission trends indicated large reductions in SO_x, NMVOCs and W-HMs, corroborated by other data sources. Between 1995 and 2007, there was a 59% reduction in pollution from the sector. Relative to hypothetical 'no-improvement' emissions, this reduction equated to pollution avoidance of 76%, and was dominated by avoidance of SO_x (97% lower), NMVOCs (71% lower), W-HMs (83% lower) and NO_x (76% lower).

Following major emission reductions for what were the sector's biggest pollutants in 1995, but a 32% absolute increase in CO_2 emissions, NMVOCs and CO_2 are now the sector's biggest pollutants, and show no sign of decreasing (despite inclusion of many pharmaceutical installations within the EU ETS for CO_2). Questionnaire responses from industry environmental managers indicated that integrated licensing was the most important driver of emission reductions for the Pharma sector, and accounted for 50% of the reduction in air pollution and 30% of the reduction in water pollution. Consequently, between 1995 and 2007, it was estimated that integrated licensing reduced pollution by 35%, and individual emissions by between 8% (TP) and 49% (SO_x) compared with hypothetical 'no-improvement' emissions.

ELV trends reflect substantial tightening in the minimum environmental performance required by integrated licensing, but actual emissions are considerably below licensed emissions. For the risk-averse and profitable pharmaceutical sector, anticipation of future ELVs encourages pre-emptive emission reductions. However, it is likely that monitoring and reporting requirements exert considerable pressure on installations to make continuous emission reductions. Voluntary self-regulation within this sector may enhance the effectiveness of integrated licensing somewhat, but is not a primary driver of emission reductions. Additional emphasis on emissions reporting and data dissemination, combined with a transparent and consistent methodology to compare emissions, could strengthen the long-term incentives for the continued pollution reductions necessary to achieve sustainability.

6 Efficiency of IPPC Licensing

6.1 Background and Aims

Integrated licensing is essentially a form of direct 'command-and-control' regulation, albeit a sophisticated form that differentiates requirements according to economic viability across sectors, and aims to avoid excessive prescription. Command-and-control-type regulation can be highly effective, as indicated in Chapter 5 and other studies (Silvo et al., 2002; Environment Agency, 2004; EEA, 2008; Mirasgedis et al., 2008). There is evidence that integrated licensing is economically efficient, in that the economic savings to society associated with avoided external pollution costs are greater than the compliance costs borne by licensees (Clinch and Kerins, 2002; AEA, 2007). However, neoclassical economic theory is critical of the comparative efficiency of command-and-control regulation, and suggests that market mechanisms could achieve environmental objectives at lower cost through allocative efficiency and by encouraging innovation. Bréchet and Tulkens (2009) demonstrate that BAT specifications effectively prescribe specific technological adaptation in some cases, which may not be economically efficient. Compliance costs may be excessive for smaller installations (Hitchens et al., 2001), and the viability or competitiveness of firms may be reduced. Consequently, there is a focus on implementing economic instruments, such as the EU ETS for CO_2, or carbon taxes.

There are considerable practical challenges to implementing market-based regulation, not least enforcing the monitoring and reporting of environmental performance metrics upon which such regulation should be based. Meanwhile, an increasing number of studies are finding that mandatory regulation can be a major driver of innovation (Honkasalo et al., 2005; Iraldo et al., 2009a). López-Gamero et al. (2009b) suggest that the environmental *and* financial performance of firms is improved by proactive environmental management. The Porter Hypothesis (Porter and van der Linde, 1995) suggests that there is scope for significant resource-efficiency improvement across most firms, and that, by driving such improvement through innovation, rigorous environmental regulation can actually improve economic competitiveness. This chapter presents information on compliance costs and competitiveness obtained from questionnaire responses from eight Pharma installations (Survey 1), and relates this information to pollution avoidance calculated in Chapter 5 in order to generate a basic cost–benefit assessment of integrated licensing. Qualitative information provided in questionnaire responses is used to explore the efficiency of integrated licensing, and its role alongside economic and 'soft' (e.g. voluntary EMS certification, green procurement) forms of regulation. The results of an Italian econometric study on the construction–chemical industry in northern Italy (Iraldo et al., 2009a) are also drawn upon. The findings of that study, comparing different types of regulatory approach, are consistent with many of the findings of this study, and the two sets of findings have been combined in a recently submitted paper (Styles et al., submitted).

6.2 Methodology

For Ireland's Pharma sector, appropriate external costs, based on literature values (see Table 6.1), were applied to estimate the annual social benefit of pollution avoidance specifically attributable to direct regulation, relative to BAU, as determined in Chapter 5. In order to estimate the cost-effectiveness of IPPC regulation, the calculated social benefit was compared with annualised IPPC compliance costs, derived from responses to a questionnaire survey sent to Pharma environment managers in November 2007 (Survey 1). Respondents were asked to break down compliance costs into application and environmental survey costs, capital investment costs, operation and maintenance costs, and monitoring and reporting costs, and provide data for as many years as possible. Costs for previous years were inflated according to the wholesale price index (CSO, 2009), and all capital investment costs were expressed as annualised depreciation costs based on a 15-year equipment lifetime. The

Table 6.1. Mass annual emission avoidance specifically attributable to direct regulation (integrated licensing) for 27 core Pharma installations in relation to business-as-usual (BAU) emissions. The external cost of avoided emissions is used to calculated social benefit attributable to direct regulation.

Emission	BAU	Actual	Regulation effect	External cost	Benefit
	t/annum			€/t	k€/annum
W-Chemical oxygen demand	1,020	783	238	348[1]	83
W-Total nitrogen	100	50	50	1,835[2]	92
W-Total phosphorus	20	17	2	48,415[2]	111
W-Heavy metals	1.29	0.46	0.82	96,830[3]	80
A-Particulate matter	3.30	1.25	2.05	75,000[4]	154
A-Sulphur oxides	2,569	83	2,485	16,000[4]	39,764
A-Nitrogen oxides	563	211	351	12,000[4]	4,214
A-Carbon dioxide	210,251	176,622	33,629	19[5]	639
A-Non-methane volatile organic compounds	2,533	1,189	1,344	2,800[4]	3,764
A-Ammonia	3.66	1.34	2.32	31,000[4]	72
A-Total heavy metals	0.13	0.09	0.05	150,000[6]	6.8
A-Carbon monoxide	38	10	28	308[1]	9
Annual benefit (k€)					**48,987**
Annual cost (k€)					**21,176**
Benefit–cost ratio					**2.31**

A-, emissions to air; W-, emissions to water.

