EXTERNE NATIONAL IMPLEMENTATION

IRELAND

A STUDY OF THE ENVIRONMENTAL IMPACTS OF THE GENERATION OF ELECTRICITY IN IRELAND AT EUROPEAT 1 AND MONEYPOINT POWER STATIONS

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TABLE OF CONTENTS

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1. INTRODUCTION

Economic development of the industrialised nations of the world has been founded on continuing growth in energy demand. The use of energy clearly provides enormous benefits to society. However, it is also linked to numerous environmental and social problems, such as the health effects of pollution of air, water and soil, ecological disturbance and species loss, and landscape damage. Such impacts are referred to as external costs, as they have typically not been reflected in the market price of energy, or considered by energy planners, and consequently have tended to be ignored. Effective control of these ‘externalities’ whilst pursuing further growth in the use of energy services poses a serious and difficult problem. The European Commission has expressed its intent to respond to this challenge on several occasions; in the 5th Environmental Action Programme; the White Paper on Growth, Competitiveness and Employment; and the White Paper on Energy.

A variety of options are available for reducing externalities, ranging from the development of new technologies to the use of fiscal instruments, or the imposition of emission limits. The purpose of externalities research is to quantify damages in order to allow rational decisions to be made that weigh the benefits of actions to reduce externalities against the costs of doing so.

Within the European Commission R&D Programme Joule II, the ExternE Project developed and demonstrated a unified methodology for the quantification of the externalities of different power generation technologies. It was launched as the EC-US Fuel Cycles in 1991 as a collaborative project with the US Department of Energy. From 1993 to 1995 it continued as the ExternE project, involving more than 40 European institutes from 9 countries, as well as scientists from the US. This resulted in the first comprehensive attempt to use a consistent ‘bottom-up’ methodology to evaluate the external costs associated with a wide range of different fuel chains. The result was identified by both the European and American experts in the field as currently the most advanced project world-wide for the evaluation of external costs of power generation (EC/OECD/IEA, 1995).

Under the European Commission’s Joule III Programme, this project has continued with three major tasks: ExternE Core for the further development and updating of the methodology, ExternE National Implementation to create an EU-wide data set and ExternE Transport for the application of the ExternE methodology to energy related impacts from transport. The current report is the result of the ExternE National implementation project for Ireland.

1.1 Objectives of the project

The objective of the ExternE National Implementation project is to establish a comprehensive and comparable set of data on externalities of power generation for all EU member states and Norway. The tasks include;

- the application of the ExternE methodology to the most important fuel chains for each country
- updating existing results as new data become available for refinement of methods
- aggregation of site- and technology-specific results to the national level
- for countries already involved in Joule II, data have been applied to policy questions, to indicate how these data could feed into decision and policy making processes
- dissemination of results
- creation of a network of scientific institutes familiar with the ExternE methodology and data, and their application
- compilation of results in an EU-wide information system for the study.

The data in this report results from the application of ExternE-methodology as developed under Joule II. However, because our understanding of the impacts of environmental burdens on humans and nature is improving continuously, this methodology (or more precise, the scientific inputs into the accounting framework) has been updated and further developed.

The National Implementation project has generated a large set of comparable and validated results, covering more than 60 cases, for 15 countries and 12 fuel chains. A wide range of generating options have been analysed, including fossil, nuclear and renewable technologies. Analysis takes account of all stages of the fuel chain, from (e.g.) extraction of fuel to disposal of waste material from the generating plant. In addition to the estimates of externalities made in the study, the project also offers a large database of physical and social data on the burdens and impacts of energy systems.

The ExternE results form the most extensive externality dataset currently available. They can now be used to look at a range of issues, including;

- internalisation of the external costs of energy
- optimisation of site selection processes
- cost benefit analysis of pollution abatement measures
- comparative assessment of energy systems

Such applications are illustrated by the case studies presented in selected national implementation reports.

1.2 Publications from the project

The current report is to be seen as part of a larger set of publications, which commenced with the series of volumes published in 1995 (European Commission, 1995a-f). A further series of reports has been generated under the present study.

First, the current report covers the results of the national implementation for Ireland, and is published by the Environmental Institute, University College Dublin. It contains all the details of the application of the methodology to the coal and peat fuel cycles, and aggregation of these results over the national electricity industry. Brief details of the methodology are provided in Chapter 2 of this report and the Appendices; a more detailed review is provided in a separate report (European Commission, 1998a). A further report covers the development of estimates of global warming damages (European Commission, 1998b). The series of National Implementation Reports for the 15 countries involved are published in a third report (European Commission, 1998c).

In addition, further reports are to be published on the biomass and waste fuel chains, and on the application and further development of the ExternE methodology for the transport sector.

This information can also be accessed through the ExternE website. It is held at the Institute for Prospective Technological Studies, and is accessible through the Internet at the URL (*http://externe.jrc.es*). This website is the focal point for the latest news on the project, and hence will provide updates on the continuation of the ExternE project.

1.3 Structure of this report

The structure of this report reflects its role as part of a wider set of publications. In order to ease comparison of results, all ExternE National Implementation reports have the same structure and use the same style of presentation of fuel cycles, technologies and results of the analysis.

The common structure is especially important for the description of the methodology. Chapter 2 describes the general framework of the selected bottom-up methodology. The major inputs from different scientific disciplines into that framework (e.g. information on dose-response functions) are summarised in the methodological annexes to this report and are discussed at full length in the separate methodology publication (see above).

In order to ease readability, the main text of the chapters dealing with the application to the different fuel cycles provide the overview of technology, fuel cycles, environmental burdens and the related externalities. More detailed information (e.g. results for a specific type of impact) is provided in the appendices.

1.4 The Irish National Implementation

1.4.1 Description of the country

The Republic of Ireland has a land area of 70,000 km^2 and a population of around 3.5 million. The overall population density of 50 persons per km^2 is distributed very non-uniformly across the country, with around 1 million people living in the capital city or its hinterland. The westernmost of Ireland's four provinces has a population density of only 25 persons per km^2. The island of Ireland is shared between the Republic of Ireland and Northern Ireland, an administrative region of the United Kingdom. The island has a maritime temperate climate, with prevailing westerly and south-westerly winds bringing moist air from the Atlantic Ocean.

The topography of the island is characterised by a mainly flat central plain, with a series of coastal mountain ranges of moderate elevation (up to 1,000 m). Rivers with their headwaters in the central region tend to travel long distances before reaching the sea. The floodplains of these great river systems, which were largely covered by lakes in the aftermath of the most recent glaciation, were converted over time into extensive tracts of peatland, Ireland's only indigenous fuel resource until the discovery of natural gas.

1.4.2 Overview of Ireland's national energy sector

The annual consumption of primary energy in Ireland is 10 Mtoe (419 PJ), of which 67% is imported and the remaining 33% is domestically produced peat (1.2 Mtoe) and natural gas (2.2 Mtoe). Of this primary energy, around 35% is used in the generation of electricity.

Primary energy consumption amounts to approximately 120 GJ per person per year. This figure is somewhat low by European standards. This is accounted for in part by the country's temperate climate with its mild winters, and partly by the relative lack of heavy industry.

The national electricity generating capacity is around 4,000 MW, or around 1.15 kW per capita. Of this capacity, around 98.5% is owned and operated by the Electricity Supply Board (ESB) whose monopoly status was until recently protected by law. The remainder is operated by industrial and commercial concerns, primarily for their own use. The EU Energy Directive will ensure third party access to the electricity generating market in Ireland in the future, ending the special status of ESB. ESB has in turn acquired interests in power generation companies in the United Kingdom. Peak electricity demand is approximately 3,000 MW.

Considering only ESB plant of greater than 5 MW capacity, there are a total of 12 thermal power stations currently operating in Ireland, of which 1 (915 MW) is coal-fired, 6 (1,900 MW) are oil and gas-fired and 5 (380 MW) are peat-fired. A further 10 hydro-power plants, including 1 pumped-storage plant, provide an additional 512 MW of peak power.

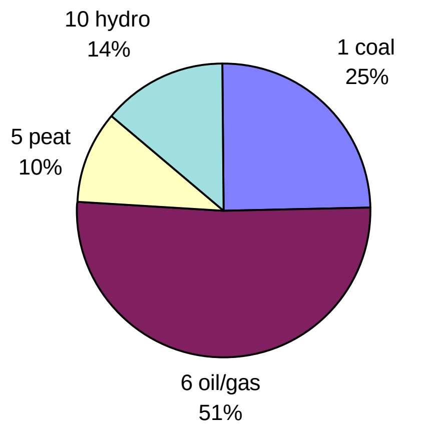

Figure 1-1: Generation Capacity

Annual production of electricity amounts to around 19 TWh (68 PJ), made up of 37% coal, 32% gas, 14% oil, 11% peat and 5% hydro. This wide range of generating technologies is the result of a policy of avoiding dependence on any single fuel.

Practically all of the ESB's thermal power stations are run in simple cycle, with no large-scale combined heat and power. This is largely because the power stations are situated in areas remote from centres of population and industry with a demand for waste heat products. A small number of industrial and commercial energy consumers operate private cogeneration plant to supply their own requirements. This amounts to a total of approximately 60 MW_e

capacity. In addition a small but growing renewables sector exists in the form of wind farms and small hydro plants.

Of the total electricity produced in Ireland, around 37% is used by industry, 38% in homes and 25% by commercial users.

In 1995, an electricity interconnector was installed between the Republic of Ireland and Northern Ireland Electricity's 2.25 GW of generating capacity, ending the status of the ESB as an island network. In addition, a 250 MW interconnector between the North of Ireland and Great Britain is under consideration. As yet no significant trade in electricity takes place.

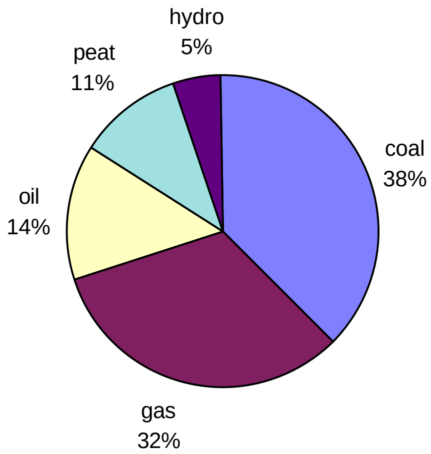

Figure 1-2: Electricity Generation by Fuel, 1996

The exploitation of such meagre amounts of native coal resources as exist or existed in Ireland has all but ceased during the 1990s. In 1993 Arigna power station in Co. Roscommon, which was fuelled by locally produced coal and had a generating capacity of 15 MW, was closed down. It had been in operation for 35 years, and generated 50 GWh of electricity during 1992. Irish coal production amounted to only 1,000 tonnes in 1995, of a total consumption of 2.93 million tonnes.

With the closure of Arigna, Moneypoint power station became the sole coal-fired electricity plant in Ireland, dependent entirely on imported coal. Coal accounts for 29% of national use of primary energy, and for 37% of electrical energy produced.

Coal enters the country at four major ports. Of these, Dublin and Cork are on the national rail network, while Foynes and Moneypoint are not, and serve local industrial markets.

Since the 915 MW coal-fuelled power station at Moneypoint came on-line during 1986 and 1987, taking its place as easily the largest of ESB's generating stations, the amount of oil used for power generation has declined greatly. This substitution of coal for oil was the result of a policy of reducing dependence on oil imports in the interests of energy security.

Considering the contribution of the remaining indigenous fuels, namely peat and natural gas, to power generation, the share of peat has reduced in recent years, while a large increase has occurred in the use of natural gas. Gas is expected to play an increasingly important role in the future.

Peatland occupies around 17% of the total land area of Ireland, or some 1.25 million hectares. Not all of these reserves are available for extraction in the form of fuel, however, since development of peatlands is ecologically damaging and increasingly unacceptable to public opinion. Some 88,000 hectares of already developed peatlands exist and are in the hands of Bord na Móna, the Irish peat board. Bord na Móna's developed bogs contain a recoverable fuel peat reserve of approximately 130 million tonnes, or 1.00 EJ (10^{18}J). Of this total, approximately 35% (45 million tonnes) is situated in the East Midland group of bogs, in Cos. Offaly, Kildare, Meath and Westmeath.

In 1990 peat amounted to 15% of total primary energy requirements, and 16% of electricity generation. By 1996 these levels had declined to 11% of primary energy, and 11% of electricity generation. 1996 production of milled peat was 6.7 million tonnes, or 51 PJ. Of total peat consumption in 1995, 47% was used for power generation by ESB.

The increase in the share of natural gas is largely due to the discovery of natural gas off the coast of Co. Cork and the development of a pipeline network connecting many of Ireland's centres of population. This has prompted the installation and commissioning of new combined cycle gas turbine plant and the conversion of existing plant to gas. In 1990 natural gas contributed 27% of the electricity generated, while in 1996 this had increased to 32%. Total production of natural gas in 1995 was around 2.25 x 10^9 m^3, or 80 PJ. An interconnector linking Scotland and Ireland was completed in 1994, allowing gas to be traded with Great Britain, and with suppliers as far away as Russia and Algeria.

1.4.3 Justification of the selection of fuel cycles

The Irish National Implementation considered two fuel cycles. These are coal, represented by the Moneypoint power plant in County Clare, and peat, for which the reference plant was Europeat 1, a planned power station in County Offaly. Moneypoint is a very large coal-burning plant which produces around 40% of all electricity generated in Ireland. Europeat 1 is a smaller plant, to be commissioned in 2001, which will be fuelled by peat, and will be about one-eighth the size of Moneypoint in terms of both production capacity and output.

The decision to include coal in the study was a straightforward one based on its overwhelming importance as the major fuel in the generation of electricity in Ireland.

Peat, on the other hand, which in the European Union is used in large-scale power generation only in Ireland and Finland, is worthy of consideration as a special case, especially in the context of the building of a new and modern peat-fired plant. This is the first such plant for over 15 years in a sector where 70% of existing plant is over 30 years old.

Peat has been included as one of the fuel cycles of both the Finnish and the Irish national implementation teams, and has turned out to be a uniquely complex and interesting fuel cycle from an environmental point of view.

It is important to note that while the coal cycle under consideration is an existing plant, in operation for over 10 years, and supplying the base-load of Ireland's electricity requirements during that time, the peat fuel cycle is based on a future reference plant, to be built using the most modern technologies available. This should therefore be borne in mind when comparing the results of the studies of the two fuel-cycles.

2. METHODOLOGY

2.1 Approaches Used for Externality Analysis

The ExternE Project uses the ‘impact pathway’ approach for the assessment of the external impacts and associated costs resulting from the supply and use of energy. The analysis proceeds sequentially through the pathway, as shown in Figure 2.1. Emissions and other types of burden such as risk of accident are quantified and followed through to impact assessment and valuation. The approach thus provides a logical and transparent way of quantifying externalities.

However, this style of analysis has only recently become possible, through developments in environmental science and economics, and improvements in computing power has. Early externalities work used a ‘top-down’ approach (the impact pathway approach being ‘bottom-up’ in comparison). Such analysis is highly aggregated, being carried out at a regional or national level, using estimates of the total quantities of pollutants emitted or present and estimates of the total damage that they cause. Although the work of Hohmeyer (1988) and others advanced the debate on externalities research considerably, the style of analysis was too simplistic for adoption for policy analysis. In particular, no account could be taken of the dependence of damage with the location of emission, beyond minor corrections for variation of income at the valuation stage.

An alternative approach was the ‘control cost’ method, which substitutes the cost of reducing emissions of a pollutant (which are determined from engineering data) for the cost of damages due to these emissions. Proponents of this approach argued that when elected representatives decide to adopt a particular level of emissions control they express the collective ‘willingness-to-pay’ of the society that they represent to avoid the damage. However, the method is entirely self-referencing - if the theory was correct, whatever level of pollution abatement is agreed would by definition equal the economic optimum. Although knowledge of control costs is an important element in formulating prescriptive regulations, presenting them as if they were damage costs is to be avoided.

Life cycle analysis (OECD, 1992; Heijungs *et al*, 1992; Lindfors *et al*, 1995) is a flourishing discipline whose roots go back to the net energy analyses that were popular twenty years ago. While there are several variations, all life cycle analysis is in theory based on a careful and holistic accounting of all energy and material flows associated with a system or process. The approach has typically been used to compare the environmental impacts associated with different products that perform similar functions, such as plastic and glass bottles. Restriction of the assessment to material and energy flows means that some types of externality (such as the fiscal externalities arising from energy security) are completely outside the scope of LCA.

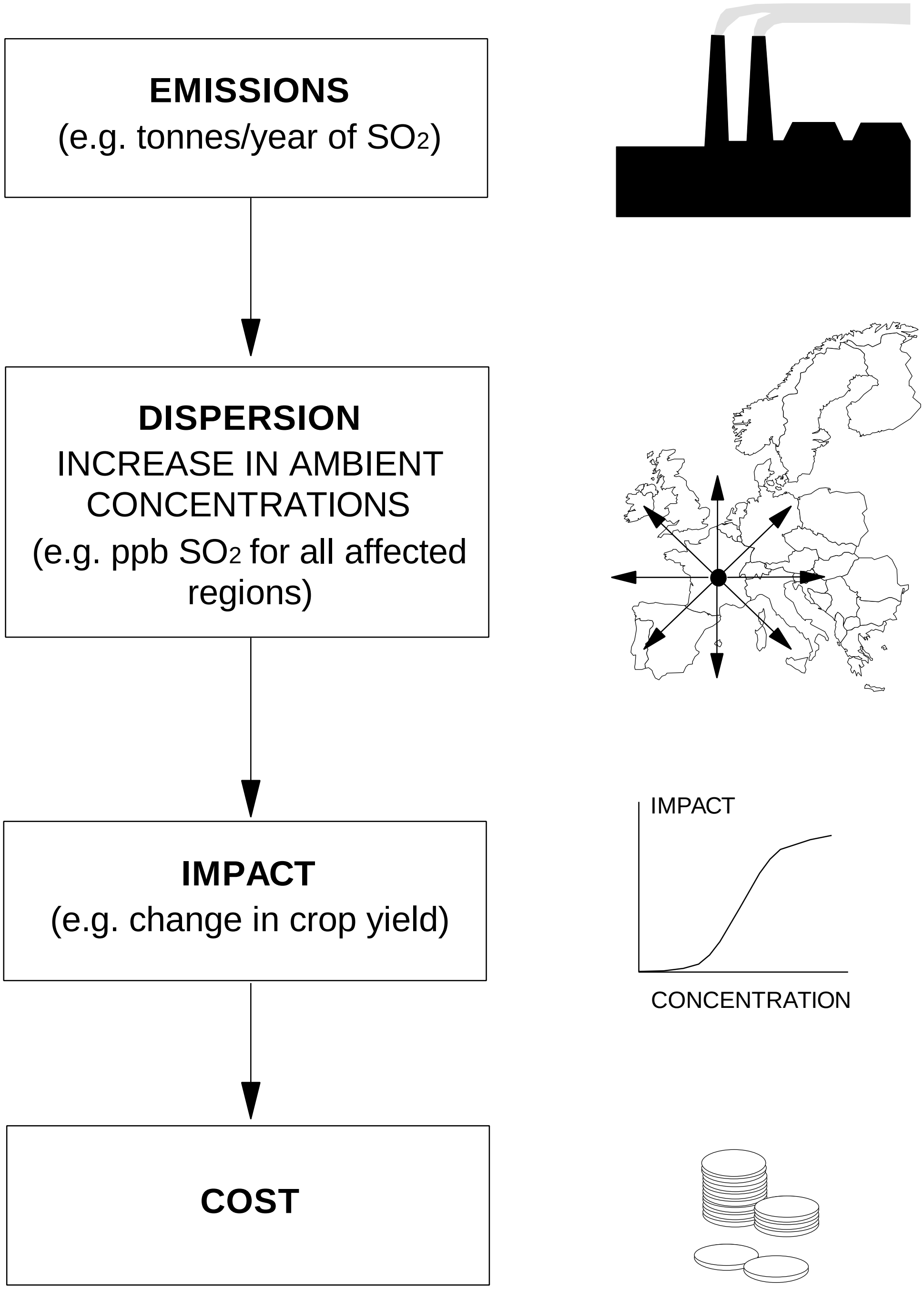

Figure 2.1 An illustration of the main steps of the impact pathways methodology applied to the consequences of pollutant emissions. Each step is analysed with detailed process models.

The ExternE method has numerous links to LCA. The concept of fuel cycle or fuel chain analysis, in which all components of a given system are analysed 'from cradle to grave', corresponds with the LCA framework. Hence for electric power fuel chains the analysis undertaken within the ExternE Project covers (so far as possible); fuel extraction, transportation and preparation of fuels and other inputs; plant construction, plant operation (power generation), waste disposal and plant decommissioning.

There are, however, some significant differences between externalities analysis as presented in this study and typical LCA analysis. Life cycle analyses tend not to be specific on the calculation of impacts, if they have attempted to quantify impacts at all. For example, the ‘classification factors’ identified by Heijungs *et al* (1992) for each pollutant are independent of the site of release. For air pollution these factors were calculated with the assumption of uniform mixing in the earth's atmosphere. While this can be justified for greenhouse gases and other pollutants with long residence times, it is unrealistic for particulate matter, NO_x, SO_2 and ozone (O_3). The reason for this radical approximation lies in the choice of emphasis in LCA: accounting for all material flows, direct and induced. Since induced flows occur at many geographically different points under a variety of different conditions, it is simply not practicable to model the fate of all emissions. In this sense, ExternE is much more ambitious and precise in its estimates than LCA.

A second difference is that most LCA studies have a much more stringent view on system boundaries and do not prioritise between different impacts. The ExternE analysts have to a large extent decided themselves if certain stages of the fuel cycle, such as plant construction or fuel transportation, can be excluded. Such decisions are made from experience of the likely magnitude of damages, and a knowledge of whether a given type of impact is *perceived* to be serious. [Note that it is recommended to quantify damages for any impact perceived to be serious whether or not earlier analysis has suggested that associated damages will be negligible]. What might be referred to as analytical ‘looseness’ is a consequence of the remit of the ExternE project, which has as a final objective quantification of the externalities of energy systems. As such the main emphasis of the study is quite properly on the impacts that are likely (given current knowledge) to dominate the results. Externalities assessments based on the ExternE methodology but conducted for other purposes may need to take a more truly holistic perspective than has been attempted here.

The analysis presented in this report places its emphasis on the quantification of impacts and cost because people care more about impacts than emissions. The quantification of emissions is merely a step in the analysis. From this perspective the choice between externalities assessment and conventional LCA is a matter of accuracy; uncertainties increase the further the analysis is continued. In general terms, however, it is our view that the fuel chain analyses of the ExternE Project can be considered a particular example of life cycle analysis.

2.2 Guiding Principles in the Development of the ExternE Methodology

The underlying principles on which the methodology for the ExternE Project has been developed are:

Transparency, to show precisely how results are calculated, the uncertainty associated with the results and the extent to which the external costs of any fuel chain have been fully quantified.

Consistency, of methodology, models and assumptions (e.g. system boundaries, exposure-response functions and valuation of risks to life) to allow valid comparisons to be made between different fuel chains and different types of impact within a fuel chain.

That analysis should be comprehensive, we should seek to at least identify all of the effects that may give rise to significant externalities, even if some of these cannot be quantified in either physical or monetary terms.

In order to comply with these principles, much of the analysis described in this report looks at the effects of individual power projects which are closely specified with respect to:

- The technologies used;
- The location of the power generation plant;
- The location of supporting activities;
- The type of fuel used;
- The source and composition of the fuel used.

Each of these factors is important in determining the magnitude of impacts and hence associated externalities.

2.3 Defining the Boundaries of the Analysis

The starting point for fuel chain analysis is the definition of the temporal and spatial boundaries of the system under investigation, and the range of burdens and impacts to be addressed. The boundaries used in the ExternE Project are very broad. This is essential in order to ensure consistency in the application of the methodology for different fuel chains.

