THE NATIONAL IMPLEMENTATION IN THE EU OF THE EXTERNE ACCOUNTING FRAMEWORK

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Implementation in Portugal of the ExternE accounting framework

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FOREWORD

There is a growing awareness that decision making related to fuel and technology choice for power generation should take into account all the costs, both internal and external. This is reflected in a large number of EU documents. For instance, the European Commission's Green Paper "For a European Union Energy Policy" states that the internalisation of external costs is central to energy and environmental policy. Hence, an EU wide common approach to the quantification of these externalities as well as a common understanding of their interpretation for policy and decision making is an important prerequisite for this internalisation.

The first important step to this purpose was made by the EC between 1991 and 1995 with the development of a methodology to evaluate the externalities associated with power generation. The ExternE Project, launched within the Joule Programme, produced a consistent "bottom-up" accounting framework demonstrated it for the most important fuel cycles. It has since then been widely recognised as the most developed methodology to account externalities of power generation.

The next step was to develop an adequate set of external cost data for different fuel cycles, technologies and countries, as well as to build up expertise in all the member states to assist policy and decision makers in the use of these results. Therefore, within Joule III the ExternE National Implementation Project was organised. Over the last two years, research teams within all member states of the EU (except Luxembourg) and Norway have implemented the ExternE accounting framework to a large number of individual fuel cycles for power generation. Parallel to this project, the methodology has been further developed and updated and this has been integrated within these data. Thus for the first time, a broad set of comparable data on external costs of power generation is now available. These data take account of site, technology and fuel cycle specificity and this set of data provide a representative overview for electricity generation in the EU. In addition, first estimates for the power generation sector as a whole have been developed.

This publication by CEEETA reports in detail the national implementation in Portugal. Similar reports have been produced for all countries involved and they all follow the same structure, both to clearly indicate consistency between the different country reports as to ease comparison. These national publications are complemented with publications by the EC on methodology and a summary overview of results for all countries.

The results for the different countries show the importance of technology, fuel and site specificity. This confirms that the approach taken by the EC is the correct one and that the big effort to develop a 'bottom-up' methodology and generate a broad set of data is well justified. Energy and environmental policy will only be really efficient and successful if it takes this specificity into account.

The project integrates existing scientific information from different areas and disciplines in a coherent framework. This work could only be successful thanks to the collaboration of the different research teams in all the countries and to the inputs from a large number of different research programmes both at the EU and national level. I want to thank all the researchers, institutes and the Ministries that co-financed this exercise for their contributions to this important work.

The EC Joule programme continues to support a further development of the ExternE project. For the next two years, it will focus on the application of energy use in transport and in this context the ExternE methodology will continue to integrate new scientific developments in the different areas.

The final step towards internalisation relates to the use of the data in policy and decision making. Over the years we have noted a growing interest from research, policy and industry for our results at national and international level. The EC services have now started to feed the ExternE numbers into the policy preparation process for energy, environmental and research policies and the EC-strategy to combat acidification and global warming have profited from this research. This illustrates that notwithstanding all the caveats, these numbers are useful and credible if presented and used in the right context.

I hope that this new series of data for all countries, supported by the expertise in the country to further develop and exploit these data, may result in multiple uses of these data for policy and decision making. In the end, the real benefit of this research agenda is to be measured by its contribution towards a more sustainable energy use.

P. Valette

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EXECUTIVE SUMMARY

ES.1 Introduction and Objectives

The use of energy causes damage to a wide range of receptors, including human health, natural ecosystems, and the built environment. Such damages are referred to as external costs, as they are not reflected in the market price of energy. These externalities have been traditionally ignored.

However, there is a growing interest towards the internalisation of externalities to assist policy and decision making. Several European and international organisms have expressed their interest in this issue, as may be seen in the 5th Environmental Action Programme, in the White Paper on Growth, Competitiveness and Employment, or the White Paper on Energy, all from the European Commission.

This interest has led to the development of internationally agreed tools for the evaluation of externalities, and to its application to different energy sources.

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. Launched in 1991 as a collaborative project with the US-DOE, and continued afterwards by the EC as the ExternE project, it has involved more then 40 different 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 this field as currently the most advanced project world-wide for the evaluation of external costs of power generation.

Under Joule III, this project has been continued with three distinguished 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 systems. The current document is the result of the ExternE National Implementation project for Portugal.

The ExternE project aims to implement the ExternE Accounting framework of the EC for the assessment of the external costs of fuel chains for power generation in the EU and Norway. To this purpose a network of scientific institutes in all these countries has been established.

The key objective of this project has been to establish a comparable set of data on the external costs of fuel chains for each member state and Norway, using the ExternE methodology which has been developed under the Joule II project. The workprogramme identified the following objectives for the National implementation project as a whole :

1. Implementation of the ExternE accounting framework to some selected fuel chains in all member states (except Luxembourg) and Norway.

2. To provide the comparable and validated data for the whole EU to feed into the database at IPTS, Seville for further dissemination.

3. Aggregation of the site and technology specific results to more general figures that should cover e.g. the power generation system of a country.

4. To apply these data to policy related case studies that indicate how these data could feed into the decision and policy making process.

5. Dissemination in the country: to inform the relevant scientific and policy making communities in the member states about the project.

ES.2 Methodology and its implementation in Portugal

The project has attempted to quantify the external costs and benefits of the major electricity generation technologies in Europe, to aggregate these damages for national power systems and to apply results to policy making issues. Therefore, representative technologies have been selected in Portugal, based on the existing power systems, or on the expected development of these systems.

The methodology used for the assessment of the externalities of the fuel chains selected has been the one developed within the ExternE Project. This is a bottom-up methodology, which uses the “impact pathway” approach. 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 way of quantifying externalities.

The underlying principles on which the methodology has been developed are transparency, consistency and comprehensiveness of the analysis. These characteristics should be present along the stages of the methodology, namely: site and technology characterisation, identification of burdens and impacts, prioritisation of impacts, quantification and economic valuation.

More details on the methodology in general, and on the specific methods for the valuation of each impact, may be found in the report issued by the ExternE Core Project (European Commission, 1998a), within which the methodology has been updated and further developed.

In Europe, the electricity generation sector is responsible for a great percentage of the total burdens due to air pollutants’ emissions. The situation in Portugal is not different. As far as the electricity sector is concerned, the implementation of ExternE project in Portugal aims at quantifying the external costs of electricity generation, which is to say, at determining the non-internalised costs of the production of one kWh. That objective is pursued in this study through the examination of a set of case studies representative of the structure of the Portuguese electricity generation sector. In such perspective coal, natural gas, hydropower, and biomass fuel cycles were analysed.

The oil fuel cycle was not subject to analysis, due to project implementation constraints. Despite this possible limitation, the EcoSense tool was applied to the major oil power plants and data from other EU case studies undertaken in the context of ExternE project were used for the implementation of the aggregation task.

ES.3 Summary of results for fuel chains

An overview of the results obtained for the fuel chains covered in Portugal, is shown in the figure ES.1 below.

Results are presented using the Years-Of-Life-Lost approach recommended by the methodology for the health impacts (which usually dominate the non-global warming impacts), and are expressed using the 95% confidence interval for global warming impacts. This presentation is expected to give an overall picture of results obtained by CEEETA. Other ranges for results, and values calculated with the Value of Statistical Life approach for human health can be obtained in the corresponding chapters.

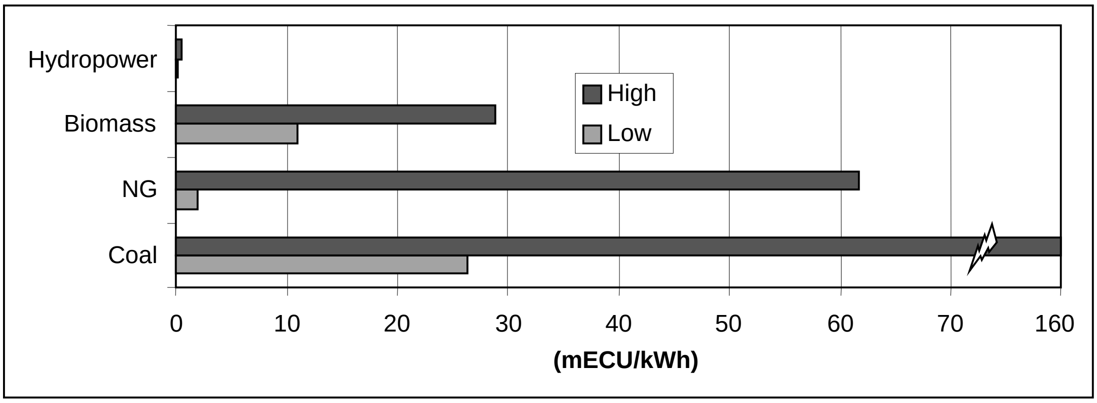

Figure ES.1 Results from the Portuguese National implementation

As may be seen, results differ considerably among fuel chains. In general terms, it may be said that fossil fuels, especially coal (and oil) present the largest damages. Natural gas is the exception, with quite low damages when the restricted range is considered for global warming impacts.

Renewable energy sources, hydropower and biomass in our implementation, present the lowest damages. This is generally due to their CO_2-free character, and to the low related pollutant emissions. This is not the case for biomass, however, since TSP and NO_x emissions of this fuel chain produce rather high damages. Furthermore, it has to be pointed out that for a large number of impacts from the hydropower fuel cycle, the economic assessment has not been possible due mainly to the absence of information or studies using the contingent valuation method.

ES.4 Summary of results for aggregation

This extension of ExternE to assess whole electricity systems can be carried out, for fossil fuels and biomass, using the EcoSense tool. This operation was done for the main existing fossil fuel power plants.

However, for local and global scale impacts, the use of EcoSense is not appropriate. For these impacts, aggregation has therefore been undertaken outside the software framework.

As may be observed in the description of the methodology, several aspects make the aggregation of results really difficult. In fact, these results should be considered in most cases as preliminary figures, which might be used as background information namely for policy-making purposes.

It has to be remarked that the results presented here are a very simple summary of the work undertaken. Therefore, it is recommended to read the details of the work in the full report, rather than directly using these figures. The range used for fossil fuels covers only the illustrative restricted range for global warming damages.

Table ES.1 Results of the aggregation for Portugal (1995)

Electricity generated (TWh/yr)				External costs (MECU/yr)				%
Coal	Oil	Hydro	TOTAL	Coal	Oil	Hydro	TOTAL	GDP (1995)
13.5	7.4	10	30.9	868-1,193	406-590	2.7-3.0	1,277-1,786	1.3-1.8

Damages have been calculated for several sites using EcoSense, and extrapolated to other plants when needed, based on the emission factors of these plants. For hydropower, results have been transferred from other countries or locations, what makes the figures produced less reliable.

The total damages obtained were translated into an average externality for the electricity generated in Portugal. The figure, ranging between 41 and 58 mECU/kWh, is only indicative. However, it may be useful for comparing the environmental impact of the different national electricity systems in Europe.

ES.5 Policy Case Study

Two major types of policy case studies have been undertaken within the National Implementation Project, which illustrate the application of the results obtained within the project.

The first one, and the most straightforward, is its use for the assessment of the social costs and benefits of different energy policies. The second one is the integration of externalities into energy planning processes. In our case we have analysed different strategies for meeting future electricity demand in São Miguel Island (Azores archipelago).

In general, both types of studies show that cleaner technologies, such as renewables, NG or pollution abatement technologies are always profitable from a social point of view, even though not all their environmental benefits have been assessed yet. This social profitability is reflected in the larger share captured by these technologies in scenarios analysing the extension of the power system in the São Miguel Island.