[1] Calculated relative to other emissions based on relative contribution to single impact category.

[2] Median of O'Doherty and Tol (2007) minimum and maximum quoted values.

[3] Approximated to twice total phosphorus impact.

[4] External cost estimates from best available techniques assessment guidance document (EC, 2006a), based on value of statistical life mean for particulate matter mortality, value of life year mean for ozone mortality, inclusion of health core, health sensitivity and crop effects, and sum of means over 0 ppb volume concentration.

[5] ExternE (EC, 2005).

[6] Approximated to twice particulate matter cost.

component of these costs associated with control of air and water emissions was identified, and extrapolated up to the 27 installations that were in operation since 1995, based on the contribution of the Survey 1 respondents to pollution loading from these 27 installations (24% in both 2001 and 2007). Survey 1 also asked detailed questions about the effect of IPC and IPPC licensing on operations, including the effect on operational efficiency and competitiveness. It was not anonymous, and received eight responses. These are combined with comments received from some of the 20 respondents to the subsequent anonymous survey questionnaire of March 2009 (used for Chapter 5) – referred to in this chapter as Survey 2.

6.3 Results

For the eight respondents to Survey 1, the mean compliance cost was €1.6 million per installation in 2007. A breakdown of these costs was provided by five respondents, and indicated that operating and maintaining environmental systems dominated compliance costs (Fig. 6.1). Twenty-three per cent of compliance expenditure was attributed to monitoring and reporting, while 8% was attributed to capital depreciation, and 2% to survey and applications. Respondents apportioned compliance expenditure in the ratios 20%, 30% and 50% to controlling air emissions, water emissions, and waste, respectively.

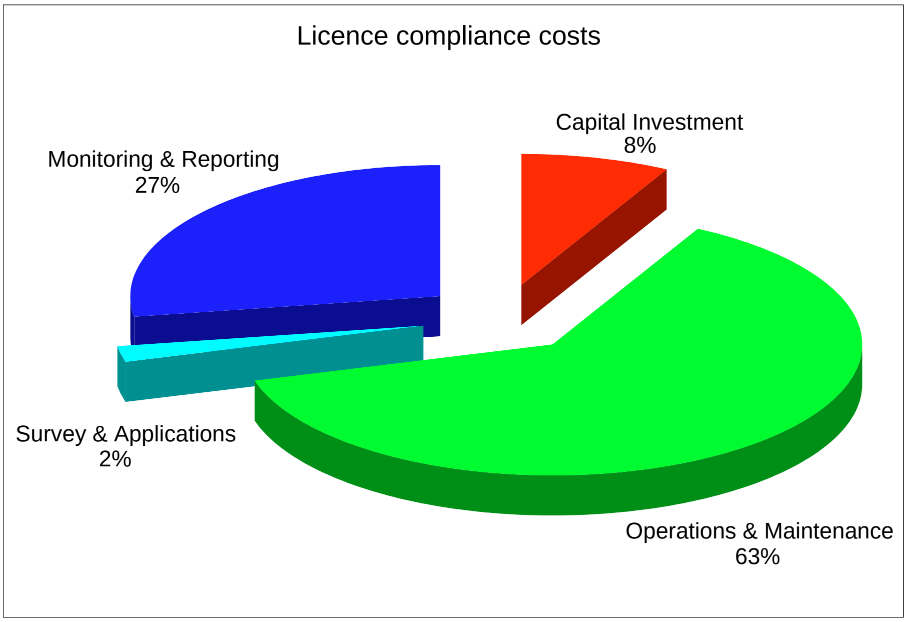

Figure 6.1. Average breakdown of annual licence compliance costs between 1995 and 2007 by category, based on detailed questionnaire cost data provided by five installations.

Extrapolated up to the 27 Pharma installations that were in operation throughout 1995–2007, annual expenditure on air and water emission control equates to €21.18 million (Table 6.1). Using external cost estimates for reported emissions from the literature, the total economic saving associated with emission avoidance specifically attributable to integrated licensing amounts to €48.99 million (Table 6.1). This is dominated by an avoidance of 2,485 t of SO_x attributable to licensing. Consequently, a basic benefit-to-cost ratio of 2.3 is calculated for direct regulation implemented through integrated licensing. This does not include possible additional economic effects (positive or negative) manifested through competitiveness impacts, or efficiency savings.

Results from Survey 1 of the Irish Pharma sector (Table 6.2) suggest that compliance with integrated licensing may temporarily constrain production output in some instances (as noted by four out of eight respondents). Comments suggest that this occurred primarily due to shutdowns required to prevent ELV exceedance (e.g. if abatement systems malfunction or become overloaded). Similarly, whilst respondents to the 2009 survey referred to in Chapter 5 (Survey 2) remarked that IPPC regulation was very effective at driving environmental performance improvements, six complained that it was too bureaucratic, and four thought that it resulted in sub-optimal outcomes (from an economic *and* environmental perspective). However, Survey 1 respondents also reported a number of positive effects, particularly through provision of technical guidance documentation and enhancement of corporate image, but also through more consistent regulation across competitors, by encouraging the identification of efficiencies, and improving access to markets with strict environmental standards (Table 6.2). Crucially, it appears that integrated licensing has driven changes in process technologies and techniques (i.e. innovation), in addition to implementation of abatement options. Overall, respondents perceived IPPC licensing to have had, on balance, a slight positive effect on their competitiveness within Ireland and Europe, but a negative effect on their competitiveness globally. A few respondents to Surveys 1 and 2 commented that their parent companies perceived environmental regulation to be stricter in Ireland than in foreign (both EU and non-EU) countries where they operated.