Certain impacts brought within these boundaries cannot be quantified at the present time, and hence the analysis is incomplete. However, this is not a problem peculiar to this style of analysis; it simply reflects the existence of gaps in available knowledge. Our rule here is that no impact that is known or suspected to exist, but cannot be quantified, should be ignored for convenience. Instead it should be retained for consideration alongside whatever analysis has been possible. Further work is needed so that unquantified effects can be better integrated into decision making processes.

2.3.1 Stages of the fuel chain

For any project associated with electricity generation the system is centred on the generation plant itself. However, the system boundaries should be drawn so as to account for all potential effects of a fuel chain. The exact list of stages is clearly dependent on the fuel chain in question, but would include activities linked to the manufacture of materials for plant, construction, demolition and site restoration as well as power generation. Other stages may need to be considered, such as, exploration, extraction, processing and transport of fuel, and the generation of wastes and by-products, and their treatment prior to disposal.

In practice, a complete analysis of each stage of a fuel chain is often not necessary in order to meet the objectives of the analysis (see below). However, the onus is on the analyst to demonstrate that this is the case - it cannot simply be assumed. Worth noting is the fact that variation in laws and other local conditions will lead to major differences between the importance of different stages in different parts of the world.

A further complication arises because of the linkage between fuel chains and other activities, upstream and downstream. For example, in theory we should account for the externalities associated with (e.g.) the production of materials for the construction of the plant used to make the steel that is used to make turbines, coal wagons, etc. The benefit of doing so is, however, extremely limited. Fortunately this can be demonstrated through order-of-magnitude calculations on emissions, without the need for detailed analysis.

The treatment of waste matter and by-products deserves special mention. Impacts associated with waste sent for disposal are part of the system under analysis. However, impacts associated with waste utilised elsewhere (which are here referred to not a waste but as by-products) should be considered as part of the system to which they are transferred from the moment that they are removed from the boundaries of the fuel chain. It is of course important to be sure that a market exists for any such by-products. The capacity of, for example, the building industry to utilise gypsum from flue gas desulphurisation systems is clearly finite. If it is probable that markets for particular by-products are already saturated, the ‘by-product’ must be considered as waste instead. A further difficulty lies in the uncertainties about future management of waste storage sites. For example, if solid residues from a power plant are disposed in a well engineered and managed landfill there is no impact (other than land use) as long as the landfill is correctly managed; however, for the more distant future such management is not certain.

2.3.2 Location of fuel chain activities

One of the distinguishing features of the ExternE study is the inclusion of site dependence. For each stage of each fuel chain we have therefore identified specific locations for the power plant and all of the other activities drawn within the system boundaries. In some cases this has gone so far as to identify routes for the transport of fuel to power stations. The reason for defining our analysis to this level of detail is simply that location is important in determining the size of impacts. There are several elements to this, the most important of which are:

- Variation in technology arising from differing legal requirements (e.g. concerning the use of pollution abatement techniques, occupational safety standards, etc.);
- Variation in fuel quality;
- Variations in atmospheric dispersion;
- Differences in the sensitivity of the human and natural environment upon which fuel chain burdens impact.

The alternative to this would be to describe a ‘representative’ site for each activity. It was agreed at an early stage of the study that such a concept is untenable. Also, recent developments elsewhere, such as use of critical loads analysis in the revision of the Sulphur Protocol within the United Nations Economic Commission for Europe’s (UN ECE) Convention on Long Range Transboundary Air Pollution, demonstrate the importance attached to site dependence by decision makers.

However, the selection of a particular series of sites for a particular fuel chain is not altogether realistic, particularly in relation to upstream impacts. For example, although some coal fired power stations use coal from the local area, an increasing number use coal imported from a number of different countries. This has now been taken into account.

2.3.3 Identification of fuel chain technologies

The main objective of this project was to quantify the external costs of power generation technologies built in the 1990s. For the most part it was not concerned with future technologies that are as yet unavailable, nor with older technologies which are gradually being decommissioned.

Over recent years an increasingly prescriptive approach has been taken to the regulation of new power projects. The concept of Best Available Techniques (BAT), coupled with emission limits and environmental quality standards defined by both national and international legislation, restrict the range of alternative plant designs and rates of emission. This has made it relatively easy to select technologies for each fuel chain on a basis that is consistent across fuel chains. However, care is still needed to ensure that a particular set of assumptions are valid for any given country. Across the broader ExternE National Implementation Project particular variation has for example been found with respect to the control of NO_x in different EU Member States.

As stated above, the present report deals mainly with closely specified technology options. Results have also been aggregated for the whole electricity generating sector, providing first estimates of damages at the national level.

2.3.4 Identification of fuel chain burdens

For the purposes of this project the term 'burden' relates to anything that is, or could be, capable of causing an impact of whatever type. The following broad categories of 'burden' have been identified:

- Solid wastes;
- Liquid wastes;
- Gaseous and particulate air pollutants;
- Risk of accidents;
- Occupational exposure to hazardous substances;
- Noise;
- Others (e.g. exposure to electro-magnetic fields, emissions of heat).

During the identification of burdens no account has been taken of the likelihood of any particular burden actually causing an impact, whether serious or not. For example, in spite of the concern that has been voiced in recent years there is no definitive evidence that exposure to electro-magnetic fields associated with the transmission of electricity is capable of causing harm. The purpose of the exercise is simply to catalogue everything to provide a basis for the analysis of different fuel chains to be conducted in a consistent and transparent manner, and to provide a firm basis for revision of the analysis as more information on the effects of different burdens becomes available in the future.

The need to describe burdens comprehensively is highlighted by the fact that it is only recently that the effects of long range transport of acidic pollutants, and the release of CFCs and other greenhouse gases have been appreciated. Ecosystem acidification, global warming and depletion of the ozone layer are now regarded as among the most important environmental concerns facing the world. The possibility of other apparently innocuous burdens causing risks to health and the environment should not be ignored.

2.3.5 Identification of impacts

The next part of the work involves identification of the potential impacts of these burdens. At this stage it is irrelevant whether a given burden will actually cause an appreciable impact; all potential impacts of the identified burdens should be reported. The emphasis here is on making analysts demonstrate that certain impacts are of little or no concern, according to current knowledge. The conclusion that the externalities associated with a particular burden or impact, when normalised to fuel chain output, are likely to be negligible is an important result that should not be passed over without comment. It will not inevitably follow that action to reduce the burden is unnecessary, as the impacts associated with it may have a serious effect on a small number of people. From a policy perspective it might imply, however, that the use of fiscal instruments might not be appropriate for dealing with the burden efficiently.

The first series of ExternE reports (European Commission, 1995a-f) provided comprehensive listings of burdens and impacts for most of the fuel chains considered. The tasks outlined in this section and the previous one are therefore not as onerous as they seem, and will become easier with the development of appropriate databases.

2.3.6 Valuation criteria

Many receptors that may be affected by fuel chain activities are valued in a number of different ways. For example, forests are valued not just for the timber that they produce, but also for providing recreational resources, habitats for wildlife, their interactions (direct and indirect) with climate and the hydrological cycle, protection of buildings and people in areas subject to avalanche, etc. Externalities analysis should include all such aspects in its valuation. Again, the fact that a full quantitative valuation along these lines is rarely possible is besides the point when seeking to define what a study should seek to address: the analyst has the responsibility of gathering information on behalf of decision makers and should not make arbitrary decisions as to what may be worthy of further debate.

2.3.7 Spatial limits of the impact analysis

The system boundary also has spatial and temporal dimensions. Both should be designed to capture impacts as fully as possible.

This has major implications for the analysis of the effects of air pollution in particular. It necessitates extension of the analysis to a distance of hundreds of kilometres for many air pollutants operating at the ‘regional’ scale, such as ozone, secondary particles, and SO_2. For greenhouse gases the appropriate range for the analysis is obviously global. Consideration of these ranges is in marked contrast to the standard procedure employed in environmental impact assessment which considers pollutant transport over a distance of only a few kilometres and is further restricted to primary pollutants. The importance of this issue in externalities analysis is that in many cases in the ExternE Project it has been found that regional effects of air pollutants like SO_2, NO_x and associated secondary pollutants are far greater than effects on the local scale (for examples see European Commission, 1995c). In some locations however, for example close to large cities, the local range impacts may be significant, and accordingly the framework for assessing air pollution effects developed within the EcoSense model allows specific account to be taken of local range dispersion.

It is frequently necessary to truncate the analysis at some point, because of limits on the availability of data. Under these circumstances it is recommended that an estimate be provided of the extent to which the analysis has been restricted. For example, one could quantify the proportion of emissions of a given pollutant that have been accounted for, and the proportion left unaccounted.

2.3.8 Temporal limits of the impact analysis

In keeping with the previous section, impacts should be assessed over their full time course. This clearly introduces a good deal of uncertainty for long term impacts, such as those of global warming or high level radioactive waste disposal, as it requires a view to be taken on the structure of future society. There are a number of facets to this, such as global population and economic growth, technological developments, the sustainability of fossil fuel consumption and the sensitivity of the climate system to anthropogenic emissions.

The approach adopted here is that discounting should only be applied after costs are quantified. The application of any discount rate above zero can reduce the cost of major events in the distant future to a negligible figure. This perhaps brings into question the logic of a simplistic approach to discounting over time scales many thousands of years into the future. There is clear conflict here between some of the concepts that underlie traditional economic analysis and ideas on sustainability over timescales that are meaningful in the context of our recorded history. For further information, the discounting of global warming damages is discussed further in Appendix V.

The assessment of future costs is of course not simply a discounting issue. A scenario based approach is also necessary in some cases in order to describe the possible range of outcomes. This is illustrated by the following examples;

- A richer world would be better placed to take action against the impacts of global warming than a poorer one;
- The damages attributable to the nuclear fuel chain could be greatly reduced if more effective treatments for cancer are discovered.

Despite the uncertainties involved it is informative to conduct analysis of impacts that take effect over periods of many years. By doing so it is at least possible to gain some idea of how important these effects might be in comparison to effects experienced over shorter time scales. The chief methodological and ethical issues that need to be addressed can also be identified. To ignore them would suggest that they are unlikely to be of any importance.

2.4 Analysis of Impact Pathways

Having identified the range of burdens and impacts that result from a fuel chain, and defined the technologies under investigation, the analysis typically proceeds as follows:

- Prioritisation of impacts;
- Description of priority impact pathways;
- Quantification of burdens;
- Description of the receiving environment;

- Quantification of impacts;
- Economic valuation;
- Description of uncertainties.

2.4.1 Prioritisation of impacts

It is possible to produce a list of several hundred burdens and impacts for many fuel chains (see European Commission, 1995c, pp. 49-58). A comprehensive analysis of all of these is clearly beyond the scope of externality analysis. In the context of this study, it is important to be sure that the analysis covers those effects that (according to present knowledge) will provide the greatest externalities (see the discussion on life cycle analysis in section 2.1). Accordingly, the analysis presented here is limited, though only after due consideration of the potential magnitude of all impacts that were identified for the fuel chains that were assessed. It is necessary to ask whether the decision to assess only a selection of impacts in detail reduces the value of the project as a whole. We believe that it does not, as it can be shown that many impacts (particularly those operating locally around any given fuel chain activity) will be negligible compared to the overall damages associated with the technology under examination.

There are good reasons for believing that local impacts will tend to be of less importance than regional and global effects. The first is that they tend to affect only a small number of people. Even though it is possible that some individuals may suffer very significant damages these will not amount to a significant effect when normalised against a fuel chain output in the order of several terawatt (10^{12} Watt)-hours per year. It is likely that the most appropriate means of controlling such effects is through local planning systems, which be better able than policy developed using externalities analysis to deal flexibly with the wide range of concerns that may exist locally. A second reason for believing that local impacts will tend to be less significant is that it is typically easier to ascribe cause and effect for impacts effective over a short range than for those that operate at longer ranges. Accordingly there is a longer history of legislation to combat local effects. It is only in recent years that the international dimension of pollution of the atmosphere and water systems has been realised, and action has started to be taken to deal with them.

There are obvious exceptions to the assertion that in many cases local impacts are of less importance than others;

- Within OECD states one of the most important exceptions concerns occupational disease, and accidents that affect workers and members of the public. Given the high value attached to human life and well-being there is clear potential for associated externalities to be large.
- Other cases mainly concern renewable technologies, at least in countries in which there is a substantial body of environmental legislation governing the design and siting of nuclear and

fossil-fired plant. For example, most concern over the development of wind farms typically relates to visual intrusion in natural landscapes and to noise emissions.

- There is the possibility that a set of conditions - meteorology, geography, plant design, proximity of major centres of population, etc. - can combine to create local air quality problems.

The analysis of certain upstream impacts appears to create difficulties for the consistency of the analysis. For example, if we treat emissions of SO_2 from a power station as a priority burden, why not include emissions of SO_2 from other parts of the fuel chain, for example from the production of the steel and concrete required for the construction of the power plant? Calculations made in the early stages of ExternE using databases, such as GEMIS (Fritsche *et al*, 1992), showed that the emissions associated with material inputs to fossil power plants are 2 or 3 orders of magnitude lower than those from the power generation stage. It is thus logical to expect that the impacts of such emissions are trivial in comparison, and can safely be excluded from the analysis - if they were to be included the quantified effects would be secondary to the uncertainties of the analysis of the main source of emissions. However, this does not hold across all fuel chains. In the reports on both the wind fuel chain (European Commission, 1995f) and the photovoltaic fuel chain (ISET, 1995), for example, it was found that emissions associated with the manufacture of plant are capable of causing significant externalities, relative to the others that were quantified.

The selection of priorities partly depends on whether one wants to evaluate damages or externalities. In quite a few cases the externalities are small in spite of significant damages. For example, if a power plant has been in place for a long time, much of the externality associated with visual and noise impacts will have been capitalised by means of adjustments in the price of housing (though *not* generally internalised in the price of electricity). It has been argued that occupational health effects are also likely to be internalised. For example, if coal miners are rational and well informed their work contracts should offer benefits that internalise the incremental risk that they are exposed to. However, this is a very controversial assumption, as it depends precisely upon people being both rational and well informed and also upon the existence of perfect mobility in labour markets. For the present time we have quantified occupational health effects in full, leaving the assessment of the degree to which they are internalised to a later date.

It is again stressed that it would be wrong to assume that those impacts given low priority in this study are always of so little value from the perspective of energy planning that it is never worth considering them in the assessment of external costs. Each case has to be assessed individually. Differences in the local human and natural environment, and legislation need to be considered.

2.4.2 Description of priority impact pathways

Some impact pathways analysed in the present study are extremely simple in form. For example, the construction of a wind farm will affect the appearance of a landscape, leading to a change in visual amenity. In other cases the link between ‘burden’ (defined here simply as something that causes an ‘impact’) and monetary cost is far more complex. To clearly define the linkages involved in such cases we have drawn a series of diagrams. One of these is shown in Figure 2.2, illustrating the series of processes that need to be accounted for from emission of acidifying pollutants to valuation of impacts on agricultural crops. It is clearly far more complex than the pathway suggested by Figure 2.1.

A number of points should be made about Figure 2.2. It (and others like it) do not show what has been carried out within the project. Instead they illustrate an ideal - what one would like to do if there was no constraint on data availability. They can thus be used both in the development of the methodology and also as a check once analysis has been completed, to gain an impression of the extent to which the full externality has been quantified. This last point is important because much of the analysis presented in this report is incomplete. This reflects on the current state of knowledge of the impacts addressed. The analysis can easily be extended once further data becomes available. Also, for legibility, numerous feedbacks and interactions are not explicitly shown in the diagrammatic representation of the pathway.

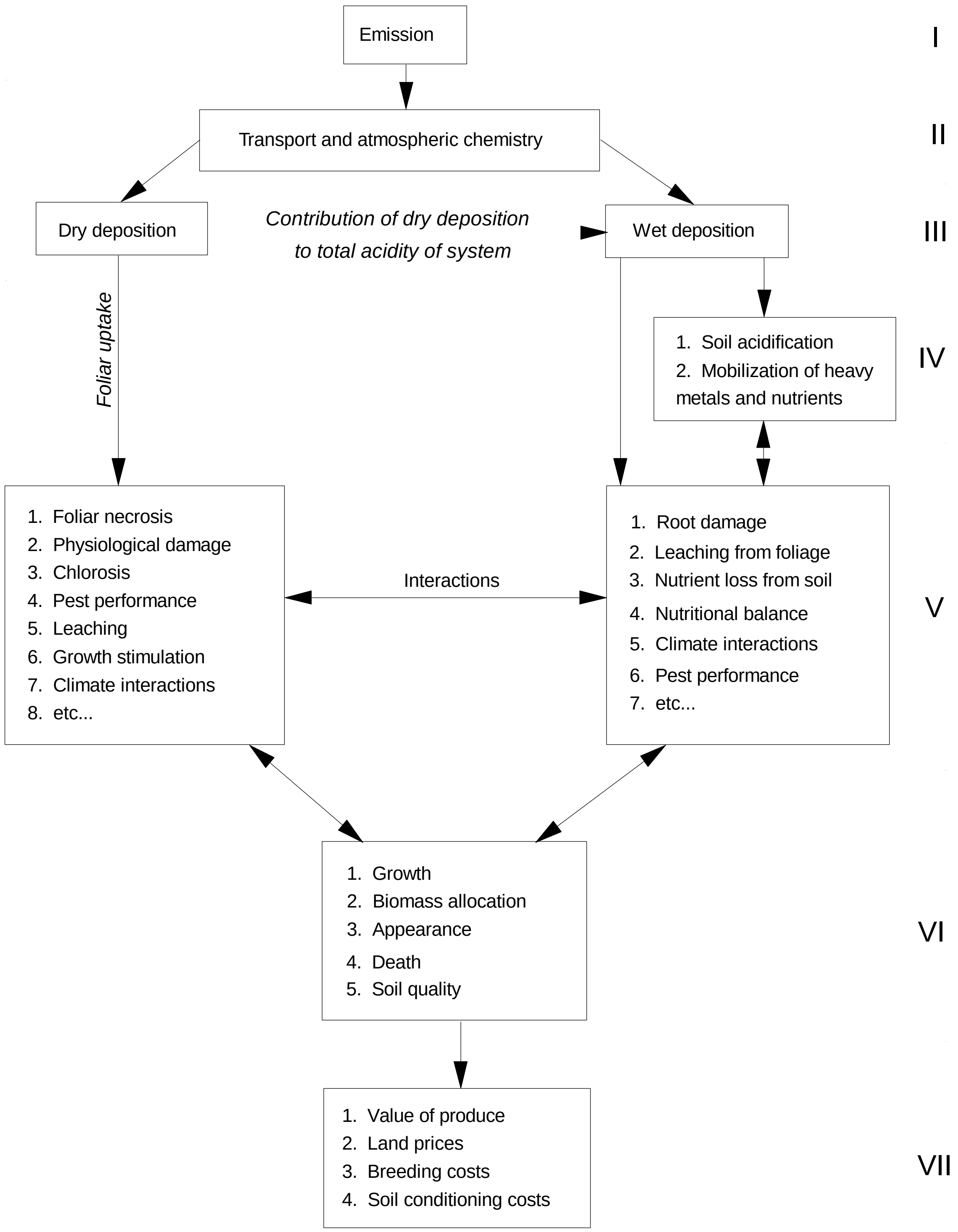

Figure 2.2 The impact pathway showing the series of linkages between emission of acidifying pollutants and ozone precursors and valuation of impacts on agricultural systems.

2.4.3 Quantification of burdens

The data used to quantify burdens must be both *current* and *relevant* to the situation under analysis. Emission standards, regulation of safety in the workplace and other factors vary significantly over time and between and within different countries. It is true that the need to meet these demands creates difficulties for data collection. However, given that the objective of this work is to provide as far as possible an accurate account of the environmental and social burdens imposed by energy supply and use, these issues should not be ignored. It is notable that data for new technologies can change rapidly following their introduction. In addition to the inevitable refinement of technologies over time, manufacturers of novel equipment may be cautious in their assessment of plant performance. As an example of this latter point, NO_x emission factors for combined cycle gas turbine plant currently coming on stream in several countries are far lower than was suggested by Environmental Statements written for the same plant less than five years ago.

All impacts associated with pollution of some kind require the quantification of emissions. Emission rates of the ‘classical’ air pollutants (CO_2, SO_2, NO_x, CO, volatile organic compounds and particulate matter) are quite well known. Especially well determined is the rate of CO_2 emission for fuel using equipment; it depends only on the efficiency of the equipment and the carbon/hydrogen ratio of the fuel - uncertainty is negligible. Emissions of the other classical air pollutants are somewhat less certain, particularly as they can vary with operating conditions, and maintenance routines. The sulphur content of different grades of oil and coal can vary by an order of magnitude, and hence, likewise, will emissions unless this is compensated for through varying the performance of abatement technologies. The general assumption made in this study is that unless otherwise specified, the technology used is the best available according to the regulations in the country of implementation, and that performance will not degrade. We have sought to limit the uncertainty associated with emissions of these pollutants by close identification of the source and quality of fuel inputs within the study.

The situation is less clear with respect to trace pollutants such as lead and mercury, since the content of these in fuel can vary by much more than an order of magnitude. Furthermore, some of these pollutants are emitted in such small quantities that even their measurement is difficult. The dirtier the fuel, the greater the uncertainty in the emission estimate. There is also the need to account for emissions to more than one media, as pollutants may be passed to air, water or land. The last category is the subject of major uncertainty, as waste has historically been sent for disposal to facilities of varying quality, ranging from simple holes in the ground to well-engineered landfills. Increasing regulation relating to the disposal of material and management of landfills should reduce uncertainty in this area greatly for analysis within the European Union, particularly given the concept of self-sufficiency enshrined in Regulation 259/93 on the supervision and control of shipments of waste into, out of and within the European Community. The same will not apply in many other parts of the world.

The problem becomes more difficult for the upstream and downstream stages of the fuel chain because of the variety of technologies that may be involved. Particularly important may be some stages of fuel chains such as biomass, where the fuel chain is potentially so diverse that it is possible that certain activities are escaping stringent environmental regulation.

The burdens discussed so far relate only to routine emissions. Burdens resulting from accidents also need to be considered. These might result in emissions (e.g. of oil) or an incremental increase in the risk of injury or death to workers or members of the public. Either way it is normally necessary to rely upon historical data to quantify accident rates. Clearly the data should be as recent as possible so that the rates used reflect current risks. Major uncertainty however is bound to be present when extreme events need to be considered, such as the disasters at Chernobyl and on the Piper Alpha oil rig in the North Sea. To some extent it is to be expected that accident rates will fall over time, drawing on experience gained. However, structural changes in industries, for example through privatisation or a decrease in union representation, may reverse such a trend.

Wherever possible data should be relevant to the country where a particular fuel chain activity takes place. Major differences in burdens may arise due to different standards covering occupational health, extension of the distance over which fuel needs to be transported, etc.

2.4.4 Description of the receiving environment

The use of the impact pathway approach requires a detailed definition of the scenario under analysis with respect to both time and space. This includes:

- Meteorological conditions affecting dispersion and chemistry of atmospheric pollutants;
- Location, age and health of human populations relative to the source of emissions;
- The status of ecological resources;
- The value systems of individuals.

The range of the reference environment for any impact requires expert assessment of the area influenced by the burden under investigation. As stated above, arbitrary truncation of the reference environment is methodologically wrong and will produce results that are incorrect. It is to be avoided as far as possible.

Clearly the need to describe the sensitivity of the receiving environment over a vast area (extending to the whole planet for some impacts) creates a major demand on the analyst. This is simplified by the large scale of the present study - which has been able to draw on data held in many different countries. Further to this it has been possible to draw on numerous databases that are being compiled as part of other work, for example on critical loads mapping. Databases covering the whole of Europe, describing the distribution of the key receptors affected by SO_2, NO_x, NH_3 and fine particles have been derived or obtained for use in the EcoSense software developed by the study team.