ES.6 Conclusions

The major conclusion of this study may be that, in spite of the uncertainties underlying the analysis, a large set of externalities for electricity generation has been generated, and therefore, a first attempt towards the integration of environmental aspects into energy policy may be carried out. The fact that this study has been implemented at an European level implies that the Portuguese results may be compared with those from other countries, thus illustrating the site-specificity of the externalities assessed.

Regarding the figures obtained for external costs, it has to be noted that, although the results are considered sub-totals (some impacts were not quantified) these figures are already significant, specially if global warming damages are taken into account. For example, and considering the restricted range for global warming impacts, the coal fuel cycle assessed show external costs of around 50 mECU/kWh, or about the same magnitude as the private costs. Natural gas, which is considered as a clean fuel, shows external costs around 10 mECU/kWh, which are also significant but considerably lower than those for coal and oil.

In general, it may be said that fossil fuels have significant external costs, while renewable energies have very small ones, namely for hydropower with less than 1 mECU/kWh. Nevertheless, biomass fuel cycles (old technologies) could induce some significant damages with external costs around 15 mECU/kWh.

When it comes to the aggregation of the damages for the whole electricity sector, the figures obtained, although still preliminary, show significant values, between 1% and 2% of the Portuguese GDP (1995). Therefore, it might be concluded that the external costs of some fuel chains are high enough to affect energy policy decisions. However, here it has to be reminded that the methodology has still a large number of uncertainties.

Several aspects should be improved, mainly the estimation of global warming damages. Atmospheric dispersion models, which, at least for some countries, should account for the complex topographic conditions are also a controversial aspect. An important issue which should also be studied is the relationship between atmospheric pollution and chronic mortality, and the valuation of the deaths produced by atmospheric pollution.

Regarding global warming damages, its range of estimated results is so broad that it dominates the results for fossil fuel chains. This produces that, when the mid or high estimate for global warming damages is considered, fossil fuels cannot compete with renewables. Therefore, these estimates for global warming benefit to a large extent these energy sources.

Considering all the uncertainties affecting the assessment of external costs, it is recommended to use the results provided by this report only as background information. This background information might be very useful for establishing economic incentives, such as environmental taxes, or subsidies for renewable energies, or for energy planning purposes. However, as said before, results should not be used directly, until the methodology is refined.

Although further research is required to refine the methodology, and thus, to produce more precise results, reducing the range of uncertainty, the ExternE project is the first comprehensive attempt to estimate the externalities of electricity generation in Portugal as well as in the other EU countries. The ExternE Project has succeeded in quantifying externalities and their associated uncertainties in more detail than any previous study. The uncertainties are rather large, but they are more a reflection of the existing knowledge than the result of the methodology used. The ExternE outcomes therefore provide the information that policy makers need to make informed decisions about energy/environment issues, enabling them to balance the risks of not taking action against the costs of doing so.

This fact has already been accepted by the scientific community, and is starting to get attention from the industry and policy makers, due to the dissemination activities carried out within the project.

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 damages 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~~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 Study in 1991 as a collaborative project with the US Department of Energy. From 1993 to 1995 it continued as the ExternE project, involving more then 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 this 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 ~~effort~~ project has continued ~~by~~ with three~~wo~~ major tasks ~~projects~~: ExternE Core for the further development and updating of the methodology, ~~and~~ 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 document is the result of the ExternE National implementation project for Portugal.~~.~~

1.1 Objectives ~~h~~of the project

The objective~~s~~ of th~~is~~e ExternE National Implementation project was to establish a comprehensive and comparable set of data on externalities of power generation for all EU member states and Norway (see fig. 1.1). The tasks include:

- ~~were to implement the~~ the application of the ExternE methodology to the most important fuel chains ~~in all~~ for each country;
- updating ~~EU member states and Norway;~~ existing results as new data become available for refinement of methods;
- aggregation of ~~to aggregate~~ site- and technology-specific results to the national level;
- for countries already involved in Joule II, ~~; to provide comparable and validated data for the whole EU; and to apply~~ data have been applied to ~~to~~ policy~~-~~ questions, ~~related case studies,~~ to indicate how these data could feed into decision and policy making processes;

- dissemination of results;
- creation of a network of scientific institutes ~~in all countries~~ 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 ~~The ExternE National Implementation project has been supported by the ExternE Core project, for the update of the methodology. This has proved to be beneficial to the present project, as it has provided a consistent framework for the assessment of the externalities of different fuel cycles. The EcoSense software developed within that project has also been a very useful tool for the achievement of this consistency.~~

~~As a result, all the objectives proposed have been achieved. A~~a large set of comparable and validated results~~ has been generated~~, covering more than ~~5~~60 cases, for 15 countries and ~~9~~12 fuel chains. ~~Several~~ A wide range of generating options have been analysed~~analyzed~~, including fossil, nuclear and renewable technologies.~~, mostly state-of-the-art 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, and

- comparative assessment of energy systems.

Such applications are illustrated by the case studies presented later in this report, and in other national implementation reports.

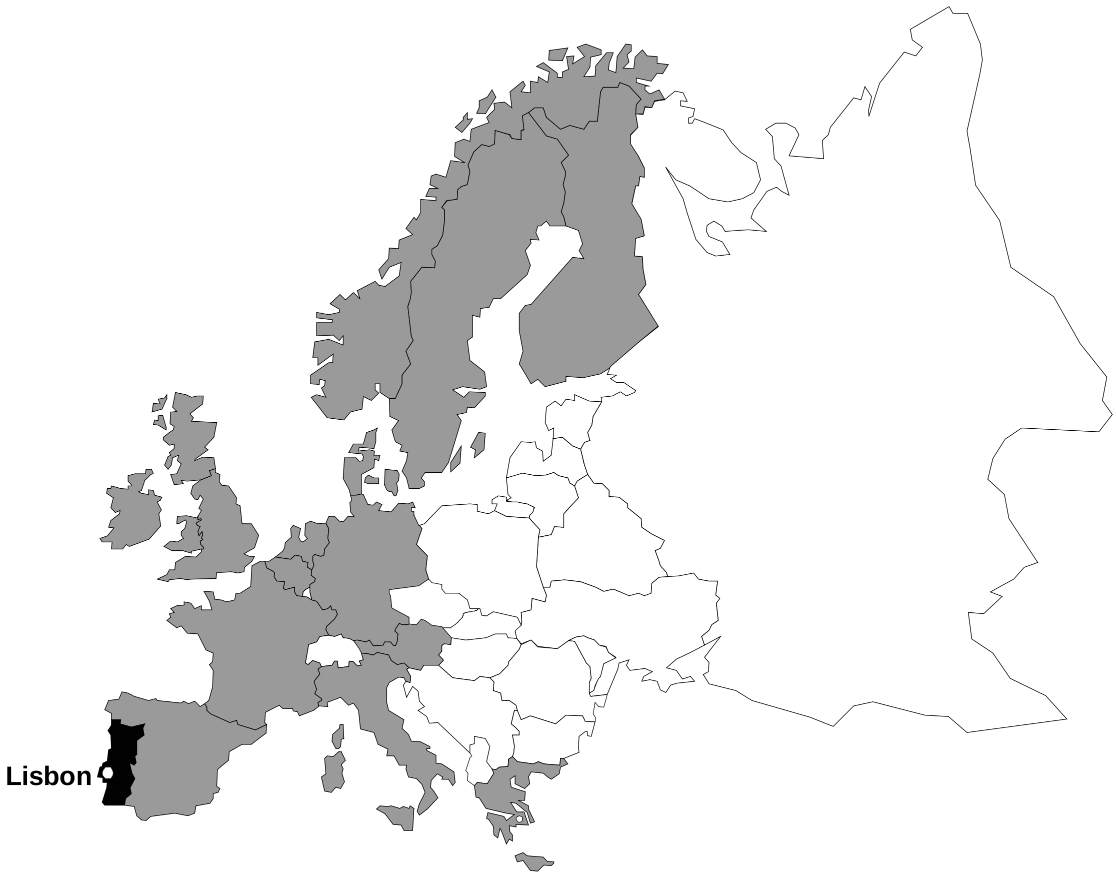

Figure 1.1 Portugal and the other European countries involved in the ExternE project

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 Portugal. It contains all the details of the application of the methodology to the selected fuel cycle cases, aggregation, and a policy case study as an illustration of the use of these results. Brief details of the methodology are provided in Chapter 2 of this report and in the Appendices; a more detailed review of the methodology 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 (located at Seville, Spain), and is accessible through the Internet (*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 that it is 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 way 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 (appendices I to VIII) 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 appendices IX to XII.

1.4 The Portuguese National Implementation

1.4.1 Description of the country

The Portuguese continental territory is located between the latitudes 37º N and 42º N and the longitudes 6.5º W and 9.5º W. The Portuguese territory also includes two archipelagos situated in the Atlantic Ocean: Madeira and Azores.

Portugal covers an area of 92,000 km^2 and has a population of 9.9 million of inhabitants. The population density is about 107.5 inhab./km^2, almost the population density for the whole EU. This population density can reach more than 320 inhab./km^2 in the littoral area where most of the population lives.

In 1995, the Portuguese GDP was about 79,600 million ECU; which gives a low per capita value when compared with other EU countries (about 8100 ECU/inhab.). In structural terms, the services represented about 56% of this GDP and 38% for the industrial sector. The importance of the primary sector has strongly decreased with less than 6% of the GDP.

Portugal has a mild climate. Heating degree-days vary between 400 and 1600 with a mean value of 770 and cooling degree-days range between 400 and 700. Due to these climate characteristics, space heating, excepting firewood and electric appliances, has a low penetration rate. On the contrary, the penetration rate of air conditioning equipment in the last years has been high. A rapid evolution can also be observed in the transport sector. The car stock has increased very fast in the last decade with a ratio near one car per 4 inhabitants in 1995. Nevertheless, this indicator remains far from the EU average of one car per 2.5 inhabitants.

1.4.2 Overview of the Portuguese energy sector

The Portuguese energy sector is small at the EU level. With about 17.5 Mtoe in 1993, it represents less than 1.5% of the primary energy consumption of the EU. In terms of energy consumption per capita, Portugal had the lowest ratio with 1.7 toe/inhabitant in 1993 (against 3.5 toe/inhabitant for the EU).

These differences can be explained by some factors like climatic conditions, level of life and industrial development. However, the annual increase between 1990 and 1993 was almost negligible in average for the EU (0.2% per year) when compared with 2.2% per year for Portugal.

The Portuguese energy sector is characterised by a low degree of self-sufficiency and a strong dependency on oil products (see figure 1.2 hereafter). Almost 90% of the total primary energy supply is imported and the share of oil stands at 70% of this consumption. The introduction of natural gas in 1997 will reduce this strong oil dependency.

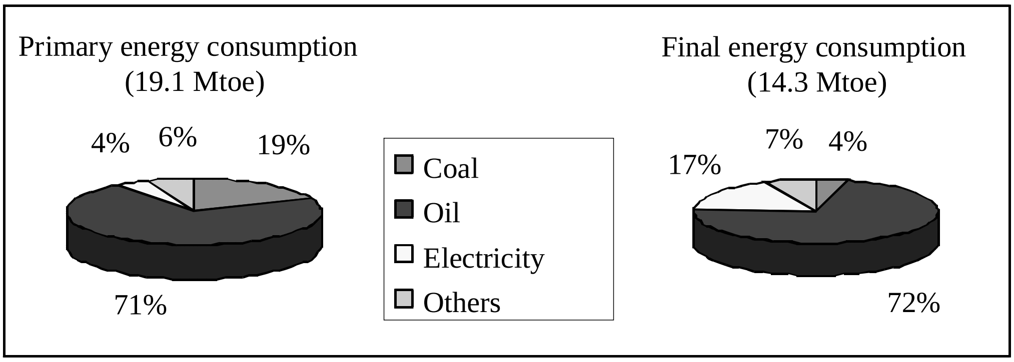

Figure 1.2 Structure of the Portuguese energy consumption in 1995

Regarding the electricity sector in Portugal (continental part), the consumption of energy to supply the electricity demand was as shown in the following table for 1995. The introduction of natural gas in this sector should reduce the oil component from 38% in 1995 to about 19% in 2010.