6.4 Discussion

The effectiveness of direct regulation such as IPPC licensing is proven. From a public perspective, apparently high IPPC compliance costs for the Irish

Table 6.2. Responses to key questions asked in Survey 1.

Question		**Response**			
		Yes	**No**		
Did licensing require…	**New process technology?**	5	3		
	New abatement technology?	5	3		
	New process techniques?	3	5		
	New abatement techniques?	7	1		
Has licensing had any positive effects through…	**Identification of efficiencies?**	4	4		
	Provision of BAT information?	6	2		
	Regulation of competitors?	5	3		
	Enhancing corporate image?	7	1		
	Improving access to markets?	4	4		
Were there negative effects in relation to...	**Production?**	4	4		
	Costs?	8	0		
		Positive	**Negative**	**None**	**Net**
What has been the effect of licensing on competitiveness?	**Within Ireland?**	3	1	4	2
	Within the EU?	3	2	3	1
	Globally?	2	4	1	–2

BAT, best available techniques.

Pharma sector are efficient, because the pollution they prevent would impose costs on society that would be greater than the compliance costs incurred by licensees. In fact, although the higher end of external cost estimates from the ECME document (EC, 2006a) was used, these included only health and crop effects for most emissions (corresponding approximately to the HTP and TOFP impact categories in the EEI). Including the wide but non-quantifiable total economic costs associated with ecosystem impacts (for example including the other four impact categories in the EEI) would improve the benefit-to-cost ratio of IPPC licensing further. Although similar positive assessments have previously been made for IPPC regulation (e.g. Clinch and Kerins, 2002; AEA, 2007), this assessment is important because it is underpinned by quantitative and comprehensive data on pollution avoidance specifically attributable to integrated licensing, and relates to a high-tech, highly financed, export-driven sector with high levels of engagement in CSR and voluntary self-regulation.

If emission costs are considered as production inputs (Telle and Larsson, 2007), then regulation clearly leads to improvements in production efficiency. Direct compliance costs are small compared with economic output from the sector, and cover a wide range of pollutants (beyond those considered in the pollution index). It was not possible to calculate direct abatement costs for each pollutant. However, using neoclassical economic theory to calculate marginal abatement costs is an inadequate approach for assessing the efficiency of IPPC regulation. Whilst it is possible that reductions for some emissions achieved by IPPC regulation of the Pharma sector could have been achieved more cost-effectively elsewhere (e.g. in more polluting sectors such as cement production and agriculture), any accurate assessment must consider the whole suite of pollution parameters controlled by IPPC regulation, and indirect costs and benefits associated with wider efficiency and competitiveness effects, in the context of viable alternative regulatory options.

No strong conclusions could be drawn from this study regarding the effect of IPPC regulation on economic competitiveness. However, there is evidence that integrated licensing resulted in modifications to process technologies and techniques in the Irish Pharma sector, indicating that IPPC licensing is being implemented as intended within the original directive: with an emphasis on pollution *prevention*. Survey respondents indicated that the mandatory EMPs acted as drivers of innovation, possibly improving operating efficiency. This finding was supported by evidence from the Italian Chem sector (Iraldo et al., 2009a; Styles et al., submitted) that suggested that direct and stringent regulation acted as a driver for innovation. It is difficult to isolate the net effect of regulation on competitiveness (López-Gamero et al., 2009b) – avoiding confounding factors such as the tendency for larger, more efficient installations to be more responsive to environmental regulation (Hitchens et al., 2001; Radonjič and Tominc, 2007). Pharma respondents suggest that IPPC regulation may have a neutral or positive effect on competitiveness at the national and EU level, but a negative effect at the global level, and complain about excessive prescription. There is scope to improve stakeholder engagement and innovation, and reduce any negative effect on global competitiveness, by reducing the prescriptiveness of IPPC licensing for BAT-compliant licensees. Moving towards a more performance-oriented enforcement approach could achieve this by combining greater flexibility in the means to achieve compliance with enhanced rigour of compliance assessment (Chapter 3).

In order to consider the results within the broader context of regulatory options, features of the three main approaches to environmental regulation in Table 6.3 have been summarised. Conclusions drawn from this study are consistent with those drawn from a study of the Italian Chem sector (Iraldo et al., 2009a) – both sets of conclusions are summarised in Fig. 6.2. Italian Chem installation managers ranked regulatory instruments in terms of operational influence thus: direct regulation > economic instruments > soft instruments. Whilst this study of the Irish Pharma sector suggests that soft regulation, implemented through EMS accreditation and voluntary reporting, plays a minor role relative to direct regulation, other studies suggest that the importance of soft regulation increases where direct regulation is less stringent (Radonjič and Tominc, 2007). Soft regulation has an

Table 6.3. Overview of the advantages and disadvantages of the three main types of regulatory instrument, in terms of industrial pollution control.

	Direct regulation	Economic instruments	Soft instruments
Environmental effectiveness	3	2	1
Consideration of localised impacts	3	1	2
Range of environmental impacts covered	3	1	2
Impact on competitiveness	1	2	3
Verification of environmental performance measurements	3	1	2
Potential to influence small firms (e.g. SMEs)	1	3	2

1, Worst/poor performance or potential; 2, mid/neutral performance or potential; 3, best/good performance or potential.
SME, small- to medium-sized enterprise.