In order to take account of future damages, some assumption is required on the evolution of the stock at risk. In a few cases it is reasonable to assume that conditions will remain roughly constant, and that direct extrapolation from the present day is as good an approximation as any. In other cases, involving for example the emission of acidifying gases or the atmospheric concentration of greenhouse gases this assumption is untenable, and more complex scenarios must be developed. Confidence in these scenarios clearly declines as they extend further into the future.

2.4.5 Quantification of impacts

The methods used to quantify various types of impact are discussed in depth in the report on the study methodology (European Commission, 1998). The functions and other data that we have used are summarised at the back of this report in Appendices I (describing the EcoSense software), II (health), III (materials), IV (ecological receptors), V (global warming effects) and VI (other impacts), VII (economic issues) and VIII (uncertainty). The complexity of the analysis varies greatly between impacts. In some cases externalities can be calculated by multiplying together as few as 3 or 4 parameters. In others it is necessary to use a series of sophisticated models linked to large databases.

Common to all of the analysis conducted on the impacts of pollutants emitted from fuel chains is the need for modelling the dispersion of pollutants and the use of a dose-response function of some kind. Again, there is much variation in the complexity of the models used (see Appendix I). The most important pollutant transport models used within ExternE relate to the atmospheric dispersion of pollutants. They need to account not only for the physical transport of pollutants by the winds but also for chemical transformation. The dispersion of pollutants that are in effect chemically stable in the region of the emission can be predicted using Gaussian plume models. These models assume source emissions are carried in a straight line by the wind, mixing with the surrounding air both horizontally and vertically to produce pollutant concentrations with a normal (or Gaussian) spatial distribution. The use of these models is typically constrained to within a distance of 100 km of the source.

Air-borne pollutant transport of course extends over much greater distances than 100 km. A different approach is needed for assessing regional transport as chemical reactions in the atmosphere become increasingly important. This is particularly so for the acidifying pollutants. For this analysis we have used receptor-orientated Lagrangian trajectory models. The outputs from the trajectory models include atmospheric concentrations and deposition of both the emitted species and secondary pollutants formed in the atmosphere.

A major problem has so far been the lack of a regional model of ozone formation and transport within fossil-fuel power station plumes that is applicable to the European situation. In consequence a simplified approach has been adopted for assessment of ozone effects (European Commission, 1998).

The term ‘dose-response’ is used somewhat loosely in much of this work, as what we are really talking about is the response to a given *exposure* of a pollutant in terms of atmospheric concentration, rather than an ingested *dose*. Hence the terms ‘dose-response’ and ‘exposure-response’ should be considered interchangeable. A major issue with the application of such functions concerns the assumption that they are transferable from one context to another. For example, some of the functions for health effects of air pollutants are still derived from studies in the USA. Is it valid to assume that these can be used in Europe? The answer to this question is to a certain degree unknown - there is good reason to suspect that there will be some variation, resulting from the affluence of the affected population, the exact composition of the cocktail of pollutants that the study group was exposed to, etc. Indeed, such variation has been noted in the results of different epidemiological studies. However, in most cases the view of our experts has been that transference of functions is to be preferred to ignoring particular types of impact altogether - neither option is free from uncertainty.

Dose-response functions come in a variety of functional forms, some of which are illustrated in Figure 2.3. They may be linear or non-linear and contain thresholds (e.g. critical loads) or not. Those describing effects of various air pollutants on agriculture have proved to be particularly complex, incorporating both positive and negative effects, because of the potential for certain pollutants, e.g. those containing sulphur and nitrogen, to act as fertilisers.

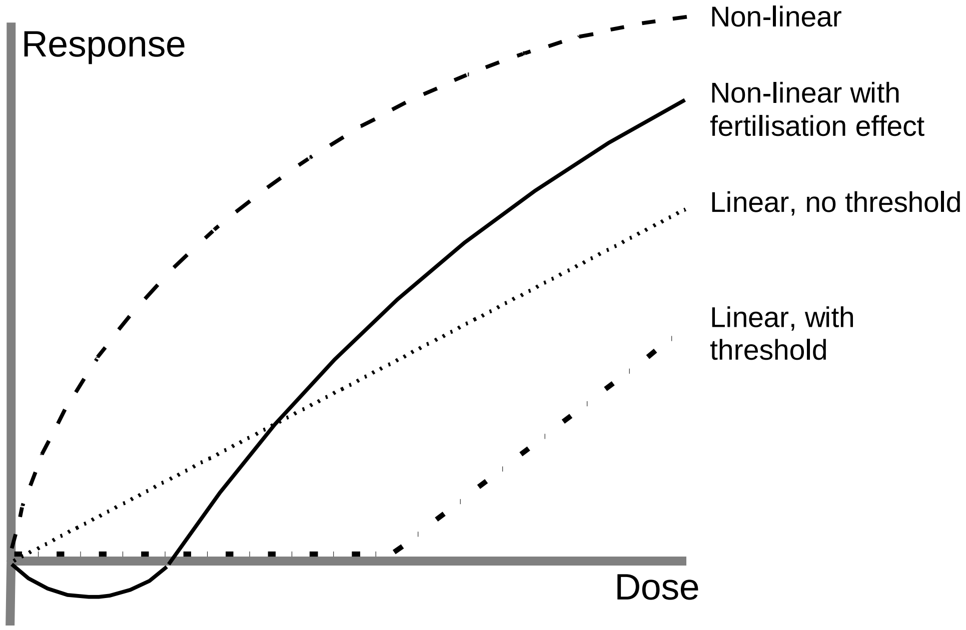

Figure 2.3 A variety of possible forms for dose-response functions.

Ideally these functions and other models are derived from studies that are epidemiological - assessing the effects of pollutants on real populations of people, crops, etc. This type of work has the advantage of studying response under realistic conditions. However, results are much more difficult to interpret than when working under laboratory conditions, where the environment can be closely controlled. Although laboratory studies provide invaluable data on response mechanisms, they often suffer from the need to expose study populations to extremely high levels of pollutants, often significantly greater than they would be exposed to in the field. Extrapolation to lower, more realistic levels may introduce significant uncertainties, particularly in cases where there is reason to suspect that a threshold may exist.

The description and implementation of exposure-response relationships is fundamental to the entire ExternE Project. Much of the report on methodology (European Commission, 1998) is, accordingly, devoted to assessment of the availability and reliability of these functions.

2.4.6 Economic valuation

The rationale and procedures underlying the economic valuation applied within the ExternE Project are discussed in Appendix VII and in more detail in the methodology report (European Commission, 1998). The approach followed is based on the quantification of individual ‘willingness to pay’ (WTP) for environmental benefit.

A limited number of goods of interest to this study - crops, timber, building materials, etc. - are directly marketed, and for these valuation data are easy to obtain. However, many of the more important goods of concern are not directly marketed, including human health, ecological systems and non-timber benefits of forests. Alternative techniques have been developed for valuation of such goods, the main ones being hedonic pricing, travel cost methods and contingent valuation (Appendix VII). All of these techniques involve uncertainties, though they have been considerably refined over the years.

The base year for the valuation described in this report is 1995, and all values are referenced to that year. The unit of currency used is the ECU. The exchange rate was approximately 1 ECU to US$1.25 in 1995.

The central discount rate used for the study is 3%, with upper and lower rates of 0% and 10% also used to show sensitivity to discount rate. The rationale for the selection of this range and best estimate, and a broader description of issues relating to discounting, was given in an earlier report (European Commission, 1995b).

2.4.7 Assessment of uncertainty

Uncertainty in externality estimates arises in several ways, including:

- The variability inherent in any set of data;
- Extrapolation of data from the laboratory to the field;
- Extrapolation of exposure-response data from one geographical location to another;
- Assumptions regarding threshold conditions;
- Lack of detailed information with respect to human behaviour and tastes;
- Political and ethical issues, such as the selection of discount rate;
- The need to assume some scenario of the future for any long term impacts;
- The fact that some types of damage cannot be quantified at all.

It is important to note that some of the most important uncertainties listed here are not associated with technical or scientific issues, instead they relate to political and ethical issues, and questions relating to the development of world society. It is also worth noting that, in general, the largest uncertainties are those associated with impact assessment and valuation, rather than quantification of emissions and other burdens.

Traditional statistical techniques would ideally be used to describe the uncertainties associated with each of our estimates, to enable us to report a median estimate of damage with an associated probability distribution. Unfortunately this is rarely possible without excluding some significant aspect of error, or without making some bold assumption about the shape of the probability distribution. Alternative methods are therefore required, such as sensitivity analysis, expert judgement and decision analysis. In this phase of the study a more clearly quantified description of uncertainty has been attempted than previously. Further discussion is provided in Appendix VIII, though it is worth mentioning that in this area of work uncertainties tend to be so large that additive confidence intervals usually do not make sense; instead one should specify multiplicative confidence intervals. The uncertainties of each stage of an impact pathway need to be assessed and associated errors quantified. The individual deviations for each stage are then combined to give an overall indication of confidence limits for the impact under investigation.

2.5 Priority Impacts Assessed in the ExternE Project

2.5.1 Fossil technologies

The following list of priority impacts was derived for the fossil fuel chains considered in the earlier phases of ExternE. It is necessary to repeat that this list is compiled for the specific fuel chains considered by the present study, and should be reassessed for any new cases. The first group of impacts are common to all fossil fuel chains:

1. Effects of atmospheric pollution on human health;
2. Accidents affecting workers and/or the public;
3. Effects of atmospheric pollution on materials;
4. Effects of atmospheric pollution on crops;
5. Effects of atmospheric pollution on forests;
6. Effects of atmospheric pollution on freshwater fisheries;
7. Effects of atmospheric pollution on unmanaged ecosystems;
8. Impacts of global warming;
9. Impacts of noise.

To these can be added a number of impacts that are fuel chain dependent:

10. Impacts of coal and lignite mining on ground and surface waters;

11. Impacts of coal mining on building and construction;

12. Resettlement necessary through lignite extraction;

13. Effects of accidental oil spills on marine life;

14. Effects of routine emissions from exploration, development and extraction from oil and gas wells.

2.5.2 Nuclear technologies

The priority impacts of the nuclear fuel chain to the general public are radiological and non-radiological health impacts due to routine and accidental releases to the environment. The source of these impacts are the releases of materials through atmospheric, liquid and solid waste pathways.

Occupational health impacts, from both radiological and non-radiological causes, were the next priority. These are mostly due to work accidents and radiation exposures. In most cases, statistics were used for the facility or type of technology in question. When this was not possible, estimations were taken from similar type of work or extrapolated from existing information.

Impacts on the environment of increased levels of natural background radiation due to the routine releases of radionuclides have not been considered as a priority impact pathway, except partially in the analysis of major accidental releases.

2.5.3 Renewable technologies

The priority impacts for renewables vary considerably from case to case. Each case is dependent upon the local conditions around the implementation of each fuel chain. For the wind fuel chain (European Commission, 1995f) the following were considered:

1. Accidents affecting the public and/or workers;

2. Effects on visual amenity;

3. Effects of noise emissions on amenity;

4. Effects of atmospheric emissions related to the manufacture of turbines and construction and servicing of the site.

Whilst for the hydro fuel chain (European Commission, 1995f) another group was considered:

1. Occupational health effects;
2. Employment benefits and local economic effects;
3. Impacts of transmission lines on bird populations;
4. Damages to private goods (forestry, agriculture, water supply, ferry traffic);
5. Damages to environmental goods and cultural objects.

2.5.4 Related issues

It is necessary to ask whether the study fulfils its objective of consistency between fuel chains, when some impacts common to a number of fuel chains have only been considered in a select number of cases. In part this is due to the level of impact to be expected in each case - if the impact is likely to be large it should be considered in the externality assessment. If it is likely to be small it may be legitimate to ignore it, depending on the objectives of the analysis. In general we have sought to quantify the largest impacts because these are the ones that are likely to be of most relevance to questions to which external costs assessment is appropriate.

2.6 Summary

This Chapter has introduced the ‘impact pathway’ methodology of the ExternE Project. The authors believe that it provides the most appropriate way of quantifying externalities because it enables the use of the latest scientific and economic data.

Critical to the analysis is the definition of fuel chain boundaries, relating not only to the different stages considered for each fuel chain, but also to the:

- Location of each stage;
- Technologies selected for each stage;
- Identified burdens;
- Identified impacts;
- Valuation criteria;
- Spatial and temporal limits of impacts.

In order to achieve consistency it is necessary to draw very wide boundaries around the analysis. The difficulty with successfully achieving an assessment on these terms is slowly being resolved through the development of software and databases that greatly simplify the analysis.

The definition of ‘system boundary’ is thus broader than is typically used for LCA. This is necessary because our analysis goes into more detail with respect to the quantification and valuation of impacts. In doing so it is necessary to pay attention to the site of emission sources and the technologies used. We are also considering a wider range of burdens than is typical of LCA work, including, for example, occupational health effects and noise.

The analysis requires the use of numerous models and databases, allowing a logical path to be followed through the impact pathways. The functions and other data originally used by ExternE were described in an earlier report (European Commission, 1995b). In the present phase of the study this information has been reassessed and many aspects of it have been updated (see European Commission, 1998). It is to be anticipated that further methodological changes will be needed in the future, as further information becomes available particularly regarding the health effects of air pollution and global warming impacts, which together provide some of the most serious impacts quantified under the study.

3. COAL FUEL CYCLE

3.1 Technology and Reference Site Description

3.1.1 Reference Site Description

The Moneypoint power plant is situated at Money Point, on the north shore of the Shannon Estuary, in County Clare on the west coast of Ireland. The site is very rural and very sparsely populated, with the nearest city, Limerick (population around 60,000) at a distance of around 50 km. The main land use in the area is pasture, with cattle being raised for both meat and dairy produce.

The site of the station occupies 170 hectares, of which 24 ha was reclaimed from the foreshore. Its location was chosen because of the favourable conditions for the construction of a deep-water berthing facility for delivery of coal shipments.

3.1.2 Reference Plant Description

Moneypoint was built between 1979 and 1987, with the first turbine coming on-line in 1985. With 3 turbines each of 305 MW_e output, the plant has a maximum rated output of 915 MW_e. The decision to build a coal plant of this size (26% of 1985 national capacity) was motivated by the oil crises of the 1970s, and a wish to reduce dependence on oil-fired capacity. This dependence was reduced from 26% in 1985 to 8% by 1988.

The 3 water-tube boilers at Moneypoint consume around 2 million tonnes of coal per annum, using pulverised coal-burner technology.

No abatement technology for SO_2 reduction has been installed. During 1995 and 1996, low-NO_x burners were retrofitted to all three boilers to reduce the station's NO_x output. Particulate reduction is achieved by means of electrostatic precipitators.

3.1.3 Fuel Cycle Definition

The fuel cycle is considered to consist of the following stages:

1. Extraction and Preparation of fuel

2. Transport, Handling and Storage of fuel

3. Transport of Personnel and Other Materials

4. Construction and Decommissioning of Plant

5. Combustion of Fuel, Generation of Electricity

6. Waste Disposal

The relationship between these stages is shown in **Figure 3-1** below.

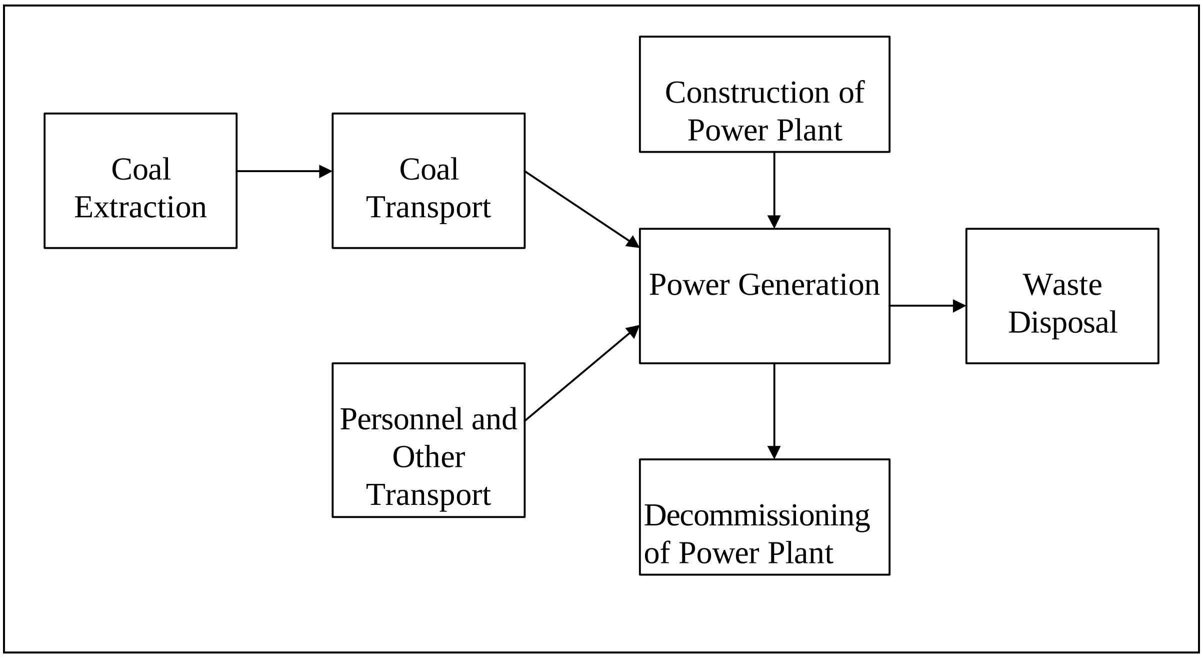

Figure 3-1: Stages of the Coal Fuel Cycle

Extraction and Preparation of Fuel

The coal used at Moneypoint is imported from a variety of foreign producing countries. The source of the coal is determined by the sulphur content required to conform to environmental legislation, and by the cost, either on the basis of a negotiated long-term contract or of the international spot-price.

Around 80% of the fuel is bought on long-term contract, 40% from the United States and 40% from Colombia. The remaining 20% may come from the USA, Colombia, the Republic of South Africa, Australia or other countries.

USA

The USA coal is mined in the central Appalachian region, in the states of West Virginia and Kentucky. The coalfields of these two states had a combined output of 295 Mt in 1991 (Porter, 1993). This represented 33% of total US coal production, and 64% of national coal exports. The majority of coal in this area, especially coal with low sulphur content, is produced by deep-mining (IEA, 1978). The coal is hard coal, characterised by a sulphur content of 0.3 to 2%.

Some preparation takes place at the point of production, principally with a view to removing dirt and ash content, in order to maintain a high calorific value before transportation. The preparation consists of crushing the coal to a grade of 1 to 4 cm, then cleaning it (OECD, 1978). This washing also has the effect of reducing pyritic sulphur content (IEA,1978). The preparation separates the raw coal into clean coal and a waste. There is a trade-off between the amount of sulphur removed and the loss of coal into the waste.

Colombia

The Colombian coal is extracted at a mine called El Cerrejón Norte, the world's largest open-pit mine, with estimated reserves of 3 billion tonnes, and an annual production of 16 million tonnes (55% of Colombia's total). This mine is located in the Guajira department of north-east Colombia, and is a joint venture between Intercor (a subsidiary of Exxon) and Carbocol (the state coal company).

This coal does not undergo any cleaning or preparation prior to shipping; the raw coal is considered to be of high enough quality to export as is.

It is assumed for the purpose of the ExternE analysis that half of the coal originates in the USA and half in Colombia, and the characteristics of the fuel are determined accordingly.

The coal used at Moneypoint has the following composition:

Fuel	C (%)	H (%)	S (%)	O (%)	N (%)	Ash (%)	Water (%)	GCV (MJ/kg)
USA 1	67.28	4.61	2.08	4.32	1.33	9.39	11	27.55
USA 2	68.38	5.56	0.80	5.44	1.31	7.53	11	27.79
Colombia	69.92	5.69	0.82	5.56	1.34	7.70	9	28.41
Average	68.9	5.39	1.13	5.22	1.33	8.08	10	28.04

Table 3-1: Chemical Composition of Coal Burned at Moneypoint

In addition to these major constituents of coal, we assume that the coal also contains trace elements in the following quantities:

Element	**Quantity** (ppm)	**Element**	**Quantity** (ppm)
Silicon	26,000	Manganese	85
Aluminium	25,500	Zinc	60
Sulphur	15,000	Chromium	60
Iron	13,200	Lead	50
Nitrogen	12,000	Cobalt	47
Calcium	9,500	Nickel	25
Magnesium	3,700	Arsenic	10
Chlorine	3,400	Selenium	7
Potassium	2,300	Cadmium	3
Sodium	1,470	Antimony	2
Phosphorus	1,000	Mercury	0.3
Vanadium	145		
Copper	130		

Table 3-2: Trace elements present in coal (Foras Forbartha, 1978)

Transport, Handling and Storage of Fuel

Transport

The journey from the overseas coal mine to Moneypoint power station has two legs: a rail journey from the mine to the port, and a sea journey from the foreign port to Moneypoint itself. No onward transport of the coal takes place in Ireland after it is unloaded at the port.

The first part of the journey is by rail. The burdens that may arise from this operation include injury to workers or the general public arising out of rail accidents, and emission of pollutants or global warming gases. Each of these burdens may be considered proportional, ceteris paribus, to the distance travelled.

Rail -USA

In the case of the USA, the coal is mined in the Appalachian mountains of West Virginia. Rail transport between the mines and the ports is operated by a variety of carriers, the most important of which is CSX Transportation. CSX transports coal from the northern sector of the Appalachian complex to the port of Baltimore, Maryland, and from the southern mines to the Hampton Roads ports (Norfolk and Newport News, VA). The distances from the mines to the ports are between 600 and 1,300 km each way (Porter, 1993).

CSX serves two terminals at Newport News, and all three export facilities at Baltimore. This gives it an export capacity of 23.2 Mt at Newport News, as well as a ground storage capacity of 2.5 Mt. This ground storage facility avoids the long term storage of coal in loaded trains, thus freeing up rolling stock. Altogether, CSX transports 23% of all export coal in the USA.

Coal is transported in unit trains of 6,350 tonnes, or in some districts in 150-carriage trains carrying 9,070 tonnes. The length of trains in long-haul applications has gradually increased, as has the capacity of each carriage. This is due to the easing of limits by the rail track operator, and new improved loading techniques.

Over 90% of coal rail shipments originating in Kentucky are transported in unit trains. These trains would be hauled by 4 (6 for the larger unit trains) 6-axle diesel locomotives of >3,000 horse-power each (Tutko, 1987). It will be assumed for this study that the coal supplied to Moneypoint is transported from the Coal River mine to Newport News, a distance of some 1,000 km by rail.

Rail - Colombia

El Cerrejón Norte is served by a specially built export terminal at Puerto Bolivar, on the Atlantic coast of Colombia. At present the capacity of the export terminal is 15 Mt/yr. A dedicated railway was built to connect the mine to the port. The distance by rail is 150 km each way. This rail link has occasionally fallen victim to disruption by guerrilla activity. Other parts of the Cerrejón complex, Cerrejón Central and Sur, depend for the moment on road transport.

The mine, railway and export terminal are all operated exclusively by Intercor.

Ocean Transport

The more important of the two sections of the journey, however, is the transport by ship. This is because of the relatively high emissions from marine diesel engines, and because of the greater absolute distance. We assume that the coal reaches Ireland by one of two routes:

a) Newport News, Virginia to Moneypoint (2,897 nautical miles, 5,366 km) or

b) Puerto Bolivar, Colombia to Moneypoint (3,970 nautical miles, 7,352 km).

For both of these routes, we assume an average coal shipment of 100,000 tonnes.

Data on transport of coal from mine to power station is summarised in **Table 3-3** below.

Table 3-3: Transport of coal to Moneypoint, total distance travelled

	Rail (km/Mt coal)	**Ship (km/Mt coal)***
USA	315,000	54,000
Colombia	47,000	74,000

*transport by sea is reckoned on a one-way basis.