Table 1.1 Energy consumption for electricity supply in 1995 and estimates for 2000 and 2010

Source	1995		2000		2010	
	ktoe	%	ktoe	%	ktoe	%
Coal	2 918	46%	3 000	41%	3 000	35%
Oil	2 382	38%	2 118	29%	1 648	19%
Hydro	732	12%	1 000	14%	1 100	13%
Natural gas	0	0%	1 000	14%	2 500	29%
Other*	269	4%	269	4%	400	5%
Total	6 301	100%	7 387	100%	8 648	100%

*Including biomass, industrial gases and imports.
Source: MIE, 1996.

In 1995, the structure of the installed power capacity was the following.

Table 1.2 Installed power capacity in Portugal (1995)

Source	MW	%
Coal	1 871	18.9
Oil	3 719	37.6
Hydropower	4 291	43.4
Other renewables	17	0.2
Total	9 898	100

Source: DGE, 1995.

The total net electricity supplied to the grid (including imports) was 31.8 TWh in 1995. For this dry year electricity generated from hydropower was reduced by 20% comparatively to 1994. This reduction was compensated by an increase of the thermal component, namely oil, and imports. The structure of electricity sent to the grid in Portugal (continental part) for 1995 in presented in the following table.

Table 1.3 Net electricity generation in Portugal in 1995*

Source	TWh	%
Coal	12.8	40.2
Oil	9.9	31.1
Hydropower	8.2	25.8
Imports (net)	0.9	2.9
Total	31.8	100

* The electricity generated in the Azores and Madeira archipelagos is not included.

As shown in this table, fossil fuels represented more than 70% of the total electricity sent to the grid in 1995. Values for 1996, considered a wet year, give a different picture with a share of about 44% for the hydropower.

1.4.3 Justification of the fuel cycles' selection

In Europe, the electricity generation sector is responsible for a great percentage of the total burdens due to air pollutants' emissions. The situation in Portugal is not different (see figure 1.3 below). With respect to the total emissions of sulphur oxides, nitrogen oxides and carbon dioxide, this sector accounts for about 62%, 23% and 25% of the total estimated emissions.

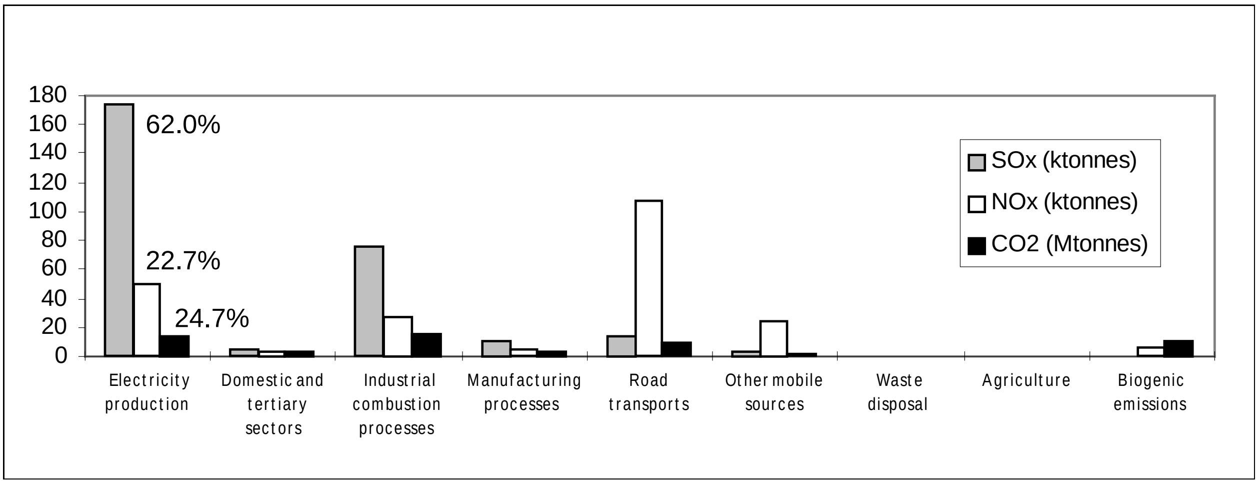

Figure 1.3 Total emissions per activity sector in Portugal in 1990 (Source: CORINAIR 90)

As far as the electricity sector is concerned, the implementation of ExternE project in Portugal aims at quantifying the external costs of electricity generation, which is to say, at determining the non-internalised costs of the production of one kWh. That objective is pursued in this study through the examination of a set of case studies representative of the structure of the Portuguese electricity production sector. In such perspective coal, natural gas, hydroelectric, and biomass fuel cycles were analysed. The following figure shows the location of the different case studies chosen by CEEETA.

Although Portuguese oil power plants could generate energy representing between 10% (in 1996) and 30% (in 1995) of the total electricity generation in Portugal (continental part), depending on the water availability for hydropower plants, the oil fuel cycle was not subject of analysis, due to project implementation constraints. Despite this possible limitation, data from other case studies undertaken in the context of ExternE accounting framework were used for the implementation of the aggregation task.

Figure 1.4 Location of Portuguese cases studied in the framework of the ExternE project

1.4.4 Related national studies

This document synthesises and presents the updated results of previous analyses. CEEETA has been involved in the ExternE project since 1993. A series of reports have been produced and presented to the European Commission. In a first phase, the biomass fuel cycle has been developed through the analysis of three different case studies (CEEETA, 1994). In the second phase, the study has been extended to new fuel cycles with the analysis of the hydropower and coal fuel cycles (CEEETA, 1995 a-b). In the last phase, the ExternE project has been enlarged with the analysis of the natural gas fuel cycle (Martins *et al.*, 1997). Furthermore, the application of the ExternE methodology has been extended to new fuel cycles in the framework of the ExternE Core project (see above). CEEETA has analysed the geothermal fuel cycle based on a power plant located at São Miguel Island in the Azores Archipelago (see Martins *et al.*, 1996).

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. 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 (LCA) 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.

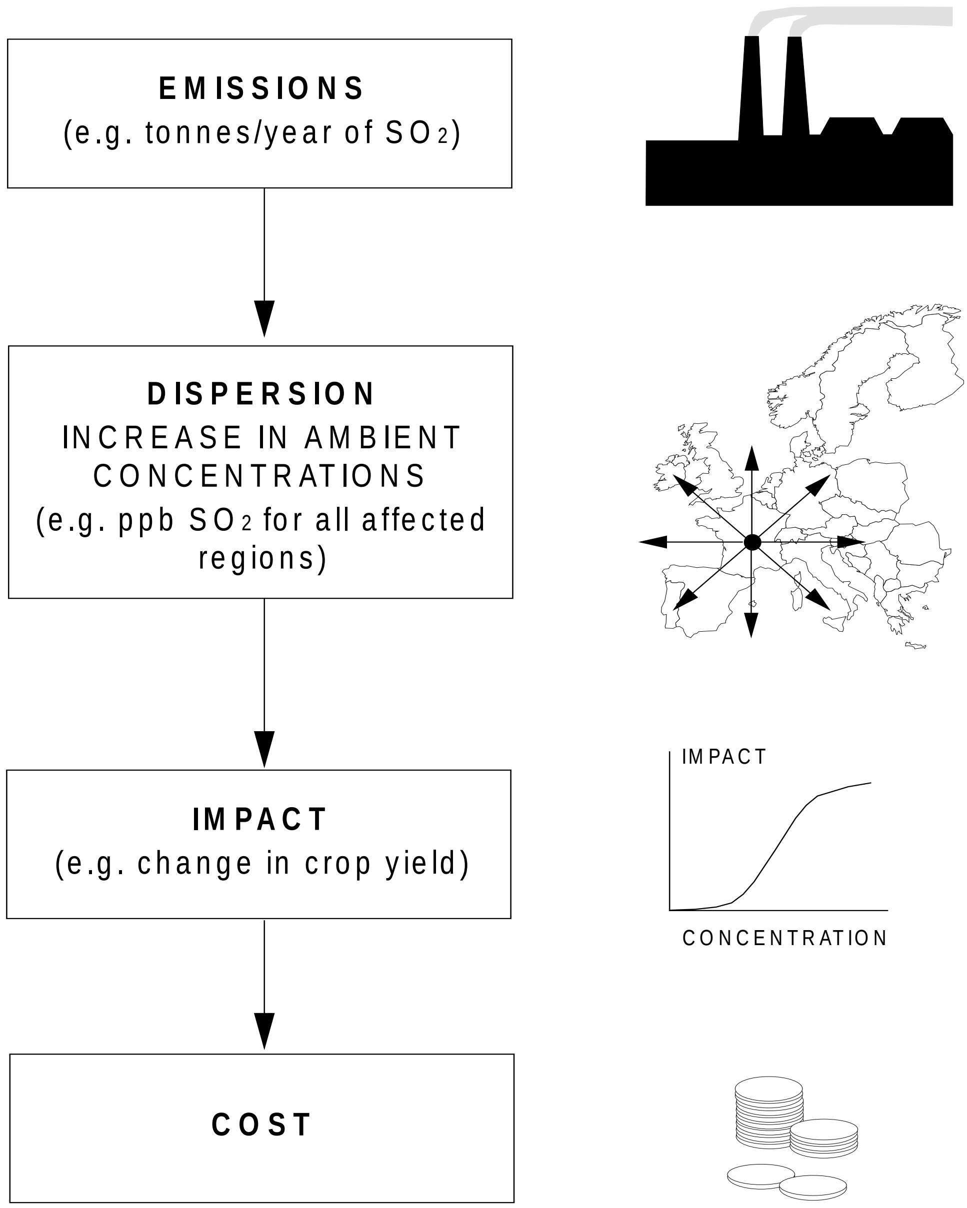

Figure 2.1 An illustration of the main steps of the impact pathways methodology applied to the consequences of pollutant emissions. Each step is analysed with detailed process models.

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 CFC's 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, for example close to large cities, this pattern is reversed, 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 running far beyond the experience of recorded history. 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 the history of the planet. 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 Tera-Watt (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 internalised through adjustments in the price of housing. 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.