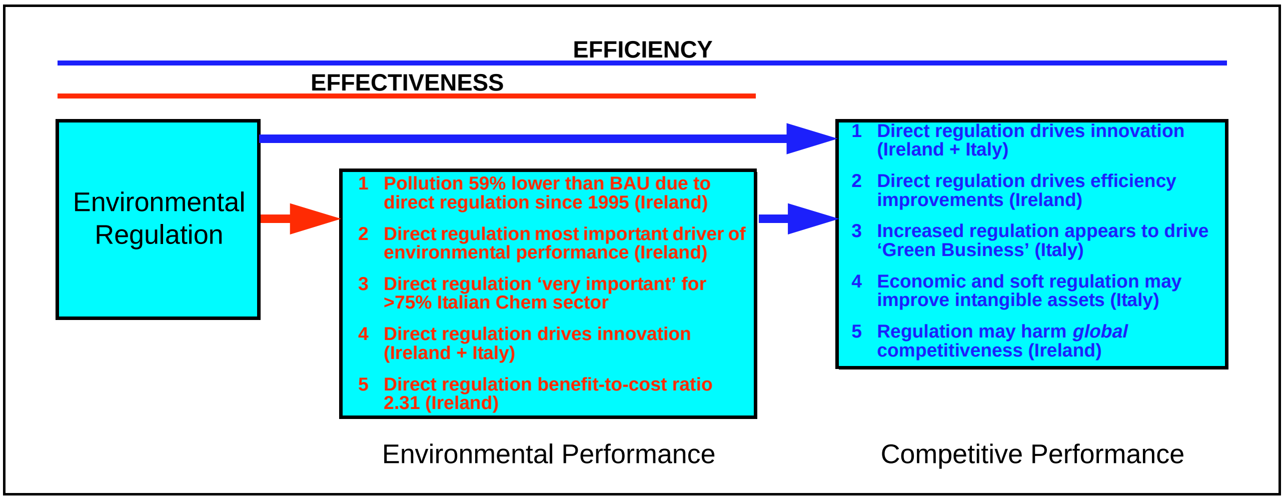

Figure 6.2. Combined conclusions from the study of Irish Integrated Pollution Prevention and Control industry and the study of the Italian Chem sector in relation to regulatory effectiveness and efficiency and business competitiveness (from Styles et al., submitted). BAU, business as usual.

important role to play in improving the environmental performance of the many small- and medium-sized enterprises (SMEs) that fall outside the scope of IPPC regulation (but that have a large cumulative impact on environmental quality). The implementation of green procurement policies by public bodies or private firms could be particularly effective at influencing less regulated SMEs (Iraldo et al., 2009b) – if the underpinning environmental performance credentials of SMEs are accurately certified, based on verified performance metrics. Private firms may be encouraged to pursue green procurement voluntarily through EMS, or through extended product life-cycle accounting in enforced IPPC EMPs.

In summary, IPPC licensing appears to be highly effective for installations that fall within its scope. In particular, IPPC licensing integrates economic considerations (through BAT determination) with incentives for continuous improvement (through reporting and EMPs), and rigorously enforces minimum standards through ELVs. Integrated licensing is economically efficient compared with no regulation, and has a proven track record. Considering the wide range of pollution IPPC licensing controls, and the efficiencies it drives, such regulation also appears to be the most efficient option available to control industrial pollution. Nonetheless, there is scope to improve its efficiency by increasing the emphasis on environmental performance outcomes. The authors suggest that some form of direct regulation will always be necessary to provide an enforceable framework for the accurate monitoring of environmental performance, including traded or taxed parameters. The main limitation of IPPC licensing is its sphere of influence, which is restricted to larger installations owing to administrative practicalities. In addition to influencing the environmental performance of SMEs through separate economic and soft regulatory approaches, aspects of these approaches could be incorporated into, and co-ordinated with, IPPC licensing. For example, licensees could be encouraged or required to report on the life-cycle environmental impacts of their operations, or to implement green procurement policies, effectively extending the reach of integrated licensing beyond large industrial installations.

6.5 Summary

From a societal perspective, direct regulation implemented through IPPC licensing of Ireland's Pharma sector was found to be highly efficient, with a benefit to direct-compliance-cost ratio of 2.3. Furthermore, innovation and production efficiency improvements attributed to integrated licensing suggest that compliance costs and harmful competitiveness impacts (e.g. the pollution haven theory) attributed to direct regulation are typically overstated, and offset by economic benefits. Traditional economic methods are inadequate (too narrow in scope) to fully assess the comparative efficiency of broad regulation such as IPPC – typically overestimating the burden and underestimating the benefits. There was no strong evidence from survey responses that efficiency improvements associated with regulation translated into competitive advantage, although it appears that operators are more likely to accept regulation such as IPPC licensing when it is implemented on an EU scale.

Questionnaire responses indicated that direct regulation (integrated licensing) has been the major driver of pollution avoidance, and that voluntary reporting has played a minor role. This is consistent with recent findings from a survey of the Chem sector (Iraldo et al., 2009a) in Padania, Northern Italy, that rated direct regulation as more effective than economic and soft (voluntary) regulation. Economic instruments are restricted to easily monitored environmental pressures, such as fuel use, and lack the environmental scope of direct regulation, whilst voluntary instruments lack the rigour and verifiability of direct regulation. Nonetheless, economic and voluntary regulations have wider spheres of influence across economic activities, and are essential components of national environmental policy. In particular, such instruments can influence SMEs currently beyond the reach of IPPC regulation. The verified monitoring and reporting of a wide range of environmental pressures enforced by IPPC licensing is an essential component of industrial pollution control. The efficiency of integrated licensing could be maximised by further focussing on environmental performance outcomes, and by co-ordination with other types of regulatory instrument. For example, inclusion of life-cycle impacts in EMPs could be used to encourage green procurement policies among licensees, in turn influencing SMEs.