Handling and Storage

The storage of coal in loaded rail cars at the ocean terminal of the railway line has the advantages of minimising handling and contamination. It has the disadvantage, however, that rolling stock is made inactive for the time during which it is used for this purpose. CSX Corporation uses ground storage facilities at its terminals in Newport News and Baltimore.

The seaport at Puerto Bolivar in Colombia is used exclusively for the export of coal mined at El Cerrejón - Zona Norte. It has a maximum draught of 17 metres, and can accommodate ships of between 25,000 and 150,000 tonnes, and between 100 and 300 metres in length. No facility exists for the ground storage of coal. Coal is loaded at a rate of 4,000 tonnes per hour.

Moneypoint's specially constructed deep-water port has a 380 metre jetty, and handles ships of between 30,000 and 175,000 tonnes (ESB). Maximum draught is 25 m. It is capable of unloading 2,500 tonnes per hour and storing 3 million tonnes of coal on-site. Total annual capacity is 4 Mt per annum. No connection exists with Ireland's railway network (IEA, 1985).

Delivery of coal to Moneypoint takes place approximately 20 times a year. Each cargo is unloaded continuously over a period of 5 or 6 days. During the unloading operation, two grab-type unloaders are used to transfer the coal from the ship to two hoppers, each of which feeds an enclosed conveyor leading to the coalyard. On arrival in the coalyard, the coal is stockpiled using two stacking machines. This activity occurs day and night approximately 120 days per year.

Moneypoint: handling and storage

Moneypoint's coalyard occupies 32 hectares of the site, and has a total storage capacity of 3 million tonnes. Coal is transferred from the coalyard to the main power station building using enclosed conveyors. In normal operation, about 7,000 tonnes of coal is transferred daily. This usually takes place during two periods of the day, for two hours in the morning and two hours in the afternoon. It is also possible to transfer coal using front-end loader equipment.

Transport of Personnel and Other Materials

The construction of the plant and the port facility required the transport of 45,000 tonnes of steel and 16,000 tonnes of precast concrete. In addition, the pouring of 166,000 cubic metres of concrete on-site required the transport of 65,500 tonnes of cement, 103,000 tonnes of fine aggregate and 178,000 tonnes of coarse aggregate.

The sources of these materials are assumed to be as follows:

Material	Source	Distance from Moneypoint
Steel	Irish Steel, Haulbowline, Co. Cork	190 km
Cement	Irish Cement Limited, Castlemungret, Co. Limerick	90 km
Aggregate	Cement Roadstone, Bunratty, Co. Clare	65 km

Table 3-4: Distance travelled by Moneypoint construction materials

The transport of these materials to the Moneypoint construction site amounts to a total of 34 million tonne-kilometres. Many of the shipments passed through heavily populated areas such as the city of Limerick on its way from the point of production to the construction site.

The road infrastructure in the rural area surrounding the site is poorly adapted to cope with these levels of traffic, and the road from Kilrush to Moneypoint had to be completely remade. Substantial improvements had to be carried out on the main road from Kilrush to Ennis.

During the construction phase of the project, an average of 550 people worked on the site. In normal operation, 390 people are permanently employed.

These people are assumed to undertake a journey by car of 17.3 km each way to travel to and from work.

Construction and Decommissioning of Plant

Moneypoint power station occupies a site of 170 hectares, of which 24 hectares was reclaimed from the foreshore. A further 35 hectares adjoining the site is used for disposal of pulverised fuel ash. The construction of the plant took place over the period from 1979 to 1987, with the first turbo-alternator set being installed in September 1985. Further units were commissioned in June 1986, and April 1987.

The construction required the movement of 3.5 million cubic metres of material in order to level the site, to set up a windbreak for the coal store and to reclaim land from the sea. The coastal section of the perimeter of the site has been shored up using large boulders to form an artificial embankment. These boulders were not available locally, so that they had to be brought by road. This required the strengthening of 5 miles of road between Kilrush and Moneypoint to accommodate the large trucks. Embankments have also been constructed around the ash disposal site.

The construction of the jetty required the driving of steel pilings of a total of 12,000 tonnes, and the use of 16,000 tonnes of precast concrete and 16,000 cubic metres of poured concrete.

The construction of the buildings required the use of 150,000 cubic metres of concrete and 33,000 tonnes of steel. The plant includes two slip-formed chimneys of 225 m in height. In addition to the jetty and the main station building there are systems and structures associated with coal-handling, cooling-water pumping, oil storage and ancillary activities.

The peak work force in the construction of the plant was 1,000, and over 1,600 people were employed on the site at one time or another. The average number of workers employed on the site over the period was 557 (O'Connor et al., 1981). This amounts to a total over the 8 year period of 7 million man-hours.

The plant has a planned lifetime of 40 years. At some time after this, some of the structures on site will be deemed unsafe and have to be demolished.

Generation of Electricity

The three steam generators, or boilers, at Moneypoint, are each fitted with 16 pulverised coal burners. The coal is milled into a fine powder by a cascading ball charge in the pulverising mills, before being dried and drawn into the burners by a stream of preheated air. Secondary air is blown directly into the combustion chambers, allowing complete combustion of the fuel. A small amount of diesel fuel is used for starting purposes.

Each boiler is fitted with 4 coal pulverising mills, each with a capacity of 8.26 kg/s. Total annual fuel consumption amounts to approximately 2.25 million tonnes of coal

Water tubes in the boiler combustion chamber carry water which is heated to generate steam. This steam is superheated to 540ºC at 16.5 MPa. This steam is expanded through the High Pressure stage of the turbines, and is then reheated before being expanded to vacuum (0.0035 MPa) in the Intermediate and Low Pressure stages of the turbines. The Low Pressure steam is exhausted to the condensers where it is condensed back into liquid and from where it is pumped back to the boiler feedwater preheater.

The shaft work from the turbines is used to generate electricity in the alternators. Each set outputs 358 MVA at 17 kV. This is stepped up to 400 kV in the station transformers and fed into the National Grid. Net of internal losses and station use, the amount of electricity sent out at full load is 880 MW. This amounts to 6.16 TWh per annum.

The flue gas is drawn out of the boiler by an induced draught fan, and passes through the superheater, the steam reheater, and the electrostatic precipitators, before passing up the chimney to be discharged to atmosphere.

The flue gas from the boiler is primarily composed of carbon dioxide, steam, nitrogen and oxygen. It also contains smaller quantities of sulphur oxides, nitrogen oxides, and fly ash which includes trace elements such as iron, magnesium, potassium, vanadium, copper and zinc. This ash is extracted from the flue gases by means of the electrostatic precipitators, and collected in hoppers for disposal. Inevitably some proportion (typically <1%) of this material will escape to be emitted to atmosphere.

As well as the electrostatic precipitators, whose role is to remove suspended particles from the flue gases, the boilers have also been fitted with low-NO_x burners, designed to reduce by 50% the amount of thermal NO_x produced during combustion. These emissions abatement devices were retrofitted during 1995 and 1996. No plans exist at present to install Flue Gas Desulphurisation (FGD).

Boiler make-up water is supplied from a reservoir of 27,000 cubic metres on-site. This reservoir is also used for domestic water supply to the station. The combined fresh-water usage of the plant is 7.5 million litres/day, or 312 m^3/hour. A sewage treatment plant also exists on-site.

Cooling water, in the form of seawater from the estuary, is supplied to the condensers at a rate of 7,700 kg/s per set. This amounts to a total cooling water flow-rate of 83,160 m^3 per hour for the three condensers. The average cooling water inlet temperature is 10ºC, and the outlet temperature is 21ºC. Chlorine, which is added on a discontinuous basis to reduce the fouling of the pipework by shellfish or algal growth, amounts to 0.2 to 0.5 ppm at discharge (Clare Co. Co. et al., 1988).

Furnace Bottom Ash (FBA) is collected in a hopper underneath the boiler.

Waste Disposal

The furnace bottom ash and the fly ash are transported by truck from the station buildings through an underpass to the ash lagoon for storage. The annual quantity of ash produced is between 100,000 and 200,000 m^3.

The ash lagoon has a capacity of 5.25 million cubic metres, if we assume that the entire 35 hectare site can be filled to a uniform depth of 15 metres. ESB quotes a capacity of 3 million cubic metres.

In general, the ash produced in coal combustion is a chemically inert, almost completely insoluble solid whose main constituents are silica, alumina, lime and iron oxide. In addition, some small quantities of unburned hydrocarbons and trace elements will be present. The ash is strongly alkaline, with an initial pH of around 11, gradually reducing to around 8 after dumping. The material is made up of small particles, 60% of which are in the range 20 to 200 µm, and 40% in the range 2 to 20 µm. The stockpile is physically stable, and resistant to wind erosion.

Wind erosion and visual impact may be further reduced by the vegetation of the surface of the ash disposal site. Nitrogen fertilisation is necessary for this purpose, since the ash has been rendered sterile and devoid of nitrogen by the combustion process. Other nutrients, such as phosphates and potassium, are present in greater quantities than in typical soils. There is no evidence of trace element contamination of grass or arable crops grown on sites of this type (ERL, 1983).

The waste material may also be used for the fabrication of cement, or as a foundation material in road-building. During 1994, 57,500 tonnes of ash was exported, mainly during the summer months. Average number of truck movements was 18 per day, with a peak of 36 movements per day.

3.2 Overview of Burdens

3.2.1 Extraction and Preparation of Coal

It is widely recognised that a variety of adverse environmental and health impacts may result from coal mining and associated activities. These include:

- Death and injury to mine-workers as a result of industrial accidents
- Occupational diseases such as pneumoconiosis and cancer among mine-workers
- Damage to (or removal of) surface habitats
- Subsidence at the surface due to collapse of mine tunnels
- Disruption of the water table
- Noise and dust blow
- Accumulation of solid waste
- Leaching of contaminant materials (acid and trace elements) from coal waste dumps
- Emission of global warming and pollutant gases from the exposed coal seam and from mining equipment

Occupational Accidents

In the case of the USA, rates of occupational injury are available for the coal mining industry as a whole. In the case of Colombia, no reliable data on occupational health is available, so it has been necessary to use information relating to Argentina instead. The values used are those supplied by the International Labour Organisation and the US Department of Labour, and tabulated in European Commission, 1998*b*.

cases/Mt coal	Argentina (proxy Colombia)	USA (underground)
Fatal Accidents	0.53	0.145
Non-fatal Accidents	217	14 (major) 3.7 (minor)

Table 3-5: Occupational Accident Rates

It may be noted that, according to environmental groups, 32 mine workers died at the Cerrejón mine over a four year period (Scholtes, 1994). This would correspond to a mortality rate of 0.5 deaths per Mt coal, in very good agreement with the Argentina figure.

Occupational Diseases

The principal occupational diseases associated with mining coal are lung diseases due to the presence of particulate matter and radon gas in the mine environment. Because of variation in standards of mine ventilation, the rates of these diseases will vary substantially between locations and between countries.

For the USA, figures quoted in European Commission, 1998*b* are 0.33 deaths from lung cancer and 0.35 deaths from pneumoconiosis per Mt coal produced.

No such figures are available for Colombia. The same source quotes a figure of 70 cases (not deaths) of pneumoconiosis per year for Brazil. Since Brazil produces only 5 Mt of coal per year, this corresponds to 14 cases per Mt.

Damage to surface habitat

The open cast mining of coal precludes the use of the land under excavation for any other purpose. In particular, any habitat which existed at the site will be displaced. After exhaustion of the fuel resource, revegetation may be undertaken to restore the land to agricultural, leisure or forestry use. It is questionable whether a programme of revegetation will be implemented in Colombia. OECD (1978) quotes reclamation costs of 3,000 to 8,000 1977 US$ per acre (17,500 to 47,000 1996 ECU per hectare). The total area of the Cerrejón mining complex (not just the pit) is up to 1,000,000 ha., and reserves are up to 3 billion tonnes. Total reclamation costs could therefore be of the order of 30 billion ECU, or 3 ECU/tonne coal. These values are however subject to a high degree of uncertainty.

Some controversy exists as to whether land can be restored to its original level of visual amenity or of fertility.

Subsidence

In underground mining, when the coal is extracted from the seam, the tunnel may collapse and the ground level at the surface directly above may sink. This effect will be most pronounced where the mine is shallow and the amount of coal removed is large. The ground level may drop by some tens of centimetres. This can cause damage to nearby structures, drainage patterns and roads. Costs of subsidence have been estimated at an average of US$1.5 (1978) (IEA, 1978), or 3.25 ECU (1996) per ton.

This damage may be avoided by back-filling of tunnels after extraction, or by adopting techniques such as “room and pillar” mining, in which the roof of the tunnel is supported by pillars of coal and remains intact after use. The “room and pillar” technique is standard in the USA (ERL, 1983). This technique is costly in terms of the need to leave some coal in situ underground.

These effects do not arise, of course, in the case of open-pit mining such as is practised in the Cerrejón mine.

Any damage arising from this burden is therefore assumed to be internalised in the cost of coal.

Disruption of the Water Table

Both open-pit mines and underground mines are prone to flooding, and so large amounts of water must be pumped out to permit coal extraction. In addition, areas where the ground level has been lowered due to subsidence or strip-mining may become flooded. Agricultural activities in the area may suffer as a result. In addition, the drainage of water through newly exposed high-sulphur coal seams may result in groundwater becoming highly mineralised, and increased sulphate levels in waterways on a regional scale. This is considered to be a problem in the Appalachian system.

Noise, Dust

Noise and dust from the mine and associated activities are considered to represent a nuisance to nearby residents. An environmentalist’s perspective on the effects of the Cerrejón mine on indigenous people is quoted here:

“To extract the coal, Exxon has sucked up the groundwater, dried up the rivers and, in the process, denuded the grasslands on which the Wayuu depend for subsistence, according to Gouriyu. […]people living near the mine are ‘in total misery’. They suffer respiratory diseases from coal dust, noise from ceaseless underground explosions and the fumes of 100 diesel trucks.” (Boswell, 1996)

Solid Waste Dumps

Very large volumes of solid waste are produced in the extraction and preparation of coal. Much of the waste consists of non-organic matter which is removed from the ground with the coal, and then separated from the coal above ground. The mass ratio of coal to waste may be as low as 1.25:1 or 1.5:1 (ERL,1983). The amount of solid waste produced at Cerrejón, for example, could be over 10 million tonnes per annum, or 6 million cubic metres. This material is usually piled up to form large heaps, with striking visual impact. Should the tips not be sufficiently compacted, they may ignite and burn for long periods. They may also result in catastrophic landslides.

Leaching of Contaminants from Solid Waste Dumps

The most widespread environmental problem that is associated with these refuse dumps is the mineralisation and acidification of the drainage water that has passed through them (Wagner et al.,1980). In an analysis of the leachate from the Appalachian Region's coal refuse, it was found to contain large absolute quantities of environmentally harmful materials, including nickel, iron, manganese, copper, aluminium and zinc. In addition, it was highly acidic, with a pH of approximately 3. These discharges destroy aquatic life, and make the water unsuitable for domestic, industrial or other uses.

It has been suggested that the leaching of harmful materials as well as the acidification could be reduced by alkaline neutralisation with the addition of lime to the solid waste. A cost of US$1 (1978) per metric tonne of cleaned coal is estimated for this technique. This corresponds to 2.2 ECU (1996) per tonne.

Global Warming and Pollutant Emissions

The operation of a coal mine will entail some methane emission. European Commission (1998*b)* presents the results of a number of studies, including those of Watson (world average for hard coal mining = 400 g/GJ) Gordon and Sullivan (0.15 to 0.25 kg CO_2 equiv/GJ ~ 10 g CH_4/GJ) and ETSU (1994) (170 to 375 t/Mt coal ~ 6 to 13 g/GJ). Astrand (1996) quotes a figure derived from Levander (1989), of 300 g/GJ. A high degree of variation is apparent in these values.

In addition, we must consider the emissions from mining equipment. For global warming gases, Gordon and Sullivan give a figure of 0.33 kg CO_2equiv/GJ for a surface mine and 0.51 kg CO_2equiv/GJ for an underground mine.

Emissions of NO_x and VOCs, which are considered to be precursors to tropospheric ozone, are as follows (ETSU, 1994):

[t/Mt coal]	NO_2	VOCs
Australia	448	28.8
USA	22.4	760.8
Average	235	395

Table 3-6: Emissions of precursors of tropospheric ozone during coal mining

3.2.2 Transport, Handling and Storage of Coal

Burdens associated with this stage of the fuel cycle are as follows:

- Pollutant and global warming gas emissions from trains
- Pollutant and global warming gas emissions from ships
- Noise and fugitive coal dust generated during loading/unloading and in transit
- Water pollution due to acid water drainage from coal bunkers
- Occupational injury due to rail accidents, accidents at sea or loading/unloading
- Visual impact and land use of storage facilities

Emissions - Rail and Ship

Rail and ocean transport using diesel engines will result in the emission to the air of potentially harmful substances including SO_2, NO_x, particulate matter and CO_2. The total quantities of these pollutant fractions emitted may be assessed by examining each of the stages in the journey from the mine to the power station separately.

1. Rail

If we consider the rail journeys in Colombia and the USA together, the average one-way distance from mine to port is 575 km. If we assume an energy intensity of 0.5 MJ/tonne km (IEA, 1993) a total of 6,765 tonnes of diesel fuel will be required to move 1 Megatonne of coal. The fuel is assumed to be diesel fuel with a heating value of 42.5 MJ/kg, and to have a carbon content of 86% and a sulphur content of 0.3% (Bosch, 1993).

The emission standards for diesel locomotives in the United Kingdom and in the USA are as follows:

g/kWh output	HCs	CO	NO_x	PM	VOCs
UK*	-	4	16	-	1.6
USA**	1.34	6.69	12.7	0.80	

Table 3-7 : Emissions regulations for freight locomotives.

* Standard for average emissions on selected points of the ISO 8159 engine cycle applicable to engines entering service from 1993 (IEA, 1993).

** Proposed standard for line-haul locomotives, which are currently unregulated in the USA (EPA, 1997*a,b*). Converted from units of g/brake-horsepower.hour.

2. Ship

The two ocean voyages from Newport News to Moneypoint and from Puerto Bolivar to Moneypoint are 5,366 km and 7,352 km respectively. The average distance is taken therefore to be 6,360 km.

Table 3-8 gives typical emissions values associated with shipping of freight.

kg/ton fuel	NO_x	CO	VOCs	Particulates
Slow Speed	59	8	2.7	2.5
Medium Speed	84	9	2.5	2.5

Table 3-8 : Emissions from marine diesel engines (IEA, 1993)

On a journey of this distance, the ship will burn approximately 790 tonnes of fuel oil. If the fuel oil is assumed to have a sulphur content of 3%, it will result in the emission of 47.4 tonnes of SO_2, approximately 60 tonnes of NO_x and 2,420 tonnes of CO_2.

t/Mt coal	CO_2	SO_2	NO_x	CO	VOCs	PM
Rail	21,332	40.53	303	160	32.1	19
Ship	24,200	474	600	67	20.5	19.75
Total	45,532	514.5	903	227	52.6	39

Table 3-9 : Atmospheric emissions from transport stage of coal fuel cycle

Noise from Rail Traffic and Handling of Coal

Noise generated by the passing of trains or in the transfer of coal into and out of trains and ships in Colombia and the USA is neglected in this analysis. This is due to the difficulty of assessing the impact of such burdens in overseas locations. It is recognised, however, that the nuisance suffered by the residents of the areas affected is real.

Noise burdens arising at Moneypoint are monitored by ESB. It is found that during the 120 days per year during which loading and unloading are taking place, the average noise level at the station perimeter is 45.7 dBA, as opposed to 43 dBA when no unloading is taking place. The nearest occupied house is 100 metres further away from the noise source, and the ESB predicts that the noise level at this site will be 2 dBA lower than the measured values. Table 3-10 below summarises this data. ESB notes that no complaints have arisen about noise level from any source associated with Moneypoint power station.

LA_{eq} (1-hr) / [dBA]	Measured Values at Site Perimeter	Predicted Values at nearest dwelling
Ship Unloading	46	44
No ship unloading	43	41

Table 3-10: Noise levels at Moneypoint coalyard perimeter monitoring station and at nearest occupied dwelling (ESB)

Leachate from Coal Bunkers

Of the total incident rainfall on the exposed surface of the stored coal, some will percolate through the stockpile and become contaminated with dissolved iron and sulphate, and become acidified. The remainder will run off the surface without having become contaminated. The respective proportions will depend on the degree of compaction of the coal. In certain cases where high sulphur coal is stored, the leachate may have dissolved iron content of 90 g/l and sulphur content of 20 g/l. These levels would not arise with the low-sulphur coal used at Moneypoint. All discharges are licensed and monitored under the terms of Moneypoint’s Waste Disposal Licences.

Occupational Injury

Safety standards and overall concern for safety are very high in the electricity industry in Ireland. Occupational injuries and fatalities which occur in this industry are conjoined with production and distribution of gas and fresh water for the purpose of record-keeping by the Health and Safety Authority. Taking this sector ("Electricity, Gas and Water Supply") as a whole, the incidence of fatalities is extremely low. A list of areas of concern to the HSA in 1995 includes no activity associated with power generation.

During the year 1995, there were no fatalities (although one was reported in 1994) and around 200 injuries (190 in 1994) necessitating an absence of 3 days or more from work in the Electricity, Gas and Water Supply sector. This corresponds to an injury rate of approximately 1.5% per year ($9.5x10^{-6}$ per man-hour), and a zero fatality rate.

Land Use and Visual Impact

The land use and visual impact associated with the coal handling and storage facilities at Moneypoint are negligible. The site of the coalyard was formerly poor quality pasture, and only two houses are situated within 500 metres of the perimeter.

No consideration has been made of the land use and visual impacts of the coal handling and storage facilities at the points of production and export of the coal in the USA and Colombia.

3.2.3 Transport of Personnel and Other Materials

Burdens associated with this stage of the fuel cycle are

- pollutant emissions from vehicles
- road accidents resulting from increased traffic flows
- damage to road infrastructure

Emissions

The use of trucks powered by direct injection diesel engines to carry freight by road requires 3.6 MJ of primary energy per tonne-kilometre (IEA, 1993). If we assume that the total carriage of materials to the site during the construction phase comes to 34 million tonne-kilometres (see Table 3-4 above) the energy used in transport would be 122.4 TJ, which corresponds to 2.9 million kg of diesel. This would lead to the formation of 9,000 tonnes of CO_2 and 17 tonnes of SO_2.

Heavy-duty diesel engines are now subject to European legislation (1995) limiting emissions. The relevant limits are:

NO_x	CO	VOC	Particulates
7.0	4.0	1.1	0.15

Table 3-11: European Legislation Stage 2 (1995) for heavy duty diesel engines (g/kWh)

Using these limits, and an estimated energy intensity of 0.25 kWh of engine output per tonne-kilometre, the total emissions from transport of construction materials is 60 tonnes of NO_x, 34 tonnes of CO, 9 tonnes of VOCs and 1.3 tonnes of particulates.

Considering next the transport of personnel to and from the plant, the annual distance travelled for this purpose in normal operation is reckoned to be 2.5 million passenger-kilometres. During the 8 years of the construction phase, the total distance was 34.7 million passenger-kilometres. Table 3-12 shows the emissions factors used to calculate the emissions from this source.

NO_x	CO	HCs	CO_2
1.07	8.16	0.90	215

Table 3-12: Emissions characteristics of passenger cars (tonnes/10^6 passenger-kilometres) (Howard, 1990).

Finally, the export of ash from the site amounted to 57,500 tonnes in 1994, and the remaining 134,500 was transported approximately 1 km from the ash handling facilities to the on-site ash disposal area. Altogether this comes to around 3 million tonne-kilometres per annum.