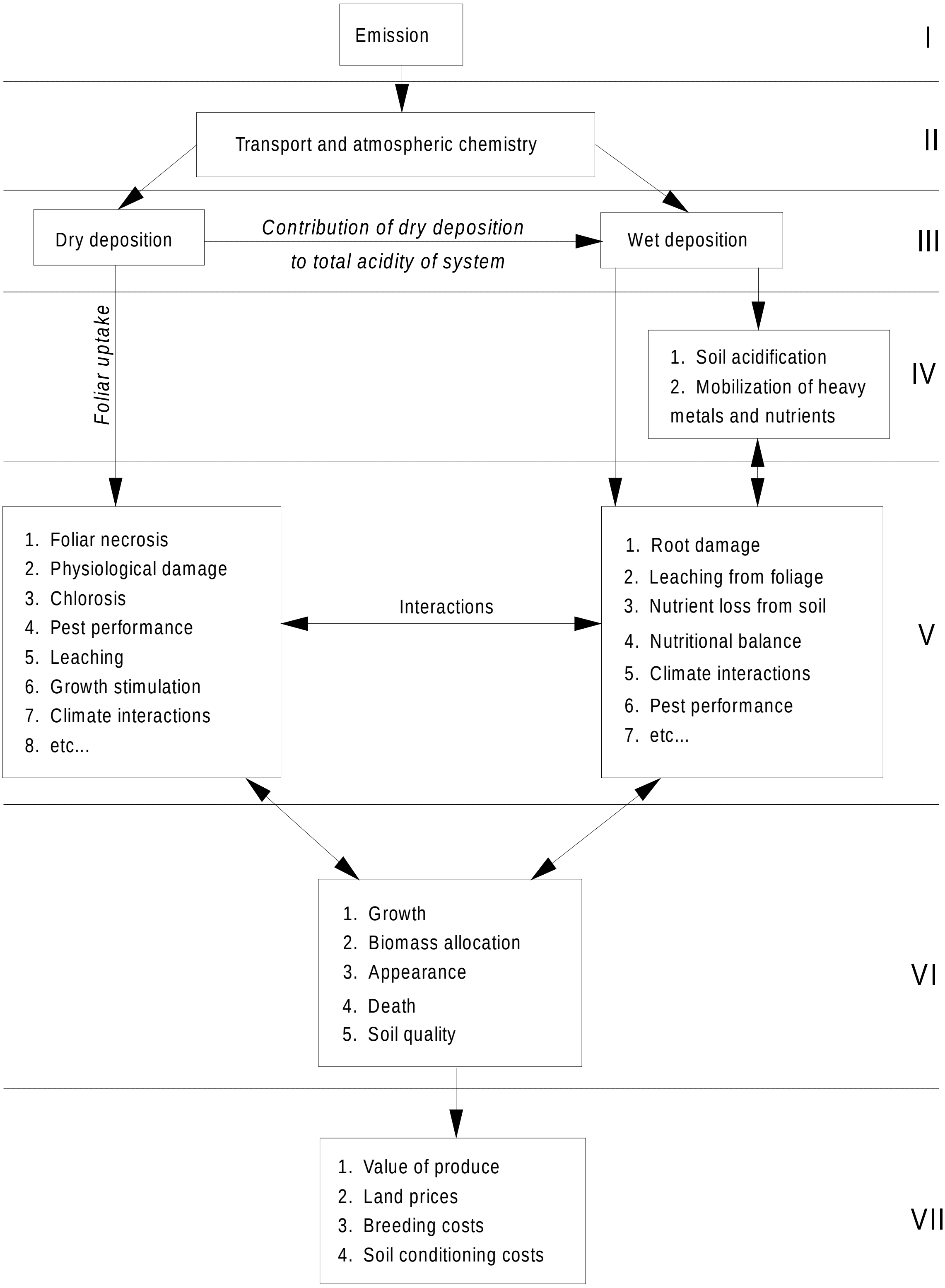

Figure 2.2 The impact pathway showing the series of linkages between emission of acidifying pollutants and ozone precursors and valuation of impacts on agricultural systems.

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 scenarios need to 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, 1998a). 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, 1998a).

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.

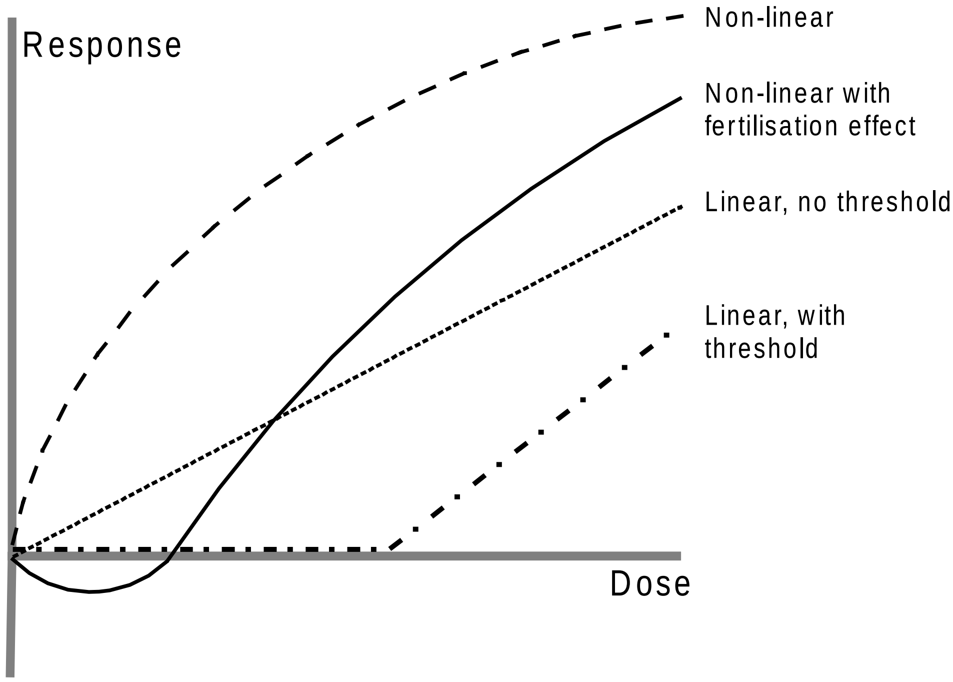

Figure 2.3 A variety of possible forms for dose-response functions

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, 1998a) 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, 1998a). 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 and CEEETA, 1995b) 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, 1998a). 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

In Portugal, two power plants are actually using coal to generate electricity. The more recent one (Pego) has been selected for the implementation of the ExternE methodology. Pego project was designed to receive 4 units of 300 MW each. Nevertheless, until now, only 2 units have been constructed and are operating. Our analysis has considered the projected plant including the installation of a flue gas desulphurization system.

3.1 Definition of the fuel cycle, technologies and sites

Pego power station occupies a site of 180 ha, close to the River Tejo, in the parishes of Pego and Concávada, municipality of Abrantes, Lisboa-Vale do Tejo region (see figure 1.4).

This power station generates electricity from pulverised coal, through direct combustion. Considering, as a theoretical case, a full use of the 4 units in 1990, with a mean availability of 65%, Pego power plant would assure an annual electricity generation of 6,220 GWh. This capacity represents about 26% of the total Portuguese consumption of electricity in 1990. The most important technological characteristics of the power plant are:

- 99.5% effective electrostatic precipitators (ESP),
- 90% effective flue gas desulphurization (theoretical case),
- low NO_x burners,
- natural draught cooling towers to recirculate 98.4% of the cooling water,
- wastewater treatment to reduce pollutant emissions to water,
- power: 1200 MW divided between 4 sets with a unit power of 300 MW,
- high output cycle: 162 bar /530ºC,
- fuel: bituminous coal (sulphur content between 0.4 and 1.5%),
- coal storage capacity: 90 days,
- condenser cooling system: closed circuit with cooling towers,
- 4 cooling towers with a height of 118 metres each,
- 2 chimney-stacks with a height of 220 metres each,
- gross power output: 6,830 GWh/year,
- internal consumption: 620 GWh/year (9%),
- availability: 65%, with 100% use,
- operating time: 5700 hours/year,
- coal consumption under nominal conditions: 2.5 Mt/year,
- life time: 25 years.

The main characteristics of the Pego power plant are summarised in the following table.

Table 3.1 Main characteristics of the Pego power plant

Characteristic	Value
Plant size (MW)	1 200
Mean availability	65 %
Efficiency	37.4 %
Operating time (h/year)	5 700
Coal consumption :	
- t/year	2 492 600
- TJ/year	59 800
Electricity generation (GWh/year)*	6 220

* Net generation = Gross electricity production - internal electricity consumption .

3.2 Overview of burdens

3.2.1 Coal extraction

The coal used in Portugal for electricity generation is mainly imported from countries like South Africa, Colombia and USA. The type of mine under exploitation in these countries is not specific, so underground and open mines have been considered in our analysis. The characteristics of coal depends upon sources. Nevertheless, the composition for Pego power plant have to fulfil some characteristics (see table IX-1 in appendix IX).

As there is no specific data for this stage, we had to rely on other studies providing data and/or indicator of burdens.

3.2.2 Coal transport

This operation is divided in two phases. The first phase relates to coal transport from the mining sites to Portuguese harbour and the second phase concerns coal transport from the harbour to the power plant. For the first phase there is no specific route. But, given the assumed sites for coal extraction, an estimate of the transport distance has been made and used to assess air emissions from this phase. The average distance considered was 7,000 km and the ship capacity about 125,000 t, which means 20 loads per year.

The second phase relates to coal transport by railway from Sines harbour to the power plant. The transport distance is of about 320 km and is carried out by trains of 27 wagons with a capacity of 57 t each and 2 diesel engines, which means 1,620 loads per year. For this stage, the main burdens assessed are related with air emissions and occupational and public accidents (see appendix IX).

3.2.3 Limestone production and transport

The production and transport of limestone is theoretical as there is no FDG system in the real case. The extraction of limestone has been assumed to be within an area up to 150 km from the power plant. Its transport by road requires, considering a truck with a capacity of 27 t, about 2300 loads per year.

3.2.4 Power generation

The main burdens from this stage could be divided into four categories: emissions to air, emissions to water, emission of solid wastes and other burdens.

Air emissions

Emission factors for the main pollutants considered in this study were either obtained from the project (EDP, 1986) or the result of CEEETA's calculations based on mass balance analysis. The following emission factors for Pego power plant have been retained.

Table 3.2 Emission factors from the power plant

	PM	SO_2	NO_x	CO_2
Emission factors (g/MWh)	258	794	1 892	690 400

Emissions to water

The main liquid effluents come from the cooling system and the idealised FGD plant. Other wastewater emissions arise from coal and ash storage areas. The following table synthesises the water consumption for Pego power plant.

Table 3.3 Water consumption

	Consumption (m^3/s)
Purged water from the cooling circuit	0.56
Waste water from FGD plant	0.10
Evaporative loss from cooling towers	0.64
Total	1.30

Source: EDP, 1986.

Water emissions also occur from cooling towers. There are two types of discharge associated with the purging of cooling tower water into the river: chemical and thermal. Data, only available for the thermal discharge, suggest that rise in river temperature will be, for the worst scenario (summer), of about 1.9ºC.

Solid waste emissions

The major solid waste emissions consist of ashes from coal combustion and gypsum from SO_2 abatement. Coal combustion produces fly ash and bottom ash with the following distribution: 80% and 20% of total ash respectively. Fly ash is collected from the electrostatic precipitator

(ESP) and then conveyed into a silo where it is stored before its final disposal. Bottom ash is taken from the bottom of the furnace and conveyed by truck to the waste disposal area.

For gypsum, the production is theoretical as actually Pego power plant has not set up a FGD system yet. So, gypsum generation is calculated with a ratio of 16.8 kg/MWhe according to European Commission (1995c).

Total solid wastes generated in this stage are summarised in the following table.

Table 3.4 Solid waste generation

	Total (t/year)
Fly ash	279 200
Bottom ash	69 800
Gypsum	104 500

Other burdens

Other burdens are related with occupational accidents, noise and visual intrusion. Some of these burdens are quantified and the impacts from these emissions are analysed in section 4 of this chapter.

3.2.5 Waste transport and disposal

All operating and waste materials, except fly ashes, are transported by trucks. For fly ashes, it was assumed that they were transported by railway from the power station to cement industries located at a distance of about 110 km. The fly ash collected is conveyed to silos with a total capacity for 5 days of the power plant operation.

Actually, Pego power plant has not set up any desulphurization system at the 2 units already built. So, transportation requirements from gypsum production are theoretical. In this context, it will be considered emissions from truck transportation assuming a loading distance of 150 km and a bulk of 104,460 t for gypsum.