7 Conclusions

7.1 The Quantification of Environmental Performance

In order to interpret air and water emissions reported by IPPC installations within a context of potential environmental impact, LCIA characterisation, normalisation and weighting methods were used to devise an EEI model. This model aggregates the 20 emission parameters routinely reported in historic AER emission summary sheets, characterises them according to six major environmental impacts (acidification, aquatic toxicity, eutrophication, global warming, human toxicity, tropospheric ozone formation), normalises loadings against national or EU15 total emission loadings, and weights impacts according to policy targets. Consequently, EEI values interpret reported emissions as a contribution to total environmental loading across these six impacts, and can be interpreted as an index of pollution. The EEI is an evolving tool that can be expanded, and should be periodically updated to reflect changes in the national and EU15 inventory emissions data used for normalisation, and the distance-to-policy targets used for weighting. Despite uncertainties in some model parameters – in particular the use of a median NMVOC toxicity factor – most of the uncertainty arising during AER data interpretation is associated with the quality and completeness of reporting. As a pollution index, the EEI is not exhaustive in its scope, and excludes non-emission impacts such as waste disposal, but does include the mass pollutants most regularly considered in environmental regulations and policy. Ideally, the EEI should be represented as an emission profile (rather than single value) so that the contribution of individual emissions can be identified and related back to specific sources, control measures, or policy. It is important to note that trends in specific emissions may deviate considerably from trends in overall pollution (as noted for CO_2 emissions in the Pharma sector).

7.2 Benchmarking for Regulation

Emissions reporting is becoming more comprehensive, especially with the recent introduction of new PRTR-compliant reporting templates. However, there is still a considerable degree of variability in the completeness of emissions reporting across installations and sectors. Whilst energy use can be used to estimate pollution loading for some installations in the absence of good emissions reporting, a number of major pollutants cannot be readily estimated by regulators. In particular, poor reporting of fugitive NMVOC emissions from Pharma and Chem installations needs to be addressed. Universally high standards of emissions reporting will be required to ensure accurate benchmarking, and achieving these should be a regulatory priority. Nonetheless, despite data shortcomings, it is important to begin quantifying pollution trends at the installation level, using best available scientific methods, in order to inform efficient management, reporting and regulation, and foster greater environmental accountability. The EEI is a tool that could help regulators to achieve this.

A significant issue that needs to be addressed is the boundary for environmental performance assessment used by regulators. Indirect emissions associated with electricity use make a large contribution to life-cycle pollution from the industrial sectors considered here, and omitting them from any benchmarking metric could incentivise pollution outsourcing. Thus it is recommended that indirect emissions associated with the use of electricity from the national grid are included in pollution benchmarking.

Confidentiality concerns present a barrier to full disclosure of production data for many installations, and full eco-intensity benchmarking was possible only for the Power Gen sector. The use of 3-year pollution trends, quantified using the EEI, to benchmark environmental performance across installations, is proposed. It was found that absolute pollution trends were strongly correlated with eco-intensity trends across Pharma installations, and use of absolute, rather than production-normalised, pollution trends would be consistent with the goal of IPPC licensing to achieve *continuous* pollution reductions at the installation level. Such environmental performance benchmarking would place the onus on operators to provide some form of production data to justify pollution increases (e.g. for rapidly expanding newly established operators), and may help to reduce the disparity between economic and environmental accountability. It is an essential component of efficient output-oriented environmental regulation.

7.3 Sectoral Eco-Efficiency Trends

As with performance benchmarking, sectoral eco-efficiency quantification is constrained somewhat by data availability. Nonetheless, whilst there is some uncertainty associated with sectoral pollution trends derived from aggregation of bottom–up installation data, when combined with alternative data sources (e.g. national NMVOC inventory: CTC, 2005), the trends derived in this study are probably the most comprehensive currently available.

There were substantial pollution reductions from all four study sectors between 2001 and 2007, although a particularly large (83%) decrease in pollution from the Chem sector reflects the cessation (and national outsourcing) of polluting fertiliser-manufacturing operations in Ireland. In terms of assessing regulatory effectiveness, it is more instructive to look at pollution trends from a constant number of long-term operational installations, or pollution intensity of production for entire sectors. Absolute aggregate pollution loading reductions from installations that reported throughout 2001–2007 ranged from 22% for Chem installations (n = 27) to 45% for Power Gen installations (n = 9).

Large reductions in emissions of SO_x and NO_x accounted for a substantial portion of pollution avoidance for all study sectors, and are attributable to changing fuel use, improved combustion control, and the installation of abatement technologies. For the Chem and Pharma sectors, there was a substantial reduction in W-HM loading, while for the Power Gen sector there were large reductions in CO_2 (>3 Mt/annum) and HM (>2 t/annum) loadings to air – in part reflecting a shift towards combined-cycle natural gas power stations. Further reductions in the pollution intensity of national electricity generation attributable to the increasing contribution of wind generation were not accounted for in this study, which looked only at IPPC-regulated combustion power stations. Trends in EEI profiles document the changing contribution of different emissions to overall pollution loading. Following substantial declines in NO_x and SO_x emissions, other emissions such as CO_2 now make greater contributions towards overall pollution loading, and will need to be substantially reduced to maintain downward pollution trends. Although industrial CO_2 emissions are primarily regulated through the ETS, in order to distribute emission reductions cost-effectively across installations and sectors, IPPC licensing has a role to play in CO_2 reduction. In particular, EMP requirements can be used to stimulate consideration of process-based CO_2 reduction options in the context of overall environmental performance improvements (i.e. considering implications for other emissions), and with reference to any consequences for off-site emissions.

In the absence of good material production data for all sectors, inflation-adjusted output indices from the CSO were used to derive sectoral eco-efficiency trends. There were some discrepancies between the sectoral boundaries used in NACE code classification of economic data and IPPC activity codes, and the resulting eco-efficiency trends deviated somewhat from eco-efficiency trends derived from material production data where available. Nonetheless, it is clear that the pollution intensity of production has decreased substantially across all four sectors. It is only as a consequence of reporting requirements enforced by IPPC licensing that this study was able to generate these comprehensive, sectoral pollution trends. With reference to the findings of Chapter 5, it is highly probable that IPPC licensing contributed significantly to pollution avoidance achieved by these four sectors.