	CO_2	NO_x	SO_2	CO	VOCs	HCs	PM
Construction Materials *	225	1.5	0.43	0.85	0.23	-	0.03
Construction Personnel *	186	0.93	-	7.1	-	0.78	-
Ash Export and Disposal	801	5.25	1.5	3.0	0.82	-	0.11
Operation Personnel	540	2.7	-	20.4	-	2.3	-
Total	**1,752**	**10.35**	**1.93**	**31.4**	**1.05**	**3.1**	**0.14**

Table 3-13: Emissions from transport of personnel and construction materials (tonnes/year)

* Values for construction annualised over 40 year lifetime of plant

Road Accidents

The increased traffic flows associated with Moneypoint power plant will result in an increased number of car accidents. For the purpose of the study it will be assumed that the accident statistics for the whole county of Clare can be applied to the traffic in the region around Moneypoint.

	Number of accidents	Number of deaths	Number of injuries
Rate (per 10 million vehicle-km)	1.9	0.166	3.18
Construction Stage (annualised)	0.17	0.014	0.28
Generation Stage	0.48	0.042	0.80
Total	0.64	0.056	1.1

Table 3-14: Expected increase in road accidents associated with Moneypoint power station car transport. Rates derived from CSO (1995).

Road accidents associated with movement of trucks and heavy machinery have been excluded from this analysis due to lack of relevant data.

Infrastructural Damage

The effect of heavy traffic on the roads in the vicinity of the plant is to increase the maintenance load to be carried by the local authority. It is likely that this impact is internalised in the cost of running the vehicle, in the form of road tax and taxes on sales, vehicle registrations, fuel, maintenance, etc.

These taxes contributed £1,900 million in revenue during 1997. Total budgeted expenditure on maintenance and improvement of roads is £432 million, of which £258 million is to be spent on national routes, and £174 million on secondary and other roads.

3.2.4 Construction and Decommissioning of Plant

The impacts associated with construction and decommissioning of the plant are:

- Occupational Injury of Construction Workers
- Land Use and Visual Intrusion

- Noise

Occupational Injury

The construction sector had a total of 13 fatalities in 1995 and 10 in 1994. The number of injuries was 266 in 1995 and 226 in 1994. Areas of concern to the HSA in the construction sector are

- Falls from Heights
- Steel Erection
- Fragile Roof Work
- Inadequate Scaffolding
- Structural Collapse during Excavation
- Traffic Control
- Trench Collapse
- Noise, Dust and Fumes
- Manual Handling

It should be noted that no fatalities were recorded in the construction of Moneypoint power station. This study seeks however to estimate the number of fatalities and injuries to be expected on a typical project of this scale, rather than to record the experience of this particular project. Therefore, although it is likely that the safety standards enforced at Moneypoint were very high, this impact may be reckoned based on the average rates of occupational injury in the construction sector as a whole. These are: 16 fatalities per 100,000 employed per year, and 1,900 injuries (>3 days out of work) per 100,000 per year.

Land Use and Visual Intrusion

The construction of Moneypoint power plant required:

- the fundamental restructuring of 146 hectares of agricultural land,
- the reclamation of 24 hectares of foreshore
- the enclosure of 35 hectares of brackish swampland for use as an ash disposal site.

1,800 metres of shoreline were modified, and chimneys and pylons were erected.

The quality of agricultural land in the area, and in Co. Clare in general, is poor. The majority (92%) of the agricultural land in the immediate vicinity is under grass (Foras Forbartha, 1978). This is further sub-classified as follows: 29% is top quality, 56% is rather weedy and 15% is very weedy, with 30% of the area covered by weeds (creeping thistle, soft rush). Dairy farming is the predominant agricultural activity.

The use of an area of marshland as an ash disposal site displaced a population of gulls and wading birds. The wintering population of 10 or more snipe may be accommodated in nearby wetlands.

Visual intrusion is not an important consideration, despite the large scale of the project, because of the remoteness and low population density of the site.

Noise

The impact on local residents of noise during the construction of the power plant is neglected in this study, due to the very low density of housing in the region.

3.2.5 Generation of Electricity

The most important impacts of the coal fuel cycle arise out of the burdens associated with this stage of the fuel cycle. For this reason, this stage is central to the analysis. Among these burdens are:

- Discharge of pollutant emissions to the atmosphere. These include sulphur oxides, nitrogen oxides and particulate matter, as well as trace elements
- Discharge of ozone precursors to atmosphere, primarily nitrogen oxides
- Discharge of global warming gases to atmosphere, primarily carbon dioxide
- Abstraction and discharge of salt water to and from the estuary
- Noise

Pollutant Emissions

The flue gas flowrate from Moneypoint at full load is 3.3 million normal cubic metres per hour, at a temperature of 125°C. The exhaust gases contain harmful or pollutant emissions in the following proportions:

	NO_x	SO_2	TSP	CO_2
mg/Nm^3	850	2,136	50	245,000
t/TWh	3,190	8,010	190	922,000
t/year	19,600	49,300	1,200	$5.68x10^6$

Table 3-15: Emissions from Moneypoint power station

In addition, the flue gas will contain traces of all those heavy metals and other elements which are present in the coal. An Foras Forbartha (1978) presents "worst case" possibilities for the aerial emission of these substances as follows:

Metal	tonnes/yr	mg/Nm^3	Metal	tonnes/yr	mg/Nm^3
Fe	1,386	60	Co	20	0.87
Mg	389	17	Se	13	0.56
K	242	10	Ni	11	0.47
V	61	2.6	Mn	9	0.39
Cu	55	2.4	As	4	0.17
Zn	25	1.1	Cd	1.3	0.06
Mo	22	0.95	Sb	0.8	0.03
Pb	21	0.91	Hg	0.6	0.03

Table 3-16: Emission of trace elements from Moneypoint power station

Cooling Water

The cooling circuits of the power plant require the abstraction of between 75,000 and 120,000 m^3 per hour of salt water from the estuary at full load. This water is chlorinated during the warmer part of the year (April to November) and passed through the condensers. The water is then returned to the estuary, its temperature having been raised to approximately 21°C.

An Foras Forbartha (1978) identifies three mechanisms by which marine organisms may be affected. These are: entrainment, chlorination and temperature rise.

Entrainment of living organisms into the condensers appears to cause insignificant losses. Most fish, crustaceans, and microscopic animal and plant life survive the passage through the condensers, in the absence of chlorination.

The chlorination of cooling water at certain periods of the year will result in mortality among animals entrained into the cooling water circuits, especially in the case of larval animals. Plants are less affected by chlorine. In general, marine animals are adapted to cope with a high level of mortality, so overall populations are not affected by these losses. In particular, commercial fisheries are unlikely to be affected.

The temperature rise in the estuary resulting from the combined effects of Moneypoint and Tarbert power stations is estimated to be 0.3°C. The effect of this moderate change in temperature is considered to be generally favourable to growth of phytoplankton. Although this may be considered to benefit the entire food chain, the effect on fish populations will be negligible.

On a more local level, the temperature near the shoreline in the immediate vicinity of the plant may be increased by an estimated 1°C, most notably on a rising tide. This will be expected to cause increased growth in seaweeds which will in turn result in increased numbers of interlittoral shellfish such as limpets and periwinkles.

During summer, when water temperatures in the estuary rise to 17°C, the cooling water discharge has been measured at 27°C (Aqua-Fact International Services, 1992). In the presence of organic pollution, such high temperatures have the potential to reduce the level of dissolved oxygen in the water to a level which is detrimental to marine life. In the absence of any source of organic pollution, this effect will not occur. In fact, turbulence generated in the outflow pumps may tend to favour high levels of dissolved oxygen.

Noise

A variety of noises result from the generation stage of the fuel cycle. Among the major sources are the boiler, the coal mills and the spinning turbines. Discontinuous sources of noise include activities such as boiler blowdowns, steam venting on boiler startup and testing of safety valves.

The number of people other than plant employees who will be in any way affected by this noise is very small. The number of occupied dwellings within 1 kilometre of the main station building is approximately 7.

In the absence of activities associated with Moneypoint power station, ambient noise level is very low in the area. Measured background L_{eq} in 1978 before the start of construction varied from 30 to 38 dB(A). Typical daytime values are around 35 dB(A).

During operation of the power plant, the noise level at the nearest house is predicted to be 41 dB(A). This represents an increase at this location of 6 dB(A) over ambient.

3.2.6 Waste Disposal

The possible environmental impacts of ash disposal are as follows:

- Visual Impact
- Leaching of Trace Elements
- Impact on Human Health

Visual Impact

The flat marshland in which the ash is stored will eventually be raised to a level 15 metres above the surrounding countryside. When this artificial stockpile is contoured and vegetated, it will resemble a natural feature. While it is in use, its visual aspect will be unattractive, but the low density of population ensures that the impact will be negligible.

Leachate from the Ash Disposal Site

The accumulation of rainwater in the ash has the effect of creating a kind of reservoir. It is probable that this water can not be effectively retained by the embankment which encloses the site, but will permeate through the underlying rock and emerge on the other side. Since mixing will therefore occur with the groundwater in the region, it is important to consider what contaminants may be leached out of the fly ash by the rainwater.

The ash is largely insoluble; its soluble components are mainly magnesium, potassium and sodium sulphates. The quantity of trace elements present appears to be too low to be of concern.

Human Health

There are two mechanisms by which humans could come into contact with harmful components of the stored ash. These are:

a) inhalation of wind-blown dust from the surface of the ash-pile

b) ingestion of agricultural produce grown on the surface of the ash-pile

Wind Erosion

The majority of the particles in the ash are either too large or too small to be vulnerable to wind erosion. Small particles stick together in a cement-like structure, while large ones are too heavy to be lifted. The particles which are likely to be affected by wind are in the range 10 to 20 µm. These constitute around 20% of the total mass. The frequent rainfalls the west of

Ireland ensure that the surface of the ash lagoon is usually wet, and so wind erosion is not likely to be a significant feature.

Samples of fly ash have been tested for carcinogenic properties and for radioactivity. It has been found to be very unlikely that carcinogens and mutagens are present in sufficient quantities to affect humans. Similarly, the concentration of radioisotopes has been found to be well below safety limits.

Uptake into Vegetation Cover

When the ash stockpile is revegetated it will most likely be used as grazing land. It is therefore important to consider the extent to which harmful substances will be present in the grass which grows on the site and in the meat or dairy products of animals which graze it. Many analyses of this kind have been carried out (Foras Forbartha, 1978).

In general, the levels of trace elements in forage crops appear to be similar whether grown on soil or on reclaimed ash. One exception is the high level of boron. The toxicity of this substance is low. Levels of arsenic and lead are below those which can cause cumulative poisoning.

3.2.7 Summary of Burdens

The major burdens associated with the coal fuel cycle are:

- Emissions of global warming gases. Emissions of carbon dioxide occur at all stages of the fuel cycle, and especially during the generation stage. In addition, emissions of smaller quantities of methane occur during the mining stage.

- Emissions of precursors of tropospheric ozone. Nitrogen oxides are emitted at all stages of the fuel cycle, and especially during the generation stage. Other ozone precursors, including VOCs and methane, are emitted during the mining and transport stages.

- Emissions of other atmospheric pollutants. The emission of particulate matter, sulphur oxides and nitrogen oxides during the generation stage, and to a lesser extent during the other fuel cycle stages, with the consequent ill effects on human health, is a very important burden. The effects of these atmospheric pollutants on crops, forests and agriculture have also been examined.

- Occupational Health. By far the most important of the occupational health burdens are deaths through accident and disease in the coal-mining industry, especially in developing countries. A certain level of occupational injury may be expected during construction of the power plant also.

- Public health. The statistical increase in the number of road accidents due to increased traffic in the area of the power station may be considered to constitute a public health burden.

- Environmental damage due to coal mining activities. The extraction of coal is very harmful to the environment, particularly in the immediate vicinity of the mine. Among the adverse environmental effects that can result are: subsidence, groundwater contamination, damage to habitats, the accumulation of mountains of waste and the generation of large amounts of dust.

All of these burdens and the resulting impacts on the environment or on the public have been quantified, and where possible and appropriate, the impact has been valued. This analysis is explicated in the following sections, and the results are presented in summary form.

3.3 Selection of Priority Impacts

	Extraction of Coal	Transport of Coal	Other Transport	Construction of Plant	Generation of Power	Waste Disposal
Global Warming	priority	priority	priority		priority	
Ozone	priority	priority	priority		priority	
Public health					priority	
Agriculture					priority	
Forests					priority	
Materials					priority	
Ecological systems	priority					
Water contamination	priority					
Subsidence	priority					
Land use						
Visual Impact						
Noise		priority				
Occupational Injury	priority			priority		
Occupational Illness	priority					
Injury to public			priority			
Infrastructural damage						

Table 3-17: Priority Impacts of Coal Fuel Cycle

The priority impacts to be investigated are as follows:

1. Global Warming as a result of emissions during extraction, transport and combustion of coal and other transport.

2. Increase in tropospheric ozone due to the release of precursors during extraction, transport and combustion of coal and other transport.

3. Public health impacts due to pollutant emissions during generation stage.

4. Damage to crops caused by pollutant emissions from the power plant.

5. Damage to forests caused by pollutant emissions from the power plant.

6. Damage to the materials of the built environment caused by pollutant emissions from the power plant.

7. Damage to ecological systems by coal mining activities.

8. Contamination of water by coal mining activities.

9. Subsidence and disruption of the water table during coal mining.

10. Occupational Injury in coal mining and plant construction.

11. Occupational Health effects of coal mining.

12. Injury to public in road accidents.

3.4 Quantification of Impacts and Damages

3.4.1 Global Warming

The emissions of global warming gases from the relevant stages of the coal fuel cycle are shown in Table 3-18 below. Note that the values for damages associated with these emissions are subject to a very high degree of uncertainty. This is because the damages incurred will depend on the nature and extent of climatic change, as well as future developments in population, land use and energy use. The valuation of these damages is also dependent on certain assumptions about the value of statistical life and the discounting of future damages. See Annex V and VI for a full treatment of these issues.

The values shown are an illustrative restricted range, and do not represent the full range of uncertainty. The geometric standard deviation for these values is estimated to be between 6 and 12, when all sources of uncertainty are considered.

Fuel-Cycle Stage	Emissions (t CO_2 equiv./ year)	Emissions (t CO_2 equiv. /TWh)	Damage (mECU/kWh)
Extraction	13,230	6,442	0.12 to 0.30
Transport (coal)	102,495	16,638	0.30 to 0.77
Transport (other)	1,752	284	0.0051 to 0.013
Generation	5.68×10^6	922,000	17 to 42
Total	5.82×10^6	945,000	17 to 43

Table 3-18: Global Warming impacts and damages (illustrative restricted range) for the coal fuel-cycle

3.4.2 Ozone

The ozone-related damages are summarised in Table 3-19.

Fuel-Cycle Stage	Mortality (mECU/kWh)	Morbidity (mECU/kWh)	Agriculture (mECU/kWh)	Total (mECU/kWh)
Extraction	0.16	0.28	0.14	0.58
Transport (coal)	0.14	0.25	0.12	0.52
Transport (other)	8.8×10^4	1.6×10^{-3}	7.5×10^{-4}	3.2×10^{-3}
Generation	1.3	2.4	1.12	4.8
Total	1.6	2.9	1.4	5.9

Table 3-19: Ozone damages for the coal fuel-cycle

3.4.3 Public Health Impacts

The effects on human health of the pollutant emissions arising from the combustion of coal at Moneypoint, as calculated using Ecosense, are summarised in Table 3-21 and Table 3-21. The uncertainties of these values are characterised by a geometric standard deviation of approximately 5.

	Impact (Cases/TWh)	Damage (mECU/kWh)
Morbidity	20,000	3.4
Acute Mortality - YOLL*	3.7	0.57
Chronic Mortality -YOLL	320	27
Chronic Mortality - deaths	*(32)*	*(83.2)*
Total		31

Table 3-20: Public Health Impacts of the Generation Stage of the Coal Fuel-Cycle, by impact category. (*YOLL = Years of Life Lost).

[mECU/kWh]	**Local**	**Regional**
SO_2	0.026	0.58
Sulphate Aerosol	n/a	21
Nitrate Aerosol	n/a	8.9
TSP	0.028	0.52
Total	0.054	31

Table 3-21: Public Health Impacts of the Generation Stage of the Coal Fuel-Cycle, by pollutant.

The term “local” in the context of this study refers to an area of 100 km x 100 km centred on the Moneypoint power plant. The impacts and damages occurring within this area are negligible in terms of the total regional values.

The additional impacts of the emissions from vehicles in the transport stage of the fuel cycle have not been calculated at this time. It may be noted that the quantities of pollutant emitted to the atmosphere from vehicles are several orders of magnitude less than those from the power plant. These emissions occur at or near ground level, so that such health impacts as do occur will be localised, and secondary effects will be negligible.

3.4.4 Agricultural Impacts

The agricultural impacts calculated by Ecosense and included in this study are:

- The reduction in yields of wheat, barley, oats, rye, potatoes and sugar beet caused by sulphur oxide emissions from the power station (Baker et al., 1986, modified).
- Soil acidification, valued according to the cost of mitigation by liming (European Commission, 1993)

These impacts are summarised in Table 3-22 below.

[mECU/kWh]	Local	Regional
Barley	0.0013	0.010
Potato	0.0014	0.015
Sugar Beet	0	0.0073
Rye	0	9.3×10^{-5}
Oats	0.00016	0.001
Wheat	0.0014	0.017
Acidification	n/a	0.042
Total	0.0043	0.093

Table 3-22: Damage to agricultural production caused by SO_2 emissions from Moneypoint power station

3.4.5 Forests

The Ecosense program allows the calculation of the effect of atmospheric pollution on the forests of Europe, both in terms of reduced timber production, and in terms of the increased area of forest classified in damage classes 2 to 4.

The calculated values for Moneypoint are:

Timber Loss	72 m^3/TWh	0.0042 mECU/kWh
Damaged Forest	2.6×10^6 m^2 (260 ha)/ TWh	non-valued

3.4.6 Construction Materials

The effect of wet acid deposition on the surface condition of building materials such as galvanised steel, limestone, mortar, stone, paint, rendering, sandstone and zinc may be calculated using Ecosense. The results for Moneypoint are summarised below.

	Impact (m^2/TWh)	Damage (mECU/kWh)
Galvanised Steel	1,300	0.66
Limestone	1.4	0.00038
Mortar	1,500	0.046
Natural Stone	1.3	0.00035
Paint	9,700	0.12
Rendering	550	0.017
Sandstone	1.8	0.0005
Zinc	35	0.00087
Total	2,500	0.85

Table 3-23: Damage to Building Material Surfaces due to atmospheric emissions from power station

3.4.7 Ecological Systems - Coal Mining Stage

The cost of reclaiming and revegetating the open-caste mine in Colombia is estimated at 3 ECU per tonne of coal (see Section 3.2.1 on page 41 above). This cost amounts to 1.1 mECU/TWh. This figure is subject to great uncertainty and may not incorporate all of the relevant externalities.

3.4.8 Contamination of Fresh Water - Coal Mining Stage

Some of the harmful effects of the leaching of materials from coal waste dumps may be mitigated by the addition of lime to the waste. At a rate of 2.2 ECU per tonne of cleaned coal (See Section 3.2.1, p.43), this cost amounts to 0.8 mECU/kWh. As in the case of the previous impact, this value is uncertain and may not include all the external costs.

The mineralisation of groundwater which percolates through the exposed coal underground is a recognised problem in the USA, but at present this damage is not known to have been valued.

3.4.9 Subsidence

Subsidence of the ground surface is relevant only in the case of underground mining. If we assume that the coal mine in the USA operates a “room and pillar” system in order to prevent subsidence, then this impact does not arise. In this case the cost is internalised in the form of coal left underground to support the roof of the mine. If subsidence does occur, and we assume a cost for damage of 3.25 ECU/tonne (IEA, 1978) for the USA coal only, then this external cost will amount to 0.6 mECU/kWh.

3.4.10 Occupational Injury

Coal Mining

Using the accident rates listed in **Table 3-5**, we expect to encounter 0.053 fatalities and 5.11 major accidents in the USA coal mining operation per TWh of electricity produced at Moneypoint. For Colombia, the respective figures are 0.19 deaths and 79 injuries per TWh.

If we use the adjusted values of statistical life for these two countries, the cost of the fatalities works out at 0.24 mECU/kWh for the USA and 0.18 mECU/kWh for Colombia. Taking the average of these two, the value is 0.21 mECU/kWh.

The nature and severity of the injuries is unknown, so that it is very difficult to assign a value to this impact. European Commission (1998*b*) recommends values for occupational injury based on a willingness to pay approach, derived from research by the UK Transport Research Laboratory. These are as follows:

Serious Injury: 95,050 ECU

Slight Injury: 6,970 ECU

Average: 27,125 ECU

Adjusting these values for Purchasing Power Parity, the cost of major injuries in USA coal mining is 0.31 mECU/kWh. The cost for minor injuries is approximately 0.016 mECU/kWh.

Assuming that 25% of the injuries in Colombia are major and the rest minor (so that major injuries occur in the same proportion to fatalities as in the USA), we can derive a cost of 0.25 mECU/kWh for major injuries and 0.054 mECU/kWh for minor injuries.

These results are presented in Table 3-24.

[mECU/kWh]	Fatalities	Major Injuries	Minor Injuries
Colombia	0.18	0.25	0.054
USA	0.24	0.31	0.016
Average	0.21	0.28	0.035

Table 3-24: Occupational Injury in Coal Mining

These costs may or may not be internalised in whole or in part by the payment of insurance premiums or direct compensation.

Construction

The construction of Moneypoint power station required an input of labour of approximately 7 million man-hours, or 4,400 man-years. The rates of occupational injury in this sector in Ireland are: 16 fatalities per 100,000 man-years, and 1,900 injuries per 100,000 man-years. The number of incidents to be expected on a typical project of this size would therefore be 0.70 deaths and 84 injuries. This represents a cost of 0.0074 mECU/kWh for deaths and 0.0092 mECU/kWh for injuries incurred in the construction of the plant.

3.4.11 Occupational Health - Coal Mining Stage

Insufficient data exists to calculate the value of this impact with any certainty. Taking first the reported fatalities arising from lung cancer and pneumoconiosis in the USA, the rate of 0.68 deaths per Mt corresponds to 1.1 mECU/kWh, using an adjusted Value of Statistical Life. In these cases, however, because of the long latency of the illness, a more sophisticated analysis may be appropriate.

Using a 3% discount rate, and assuming a latency period of 15 years, with an average of 16 years of life lost (European Commission, 1998*b*) the cost of these fatalities would be 1.08 MECU. In addition, the suffering, direct cost of illness and foregone earnings of the patient represent an extra cost, valued at 450,000 ECU in the case of cancer. These figures would suggest a value of 0.38 mECU/kWh.

Considering next the case of Colombia, where no data at all is available on occupational health in coal mines, one may as a first approximation assume that the rate of occupational ill-health is the same as that of the USA. This is likely to constitute an underestimation, since the rate in the USA is significantly lower than that of other developing countries. It is likely, however, that the open-caste mine at Cerrejón, which has no problems with ventilation, or radon gas buildup, will have different kinds of health problems from underground mines.

3.4.12 Road Accidents

The death or injury caused by road accidents may be valued in the same way as occupational accidents. In addition, each road accident severe enough to cause injury may be considered to cause material damage also. A representative figure of 4,000 ECU has been used to quantify this damage. The distribution of severe and slight injuries is assumed to be the same as that in the UK Transport Research Laboratory, so the average figure of 27,125 ECU may be applied.