Production of bottom ash is estimated to be 69,800 t per year. It will be removed from the power station to be disposed of in a proper area (ash disposal of 60 ha inside the power plant area).

The following table presents the emission factors in t/TJ of diesel-oil consumption for truck transportation of lime, gypsum and bottom ashes.

Table 3.5 Air emissions from truck (t/TJ of fuel)

	CO	VOC's	SO_2	CO_2	NO_x	PM
Truck transport	0.4756	0.1664	0.137	71.9	1.46	0.1

Source: CEEETA, 1991.

3.2.6 Construction and dismantling of facilities

Construction and dismantling of facilities (namely mine and power plant) involve a large number of operations such as extraction, production and transport of materials, manufacture and installation of equipment, removing of materials and equipment, etc. The main burdens are related to air emissions from extraction, production and transport of materials, occupational and public accidents, noise and visual intrusion.

Data on construction and dismantling of facilities (namely mine and power plant) are not available in this case. As a raw estimate, data from previous studies (European Commission, 1995c) was used to quantify some burdens from the construction stage. As there is no estimate for the dismantling stage, it was assumed that the same volume of materials and equipment has to be removed and transported as for construction (see appendix IX).

Emissions factors from road transport have been presented in table 4.5. Accident risks associated with construction and dismantling of facilities are not available. But impacts in terms of mortality and injury will be estimated using ratios from European Commission (1995c) coal report.

The transport requirements assumed for this stage are presented in the following table.

Table 3.6 Transport requirements for the construction and dismantling stage

Material	Quantity (t)	Transport distance (km)	Transport requirement (t-km)
Steel	109 600	100	10 956 500
Concrete	304 400	50	15 217 400
Others	3 830	100	382 600
Total			26 556 500

3.3 Selection of priority impacts

The following impacts were considered for a priority analysis in our study:

1. Global warming impacts due to green house gas emissions.
2. Effects of air pollutants on human health.
3. Effects of air pollutants and acidic deposition on ecological receptors (agricultural crops, forests and other ecosystems).
4. Effects of air pollutants on materials.
6. Effects of thermal discharges in the aquatic environment.
7. Effects of noise on human health and amenity.
8. Impacts on visual amenity.
9. Effects of road traffic on road conservation.
10. Occupational and public health effects from accidents.
11. Effects in terms of employment.

The overall approach followed for the assessment of these impacts has been described in chapter 2.

Although employment effects have not been retained in the framework of the ExternE project, CEEETA's has performed such assessment in terms of employment need (direct and indirect) induced by the activities required by this fuel cycle.

3.4 Quantification of impacts and damages

3.4.1 Contribution of greenhouse gas (GHG) emissions to global warming

The impacts of global warming are diverse and potentially problematic to evaluate from the economic point of view (see appendix V). Given the lack of GHG emissions from some stages of our coal fuel cycle, we used values from other ExternE studies in order to quantify the total emissions (see table hereafter).

Table 3.7 Total emissions of GHG in terms of CO_2 equivalent*

Activity	g/kWh	%
Coal mining outside EU	9.9	1.1%
Coal transport outside EU	79.4	9.2%
Transport of pollution abatement materials	3.72E-02	0%
Transport of coal within EU	4.24	0.5%
Transport of ashes, lime and gypsum	0.38	0%
Power plant operation	769.9	89.1%
Power plant construction and dismantling	2.26E-02	0%
Total	863.8	100%

* Emissions of CH_4 and N_2O were converted in terms of CO_2 equivalent using values suggested by the IPCC (1995) or 21 and 310 respectively.

The electricity generation stage is the most important stage regarding GHG emissions with more than 89% of the total emissions. The other relevant stage in our case is coal transport by ship from long distances with more than 9% of the total emissions. Emissions from the other stages can be considered negligible.

Giving the damage costs established in the framework of this project (3.8-139 ECU per t of CO_2 equivalent for the conservative 95% confidence interval and 18-46 ECU per t of CO_2 equivalent for the illustrative restricted range) and the GHG emissions estimated in this case, impacts from global warming are as shown in the following table.

The σ_g column gives a label (A, B or C) for the range of uncertainty estimated for the defined damage. The label A is used for results with a high confidence (geometric standard deviation of 2.5 to 4) and the label C is associated with a low confidence in results (geometric standard deviation of 6 to 12). For more details on the uncertainty issue see appendix VIII.

Table 3.8 Damage costs from GHG emissions

	mECU/kWh	σ_g
POWER GENERATION		
Global warming		C
low and high estimates (95% confidence interval)	2.9 - 107	
mid 3% and mid 1% (restricted range)	13.9 - 35.4	
OTHER FUEL CYCLE STAGES		
Global warming		C
low and high estimates (95% confidence interval)	0.36 - 13.1	
mid 3% and mid 1% (restricted range)	1.7 - 4.3	

3.4.2 Impacts of air pollutants on human health

Giving the differences in the methodological approach, impacts from primary pollutants and aerosols on human health and impacts from ozone formation have been considered separately.

Impacts of primary pollutants and aerosols on human health

Emissions of atmospheric pollutants occur in all the stages of the coal fuel cycle. However, the power generation stage is, in this case, the main source of these emissions. Consequently, this stage is the only one considered for the assessment of the category of impacts.

The methodology used to estimate the physical and economic damages from primary pollutants (particulates, SO_2 and NO_x) and aerosols (sulphates and nitrates) is supported by the computer tool EcoSense 2.0 (see appendix I). For each atmospheric pollutant considered it has been performed a physical and economic assessment for three scenarios (low, mid and high). Analytical details for human health used to assess this impacts (stock at risk, exposure-response data and valuation data) are presented in appendix II. Results are presented for the mid estimate or the best estimate giving the present knowledge.

Table 3.9 Summary results of damages on human health from primary pollutants and aerosols

	mECU/kWh	σ_g
POWER GENERATION		
Public health		
Mortality*- YOLL *(VSL)*	14.7 *(59.9)*	B
Morbidity	1.85	A-B
OTHER FUEL CYCLE STAGES		
Public health	nq	-

*YOLL: years of life lost, VSL: value of statistical life.
nq: not quantified; - : not relevant.

For more details on these results see appendix IX on coal fuel cycle. Mortality impacts are assessed using two approaches. The first one is based on the valuation of the years of life lost

(YOLL) and the second one is based on the value of a statistical life (VSL). These two methods are discussed in appendix II on human health.

Impacts of ozone on human health

The estimates of ozone damages on human health per tonne of precursor emission (NO_x and VOC's) suggested by Rabl (1996) range between 230 and 5750 ECU per tonne of NO_2 equivalent (NOx emissions are NO_2 equivalent), with a mid point estimate of 1150 ECU/t of NO_2 equivalent. The following table gives the results of the ozone damage costs for the Portuguese coal fuel cycle.

Table 3.10 Summary results of damages on human health from ozone formation

	mECU/kWh	σ_g
POWER GENERATION		
Public health		
Mortality*- YOLL *(VSL)*	0.75	B
Morbidity	1.34	A-B
OTHER FUEL CYCLE STAGES		
Public health		
Mortality*- YOLL *(VSL)*	0.12	B
Morbidity	0.20	A-B

3.4.3 Effects of air pollutants and acidic deposition on ecological receptors

As for effects on human health, impacts on ecological receptors (crops, forests and other ecosystems) from primary pollutants and aerosols and from ozone formation will be considered separately.

Effects of primary air pollutants and acidic deposition on ecological receptors

The methodology used to estimate the physical and economic damages from primary pollutants and aerosols is also supported by the computer tool EcoSense 2.0 (see appendix I). For each atmospheric pollutant considered it has been performed a physical and economic assessment for three scenarios (low, mid and high). Nevertheless, results are only presented for the mid estimate with a range of variation given by σ_g column. Analytical details for ecological effects are presented in appendix IV. See appendix IX for more details on the following results.

Table 3.11 Summary results of damages on ecological receptors from primary pollutants and acidic deposition

	mECU/kWh	σ_g
POWER GENERATION		

Crops	-3.29E-02	B
Other ecosystems	nq	-
OTHER FUEL CYCLE STAGES		
Ecological effects	nq	-

nq: not quantified; - : not relevant.

Effects of ozone on ecosystems

The estimates of ozone damages on ecological receptors per tonne of precursor emission (NOx and VOC's) suggested by Rabl (1996) range between 70 and 1750 ECU per tonne of NO_2 equivalent (NO_x emissions are NO_2 equivalent), with a mid point estimate of 350 ECU/t of NO_2 equivalent. The following table gives the results of the ozone damage costs for the Portuguese coal fuel cycle.

Table 3.12 Summary results of damages on ecological receptors from ozone formation

	mECU/kWh	σ_g
POWER GENERATION		
Crops	0.63	B
Other ecosystems	nq	-
OTHER FUEL CYCLE STAGES		
Crops	9.77E-02	B
Other ecosystems	nq	-

nq: not quantified; - : not relevant.

3.4.4 Effects of air pollutants on materials

Both wet and dry deposition can be important to atmospheric deterioration of materials. Their relative importance depends on the type of material, its orientation on a structure, air and precipitation quality, and climatic factors, particularly rainfall amounts and frequency of high relative humidity. Other climatic factors that may enhance materials degradation include freeze-thaw cycles, intensity of solar radiation, and wind conditions (Lipfert, 1989).

With respect to the impacts of air pollutants on materials, pollutants can be grouped into three major categories: (1) particles, (2) gases, and (3) acidic precipitation. Exposure-response functions considered in this project are described in appendix III. This appendix includes also other analytical details.

The methodology used to estimate the physical and economic damages is supported by the computer tool EcoSense 2.0 (see appendix I). For each atmospheric pollutant considered it has been performed a physical and economic assessment for three scenarios (low, mid and high). However, results are only presented for the mid estimate with a range of variation given by σ_g column. See appendix IX for more details on the following results.

Table 3.13 Summary results of damages on materials

	mECU/kWh	σ_g
POWER GENERATION		
Materials	8.89E-02	B
OTHER FUEL CYCLE STAGES		
Materials	nq	-

nq: not quantified; - : not relevant.

3.4.5 Effects of thermal discharges in the aquatic environment

Thermal discharges of wastewater have two major direct impacts on the aquatic environment of a river stream. As temperature increases because of the thermal discharge, oxygen solubility in water decreases and the settling velocity of suspended particles increases.

The behaviour of oxygen solubility with temperature is well known, and for freshwaters (with chlorinity equal to zero) it can be calculated using empirical relationships. The increase in settling velocity is due to the conjunction of two factors. On one hand, as water temperature increases, water density decreases. On the other hand, as water temperature increases, its dynamic viscosity decreases.

There are two different kinds of impacts that must be evaluated according to this direct physical effects. Dissolved oxygen depletion causes the decrease of biological respiration and induces disturbances to fish populations, also because the demand of the animals rises. The increase in settling velocity of suspended particles can cause siltation downstream of the discharge point.

Two scenarios of discharge flow were studied: a discharge of 8 m^3/s and a lower, but hotter, cooling water discharge of 5 m^3/s. The average thermal characteristics of the discharge, as well as the average temperature of the receiving river water, are depicted in following figure.