7.4 Effectiveness of IPPC Licensing

This study used a highly quantitative approach to assess the effectiveness of integrated licensing in relation to the Pharma sector since 1995. It was clear from survey responses that industry environmental managers perceived integrated licensing to have been the largest single driver of pollution reductions, despite high levels of self-professed CSR and voluntary reporting to Pharmachemical Ireland. Whilst the sector has achieved production-normalised pollution avoidance of 42% since 1995, based on the evolution of BAU, integrated licensing has been responsible for an additional 35% pollution avoidance. Integrated licensing thus appears to have been highly effective at reducing pollution from Ireland's Pharma sector. This would suggest that even highly financed, responsible sectors require direct regulation to incentivise the implementation of viable pollution avoidance options. On the other hand, the scale of eco-efficiency improvement achieved by the Pharma sector in response to integrated licensing may reflect an unusual responsiveness, based on the sector's financial security, public relations sensitivities, and employment of dedicated environmental managers in many installations. It appears that integrated licensing has driven emission reductions as much through the enforcement of monitoring, reporting and installation-specific EMPs, as through enforcement of minimum BAT standards. These results emphasise the essential role of comprehensive and direct regulation, such as IPPC licensing, in reducing industrial pollution.

Pharma sector pollution avoidance was dominated by reductions in NMVOCs, NO_x, SO_x, and W-HMs since 1995. One of the strengths of integrated licensing is its comprehensive scope, covering a wide range of environmental pressures. In recent years, emissions of NMVOCs and CO_2 have stabilised or increased, and now dominate sectoral pollution. It will be necessary for regulators to focus more intensely on these emissions in order to continue the downward trend in pollution from the sector. There is evidence from survey responses that integrated licensing has achieved genuine pollution prevention by driving process changes, partly through compulsory EMPs. In contrast to the abatement options available for some emissions, process changes and genuine pollution avoidance will be essential in order to achieve significant reductions in CO_2 (and NMVOC) emissions.

7.5 Efficiency and Prospects for IPPC Licensing

Integrated licensing is cost-effective, in that direct compliance costs borne by operators are considerably lower than the avoided external pollution costs. Integrated licensing represents a sophisticated form of command-and-control-type direct regulation that appears to drive innovation and genuine pollution prevention. Neoclassical economic theory is inadequate to assess the comparative efficiency of integrated licensing because it disregards the economic benefits associated with innovation and pollution prevention, such as improved operating efficiency, referred to by a number of Pharma respondents.

Perhaps the most important aspect of integrated licensing is the enforcement of a monitoring and reporting framework for environmental performance measurement. Whilst such measurement is encouraged by soft regulations (e.g. voluntary reporting and EMS certification), and is a prerequisite for implementation of many economic instruments, some form of direct regulation by an independent regulator is imperative to verify authenticity. As referred to in Chapter 3, verified environmental monitoring and reporting is a prerequisite for any shift towards performance-based environmental regulation, and will reduce the disparity between economic and environmental accounting, and accountability. Direct regulation has scope (covers a wide range of environmental pressures) and verifiability advantages compared with economic and voluntary regulatory approaches, but has limited reach across economic sectors. Whilst IPPC regulation provides indispensable, cost-effective control of pollution from large industrial installations, effective environmental regulation of other sectors requires a combination of instruments (direct, economic and voluntary). The most important attribute of economic and soft approaches is their wide sphere of influence, encompassing SMEs. The reach of integrated licensing could be extended beyond large industrial installations through the inclusion of aspects of soft regulation, such as green procurement, or through the incorporation of LCA into environmental reporting and EMPs.

8 Recommendations

8.1 Further Study

- It would be useful to generate full LCA case studies for a few installations from each IPPC sector, identifying the main sources of environmental pressures and the proportion of those pressures accounted for within the gate-to-gate scope of current emissions reporting. This could lead to the identification of effective pollution avoidance options. In particular, it would be useful to compare pharmaceutical production in traditional chemical and new biopharma plants.

- The case studies referred to above could also be used to inform the development of targeted verification methodologies for monitoring and reporting of the most environmentally significant emissions. This study identified a major reporting problem in relation to fugitive NMVOC emissions. Where emissions cannot be monitored directly, the EPA could issue more guidance on the most appropriate and reliable estimation methods available.

- The EEI could be expanded to include some of the major additional emissions, and other impacts such as resource depletion and waste export, reported under the new PRTR-compliant reporting system.

- From a policy and regulatory perspective, there is a need to consider longer-term strategies for pollution avoidance across sectors, considering whole production chains and longer-term trends. One example is electricity use: the current life-cycle pollution burden associated with industrial electricity consumption should be reduced substantially in the coming decade with the anticipated connection of substantial renewable input to the grid. Similarly, LCA studies could identify possibilities for efficiency benefits through co-ordination or integration of industrial activities.

- Quantification of pollution reductions attributable to integrated licensing should be performed for all sectors, using material or EPI data to quantify hypothetical ‘no-improvement’ pollution trends, and questionnaire surveys to estimate the contribution of integrated licensing to pollution reductions.

- Questionnaire studies could be used to further investigate the specific drivers of pollution reduction within the licensing process (i.e. to identify the relative importance of ELVs, reporting and EMPs).

- Further work is needed to explore the potential, and enforcement mechanisms, for less prescriptive but rigorous performance-oriented environmental regulation. In particular, there may be differences between sectors in terms of responsiveness to regulation through ELVs versus environmental performance measurement and reporting.

8.2 Regulation

- Quantitative emissions, waste and resource-use data are integral to assessing IPPC compliance, and quantifying environmental performance trends. The standard of reporting varies considerably across installations, and remains poor for some sectors overall (although it appears to be improving with new PRTR requirements). Enforcement of monitoring and reporting is an essential component of IPPC licensing, and needs to be prioritised across all IPPC licensees.

- This study provides conclusive evidence that integrated licensing is highly effective at controlling and reducing pollution and strong evidence that integrated licensing can stimulate innovation and economic efficiency improvements. Considering limitations inherent in economic and voluntary regulatory approaches, the authors suggest that IPPC licensing is the most efficient method of controlling the wide range of environmental pressures arising from industrial production.