	Deaths/TWh	Injuries/TWh	Damage [mECU/kWh]
Construction	0.0023	0.045	0.0073
Generation	0.0067	0.13	0.021
Total	0.0090	0.18	0.028

Table 3-25: Road accident damages

3.5 Summary and Interpretation of Results

	mECU/kWh	**s_g**
POWER GENERATION		
Public Health		
Mortality YOLL *(VSL)*	29 *(83)*	B
Morbidity	5.8	A-B
Total	35	B
Of which:		
SO_2	22	
NO_x	13	
(of which via ozone)	*(3.7)*	
TSP	0.52	
Agricultural via SO_2	0.093	B
via Ozone	1.12	
Forests	negl.	B
Materials	0.85	B
Sub-total	*37*	

	mECU/kWh	s_g
Global Warming (illustrative restricted range)	17 to 42	C
TOTAL (including Global Warming)	54 to 79	
OTHER FUEL CYCLE STAGES		
Global Warming	0.41 to 1.1	C
Ozone	1.1	B
Mining: Ecosystems	1.1	B
Groundwater Contamination	0.8	B
Subsidence	*(0.6)*	*B*
Occupational Injury	0.53	A
Occupational Health	0.38	B
Construction: Occupational Injury	0.017	A
Road Accidents	0.028	A
TOTAL ALL STAGES (excl. Global Warming)	41	
TOTAL ALL STAGES (incl. Global Warming)	**59 to 84**	

Table 3-26: External Costs of the Coal Fuel Cycle

It may easily be seen that the impacts associated with the generation stage alone are very much greater than those from all other stages combined. Furthermore, within the generation stage, two types of impact in particular predominate. These are global warming and public health effects.

Global warming values are presented as an illustrative restricted range. This limited range is intended to be representative of the base-case estimates using discount rates of 1% and 3%. It does not take into account all of the uncertainty.

Considering only the illustrative restricted range, the global warming damage resulting from the generation stage accounts for between 31% and 53% of the total damage from that stage.

If we leave aside global warming, and consider separately the other types of damage, about whose magnitude we may be more certain, we find that the public health effects of atmospheric emissions from the generation stage amount to 85% of the total.

Of the public health damages, which total 35 mECU/kWh, we find that the proportion of this damage which is caused by particulates is relatively insignificant, at 0.52 mECU/kWh. This is explained in part by the lower absolute quantities of particulate matter emitted from the stack, and partly by its shorter residence time in the atmosphere as compared with the precursors of the acid aerosols. Of these, nitrogen oxides are important, at 13 mECU/kWh, but the largest contribution to the total damage is sulphur dioxides, at 22 mECU/kWh.

Again this may be explained by reference to the larger amount of sulphur dioxide (8 kg/MWh) than nitrogen oxides (3.2 kg/MWh) produced, largely as a result of the installation of low-NO_x burners. The exposure response functions of similar form for nitrate and sulphate aerosols, with the constants of proportionality differing by less than a factor of two.

The sulphur emissions from Moneypoint power station are considerably higher than the emissions from similar stations which are fitted with Flue Gas Desulphurisation equipment (FGD), increasingly the norm throughout Europe. FGD can serve to reduce the sulphur dioxide emissions by some 95%. This improvement comes at the cost of some small increase in the emission of carbon dioxide, and brings with it also some new considerations associated with the production and disposal of limestone.

Moneypoint is by Irish standards a very large power plant which supplies the base-load of national electricity demand efficiently and economically, but also represents by far the largest point source of both sulphur dioxide and nitrogen oxides in the country. The atmospheric formation of secondary aerosol pollutants, which represent the most significant risk to public health, takes place at some distance from the plant. The location of the plant on the western periphery of Europe ensures that the incremental concentration of these harmful species at Europe's population centres is low. Overall, the calculated damage is not especially high by comparison with similar large coal-fired plant in other countries.

	Tonnes emitted per annum	**Damage (ECU/tonne)**
CO_2	5,700,000	18 to 46 (restricted range)
NO_x	19,600	4,300 *(of which 1,500 via ozone)*
SO_2	49,300	2,800
TSP	1,200	2,813

Table 3-27: Damage per tonne of pollutant

It may be seen from Table 3-27 that when ozone is included in the damage figure per tonne of NO_x emitted, NO_x is considerably more harmful than SO_2. The installation of low-NO_x burners during 1995 and 1996 which led to a decrease of around 50% in NO_x emissions from the plant may therefore be seen to have been very beneficial. It should be noted, however, that the technology exists to reduce SO_2 emissions to a much greater extent, by in excess of 95%.

4. PEAT FUEL CYCLE

4.1 Technology and Reference Site Description

4.1.1 Reference Site Description

The proposed site for the Europeat 1 facility is near the village of Clonbullogue, on the border of Counties Offaly and Kildare. This is a very rural and sparsely populated region of the East Midlands of Ireland. Primary land use in the area is peat production, and economic activities are mainly based on peat-related activities, including peat production, power production and peat processing. Other activities in the region include dairy farming. The choice of site is governed primarily by its location at the heart of the East Midlands group of bogs. Bord na Móna is in possession of around 45 million tonnes of recoverable peat reserves in this region. Of this total, around 10 million tonnes is committed to supply existing customers. **Table 4-1** below shows how these reserves break down by location. These peatlands are served by Bord na Móna's narrow-gauge railway, which will be used to carry peat to the power station. In addition there exist reserves of 8.6 million tonnes in outlying areas and 2.7 million tonnes in the hands of private producers, which will be transported to the site by road.

Location	**Million tonnes of peat**
Derrygreenagh	19.9
Ballydermot	8.6
Timahoe	4.8
Lullymore	2.6

Table 4-1: Bord na Móna peat reserves in the Europeat 1 catchment area

The closure during the 1990s of the peat-fired power stations at Portarlington, Co Laois and Allenwood, Co. Kildare, as well as the briquetting factory at Lullymore, Co. Kildare, has resulted in a reduced demand for peat in the East Midlands region. The planned Europeat 1 plant will allow the use of some 30 million tonnes of peat from developed peatland over its lifetime.

Major road and rail routes between Dublin and the cities of the south and west pass near to the site. The conurbation of Dublin lies within 50 km or so of the proposed plant, and ribbon development along the motorways has brought the commuter belt to within 20 km of the site.

4.2 Reference Plant Description

It is intended that the Europeat 1 plant will be commissioned in 2001, after a construction period of 3 years. It will be a condensing plant with a net electrical output of around 111 MW. It is assumed that the boiler will be of the bubbling fluidised bed type, allowing combustion with very high efficiency and reduced emissions.

The plant will run with a very high load factor, operating for some 7,500 hours per year. This will require a fuel input of around 1,000,000 tonnes of milled peat at 55% moisture content. Net conversion efficiency will be approximately 37%, yielding an annual electrical production of 825 GWh.

No specific emissions abatement technologies will be installed, apart from electrostatic precipitators to remove dust from the exhaust. Nevertheless, the use of milled peat fuel in a fluidised bed combustion process is intrinsically favourable to low emissions output. Peat is a low-sulphur fuel, and reactions between the products of combustion and the mixture of ash and sand in the fluidised bed tends to further reduce the emissions of sulphur oxides. The formation by thermal means of nitrogen oxides is also low due to the relatively low combustion temperature.

4.2.1 Fuel Cycle Definition

The Peat Fuel Cycle consists of the following fuel-cycle stages:

1. Peatland Preparation
2. Peat Production
3. Transport, Storage and Handling of Fuel
4. Construction of Power Plant
5. Transport of Personnel and Materials
6. Combustion of Peat and Generation of Electricity
7. Waste Disposal

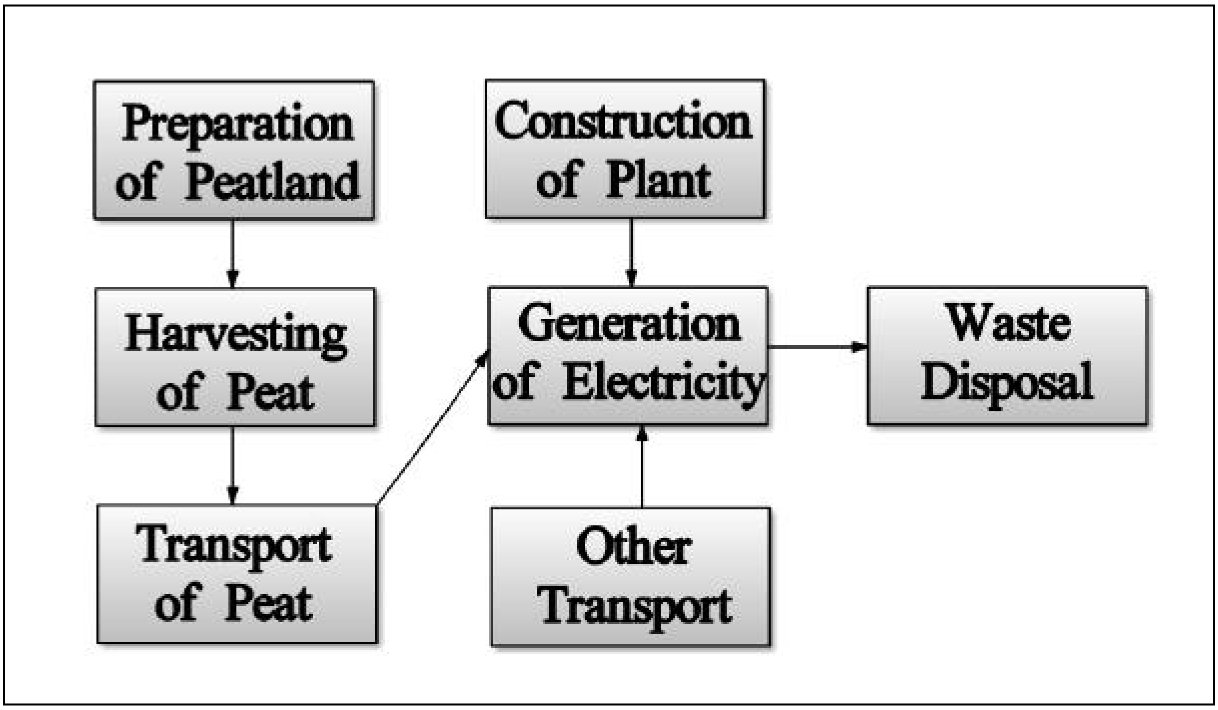

Figure 4-1: Stages of the Peat Fuel Cycle

Preparation of Peatland

The peatland is prepared for fuel extraction by a process of removal of the living surface layer, draining and the development of infrastructure such as narrow gauge railways.

The primary method of peatland preparation and peat harvesting used in Ireland is the PECO system of milled peat production. First, the layer of vegetation which is growing on the surface of the bog is stripped away by ploughing, which ends the continuing growth of the bog and its ability to serve as a viable habitat. Drainage ditches or canals are dug in the virgin peatland, using ditching machines fitted with large disc cutters. These serve to divide the bog into a series of rectangular fields around 800 to 1,200 m long, and 11 metres wide.

The drains are initially cut to a depth of 0.5 m, and are progressively deepened until they are 1.5 m deep. They must be regularly maintained and deepened both during the preparation and harvesting stages, since they exhibit a natural tendency to fill up with silt and collapse. Over a period of around two years, the surface of the peat dries out, its moisture content decreasing from 95% to 82%.

The surface of the bog must be levelled to permit machine access, and sloped slightly downwards in the direction of the ditch, to promote drainage of surface water.

Finally a railway line is laid to carry the harvested peat to the power station.

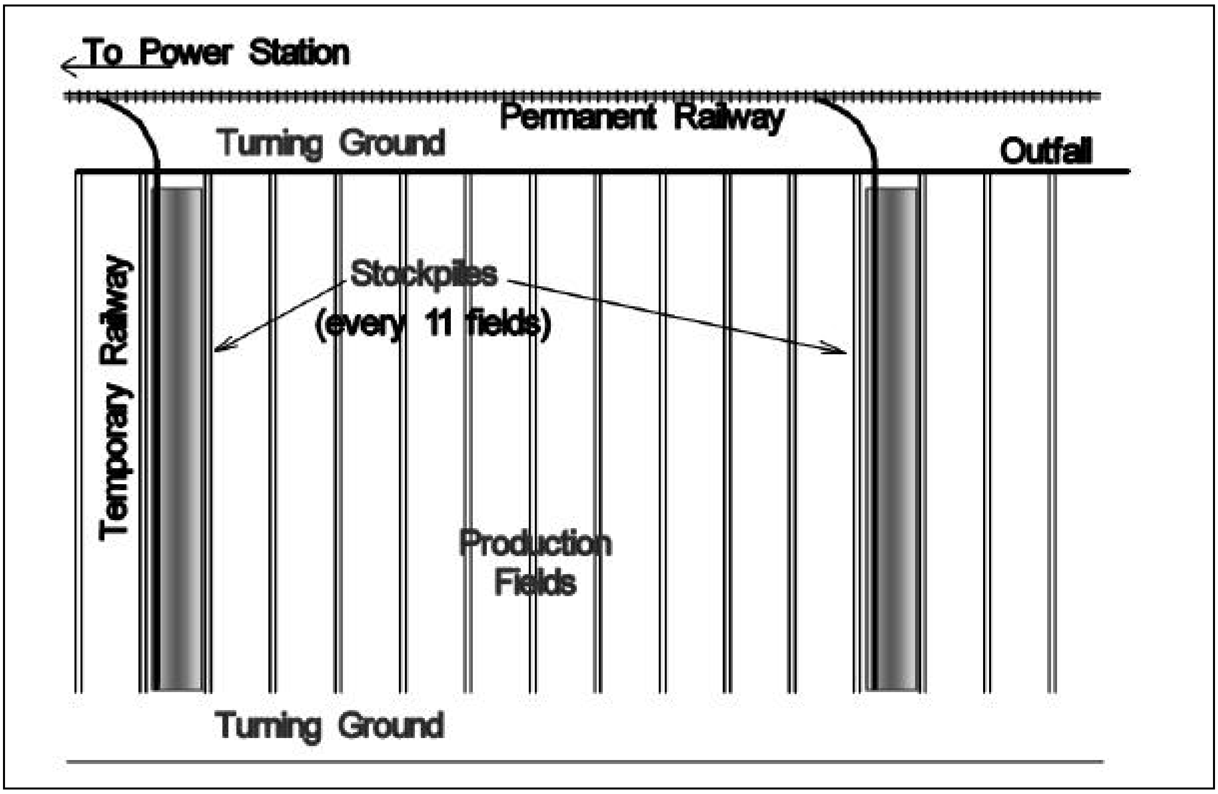

Figure 4-2: Layout of Bog in PECO milled-peat production system

The peatland which is to be used for the supply of fuel to Europeat 1 has already been drained and developed for production, and is partially cut-over. It has been used to supply milled peat to the briquetting factory at Lullymore, Co. Kildare, and sod-peat to the ESB power station at Allenwood, retired in 1994. The conversion from sod-peat production to milled-peat production should be environmentally innocuous.

It is considered that the infrastructural activities associated with the preparation of these peatlands, rail, etc., will require a labour input of 420 man-years during the 3 years of power station construction.

Harvesting of Peat

The PECO system has been found to be best suited to Irish conditions, where there exist large tracts of uninterrupted peatland.

During the summer months (May to September, depending on weather) up to 12 harvests are taken from each peatland. The harvest consists of milling, harrowing, ridging and stockpiling. The machines used for these operations are designed and manufactured in Bord na Móna’s engineering workshops, and are optimised for the PECO system. Each tool is 11 m wide to match the width of the peat “fields”. All of the machines used in the preparation and harvesting stages are diesel or diesel-electric powered. They must be designed to ensure that they have a large “footprint”, so that they do not sink into the soft surface of the bog.

In each harvest the surface of the bog is milled, using pin rollers, to a depth of 10 to 15 mm. The milled peat lies on the surface of the bog for one day in order to dry out. A harrow is used to turn it over once during this time. It takes two to three days for the milled peat to reach its final moisture content of 40 to 65%.

A ridging machine is then used to collect the peat into a long strip running along the centre of the field. Finally, all of the peat from 11 fields is piled up in a central stockpile, or rail pile, from which it may be transported to the power station by rail as required. This stockpile must be compacted several times per season to reduce wind losses. In addition, if the stockpile is to be allowed to remain over the winter, it is covered with polythene sheeting.

In addition to the PECO system, other systems of peat extraction are used or have been used in Ireland. These include:

- The Kaas system, a Danish milled-peat production system used at Lullymore until 1943.

- The HAKU system, useful where the depth of the bog is very variable and the production area is broken up by soil or rock outcroppings. This is the system most commonly used in Finland. This method is used at the Oweninny bog in Co. Mayo since 1990.

- Machine sod-peat harvesting, where an excavating machine takes long vertical slices of peat from an exposed section of bog. These slices are then cut into sods. Extraction of peat begins at the driest part of the bog, the wall of the central drainage ditch, which is thus gradually widened until the whole surface area has been lowered by up to 1.5 metres. Because this procedure requires the whole depth of the peat to be dried, rather than just the surface, the preparatory drainage takes 5 to 7 years. This method is still used in the Ballydermot and Timahoe bogs of the Midlands, and accounts for some 1% of total Bord na Móna production.

- Manual sod-peat harvesting. Since the 1950s, Bord na Móna’s production has been completely mechanised. Nonetheless, private individuals who own or lease turbary rights continue to produce sod-peat by hand, as has been done since time immemorial.

- Hydropeat, developed to suit Russian conditions, where the bog has a high buried wood content. This method, where a high-pressure jet of water is used to turn the peat into a slurry, was briefly tried in the early 1950s in Co Laois.

For the purpose of this analysis, the fuel peat is assumed to have the following characteristics:

Table 4-2: Characteristics of Bord na Móna milled peat

	Average Value	**Range**
Lower Heating Value	7.7 MJ/kg	7.3 - 8.2 MJ/kg
Moisture content by weight	55%	40 - 65 %
Density	290 kg/m^3	150 - 400 kg/m^3

Composition (dry):

C	**H**	**N**	**O**	**S**	**Cl**	**Ash**
55.4%	5.4%	1.3%	32.5%	0.3%	0.09%	5%

Transport, Storage and Handling of Peat

Because of the extensive and contiguous nature of the raised bogs of the Irish midlands, Bord na Móna has found it economical to install and maintain a network of narrow-gauge railways for the purpose of transporting milled peat from the production fields to the ESB power stations and the briquette factories. Bord na Móna maintains a total of 900 km of 3’ gauge permanent railway and a further 240 km of temporary railway.

The average distance over which the peat must be carried is quite short, due to the situation of the power station near the centre of the peat production area.

It is envisaged that 82% of the peat burned at Europeat 1 over its lifetime will be produced within 20 km of the station, and all of the remainder will come from no more than 50 km away. Around 90% of the peat will arrive by rail, and the remainder, from smaller or more distant bogs, will be transported by road.

The rail shipments will consist of 80 tonnes of milled peat, and will travel an average of 13 km to reach the plant. Approximately 225 of these shipments will be delivered to the station per week. Road transport will consist of truckloads of 22 tonnes each, travelling an estimated 15 km on average. It is expected that some 90 deliveries of this type will arrive per week.

Peat is stored mainly on the bog until required, every 11th production field being used as a stockpile as shown in Figure 4-2. In general, storage in the railway carriages at the power station is to be avoided, in order to minimise the use of rolling stock for this purpose.

Storage of the milled peat at low moisture content in the stockpiles can result in losses due to microbial action. In certain ambient conditions, spontaneous combustion may occur.

The peat is delivered to the power station about 24 hours in advance. It undergoes a complex blending process designed to ensure maximum homogeneity of the peat composition, calorific value and moisture content. The handling procedures are completely mechanised from the point where the milled peat is tipped from the railway carriages or lorries into the temporary storage silo, until it is fed into the base of the combustion chamber.

Construction and Decommissioning of Power Plant

The planned construction period for the Europeat 1 power plant is 3 years. It is estimated that a labour input of 700 man-years will be required during this period to build the plant (Bord na Móna, 1993). It is not known at this time what quantity of materials will be required for the construction, since the plans of the station have not yet been decided. Nonetheless, it is likely that the plant will occupy a site of 6 or 7 hectares. It will be necessary to construct a new access road.

Transport of Personnel and Other Materials

The planned employment levels over the peat fuel cycle are as follows:

Construction	700 man-years
Preparation of Peatland	420 man-years
Harvesting of peat	246 (permanent) 250 (seasonal)
Operation of Power Station	85

Table 4-3: Employment at various stages of peat fuel cycle

Personnel are considered to travel an average of 11 km each way to work. It may be possible to use the narrow-gauge rail network for the transportation of some construction materials. The remainder will be carried by road. According to IVO (1993) the projected increase in traffic in the neighbourhood of the site during the operation of the power plant is 5 to 10%.

Combustion of Peat and Generation of Electricity

Europeat 1 is a planned peat-fired power plant, using the most modern combustion technology, to be built on a site in the east of Co. Offaly, on the borders of Co. Kildare. This site is owned by Bord na Móna, and will be sold to the bidder who is successful in the competition to build, own and operate the plant.

The plant is expected to conform to a number of criteria:

The ESB requires a gross power output of around 120 MW (c.111 MW net), running for around 7,500 hours per annum. This amounts to a gross production of around 900 GWh per annum (c.825 GWh net), or an increase of around 5% on the national electricity generated in 1996.

The fuel purchase agreement with Bord na Móna requires the use of 1,000,000 tonnes of peat annually, amounting to 30,000,000 tonnes over the 30 year lifetime of the plant. This corresponds to between 7.5 and 8 PJ (2,200 GWh) of fuel per annum, so the net conversion efficiency of the plant should be around 37%.

In order to achieve this conversion efficiency, it is likely that the plant would have to use fluidised bed combustion technology. It is conceivable, however, that this efficiency could be attained by conventional pulverised fuel technology. It is likely that the plant will consist of a single steam boiler driving a single steam turbine running in simple cycle (condensing) mode. On the balance of probabilities, it will be assumed for the purposes of this report that the boiler will be a bubbling fluidised bed boiler, of 300 MW thermal capacity, as used at the IVO plant in Rauhalahti, Finland. This plant has a flue gas flowrate of 558,000 Nm^3/h at full load, which corresponds to 5 Nm^3/kWh (net). **Table 4-4** below summarises the assumptions that have been made about the technical characteristics of the plant, for the purposes of this study.

Table 4-4: Technical Characteristics of Europeat 1 plant

Name of Plant	**Europeat 1**
Location	Clonbullogue, Co. Offaly, Ireland
Fuel	Milled Peat
Combustion technology	Bubbling fluidised bed boiler, 300 MW_{th}
Average Net Thermal Efficiency	36.7%
Gross Power Output	123 MW_e
Net Power Output	111 MW_e
Load Factor	85.5% (7,500 hours at full load)
Fuel Input	1,000,000 tonnes per annum (8 PJ)
Projected date of completion	2,001

A fluidised bed boiler contains a mass of inert material, in the form of sand, which is fluidised by means of air being pumped upwards through it. It allows stable combustion at relatively low temperatures, with good mixing and long residence times.

The fluidised bed technology enhances stability of combustion of a highly variable fuel like peat, and even allows for the possibility of burning other materials such as wood and coal. It is not envisaged, however, that other fuels would be used, except for a diesel pilot flame at start-up.

The milled peat will be conveyed directly into the base of the boiler where it will be burned to raise steam. This steam will then be superheated to a temperature of 540 ºC.

Air is pumped into the combustion chamber in two stages; primary air at the base, whose main role is to fluidise the bed, and secondary air at the furnace walls to allow complete combustion.

Both the boiler feedwater and the combustion air are preheated before entering the boiler, by means of heat transfer from the flue gas.

The superheated steam is piped to a turbine, where it is expanded first in the high pressure stage, and is then reheated before undergoing complete expansion to vacuum in the intermediate and low pressure stages. The low pressure steam is then condensed and undergoes a purification stage before returning to the boiler feedwater preheater and being pumped back into the boiler.

The return cooling water from the condenser is piped to a cooling tower where its excess heat is given up to the atmosphere. A forced draught cooling tower will be used, in order to reduce construction costs. Approximately 100 to 150 litres/second of make-up water will be required for the cooling water circuit. This will be taken up from an aquifer. Approximately two days' requirement of water will be stored on site.