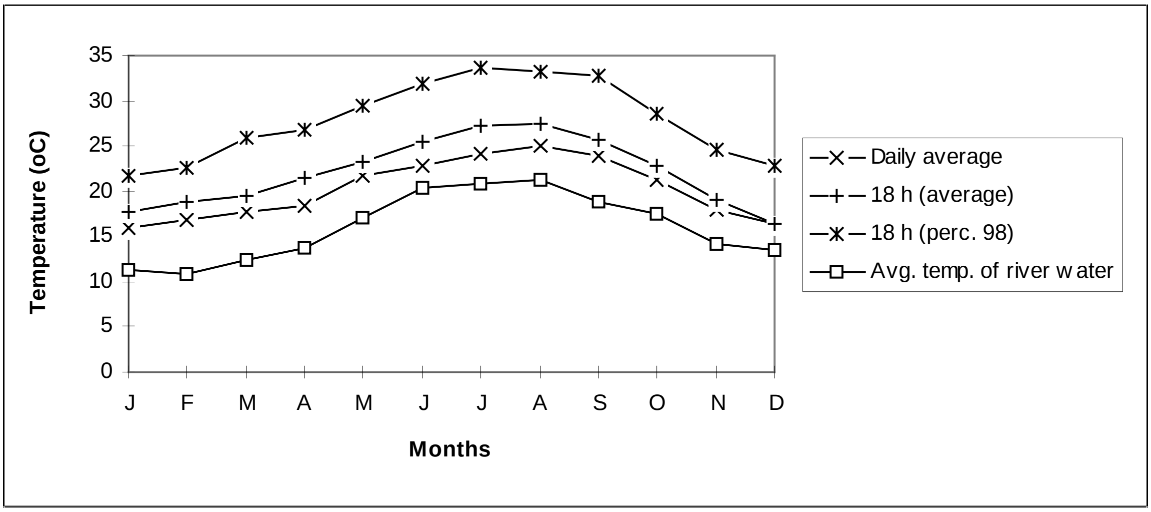

Figure 3.1 Evolution of thermal characteristics of the discharge and of the receiving river water

The results obtained for the simulated scenarios show that the highest impact is expected during summer, when the river flows are low. In summer, for the worst discharge scenario, the increase in river water temperature close to the discharge point is about 1.9 °C. Downstream of the discharge point the increase in river water temperature falls to about 1.2 °C (6 km downstream).

The impacts of this increase in river water temperature were not evaluated in this study, partly because of the project constraints. However, they are though to be negligible. Thus, an upper estimate of 0.001 mECU/kWh was considered.

3.4.6 Effects of noise on human health and amenity

Noise emission occurs along the different stages of this fuel cycle. In most cases the situation is a point source with human receptors at different distances. The transportation stages are an exception with linear sources along the transportation routes.

Noise has many effects upon humans and these can be categorised in as many different ways as there are categorisers. One listing of noise effects would separate them into 5 categories: (i) damage to the hearing system, (ii) impairment of hearing, (iii) task performance disruptions, (iv) non-acoustic physiological effects, and (v) annoyance. The same considerations could be applied to animals species but the disamenity caused by noise emission has a small value when compared to that of humans.

In the absence of specific studies for assessing damage costs from noise emissions in Portugal, a monetary valuation of this impact was defined considering values presented in previous studies carried out within the ExternE project (European Commission, 1995a-f). A damage cost of 0.03 mECU/kWh was suggested for this impact.

3.4.7 Impact on visual amenity

Coal fuel cycle comprises a variety of artificial elements susceptible to reduce the visual amenity of the sites in which they are located. Visual effects result from the power plant itself (different buildings, towers and chimneys and also the plumes emitted from the cooling towers), its access routes and the coal mining, transportation and storage. The disposal of bottom ashes, even temporary, can also represent an element of visual intrusion.

The visual perception of the affected landscape is directly related to the position of the observer in the terrain and to the range of vision of the affected areas. Such aspects are the result of a series of natural and cultural factors, namely:
- terrain morphology,
- land use,
- social values,
- visibility (amplitude of the visual impact),
- landscape sensitivity (visual compatibility of the development with the characteristics of the affected areas).

The most obvious characteristic when assessing the visual amenity damage is the difficulty in making an objective description of the visual impact. The lack of evaluation measures and tools for the visual effects creates uncertainty in evaluating visual intrusion, as there is no common basis for defining visual impact and for the quantification of the resulting externalities.

In general, during the construction phase of the power plant (and of the coal transportation facilities) there are a number of negative impacts that, although temporary, may have considerable magnitude. During operation some of the impacts identified during construction are eliminated. However, the impacts related to the presence of artificial elements in the landscape, as well as the impacts from changes in the terrain morphology, become definitive.

The assessment of the impact from visual intrusion is considered one of the most controversial and complex in terms of quantification. Direct assessments have been made from contingent valuation studies available for a relatively small number of cases. Values from these studies are difficult to transfer. Nevertheless, as a rough estimate, a value of 0.001 mECU/kWh was considered for this fuel cycle.

3.4.8 Effects of road traffic on road conservation

Truck traffic generates a variety of emissions and impacts. One of them is the impact in terms of road wear. The methodology used for determining the impact in physical terms related with the transportation of lime and gypsum is, to a certain extent, similar to that used in the US report (ORNL/RFF, 1992). However, the reduction in the lifetime of the road surface is calculated in a more pragmatic way.

The calculation of the lifetime of a road depends on the development of heavy vehicle traffic, expressed in the number of standard axle-passages (given the physical characteristics of the road). This development not being linear, the new lifetime was deduced by approximation in time. The methodological approach followed to assess this impact has been described in CEEETA (1995a). Giving the transport requirements in this case, it is possible to estimate the physical impact related with road use in terms of road life-time reduction.

The increase in traffic over and above the predicted level accelerates wear of the roads used. Therefore maintenance needed changes the resurfacing schedule, or each 20 years in the cases analysed. To assess the annual cost of this reduction, the difference is calculated between the two constant annuities determined by the actual cost of maintaining the road surface. The total cost of road damages per kWh of electricity generated range from 0.0015 mECU to 0.0023 mECU with a mid estimate of 0.0022 mECU.

Part of these damage costs are internalised through taxes and fees (applied to heavy vehicles, diesel oil...). So these damage costs should not be strictly regarded as externalities. The real external costs are lower than these values. So in this case, they can be considered as negligible.

3.4.9 Occupational and public health effects from accidents

Occupational and public accidents occur along the different stages of the coal fuel cycle. Giving statistical data for Portugal and data for stages outside EU, it was concluded to consider the following fuel cycle stages:

- Coal mining and transport (outside EU)
- Transport within EU (railway for coal and fly ash and road transportation for construction materials and equipment, lime, bottom ash and gypsum).
- Power plant operation (electricity sector)
- Construction and dismantling of the facility.

The approach followed to estimate the number of injuries and fatalities due to occupational and public accidents has been formerly described (CEEETA, 1995a). Ratios derived from statistical data have been considered to assess the impacts induced by an additional facility. For occupational accidents occurring outside the EU we had to rely on data from other studies compiled in the framework of the ExternE project (European Commission, 1998c). The specific monetary values used to quantify these impacts are described in this report (see appendix II).

The following table presents the results from our assessment. Total damages are high due essentially to a high level of mortality rate in railway transport. Giving the tendency observed during the last years, which shows a reduction of the number of deaths and injuries, and measures under implementation to lower these damages, statistical data of the last year available have been used in this case instead of an average value for the several years.

Table 3.14 Occupational and public accidents for the coal fuel cycle

Sector	Damage costs (mECU per kWh)			
	Killed	Major injury	Minor injury	Total
Mining (outside EU)	7.70E-01	5.99E-01	4.64E-04	1.37E+00
Ship transport (outside EU)	-	-	-	-
Railway transport	4.84E+00	1.38E-02	1.38E-02	4.86E+00
Road transport	1.06E-01	1.68E-02	5.64E-03	1.22E-01
Power plant operation	2.20E-03	1.52E-03	5.30E-03	3.72E-03
Power plant building/dismantling	4.40E-02	3.61E-02	1.28E-02	8.01E-02
Total	5.77E+00	6.68E-01	3.80E-02	6.43E+00

Impacts occurring outside EU were not totally assessed. Data on occupational accidents from ship transport are not available. Nevertheless, they are though to be low compared to occupational accidents from mining which represent, in our case, more than 20% of the total damage cost.

3.4.10 Effects in terms of employment

To assess impacts in terms of employment needs, we have to distinguish between direct and indirect employment.

Direct employment is related with employment existing at the different stages of coal fuel cycle (mining, construction and dismantling of the power plant, transport of lime, gypsum, coal and ashes and operation of the power plant). Statistical data on employment have been used to estimate the direct labour required by the coal fuel cycle. Indirect employment, or employment generated by the production of goods and services needed to build and operate the power plant of Pego, can be estimated using an input-output methodology.

The approach followed to estimate the effects on employment has been formerly described (CEEETA, 1995a). This approach is summarised in appendix VI.

The following table gives an estimate of the total direct labour required for the Portuguese coal fuel cycle.

Table 3.15 Direct labour required

Activities	Mean annual hours
1) Mining (outside EU)	N.A.
2) Coal transport by ship (outside EU)	N.A.
3) Transport of coal by railway	7 780
4) Transport of lime	6 980
5) Operation of the power plant	466 280
6) Transport of gypsum	16 230
7) Transport of bottom ashes	1 750
8) Transport of fly ashes	540
9) Construction and dismantling of the power plant	N.A.
Total working hours required per year	> 499 550
Number of jobs-equivalent required per year (1)	> 284
Number of jobs-equivalent required per TWh (1)	> 45.6

(1) 1 job-equivalent = 1760 h/year

Annual average direct labour required in Pego case is relatively substantial, even not completely quantified: more than 284 jobs-equivalent per year or more than 45.7 jobs-equivalent per TWh.

In the absence of multipliers, we had to rely on Input-Output and Employment tables published by the National Institute of Statistics. These data were treated in order to extract Keynesian type employment multipliers, in other words, multipliers incorporating the effects of final household consumption. By conjugating data from mean annual increases in demand with the employment multipliers we can estimate the indirect employment required a priori by the increase in final demand.

The impacts in terms of direct and indirect labour required are summarised in the following table.

Table 3.16 Labour needed

	Nº of job- equivalent/year	Nº of job- equivalent/TWh
Direct labour	284	46
Indirect labour	33 486	5 385
Total labour	33 770	5 431

The employment required a priori by the implementation of a new power plant should not be understood as job creation. So, the next step of the impact pathway approach should be the assessment of jobs created and their economic valuation. But until now, any methodology has been defined to perform this final step. This important work has to be conducted in further developments of the ExternE project.

3.5 Summary and interpretation of the results for the coal fuel cycle

The following tables summarise the results obtained for the Portuguese coal fuel cycle.