- More generally, neoclassical economic theory overstates the costs, and underestimates the benefits, of direct environmental regulation. Whilst economic and voluntary regulatory instruments have a crucial role to play in controlling pollution from diffuse sectors and SMEs, policy makers and regulators should not shy away from robust direct regulation. Such regulation is required to verify the environmental monitoring and reporting that is integral to (identifying opportunities for) environmental performance improvement, and can also be a major driver of innovation and economic efficiency.

- Success in reducing some emissions, particularly NO_x, SO_x and W-HMs, has increased the relative importance of other emissions, particularly CO_2 and NMVOCs. The focus of IPPC licensing needs to shift towards these emissions. Reductions in these emissions will necessitate significant process changes, including efficiency improvements and energy-supply substitution in the case of CO_2. The multi-impact and process-based view of operations required under IPPC EMPs complements the economic incentive for CO_2 emission reductions provided by the ETS.

- It would be useful for regulators to have a pollution metric, such as the EEI devised in this study, to: (i) assess the relative importance of different emissions; (ii) compare pollution across installations and sectors; and (iii) quantify pollution trends. The EEI adds value to emissions interpretation, integrating scientific characterisation and normalisation procedures with policy targets to consider emissions within a coherent environmental context.

- There is a promising opportunity to move towards more performance-oriented compliance assessment within the IPPC framework. For BAT-compliant sectors where regulation is mature and reporting levels high (e.g. Pharma sector), this would ensure continued pollution reductions beyond BAT ELV standards. However, for less compliant sectors, IPPC enforcement needs to continue focussing on monitoring, reporting and BAT ELV compliance.

- The authors suggest that a tool such as the EEI could be used by regulators to benchmark continuous environmental performance improvement across IPPC installations. Published, 3-year trends in pollution loading, measured using such a tool, would provide an overview of installations' environmental performance. The onus would be on operators to justify any increase in pollution (e.g. by providing production data to demonstrate that eco-intensity had been significantly reduced).

- The authors suggest that indirect emissions associated with electricity use are considered in any metric used to benchmark environmental performance trends, in order to avoid incentives to outsource pollution: these emissions contribute significantly to overall pollution and are easy to calculate. In the longer term, it may be possible to accurately include additional life-cycle impacts in performance metrics, for example using data from the European Commission's European reference life-cycle database (http://lca.jrc.ec.europa.eu/lcainfohub/datasetArea.vm). This could extend the sphere of influence of IPPC licensing beyond large industrial installations, for example by encouraging green procurement.

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Acronyms

A-	Air (emissions to)
AER	Annual Environmental Report submitted by IPPC installations
AP	Acidification potential
API	Active pharmaceutical ingredient
ATP	Aquatic toxicity potential
BAT	Best available techniques
BATNEEC	Best available technology not entailing excessive cost
BAU	Business as usual
CF	Characterisation factor, applied to substances to calculate EIS
CLTRAP	United Nations Convention on Long-Range Transboundary Air Pollution
CML	Leiden University's Institute of Environmental Sciences
CO_2	Carbon dioxide
COD	Chemical oxygen demand
CSO	Central Statistics Office
CSR	Corporate social responsibility
ECME	Economics and Cross-Media Effects briefing document
EEI	Environmental Emissions Index
EI	Environmental indicator (representing each impact category)
EIPPCB	European Integrated Pollution Prevention and Control Bureau
EIS	Environmental Impact Statement
ELVs	Emission limit values
EMEP	European Monitoring and Evaluation Programme
EMPs	Environmental Management Plans (required by Irish IPC licenses)
EMS	Environmental Management Systems (e.g. ISO14001)
EP	Eutrophication potential
EPA	Environmental Protection Agency
EPER	European Pollutant Emission Register
EPI	Economic Performance Indicator
EPRTR	European Pollutant Release and Transfer Register
ETS	EU Emissions Trading Scheme (for CO_2)
FW	Freshwater
GHG	Greenhouse gas

GWP	Global warming potential
HM	Heavy metal
HTP	Human toxicity potential
IPC	Integrated Pollution Control
IPCC	International Convention on Climate Change
KPI	Key Performance Indicator
LCA	Life-cycle assessment
LCIA	Life-cycle impact assessment
LCPD	Large Combustion Plant Directive
M	Marine
mEEI	Modified Environmental Emissions Index
NACE	Nomenclature générale des activités économiques dans les Communautés Européennes (General Industrial Classification of Economic Activities in the European Communities)
NH_3	Ammonia
NMVOC	Non-methane volatile organic compound
NO_x	Nitrogen oxide
ODP	Ozone depletion potential
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
PM	Particulate matter
PO_4	Phosphate
POCP	Photochemical ozone creation potential
PRTR	EU Pollutant Release and Transfer Register
SME	Small- and medium-sized enterprises
SML	Single Media Licensing
SO_x	Sulphur oxide
STRF	Sewage treatment reduction factor
STRIVE	Science, Technology, Research and Innovation for the Environment
THM	Total heavy metal
TN	Total nitrogen
TOFP	Tropospheric ozone formation potential
TP	Total phosphorus
W-	Water (emissions to)

An Ghníomhaireacht um Chaomhnú Comhshaoil

Is í an Gníomhaireacht um Chaomhnú Comhshaoil (EPA) comhlachta reachtúil a chosnaíonn an comhshaol do mhuintir na tíre go léir. Rialaímid agus déanaimid maoirsiú ar ghníomhaíochtaí a d'fhéadfadh truailliú a chruthú murach sin. Cinntímid go bhfuil eolas cruinn ann ar threochtaí comhshaoil ionas go nglactar aon chéim is gá. Is iad na príomh-nithe a bhfuilimid gníomhach leo ná comhshaol na hÉireann a chosaint agus cinntiú go bhfuil forbairt inbhuanaithe.

Is comhlacht poiblí neamhspleách í an Ghníomhaireacht um Chaomhnú Comhshaoil (EPA) a bunaíodh i mí Iúil 1993 faoin Acht fán nGníomhaireacht um Chaomhnú Comhshaoil 1992. Ó thaobh an Rialtais, is í an Roinn Comhshaoil agus Rialtais Áitiúil a dhéanann urraíocht uirthi.