After the exhaust gases have yielded up their excess heat in the superheater, economiser and air preheater, fly ash is removed by an electrostatic precipitator. The exhaust gases are then released to atmosphere, via a 100 metre stack.

Waste Disposal

If we assume an ash content of 5%, we will expect an annual production of around 50,000 tonnes of ash. Around 80% of this will be fly ash collected from the hoppers of the electrostatic precipitators, and the remainder will be furnace bottom ash. This ash consists of the mineral content of the peat, which is mainly limestone. The ash will probably be disposed of by spreading on cut-over peat bogs in the vicinity.

It is possible to use combustion ash from power stations as a raw material in the construction industry (*cf*. the Coal Fuel Cycle). It is not yet known whether such a market exists for some or all of the ash produced at Europeat 1.

Purge and waste water from the power station will amount to some 60 to 90 l/s. This water will be discharged into the surrounding bog, through which it will drain before eventually reaching local watercourses.

4.3 Overview of Burdens

4.3.1 Preparation of Peatland

The area of peatland from which fuel will be extracted by Bord na Móna to serve the new power station is approximately 14,800 hectares. All these peatlands have already been drained and prepared for peat production; some are partially cutover already. Approximately 44 million tonnes of peat reserves exist in this area. In addition, smaller reserves of peat in private ownership contribute another 3 million tonnes of reserves (Bord na Móna, 1993). If we subtract existing commitments, there remains around 37 million tonnes of peat unaccounted for in the catchment area of Europeat 1. This is sufficient to power the station for its lifetime, without the necessity of developing any virgin peatland.

The preparation of virgin peatland has a number of negative environmental consequences. These include

- the visual impact associated with the change in appearance of a large area of the countryside,
- the removal of an increasingly precious habitat with a unique range of flora and fauna, and
- a drastic change in the role of the bog in the carbon cycle, converting what has been a carbon sink, steadily sequestering carbon dioxide from the atmosphere year by year as it grows, into a source of carbon dioxide and other greenhouse gases.

For these reasons it is in the opinion of the authors unlikely that permission would be available in the future for the industrial development of a bog.

The conversion of peatlands at Timahoe and Ballydermot from sod-peat to milled-peat production may be assumed to be environmentally neutral.

4.3.2 Peat Production

The production of fuel peat may be expected to have the following consequences:

- Emission of pollutant and greenhouse warming gases from the diesel engines of industrial machinery
- Injury to personnel in the operation of machinery
- Wind-blown dust from the peat fields
- Siltation of rivers by run-off from peat fields
- Fire

Pollutant Emissions

Pollutant emissions from peat harvesting machinery (derived from emissions characteristics for a variety of off-road and agricultural equipment, supplied by the US EPA) are taken to be as follows:

NO_x	**PM**	**SO_2**	**CO**
7	1.4	0.6	3.5

Table 4-5: Emissions characteristics of peat-harvesting machinery (g/GJ peat)

Considering greenhouse gas emissions, Savolainen et al (1994) present figures of 0.4 g CO_2/MJ and 0.015 mg N_2O/MJ.

Occupational Injury

The Health and Safety Authority recorded zero fatalities in the Mining and Quarrying sector in 1995, and 119 injuries. This sector includes the mining and processing of ores, coal, peat and lignite, the extraction of natural gas and oil. Clearly, the other activities in this are more hazardous in general than peat harvesting, which is a land-based and surface activity. It is proposed to neglect this burden, which may be considered inconsequential.

Wind-blown dust

In certain weather conditions the milled peat on the surface of the bog will tend to blow around, creating a very dusty environment. This could represent a burden both to the public and to the employees. It is worth noting however that no incidence of occupational ill-health is reported to have resulted. This may be partly explained by the fact that the modern machines provide an enclosed and air-conditioned working environment. The extremely low population density in the area where peat is extracted ensures that effects on the public are minimal. Shelter belts of mature trees and bushes help to reduce wind-blow.

Siltation

It is a necessary consequence of the drainage of the bog and the maintenance of a dry peat surface that run-off of water from the bog is greatly increased. This run-off water carries with it large quantities of peat particles, amounting to 50 m^3 of sludge per hectare per year.

The environmental effects of such material, if it finds its way into rivers, streams and lakes, are poorly understood and unquantified. Certainly, the peat is poor in nutrients, and so it will not tend to impose an oxygen demand on the aquatic environment. Peat is responsible for less than 2% of the phosphorus which enters Lough Derg, for example (Feehan & O'Donovan, 1996). Some temporary increase in turbidity may be expected, until the silt settles. The formation of a layer of peat sediment which covers the gravel beds of lakes and rivers is considered to be a threat to fish which use these beds for spawning.

In order to reduce this environmental impact, silt ponds are constructed at the outlets of the bog's internal drainage system. These ponds trap up to 90% of the silt in the outflow.

Fire

There is a fire risk associated with peat production. During dry conditions in summer, the surface layer of peat can become very dry. In this state it can be ignited easily by a single spark, for example from the machinery nearby. Large volumes of smoke are generated in this case and the fire is very difficult to extinguish. There is no valuable property in the surrounding area, and so the potential for economic damage to third parties is negligible. Workers are trained in fire prevention.

4.3.3 Transport, Storage and Handling of Peat

The burdens from this stage of the fuel cycle are:

- Emissions of pollutant and greenhouse warming gases from diesel locomotives and trucks
- Occupational and Public Injury in Rail and Road Transport
- Disposal of Polythene Sheeting from Peat Stockpiles

Transport Emissions

The annual fuel requirement of 1.06 Mt of peat is assumed to be hauled by rail (90%) and by road (10%). Rail haulage comes to 12.4 million tonne.km and road haulage to 1.6 million tonne.km, requiring the use of 67,000 and 85,000 tonnes of diesel respectively.

Using the same emissions characteristics as laid out in **Table 3-7** and Table 3-11 (Coal Fuel Cycle, above), we can derive the following annual emissions of atmospheric pollutants:

[t/yr]	**NO_x**	**CO_2**	**SO_2**	**CO**	**PM**	**VOC**
Rail	5.2	210	400	1.3	-	0.5
Road	1.8	270	510	1.0	0.034	0.28

Table 4-6: Emissions from locomotives and lorries transporting peat to Europeat 1

Occupational and Public Injury

This burden is unquantified due to lack of quantitative data on accident rates in the operation of the Bord na Móna narrow-gauge rail network.

Polythene Sheeting

Large quantities of non-biodegradable materials are used in the protection of peat stockpiles against winter storms. The used material is collected up by Bord na Móna and supplied to a contractor for recycling.

4.3.4 Construction and Decommissioning of Power Plant

Burdens from this stage are as follows:

- Occupational Injury
- Land Use
- Visual Impact
- Noise

Occupational Injury

The construction sector had a total of 13 fatalities in 1995 and 10 in 1994. The number of injuries was 266 in 1995 and 226 in 1994 (HSA, 1996). This corresponds to a rate of 16 fatalities per 100,000 employed per year, and 1,900 injuries (>3 days out of work) per 100,000 per year.

We will assume for the purpose of this study that the construction of the Europeat 1 plant is representative of the sector as a whole. Then, with 700 man-years of labour required, we may expect 0.11 deaths and 13.3 injuries over the three year construction period.

Land Use and Visual Impact

At present the site of the future power plant and the immediate vicinity are used for pasture and peat production. The area is predominantly flat and uninterrupted landscape. The power station, especially its 100 m chimney, will therefore be visible from a considerable distance. This need not in itself, however, constitute a nuisance, as peat power stations in other parts of the Midlands have become an accepted feature of the landscape.

The power plant will occupy an area of some 6 hectares.

Noise

The noise level during construction will occasionally be high, especially in the excavation and pile-driving phases. The remote location of the site, far from residential areas, should ensure that little or no nuisance is caused to the public by this noise.

4.3.5 Transport of Personnel and Materials

This stage of the fuel cycle may give rise to the following burdens:

- Emission of atmospheric pollutants from passenger cars and other vehicles
- Road Accidents
- Damage to Road Infrastructure

Atmospheric Emissions

The construction and peat preparation phases of the fuel cycle will require a labour input of 250,000 man-days over three years. These workers may be estimated to travel 5.38 million km to and from work during this period. During the operation of the plant and the extraction of the peat, there will be a total of 339 permanent workers and 250 seasonal workers, travelling a total of 1.9 million km per annum.

If the initial burdens are distributed over the lifetime of the station, the average distance travelled will be 2.1 million km per annum. This results in the following emissions:

CO_2	NO_x	CO	HC	SO_2
540	2.7	20	2.3	1.0

Table 4-7: Emissions from passenger vehicles associated with Europeat 1 (t/TWh)

No information is available at present about construction-related transport.

The disposal of 24,000 tonnes of ash per annum from the power station, if the material is transported 10 km by rail, will result in the following diesel locomotive emissions:

	CO_2	NO_x	SO_2	CO	VOC
kg/year	6,500	390	12	97	39
kg/TWh	7,800	470	15	117	47

Table 4-8: Emissions from transport by rail of solid waste from Europeat 1 power station.

Road Accidents

Considering passenger vehicles, the road accident rates for the counties of Kildare and Offaly, on the borders of which the station will be located, are as follows:

	Accidents	Deaths	Injuries
Offaly	1.9	0.11	3.04
Kildare	1.7	0.122	3.02
Average	1.8	0.16	3.03

Table 4-9: Road accident and casualty statistics for Cos. Offaly and Kildare (1995) (NRA, 1996)

Based on these statistics, we would expect 0.38 accidents per annum, resulting in 0.034 deaths and 0.63 injuries.

Damage to Road Infrastructure

This burden has not been quantified, because of the lack of available data on the construction traffic. It is believed that the taxation regime serves to internalise these costs. (See Section 3.2.3 above).

4.3.6 Generation of Electricity

This stage of the fuel cycle, which is of primary importance in terms of the magnitude of its environmental impacts, results in the following burdens:

- Discharge of pollutant emissions to the atmosphere. These include sulphur oxides, nitrogen oxides and particulate matter, as well as trace elements
- Discharge of ozone precursors to atmosphere, primarily nitrogen oxides
- Discharge of global warming gases to atmosphere, primarily carbon dioxide
- Cooling water requirements
- Noise

Atmospheric Emissions

The volume flowrate of exhaust gas from the Europeat 1 plant will be 558,000 Nm^3 per hour. This will contain polluting emissions or greenhouse gases in the following quantities:

	NO_x	SO_2	TSP	CO_2
mg/Nm^3	667	486	50	227,000
t/TWh	3,335	2,430	250	1,143,000
t/year	2,751	2,004	206	951,000

Table 4.10

Atmospheric Residence Times - Carbon Dioxide

Anthropogenic and other emissions of carbon dioxide cause an increase, or perturbation, in the atmospheric CO_2 concentration. This perturbation will be countered by the various uptake mechanisms by which carbon is exchanged between the atmosphere and other reservoirs, such as living plant material, soils, and the oceans. The sum of these exchanges is known as the *Carbon Cycle*.

The largest natural exchanges are those between the atmosphere and land-based living organisms (by photosynthesis and decay) and between the atmosphere and the ocean surface (driven by partial pressure difference). These relatively rapid processes are sufficient to turn over the atmospheric load of CO_2 in approximately 4 years. A slower exchange occurs between the ocean surface and the deeper waters of the ocean. A rain of detritus from the surface is balanced by the upward movement of carbon-rich water from the deep ocean. In most oceanic regions, this process occurs over periods of 100 to 1,000 years. Finally, the ultimate sink of the carbon cycle is the deep oceanic sediment

Because there are a number of such mechanisms, all operating at different rates, it is not appropriate to speak of a single “atmospheric residence time” for carbon dioxide. Instead, the increment of carbon emitted to atmosphere will decay in a complex manner. After 50 years, some 50% of the burden will have been removed from the atmosphere. The removal of another 25% of the original input may take another 250 years. A portion of the excess CO_2 will still be airborne for thousands of years because transfer to the ultimate sink (ocean sediments) is so slow (IPCC, 1995).

A widely used model developed by Siegenthaler (1983) takes the form:

$$pCO_2(t) = pCO_2(t_0) \times (0.42e^{-t/13} + 0.58e^{-t/285})$$

which approximates the decay using two time constants of 13 years (representing transfer to the biota and surface of the ocean) and 285 years (transfer to the deep ocean).

A more complex pulse-response model, developed by Maier-Reimer & Hasselmann, is quoted in Korhonen et al. (1993). This takes the form:

$$pCO_2(t) = pCO_2(t_0) \times (0.098e^{-t/1.9} + 0.249e^{-t/17.3} + 0.321e^{-t/73.6} + 0.201e^{-t/362.9} + 0.131)$$

This model takes into account four different transfer processes for removal of CO_2. In addition there is some portion of the CO_2 remaining in the air at t=∞.

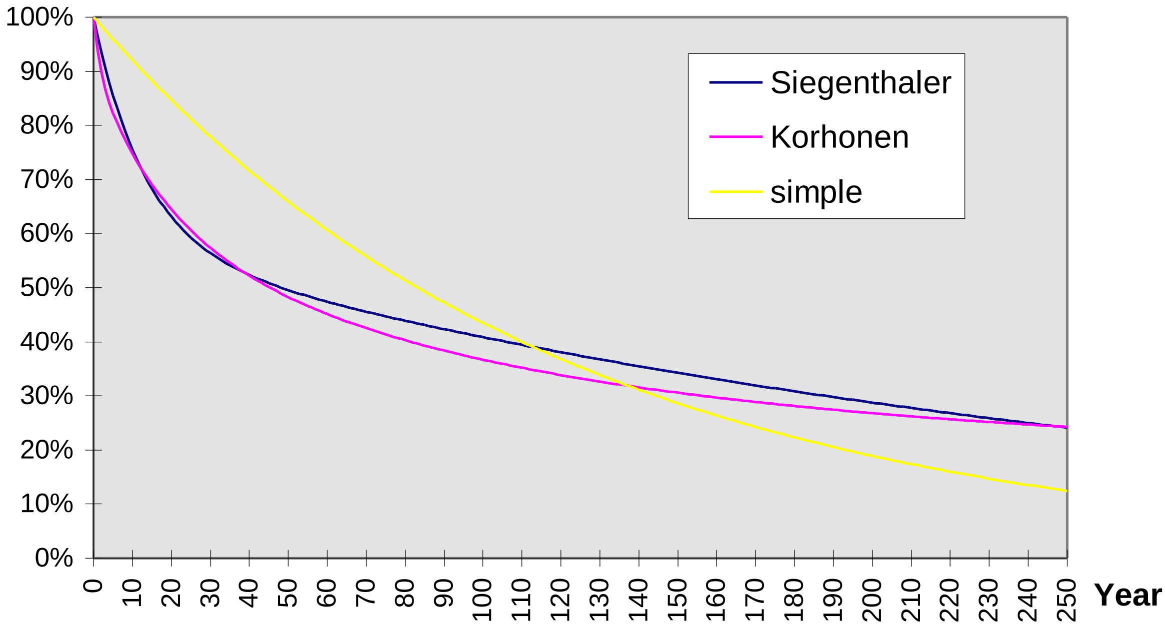

Figure 4-3: Models of Carbon Dioxide removal from the atmosphere

The decay curves represented by these two models are shown in Figure 4-3, and a simple exponential curve with a time constant of 120 years is included for the purpose of comparison.

Atmospheric Residence Times - Methane

Methane is another important global warming gas. Its radiative forcing effect is 58 times that of CO_2 per unit mass, although its Global Warming Potential is less than that of CO_2 because of its shorter residence time. The current atmospheric concentration of methane (approximately 1.7 ppm) is the highest ever, having increased from less than 1 ppm at the beginning of the twentieth century.

The principal mode of removal of methane from the atmosphere is reaction with hydroxyl (OH^-) radicals in the troposphere. Some exchange also takes place with the stratosphere and the soil, but these mechanisms amount to only around 10% of the total sink (IPCC, 1996). The rate of removal of methane therefore depends mainly on the abundance of hydroxyl radicals in the atmosphere, which in turn is influenced by the atmospheric methane concentration. The higher the concentration of methane, therefore, the more slowly it will be removed.

In order to model the changing loss frequency, atmospheric methane levels will be assumed to follow the IS92a scenario, doubling over the next hundred years. Atmospheric loss rate is assumed to decrease by 0.3% for every 1% increase in methane concentration (IPCC 1996). This yields an adjustment time varying from 12.25 years now to 16.9 years in 2100.

Atmospheric Residence Times - Nitrogen Oxides

Nitrogen oxide is a major greenhouse gas despite the relatively small quantities in which it is emitted, because of its high radiative forcing potency (206 times that of carbon dioxide by mass) and its long atmospheric residence time. Atmospheric concentration is currently increasing at a rate of some 0.25% per annum.

N_2O is removed from the atmosphere by a process of photolytic decomposition in the stratosphere. This process may be modelled as a simple exponential decay curve. We have assumed a time constant of 132 years, after Hillebrand (1993).

$$pN_2O(t) = pN_2O(t_0) \times e^{-t/132}$$

Fuel Cycle Emissions

Figure 4-4 shows the net emissions of CO_2, N_2O and CH_4 from the fuel cycle, taking as the reference case the emissions from peatland in its natural state. The three phases may easily be distinguished.

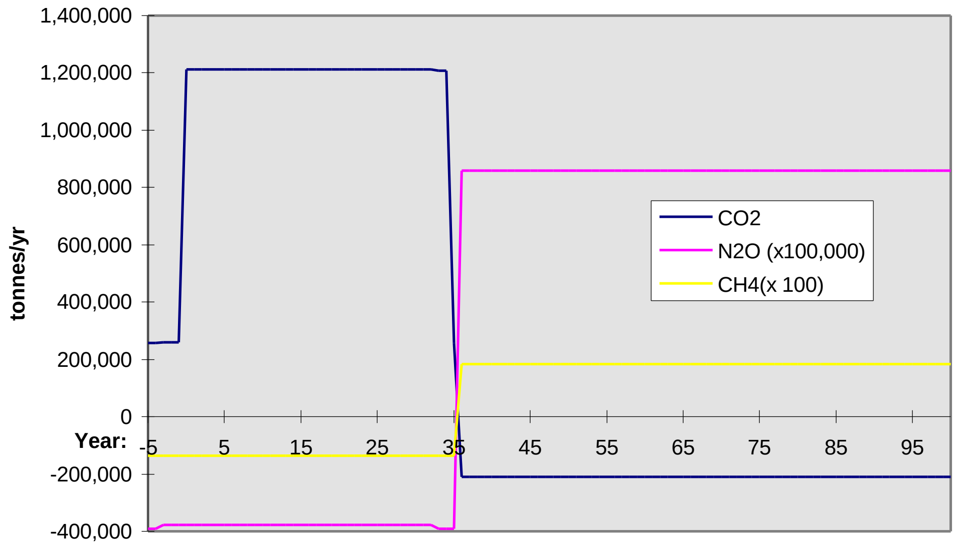

Figure 4-4: Annual **Net** Emissions of Global Warming Gases from Peat Fuel-Cycle

In phase one (year -5 to year 0) the peatland is ditched and drained and harvesting begins, in order to stockpile peat for the combustion phase. Peatland carbon dioxide emissions are increased from the reference case, while emissions of nitrogen oxides and methane are reduced. Harvesting machinery also produces some carbon dioxide and nitrogen oxides from year -3 on.

Phase two (year 0 to year 34) is the lifetime of the power plant, during which the major global warming emissions are in the form of carbon dioxide from the combustion process.

In Phase three (after year 35), the peatland has been converted to use as forestry, wetland and grassland, and becomes a net absorber of carbon dioxide. Emissions of nitrogen oxides and methane show a marked increase at this point.

The cumulative incremental concentrations of the three global warming gases for the period under consideration are modelled in Figure 4-5. This is based on the annual fluxes and the decay characteristics detailed above.

In addition, the "CO_2-equivalent" is plotted, based on the summed instantaneous radiative forcing characteristics of the three gases. It may be seen that in the early stages the CO_2-equivalent curve tends to track the curve of CO_2 itself, indicating that global warming effects of carbon dioxide are dominant, outweighing those of the other gases. Towards the end of the period, however, the relative importance of N_2O and methane increases.

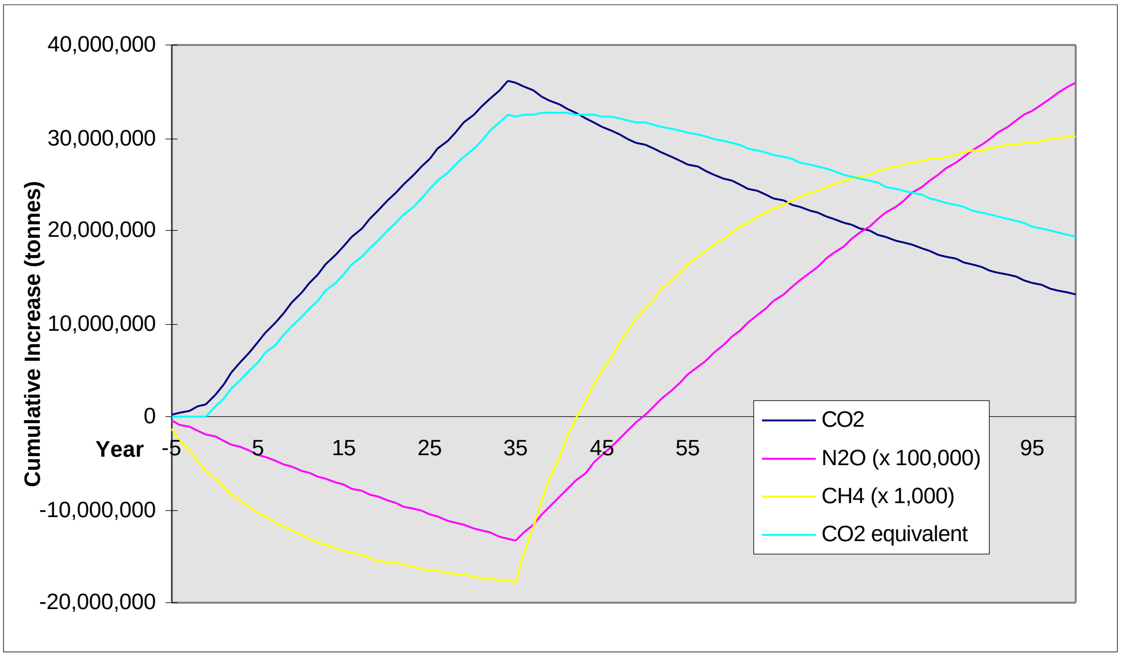

Figure 4-5: Cumulative Increase in Atmospheric Concentrations of Global Warming Gases

Analysis

If we consider the area under these curves, we can estimate the one-off emission of each global warming gas which will produce the same overall effect. These emissions would be as follows:

	CO_2	N_2O	CH_4	CO_2 (equivalent)
One-off emission (t)	31,659,215	81.2500	61,463	3,186,622

Table 4-10: One-off emissions equivalent to the total fluxes of global warming gases over the peat fuel cycle

When we come to value this impact, however, a once-off release of global warming gases is not equivalent in value to an annual release over an extended period. Appropriate discounting must be applied to impacts resulting from burdens in the future, relative to immediate impacts.