Table 3.17 Damages of the coal fuel cycle

	mECU/kWh	σ_g
POWER GENERATION		
Public health		
Mortality*- YOLL *(VSL)*	15.9 (60.7)	B
of which TSP	1.3 (5.0)	
SO_2	3.4 (15.5)	
NO_x	10.0 (39.5)	
NO_x (via ozone)	0.75	
Morbidity	3.19	A-B
of which TSP, SO_2, NO_x	1.85	
NO_x (via ozone)	1.34	
Occupational and public health	9.02E-03	A
Crops	6.59E-01	B
of which SO_2	2.30E-02	
NO_x (via ozone)	6.36E-01	
Ecosystems	nq	
Materials	8.89E-02	B
Monuments	nq	
Noise	ng	A
Visual impacts	ng	A
Employment	iq	
Global warming		C
low and high estimates (95% confidence interval)	2.9 - 107	
mid 3% and mid 1% (restricted range)	13.9 - 35.4	
OTHER FUEL CYCLE STAGES		
Occupational and public health	6.90	
Outside EU	1.80	B
Inside EU	5.10	A
Ecological effects	ng	B
Road damages	ng	A
Employment	iq	
Ozone on human health		
Mortality*- YOLL *(VSL)*	0.12	B
Morbidity	0.20	A-B
Ozone on crops	9.77E-02	B
Global warming		C
low and high estimates (95% confidence interval)	0.36 - 13.1	
mid 3% and mid 1% (restricted range)	1.7 - 4.3	

*Yoll= mortality impacts based on ‘years of life lost’ approach, VSL= impacts evaluated based on ‘value of statistical life’ approach.
ng: negligible; nq: not quantified; iq: only impact quantified; - : not relevant

Table 3.18 Sub-total damages of the coal fuel cycle

		mECU/kWh
YOLL *(VSL)*	low	26.4 *(69.3)*
	mid 3%	**42.3 *(87.6)***
	mid 1%	**66.5 *(112)***
	upper	160.7 *(216.4)*

Table 3.19 Benefits of the coal fuel cycle

	mECU/kWh	σ_g
POWER GENERATION	5.58E-02	B
OTHER FUEL CYCLE STAGES	-	
SUBTOTAL	5.58E-02	

Table 3.20 Damages by pollutant

	ECU / t of pollutant
SO_2 *- YOLL *(VSL)*	4 959 (20 128)
NO_x *- YOLL *(VSL)*	5 975 (21 530)
PM_{10} *- YOLL *(VSL)*	5 565 (20 050)
NO_x (via ozone)	1 500
CO_2	3.8 - 139**

*Yoll= mortality impacts based on ‘years of life lost’ approach, VSL= impacts evaluated based on ‘value of statistical life’ approach.
**using the 95% confidence interval.

For the Portuguese coal fuel cycle, as illustrated by Pego power plant case study, the total damages evaluated (excluding GWI) range between 23.1 and 40.6 mECU/kWh. Considering the mid point estimates, about 72% of the estimated results are impacts from air pollutants on human health and 26% impacts from occupational and public accidents. If global warming impacts are included in these figures, both the uncertainty and the final estimate of damage costs raise substantially, becoming the final figure in the range between 26.4 and 160.7 mECU/kWh. Considering the total estimated external costs, GWI represent between 12% and 75% of these figures. The large uncertainties that remain for the assessment of GWI require an extension of the research in this area.

Mortality associated with transportation is very high in Portugal (CEEETA, 1992) comparing with other European countries (a factor 3 to 5). Considering the same scenario of mortality from transportation activities during the next 25 years is a strong assumption. One could expect a substantial reduction of these damages during this relatively large period of time.

Impacts from occupational accidents are to a certain extent already internalised in the cost of electricity. Hence, part of this cost should not be considered as an externality. But to extract the real external cost from occupational damages, further research is still necessary.

4. NATURAL GAS FUEL CYCLE

In Portugal, natural gas is only available since 1997. The introduction of natural gas has been a priority of the Portuguese energy policy in the last years. The power plant under study has been planned to fulfil this strategy. The implementation of the ExternE methodology will consider this projected plant.

4.1 Definition of the fuel cycle, technologies and sites

The natural gas power plant is located near Porto City, in the North of Portugal (see figure 1.4), in the right margin of Douro River, municipality of Gondomar (Medas site). The total area allocated to the power plant is of about 73 ha, but only part of this area is occupied by the power plant (EDP, 1992).

The generation technology is a combined cycle gas turbine (CCGT) with a net efficiency of 48%. A CCGT associates a gas turbine, which generates electricity, to a heat recovery steam generator and a steam turbine which produces additional electricity (see figure hereafter). Combined cycle technologies can significantly raise the efficiency of power plants from 30-33% to 45-55%.

The Tapada do Outeiro power plant is composed by two main platforms: the first one integrates the gas turbines, steam boiler and turbines and transformers. The second platform ensures the connection to the electricity network. The connection is done through two power lines of 220 kV.

The general characteristics of natural gas, which will be used at the Tapada do Outeiro power plant, are presented in appendix X. In average conditions of water and air temperature, the consumption of natural gas was estimated in 12.7 Nm^3/s (or 9.93 kg/s) for each gas turbine. Hence, the total annual consumption of natural gas should be of about $1.4x10^9$ Nm^3 (about 57% of the national consumption estimated in $2.5x10^9$ Nm^3).

The power plant to be fully operational in 1998 presents a total net power capacity of 918 MW distributed in two groups of 459 MW each with a mean availability of 86%. This capacity represents about 10% of the total Portuguese power capacity and will ensure an annual electricity generation of 6,916 GWh (about 20% of the electricity consumption in 1995).

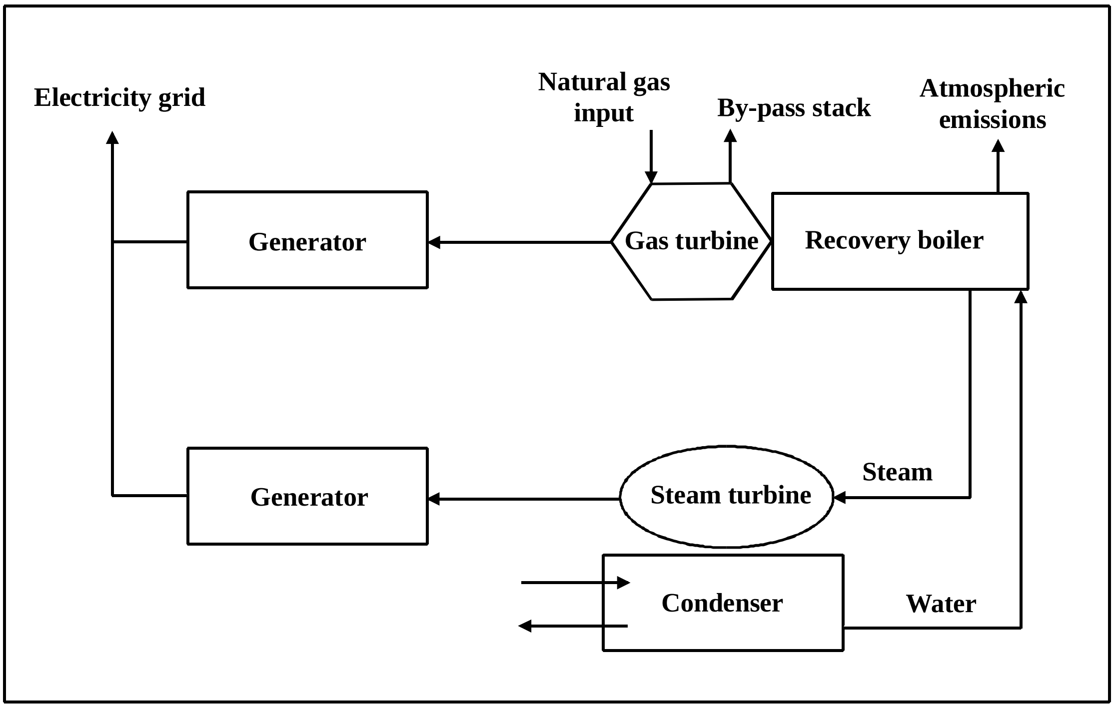

Figure 4.1 Combined Cycle Gas Turbine

The main characteristics of the NG power plant are summarised in the following table.

Table 4.1 Main characteristics of the NG power plant

Characteristic	Value
Gross capacity (MW)	1 000
Mean availability	86 %
Efficiency	48 %
Operating time (h/year)	7 500
NG consumption :	
- Nm^3/year	$1.378x10^9$
- TJ/year	52 150
Electricity generation (GWh/year)*	6 916

* Net generation = Gross electricity production - internal electricity consumption.

4.2 Overview of burdens

The main stages of the natural gas fuel cycle are basically: (i) gas prospecting and extraction, (ii) gas treatment, (iii) transportation (by pipeline from the gas field, to the gas treatment unit and then to the power station) and (iv) electricity generation.

4.2.1 Natural gas prospecting and extraction

The production phase consists on extracting hydrocarbons from the reservoir and transporting them to a processing facility. The gas-liquid mixture extracted from the reservoir contains methane, hydrocarbon liquids, free water, water vapour, solids and other contaminants.

Two types of extraction methods are used: conventional extraction and enhanced recovery. In conventional extraction method, natural gas is extracted by either the existing pressure of the reservoir or by using pumps. In the second method, which is less disseminated, natural gas is extracted by fracturing and directional drilling. Fracturing involves the use of either chemical explosives or water under pressure.

The primary waste products from gas wells are, in general, oils, heavy metals toxicants and dissolved solids contained in the drilling mud or produced water (ORNL & RFF, 1993). Specifically, the waste products are oil and grease, suspended solids, phenol, arsenic, chromium, cadmium, lead and barium. The drilling wastes from gas do not change significantly from one site to another.

Drilling operations also induce significant amounts of air pollution. Large diesel engines typically power the drilling equipment and emit significant quantities of air pollutants (namely hydrocarbons, particulates, sulphur oxides, nitrogen oxides and carbon dioxide). These emissions can be important during drilling of deep wells requiring large power outputs or in large fields where multiple drilling operations occur simultaneously.

Other sources of air pollution include light organic compounds that may volatilise from reserve and other holding pits used as waste repositories during drilling (e.g. volatilised from solvents, recovered hydrocarbons and other chemicals used in drilling process); the volume of volatile organic compounds is insignificant when compared to diesel engine emissions.

4.2.2 Treatment of natural gas

The natural gas extracted requires a specific treatment before it can be commercially useful. This treatment can be done directly in the field. The purpose of the field processing is to remove the unwanted ingredients of the well stream and to separate the desirable components. The processing of natural gas in the field consists of four basic processes (Beggs, 1984): (i) separation of natural gas from free liquid and solid contaminants; (ii) processing the gas to extract recoverable hydrocarbons vapours; (iii) gas processing to condensable water vapour which could possibly cause hydrate formation; (iv) the removal of hydrogen sulphide dioxide and other unwanted well stream components. This treatment is generally operated with wells associating gas and oil.

The gas sold to gas transmission companies must meet constituent requirements with respect to water content, hydrocarbon's dewpoint, heating value, and hydrogen sulphide content. To satisfy the requirements of the sales contract a gas processing plant must treat most gas streams. Typical processes performed in a gas processing plant include: (i) hydrocarbon removal; (ii) dehydration; (iii) gas sweetening.

4.2.3 Natural gas transportation and storage

The transport of natural gas from the Hassi R'Mel gas field to the power plant will be done by pipeline. It will be used the Maghreb-Europe pipeline (1,870 km) being constructed to supply Algerian gas to Spain and Portugal through Morocco - strait of Gibraltar (the figure 4.2, hereafter, shows the pipeline route from Africa to Portugal and the gas network of the Iberian Peninsula).

The sector of the pipeline that crosses the Strait of Gibraltar will have a length of 48 km, joining Tangier in Morocco and Sahara de los Atunes in Spain. The gas transport will use two pipelines with a nominal diameter of 527 mm made of steel (Transgás, 1993). For the terrestrial sectors it will be used a pipeline (diameter of 1.22 m) made of high resistant steel with an outside coating of polyethylene and an interior of epoxy coating. The wall thickness will vary from 14 to 20 mm.

The main structure of natural gas project in Portuguese territory is divided in the following components: (i) connection line between Campo Maior (border with Spain) and Monte Redondo to Maghreb-Europe pipeline; (ii) main line between Setúbal and Braga; (iii) branch lines to supply different urban and industrial sites; (iv) branch line to Tapada do Outeiro power plant; (v) connection line with subterranean storage station at Monte Redondo; (vi) compressor station (option under study). The pipeline length in Portugal is of about 800 km (including major branch lines).