ÁR bhFREAGRACHTAÍ

CEADÚNÚ

Bíonn ceadúnais á n-eisiúint againn i gcomhair na nithe seo a leanas chun a chinntiú nach mbíonn astuithe uathu ag cur sláinte an phobail ná an comhshaol i mbaol:

- áiseanna dramhaíola (m.sh., líonadh talún, loisceoirí, stáisiúin aistrithe dramhaíola);
- gníomhaíochtaí tionsclaíocha ar scála mór (m.sh., déantúsaíocht cógaisíochta, déantúsaíocht stroighne, stáisiúin chumhachta);
- diantalmhaíocht;
- úsáid faoi shrian agus scaoileadh smachtaithe Orgánach Géinathraithe (GMO);
- mór-áiseanna stórais peitreail.
- Scardadh dramhuisce

FEIDHMIÚ COMHSHAOIL NÁISIÚNTA

- Stiúradh os cionn 2,000 iniúchadh agus cigireacht de áiseanna a fuair ceadúnas ón nGníomhaireacht gach bliain.
- Maoirsiú freagrachtaí cosanta comhshaoil údarás áitiúla thar sé earnáil - aer, fuaim, dramhaíl, dramhuisce agus caighdeán uisce.
- Obair le húdaráis áitiúla agus leis na Gardaí chun stop a chur le gníomhaíocht mhídhleathach dramhaíola trí comhordú a dhéanamh ar líonra forfheidhmithe náisiúnta, díriú isteach ar chiontóirí, stiúradh fiosrúcháin agus maoirsiú leigheas na bhfadhbanna.
- An dlí a chur orthu siúd a bhriseann dlí comhshaoil agus a dhéanann dochar don chomhshaol mar thoradh ar a ngníomhaíochtaí.

MONATÓIREACHT, ANAILÍS AGUS TUAIRISCIÚ AR AN GCOMHSHAOL

- Monatóireacht ar chaighdeán aeir agus caighdeáin aibhneacha, locha, uiscí taoide agus uiscí talaimh; leibhéil agus sruth aibhneacha a thomhas.
- Tuairisciú neamhspleách chun cabhrú le rialtais náisiúnta agus áitiúla cinntí a dhéanamh.

RIALÚ ASTUITHE GÁIS CEAPTHA TEASA NA HÉIREANN

- Cainníochtú astuithe gáis ceaptha teasa na hÉireann i gcomhthéacs ár dtiomantas Kyoto.
- Cur i bhfeidhm na Treorach um Thrádáil Astuithe, a bhfuil baint aige le hos cionn 100 cuideachta atá ina mór-ghineadóirí dé-ocsaíd charbóin in Éirinn.

TAIGHDE AGUS FORBAIRT COMHSHAOIL

- Taighde ar shaincheisteanna comhshaoil a chomhordú (cosúil le caighdéan aeir agus uisce, athrú aeráide, bithéagsúlacht, teicneolaíochtaí comhshaoil).

MEASÚNÚ STRAITÉISEACH COMHSHAOIL

- Ag déanamh measúnú ar thionchar phleananna agus chláracha ar chomhshaol na hÉireann (cosúil le pleananna bainistíochta dramhaíola agus forbartha).

PLEANÁIL, OIDEACHAS AGUS TREOIR CHOMHSHAOIL

- Treoir a thabhairt don phobal agus do thionscal ar cheisteanna comhshaoil éagsúla (m.sh., iarratais ar cheadúnais, seachaint dramhaíola agus rialacháin chomhshaoil).
- Eolas níos fearr ar an gcomhshaol a scaipeadh (trí cláracha teilifíse comhshaoil agus pacáistí acmhainne do bhunscoileanna agus do mheánscoileanna).

BAINISTÍOCHT DRAMHAÍOLA FHORGHNÍOMHACH

- Cur chun cinn seachaint agus laghdú dramhaíola trí chomhordú An Chláir Náisiúnta um Chosc Dramhaíola, lena n-áirítear cur i bhfeidhm na dTionscnamh Freagrachta Táirgeoirí.
- Cur i bhfeidhm Rialachán ar nós na treoracha maidir le Trealamh Leictreach agus Leictreonach Caite agus le Srianadh Substaintí Guaiseacha agus substaintí a dhéanann ídiú ar an gcrios ózóin.
- Plean Náisiúnta Bainistíochta um Dramhaíl Ghuaiseach a fhorbairt chun dramhaíl ghuaiseach a sheachaint agus a bhainistiú.

STRUCHTÚR NA GNÍOMHAIREACHTA

Bunaíodh an Ghníomhaireacht i 1993 chun comhshaol na hÉireann a chosaint. Tá an eagraíocht á bhainistiú ag Bord lánaimseartha, ar a bhfuil Príomhstiúrthóir agus ceithre Stiúrthóir.

Tá obair na Gníomhaireachta ar siúl trí ceithre Oifig:

- An Oifig Aeráide, Ceadúnaithe agus Úsáide Acmhainní
- An Oifig um Fhorfheidhmiúchán Comhshaoil
- An Oifig um Measúnacht Comhshaoil
- An Oifig Cumarsáide agus Seirbhísí Corparáide

Tá Coiste Comhairleach ag an nGníomhaireacht le cabhrú léi. Tá dáréag ball air agus tagann siad le chéile cúpla uair in aghaidh na bliana le plé a dhéanamh ar cheisteanna ar ábhar imní iad agus le comhairle a thabhairt don Bhord.

The EPA's Environmental Research Centre (ERC) was established as a centre of excellence under the National Development Plan (NDP) to build capacity in environmental data handling, modelling, assessment and guidance. The objective of the ERC is to allow for a more structured approach to environmental research, through the development of advanced innovative techniques and systems to address priority environmental issues and thereby support environmentally sustainable development.

epa
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