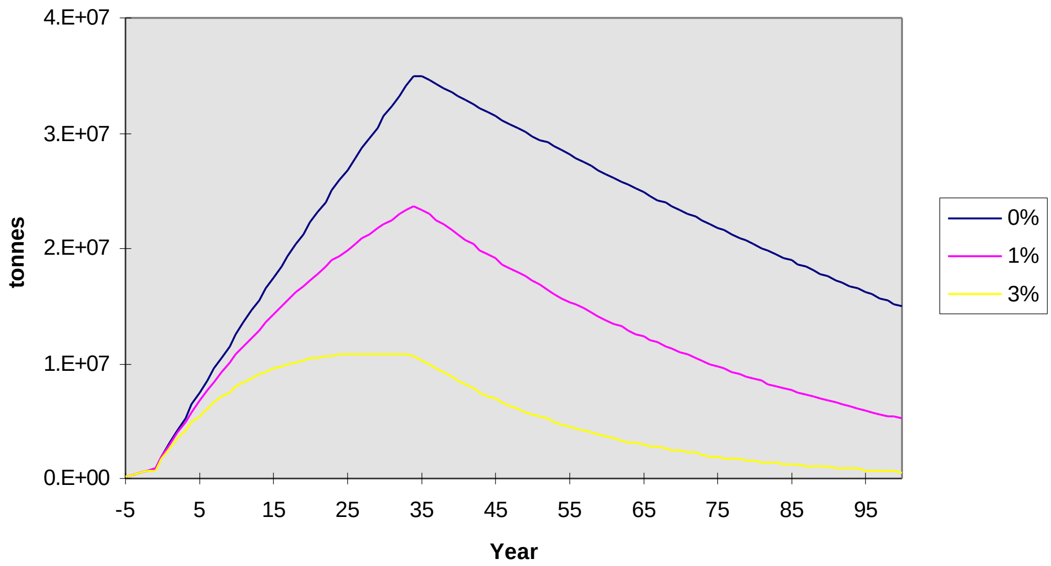

Figure 4-6: Cumulative incremental burden of CO_2-equivalent, discounted to present value

Figure 4-6 shows the effect of a 0%, 1% and 3% discounting on the cumulative burden of global warming gases, expressed in terms of CO_2-equivalent. The values for equivalent once-off emissions, discounted accordingly, are shown in Table 4-11.

Discount Rate	**tonnes**	**tonnes/TWh**
0%	35,240,789	1,209,465
1%	19,475,740	668,408
3%	6,964,463	239,021

Table 4-11: Discounted once-off emissions corresponding to the life-cycle global warming emissions of the peat fuel-cycle.

The valuation of these burdens is shown in Table 4-12.

Impact (mECU/kWh)	**95% confidence interval**	**Illustrative Restricted Range**
Discount Rate = 0%	4.6 to 168	22 to 56
Discount Rate = 1%	2.5 to 93	12 to 31
Discount Rate = 3%	0.9 to 33	4.3 to 11

Table 4-12: Valuation of Global Warming Impact of Peat Fuel Cycle

The discount rates of 1% and 3% (from the time of emission) are assumed in setting the bounds of the illustrative restricted range (See Appendix V for further explanation of these ranges, and the associated uncertainties). For consistency therefore, it is proposed that the same discount rates (1% and 3%) should be applied in this analysis to future emissions.

Conclusion

The Europeat life-cycle global warming impact will have a value of between 4.3 and 31 mECU/kWh (illustrative restricted range).

B. Restricted Analysis

If we consider that the peatlands from which the peat for the Europeat 1 power station are already partially cutover, and that their future restoration does not depend on the existence of the power station, it may be considered appropriate to carry out a more restrictive analysis, taking into account only those emissions which result directly from the construction and operation of the plant, as shown in Table 4-13.

t/year	**CO_2**	**N_2O**	**CO_2 equivalent**
Harvesting of Peat	3,266	0.122	3,303
Combustion of Peat	951,000	-	951,000
Transport of Peat	480	-	480
Transport of Personnel	409	-	409
Transport of Waste	6.5	-	6.5
Total	955,162	0.122	955,199

Table 4-13: Annual emissions of global warming gases from peat fuel cycle (restricted)

The damage impact of this burden may be valued as follows:

	95% confidence interval	**Illustrative Restricted Range**
Impact (mECU/kWh)	3.6 to 133	17 to 44

Table 4-14: Valuation of Global Warming Impact of Peat Fuel Cycle (restricted)

4.3.7 Ozone Damages

Ozone precursors are emitted from the peat fuel cycle in the following quantities:

	NO_x	**VOC**
Peat Harvesting	68	-
Peat Transport	8.5	0.94
Personnel Transport	2.7	-
Combustion of Peat	3,335	-
Transport of Solid Waste	0.47	0.047
Total	3,414	0.99

Table 4-15: Emissions of Precursors of Tropospheric Ozone from Peat Fuel Cycle (restricted cycle)

In addition, the fluxes of methane from the peatland during and after the lifetime of the power station may optionally be taken into account. The net fluxes are:

Reduced emissions of 1,352 tonnes of CH_4 per annum during the preparation of the peatland and operation of the plant (year -5 to year 34)

Increased emissions of 1,846 tonnes of CH_4 per annum from the peatland when converted to use for pasture, forestry and wetlands,

compared to the reference case of the peatland being left intact.

These fluxes are equivalent to a one-off emission of 3,595 tonnes of methane, or 120 tonnes per TWh of electricity produced during the lifetime of the plant.

The total damages arising from this impact are:

	Generation	Other Stages	Total
Mortality (mECU/kWh)	1.4	0.036	1.4
Morbidity (mECU/kWh)	2.5	0.067	2.6
Agriculture (mECU/kWh)	1.2	0.031	1.2
Total	**5.0**	**0.13**	**5.1**

Table 4-16: Ozone Damage from Peat Fuel Cycle

4.3.8 Occupational Injury

Over the three years of construction of the power plant, we will expect 0.11 deaths and 13.3 injuries to occur, based on the assumption that statistics for the construction industry in Ireland as a whole are applicable to this project.

The valuation of this damage is 647,000 ECU in total, or 0.21 mECU/TWh.

4.3.9 Road Accidents

In Section 4.3.5 above the expected increase in the number of road accidents and casualties was calculated. The valuation of this impact is shown in Table 4-17.

	Accidents	Deaths	Injuries
cases per year	0.38	0.034	0.63
cases per TWh	0.46	0.041	0.76
Value per incident	4,000 ECU	2.6 MECU	27,125 ECU
Damage mECU/kWh	0.0018	0.11	0.020

Table 4-17: Road Accident Damages for Peat Fuel Cycle

4.3.10 Public Health Impacts

The effects on human health of the pollutant emissions arising from the combustion of peat at Europeat 1, as calculated using Ecosense, are summarised in Table 4-18 and Table 4-19.

	Impact (Cases/TWh)	Damage (mECU/kWh)
Morbidity	15,000	2.6
Acute Mortality - YOLL	2.7	0.41
Chronic Mortality -YOLL	240	21
Chronic Mortality - deaths	*24*	*62*
Total		24

Table 4-18: Public Health Impacts of the Generation Stage of the Peat Fuel-Cycle, by impact category

Of this total, the local effects (within the 100 km x 100 km square centred on the Europeat 1 plant) account for just 4%.

[mECU/kWh]	**Local**	**Regional**
SO_2	0.21	0.42
Sulphate Aerosol	n/a	12
Nitrate Aerosol	n/a	9.9
TSP	0.73	1.3
Total	0.94	24

Table 4-19: Public Health Impacts of the Generation Stage of the Peat Fuel-Cycle, by pollutant

The additional impacts of the emissions from vehicles in the transport stage of the fuel cycle have not been calculated at this time. It may be noted that the quantities of pollutant emitted to the atmosphere from vehicles are several orders of magnitude less than those from the power plant. These emissions occur at or near ground level, so that such health impacts as do occur will be localised, and secondary effects will be negligible.

4.3.11 Agricultural Impacts

The agricultural impacts calculated by Ecosense and included in this study are:

- The reduction in yields of wheat, barley, oats, rye, potatoes and sugar beet caused by sulphur oxide emissions from the power station (Baker et al., 1986, modified).
- Soil acidification, valued according to the cost of mitigation by liming (European Commission, 1993)

These impacts are summarised in Table 4-20 below.

[mECU/kWh]	Local	Combined Local/Regional
Barley	0.0035	0.0079
Potato	0.0037	0.012
Sugar Beet	0	0.0063
Rye	0	6.9×10^{-5}
Oats	0.00044	0.0011
Wheat	0.0038	0.013
Acidification	n/a	0.024
Total	0.012	0.064

Table 4-20: Damage to agricultural production caused by SO_2 emissions from Europeat 1 power station

These damages are of very minor significance by comparison with such categories of damage as public health or global warming impacts. Annual damage in this category is approximately 50,000 ECU on a Europe-wide basis. It is interesting in passing, however, to note that a significant proportion of this damage occurs locally (c. 19%). This is in spite of the fact that cereal crops are not of primary importance in Irish agriculture.

4.3.12 Forests

The Ecosense program allows the calculation of the effect of atmospheric pollution on the forests of Europe, both in terms of reduced timber production, and in terms of the increased area of forest classified in damage classes 2 to 4.

The calculated values for Europeat 1 are:

Timber Loss	50 m^3/TWh	0.0029 mECU/kWh
Damaged Forest	1.8×10^6 m^2 (180 ha)/ TWh	non-valued

4.3.13 Construction Materials

The effect of wet acid deposition on the surface condition of building materials such as galvanised steel, limestone, mortar, stone, paint, rendering, sandstone and zinc may be calculated using Ecosense. The exposure-response functions are those of Kucera et al., 1995, and Haynie, 1986 (paint). The results for Europeat 1 are summarised below.

	Impact (m^2/TWh)	**Damage (mECU/kWh)**
Galvanised Steel	9,400	0.47
Limestone	0.91	2.5×10^{-3}
Mortar	970	0.03
Natural Stone	0.84	0.00024
Paint	7,400	0.093
Rendering	380	0.012
Sandstone	1.2	3.4×10^{-3}
Zinc	25	6.3×10^{-3}
Total		0.60

Table 4-21: Damage to Building Material Surfaces due to atmospheric emissions from power station

4.4 Summary and Interpretation of Results

	mECU/kWh	s_g
POWER GENERATION		
Public Health		
Mortality YOLL *(VSL)*	22 *(63)*	B
Morbidity	5.1	A
Total	29	
Of which:		
SO_2	12	
NO_x	14	
(of which via ozone)	*3.9*	
TSP	1.34	
Agricultural (via SO_2)	0.064	B
(via ozone)	1.2	
Forests	0.003	B
Materials	0.60	B
Sub-total	*29*	
Global Warming (95% confidence interval)	3.6 to 133	
Global Warming (illustrative restricted range)	17 to 44	C
TOTAL (including Global Warming)	46 to 73	

OTHER FUEL CYCLE STAGES		
Global Warming (based on restricted analysis)		
(95% confidence interval)	0.011 to 0.42	C
(illustrative restricted range)	0.054 to 0.14	
Global Warming (based on life-cycle analysis; all stages)		
(illustrative restricted range)	4.3 to 31	
Ozone	0.13	B
Occupational Injury	0.21	A
Road Accidents	0.13	A
TOTAL ALL STAGES (excl. Global Warming)	29	
TOTAL ALL STAGES (incl. Global Warming)	**33 to 60**	

Table 4-22: External Costs of the Peat Fuel Cycle

Global warming values are presented as an illustrative restricted range. This limited range is intended to be representative of the base-case estimates using discount rates of 1% and 3%. It does not take into account all of the uncertainty.

Considering only the illustrative restricted range, the global warming damage resulting from the generation stage accounts for between 37% and 60% of the total damage from that stage.

A comparison of the results of the two separate analyses for global warming shows that the global warming figures are potentially much lower when the full life-cycle is taken into account than when only a restricted sub-set of the stages is considered. The restricted analysis results in a global warming value of 17 to 44 mECU/kWh, where the full life-cycle analysis shows a global warming damage of only 4.3 to 31 mECU/kWh. The important difference between the two figures, is explained by the assumption that 50% of the peatland would be afforested after use. The trees planted on the bog would then reabsorb much of the carbon dioxide which had been released over the lifetime of the power plant.

Excluding global warming, the most severe damages are those associated with public health impacts. These amount to 27.1 mECU/kWh, or 93% of the total non-global warming damages. Of this total, only 5% is associated with suspended particulate matter, a strictly local burden. The remainder is shared between NO_x (52%) and SO_2 (44%). The relatively higher share caused by NO_x is a result of the low levels of sulphur present in the peat fuel.

The effects of a unit emission of each category of pollutant from Europeat 1 can be seen in Table 4-23 below.

	Tonnes emitted per annum	**Damage (ECU/tonne)**
CO_2	951,000	18 to 46 (illustrative restricted range)
NO_x	2,751	4,600 *(of which 1,600 via ozone)*
SO_2	2,004	5,300
TSP	206	5,415

Table 4-23: Damage per tonne of pollutant

5. AGGREGATION

5.1 Electricity Production in Ireland

In 1996 16,416 GWh of electricity was produced in the Republic of Ireland. Around 99% of this total was produced by the national generating utility, ESB.

The ESB operates 9 hydro-electric stations, and one pumped storage hydro station. These facilities had a net output of 1,017 GWh in 1996, or 6.2% of the total. The total capacity of the hydro-power stations is 220 MW. The pumped storage station can generate a further 292 MW of power at peak times.

The remainder, 15,381 GWh was produced in the ESB's thermal power plants. These are:

Type of plant	no. of units	Capacity	1992 Output (GWh)[1]	
Coal plants	1	915 MW	6,140	44.7%
Milled peat plants	5	420 MW	1,906	13.9%
Sod peat plants	2	10 MW	19.7	0.1%
Oil	2	740 MW	1,379.5	10.1%
CCGT	2	261 MW		
Gas turbine	3	629 MW	4,279.2	31.2%
Gas (other)	2	780 MW		
Total thermal		3,755 MW		

In addition to the plants listed above, there are many decommissioned units in long-term storage, up to a possible 400 MW.

5.2 Aggregation Methods

By consideration of the two fuel cycles which have comprised the Irish National Implementation, and extension over the whole of the Irish electricity sector, it is hoped to be able to arrive at an estimate of the total external costs associated with the production of electricity in Ireland.

[1] Latest year for which output figures are available broken down by plant

The method to be used is as follows:

- The regional impacts of the two reference plants will be normalised to give a value for total damage per tonne of pollutant.
- The total quantity of each pollutant produced will be found by summing the values for all of the power stations in the country.
- By combining these two values, it will be possible to arrive at a gross approximation of the total costs as required.
- For global warming, a similar methodology will be applied to the total carbon dioxide output of the electricity industry in Ireland. Only the generation stage will be considered.
- Some damages from non-generation stages of the fuel cycles may be taken into account either by direct comparison with the coal or peat fuel cycles or by inspection.
- Noise impacts, which are neglected in the coal and peat studies because of the isolated locations of the power stations, will be estimated for those power stations which are located in populated areas.

The result will only be an approximation, for a variety of reasons.

First, we have found that certain categories of damages associated with a plant are highly dependent on the geographical location of the plant, even over a relatively short range within a single country. This is because of the sensitivity of the results to the proximity of centres of population.

Second, it may be seen that neither of the two reference plants is representative of a class of plant in Ireland, since Moneypoint is the only coal plant, and Europeat 1 is unique in its combustion technology. The only stage of the coal fuel cycle which may be generalised from the Moneypoint analysis is the generation stage. For the Europeat 1 analysis, the fuel production and transport stages may also be used.

The extension of results from the fuel cycles studied to other fuel cycles will be far from comprehensive. Other fuel cycles will have their own unique burdens, which will not be included in this analysis.

5.3 Aggregation - Regional Impacts

Total national emissions from all sources for selected years are as shown in **Table 5-1**, while **Table 5-2** shows the contribution of power plant (UNECE Category 1) to this total.

Table 5-1: National pollutant emissions (kt)

	1980	1985	1990	1993
SO_2	222	141	178	157
NO_x	83	85	116	122
NMVOC	79	64	197	202
CO	-	-	431	416
Smoke	-	-	41	35

Table 5-2: Emissions from power plant (kt)

	1980	1985	1990	1993	1996
SO_2	101	39	103	87	81
NO_x	27	29	46	46	42
NMVOC	0.1	0.1	0.25	0.25	-
CO	-	-	3.3	3.3	-
Smoke	-	-	11	12	12

A significant drop in SO_2 output may be noted between 1980 and 1985. This reflects the reduction in the amount of oil used in power generation, in favour of natural gas. After 1985, with the coming on stream of Moneypoint, there was a sharp increase in both SO_2 and NO_x output.

The 1996 figures, as supplied by ESB, show a favourable trend, with reductions since 1993 in both SO_2 and NO_x, despite the overall increase in generated units during that time. The NO_x reduction is largely due to the installation of low-NO_x burners at Moneypoint, as well as the installation of Combined Cycle Gas Turbine plant in Dublin.

Table 5-3: Emissions in tonnes from reference plant during 1996 (percentage of national total)

	National	Moneypoint	Europeat 1
SO_2	81,400	41,470 (51%)	2,790 (3.5%)
NO_x	41,840	23,920 (57%)	2,033 (4.9%)
TSP	12,140	1,190 (10%)	209 (1.7%)

Using the scaling factors derived from **Table 5-3**, together with the Ecosense results for the two plants (Table 3-27 and Table 4-23), it is possible to estimate the total costs of the emissions from all power plant in Ireland. The estimate differs according to whether Moneypoint or Europeat 1 is taken as the base. This difference reflects the difference in geographic location between the two plants. The results are summarised below.

Table 5-4: Aggregated Regional Damage (MECU/yr)

	SO_2 (and sulphates)	NO_x (and nitrates)	TSP
Based on Moneypoint	228	180	34
Based on Europeat 1	431	192	66

5.4 Global Warming Damages

5.4.1 Direct Emissions

Carbon dioxide emissions from all sources amounted to 31.6 million tonnes in 1990. Power plant accounted for 10.86 million tonnes of this total. Taking other global warming gases into account (principally N_2O), the total equivalent CO_2 directly emitted from power plant is 11.29 million tonnes. This corresponds to 3.08 million tonnes of carbon.

Using the illustrative restrictive range to value this impact, the damage is 43 to 1,600 MECU/year (full 95% confidence interval) or 203 to 519 MECU/year (illustrative restricted interval).

5.4.2 Upstream emissions

Coal

The methane emissions associated with mining coal to supply Moneypoint amount to 396 tonnes/yr, or 8,316 tonnes of CO_2 equivalent.

Combustion of fuel oil in shipping coal from Colombia and the USA to Moneypoint results in the production of another 24,000 tonnes of CO_2 per Mt of coal, or 57,000 tonnes per annum.

Total upstream emissions for coal are therefore around 65,000 tonnes per annum, or an extra 1% on the direct emissions from Moneypoint.

Peat

This is a very complex and technology-dependent analysis. It is not therefore possible merely to transfer the results for the Europeat 1 plant to the other peat plants. For this reason it is proposed to consider the direct power station emissions only.

Oil/Gas

As no analysis has been done on oil and gas fuel cycles in Ireland, a good starting point is to consider the total methane emissions from production and distribution of fuels in Ireland (UNECE 5). This category would include oil refining, gas extraction and gas distribution by pipeline. This figure is 10,178 t/yr, equivalent to 214,000 tonnes of CO_2 per annum. If we further assume that 35% of the fuel produced and distributed is used in electricity generation, than we arrive at a figure of 75,000 tonnes CO_2 equiv. per annum.

Upstream emissions for all fuels may therefore contribute an extra 140,000 tonnes of CO_2 equivalent to radiative forcing, valued at 2.5 MECU to 6.44 MECU per annum.

Total aggregated global warming effects would therefore be 205 to 525 MECU/yr (illustrative restricted range.

5.4.3 Ozone

Emissions of precursors of tropospheric ozone from Ireland's power generation sector in 1996 were:

NO_x	46,370 tonnes
NMVOCs	250 tonnes

The value of the aggregated damages (health, agricultural, materials) associated with the ozone produced is approximately 70 MECU/yr.

5.4.4 Noise

Noise has been considered to be negligible for the two reference plants, Moneypoint and Europeat 1, because of their location in sparsely populated rural areas. Nonetheless, several of Ireland's power stations are situated in cities and towns, where noise impacts may be worthy of consideration.

Table 5-5: Thermal power stations in populated areas in Ireland (1996)

Station	**Fuel**	**Energy Output (GWh)**	**Situation**
Poolbeg	Gas (Oil)	2,800	Near city
Aghada	Gas	1,860	Rural
Marina	Gas	790	City Centre
North Wall	Gas	920	Near city
Shannonbridge	Peat	780	Near town
Lanesboro	Peat	600	Near town

If we use generalised noise valuation figures of 0.2 mECU/kWh for peat and 0.03 mECU/kWh for gas, the total damage works out to be 461 kECU/yr.

5.5 Total Aggregated Damages

MECU/year	Based on Moneypoint	Based on Europeat 1
Public Health	442	689
Global Warming	205 to 525	205 to 525
Ozone	70	70
Noise	0.5	0.5
Total	720 to 1040	970 to 1300

Table 5-6: Aggregated Externalities arising from Power Generation in Ireland

6. CONCLUSIONS

If we compare the results from Moneypoint and Europeat 1, we find more similarities than differences. Among these similarities are the importance of global warming (although the peat cycle is a special case if a full life-cycle analysis is carried out), and of the public health impacts of atmospheric pollutants. In both cases, these two categories of impact dwarf the effect of all the others.

Another notable similarity is the relative importance of the generation stage of the fuel cycle, where the fuel is burned, releasing pollutant emissions. In both cases, all the other stages of the fuel cycle taken together are of only minor significance when compared with the damages from the generation stage. Again, however, the special case of the global warming impacts from peat should be noted. Effectively, the large positive emission of carbon dioxide during the combustion process is all but cancelled out by the cumulative and long-term effect of carbon dioxide absorption at other stages, specifically in the after-use phase of the peatland.

When we consider the differences between the damages from the two cycles, we see that the total of non-global warming impacts amounted to 29 mECU/kWh for Europeat 1 and 41 mECU/kWh for Moneypoint. We are drawn to acknowledge how close these two values are, since the fuel cycles are very different. Once again, this is because of the predominance of the public health impacts, which are broadly similar for the two plants.

In the case of sulphur oxides, less are emitted per unit of electricity generated from Europeat 1 than are emitted from Moneypoint. This favourable tendency is counterbalanced, however, by the higher damage per tonne of SO_2 emitted from Europeat 1 than from Moneypoint. Similarly, although less NO_x is emitted from Europeat 1 than from Moneypoint (2.4 g/kWh as opposed to 3.4 g/kWh), the damage per tonne of NO_x emitted is higher at Europeat 1 than at Moneypoint.

In each case, the difference arises from the location of Europeat 1 some 200 km closer to the populated centre of Europe, and also nearer to the large population centre of Dublin, than Moneypoint. It may readily be seen that if Moneypoint or a similar plant were to occupy the site proposed for the Europeat 1 plant, the damages would be considerably higher than they are. This difference would be manifested on a regional and not primarily a local level, however.

The aggregation of the results for Moneypoint and Europeat 1 to the entire fossil-fuel based power generation industry in Ireland, while necessarily very approximate and incomplete, yields a provisional figure of around 1 billion ECU per annum. Most of this damage will occur outside of Ireland, either on a global basis in the case of global warming and ozone damages, or on a continental scale in the case of public health impacts. This corresponds to a unit external cost of around 65 mECU/kWh (with a very high degree of associated uncertainty) produced. This is of a similar order of magnitude to the cost of electricity to the domestic consumer, which is approximately 100 mECU/kWh. It must be emphasised however that a full aggregation analysis would require considerable further research.

In summary, the emissions of SO_2 and NO_x from Europeat 1 are relatively low compared to Moneypoint, but their effect is proportionally stronger.

Global warming effects of the peat fuel cycle are complex, but a full life-cycle analysis suggests that the damages may be very low, depending on initial assumptions.

Neither Moneypoint nor Europeat 1 may be said to impose particularly high nor particularly low external costs, by comparison with similar plants in other European countries (see European Commission, 1998*c*), but some room for improvement exists in the case of Moneypoint.

The main conclusion to be drawn from a comparison of the results for the two plants is their surprising sensitivity to geographical location. This is something which may be a factor in decisions on the siting of new plant.

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