During the transmission of natural gas through pipelines methane can be emitted either through leaks or it can be vented on purpose due to normal operations, maintenance and construction. Natural gas or methane emissions from pipelines can be either voluntary or accidental. Gas pipeline personnel for a variety of reasons commonly perform venting of methane: normal operations, maintenance and construction, natural equipment leaks, methane releases from transmission pipelines.

The natural gas industry uses engines to power compressors for pipeline transportation of gas. The major pollutant of natural gas-fired compressor engines is NO_x, which is immediately formed in combustion due to the high temperature, pressure and abundant air environment in the internal combustion engines. CO and hydrocarbons are emitted, although these pollutants are produced in smaller amounts than NO_x. Emissions of sulphur oxides are usually low due to the negligible amount of sulphur contained in natural gas.

Figure 4.2 The Maghreb-Europe natural gas pipeline (Transgás, 1995)

Natural gas fuel cycle generates small amounts of hazardous and toxic wastes, as well as sometimes relatively small amounts of solid wastes in general (European Commission, 1995d). However, during pipeline construction, and as far as NG transport stage is concerned, large amounts of soils and sediments are produced. The amount of soils that was necessary to remove during the construction of the pipelines in Portugal is estimated in $3.28 * 10^6$ m^3. In most of the cases such amounts of solid materials are not suitable (or necessary) for other uses. In some areas, such as rivers which are crossed by pipelines, sediments that must be removed from the bottom may contain chemical contaminants (e.g. heavy metals) and hence they should be disposed in landfills or undergo some other specific treatment. An inventory of burdens from the NG fuel cycle is presented in table X-2 (see appendix X).

4.2.4 Power and electricity generation

The Tapada do Outeiro power plant is composed by two main platforms: the first one integrates the gas turbines, steam boiler and turbines, and transformers. The second platform ensures the connection to the electricity network. The connection is done through two power lines of 220 kV.

A CCGT associates a gas turbine, which generates electricity, to a heat recovery steam generator and a steam turbine that produces additional electricity. Combined cycle technologies can significantly raise the efficiency of power plants from 30-33% to 45-55%.

This technology is supported in a gas-fired combustion turbine in which natural gas is injected into compressed air in a combustion chamber. The fuel ignites, generating heat and combustion gases, and the gas mixture expands to drive a turbine, which is usually located on the same axle as the compressor. Various heat recovery staged compression, and combustion designs are used to increase overall efficiency.

This type of technology uses both gas and steam turbines. Hot exhaust gases from the gas turbine (at about 500-600^o C temperature) are partially recovered in a heat recovery steam generator without additional fuel burning. Steam produced is then expanded through a conventional steam turbine associated to an electricity generator. In this cycle 2/3 of total power is produced by gas turbines.

Each group of the Tapada do Outeiro power plant (2 groups) is composed by two gas turbines of 150 MWe, a heat recovery system and one steam turbine/electricity generator of 170 MWe.

Atmospheric emissions from the power generation stage

Most of the atmospheric emissions result directly from combustion process, with total emissions dominated by natural gas utilisation at the generation plant. Flue gases from natural gas burning are rejected to the atmosphere through a set of 4 stacks with 40 m height and a diameter of 6 m each. Table X-1 in appendix X summarises the main characteristics of the flue gas exit system. The atmospheric emissions are basically NO_x and very low concentrations of SO_2, VOC's and particulates.

Emissions to water at the power plant

Cooling water is pumped from Douro River, being the discharge made downstream in the same river. An open circuit was the alternative chosen, mainly because of the Douro flow regime, which is characterised by high flow rates during most of the year. At the normal capacity of the power plant, each generating group releases about 8.5 m^3/s of heated water into the river, thus resulting in a total discharge of heated water from the power plant of about 17 m^3/s. The water temperature increase after passing through the cooling circuit is estimated to be lower than 10° C in the worst scenario.

With regard to other liquid effluents (amount and characteristics) produced in the plant during power generation, they are presented in table X-1 (see appendix X).

4.3 Selection of priority impacts

Natural gas fuel cycle presents a diversity of impacts with more or less complex pathways. Yet, since the different components of a given NG development have specific impacts, it seems quite difficult to establish a common framework capable of handling all of them with equal accuracy. Given the constraints of an *a-priori* establishment of priority impacts, and once considering the particular features of our NG case study, we have defined the impacts listed hereafter.

The following impacts are listed for a priority analysis in our study:

1. Global warming impacts.
2. Effects of air pollutants on human health.
3. Impacts on terrestrial and freshwater ecosystems:
   Effects of ozone and acidic deposition on agricultural crops and forests
   Effects of opening corridors for pipelines on terrestrial ecosystems
   Effects of thermal discharges upon freshwater ecology
4. Impacts of air pollutants on building materials
5. Risks associated with natural gas transport (pipeline leaks/failures)
   Social risk associated with NG transport
   Ecological risk associated with NG transport
6. Impact on visual amenity.
7. Occupational and public health effects from accidents.
8. Effects of noise on human health and amenity.

The overall approach followed for the assessment of these impacts has been described in chapter 2. Nevertheless, the impact related with risks associated with natural gas transport has not been retained in the framework of previous ExternE studies. Given the dimension of the pipeline in our case, CEEETA has conducted such analysis and quantified this impact (the methodological approach is presented in appendix VI).

4.4 Quantification of impacts and damages

4.4.1 Contribution of greenhouse gas (GHG) emissions to global warming

The impacts of global warming are diverse and potentially problematic to evaluate from the economic point of view (see appendix V). Given the scope of our study, we use values derived from other ExternE studies (European Commission, 1998b), which are presented in ECU/t, and apply them to our fuel cycle.

Considering these values, as well as the GHG emissions for the Portuguese natural gas fuel cycle (see table hereafter), we obtain estimates of the external costs of global warming.

Table 4.2 Total emissions of GHG in terms of CO_2 equivalent*

Activity	g/kWh	%
Extraction (outside EU)	nq	-
Treatment (outside EU)	3.0	0.7%
Transport (pipeline)	5.1	1.2%
Building of facilities	nq	-
Power plant operation	432.1	98.2%
Dismantling of facilities	nq	-
Total	440.2	100%

* Emissions of CH_4 and N_2O were converted in terms of CO_2 equivalent using values suggested by the IPCC (1995) or 21 and 310 respectively.

The electricity generation stage is the most important stage regarding GHG emissions with more than 98% of the total emissions. Emissions from the other stages seem to be negligible. Nevertheless, no data is available for the extraction stage where emissions might have some relevance.

Giving the damage costs established in the framework of this project (3.8-139 ECU per t of CO_2 equivalent for the conservative 95% confidence interval and 18-46 ECU per t of CO_2 equivalent for the illustrative restricted range) and the GHG emissions estimated in this case, impacts from global warming are as shown in the following table.

The σ_g column gives a label (A, B or C) for the range of uncertainty estimated for the defined damage. The label A is used for results with a high confidence (geometric standard deviation of 2.5 to 4) and the label C is associated with a low confidence in results (geometric standard deviation of 6 to 12). For more details on the uncertainty issue see appendix VIII.

Table 4.3 Damage costs from GHG emissions

	mECU/kWh	σ_g
POWER GENERATION		
Global warming		C
low and high estimates (95% confidence interval)	1.6 - 61.1	
mid 3% and mid 1% (restricted range)	7.8 -19.9	
OTHER FUEL CYCLE STAGES		
Global warming		C
low and high estimates (95% confidence interval)	0.03 - 1.1	
mid 3% and mid 1% (restricted range)	0.15 - 0.37	

4.4.2 Impacts of air pollutants on human health

The computer tool EcoSense 2.0 supports the methodology used to estimate the physical and economic damages or benefits from primary air pollutants and aerosols. For each atmospheric pollutant considered (particulate and aerosols) it has been performed a physical and economic assessment for three scenarios (low, mid and high). Impacts from ozone formation are considered separately.

Impacts of primary pollutants and aerosols on human health

Emissions of atmospheric pollutants occur at all the stages of the NG fuel cycle. Nevertheless, the power generation stage is, in this case, the main source of these emissions. Consequently, this stage is the only one considered for the assessment of the present category of impacts.

The EcoSense model used to estimate the physical and economic damages from primary pollutants (particulates, SO_2 and NO_x) and aerosols (sulphates and nitrates) is described in appendix I. Analytical details for human health used to assess this impacts (stock at risk, exposure-response data and valuation data) are presented in appendix II. Results are presented for the mid estimate or the best estimate giving the present knowledge. For more details on these results see appendix X.

Table 4.4 Summary results of damages on human health from primary pollutants and aerosols

	mECU/kWh	σ_g
POWER GENERATION		
Public health / Mortality*- YOLL *(VSL)*	0.18 *(0.73)*	B
Public health / Morbidity	0.02	A-B
OTHER FUEL CYCLE STAGES		
Public health	nq	-

*YOLL: years of life lost, VSL: value of statistical life.
nq: not quantified; -: not relevant.

Impacts of ozone on human health

The estimates of ozone damages on human health per tonne of precursor emission (NO_x and VOC's) suggested by Rabl (1996) range between 230 and 5750 ECU per tonne of NO_2 equivalent (NO_x emissions are NO_2 equivalent), with a mid point estimate of 1150 ECU/t of NO_2 equivalent. The following table gives the results of the ozone damage costs for the Portuguese NG fuel cycle.

Table 4.5 Summary results of damages on human health from ozone

	mECU/kWh	σ_g
POWER GENERATION		
Public health / Mortality- YOLL	1.29E-02	B
Public health / Morbidity	2.28E-02	A-B
OTHER FUEL CYCLE STAGES		
Public health / Mortality- YOLL	ng	B
Public health / Morbidity	ng	A-B

ng: negligible.

4.4.3 Impacts on terrestrial and freshwater ecosystems

The main pollutant of concern for natural gas fuel cycle is ozone; a secondary pollutant formed subsequently in the atmosphere induced by the NO_x emissions at the power plant. Acidic deposition in consequence of NO_x emissions is also of concern in what regards soil acidification.

Impacts of primary air pollutants and acidic deposition on ecological receptors

The methodology used to estimate the physical and economic damages from primary pollutants and aerosols is also supported by the EcoSense model. For each atmospheric pollutant considered it has been performed a physical and economic assessment for three scenarios (low, mid and high). Nevertheless, results are only presented for the mid estimate with a range of variation given by σ_g column. Analytical details for ecological effects are presented in appendix IV. See appendix X for more details on the following results.

Table 4.6 Summary results of damages on ecological receptors from primary pollutants and acidic deposition

	mECU/kWh	σ_g
POWER GENERATION		
Crops	-7.44E-04	B
Other ecosystems	nq	-
OTHER FUEL CYCLE STAGES		
Ecological effects	nq	-

nq: not quantified; -: not relevant.

Impacts of ozone on ecological receptors

Access of ozone into the leaf is now known to be mainly through the stomata, although waxy leaf surfaces may be partially degraded by ozone. Most plants have open stomata during the day, so damage is largely confined to this period. It is thought by many that the degree of stomatal opening is the principal, or even the sole, response in determining differences in plant response to ozone. There are a number of factors that determine plant response to ozone. They can be divided in two categories: the (i) genetic and the (ii) environmental factors.

Perhaps due to this inherent complexity of plant responses to ozone, and because forest ecosystems comprise a large variety of plant species living in a large variety of environmental conditions, no dose-response functions have been established to evaluate the impacts of ozone on forest ecosystems, and so they will not be physically quantified in this study.

As for the monetary quantification of impacts of ozone on human health we use the approach presented by Rabl (1996). In the next table are shown the results obtained. NOx emissions at Tapada do Outeiro NG power plant are of 214 tonnes per year.

Table 4.7 Summary results of damages on ecological receptors from ozone

	mECU/kWh	σ_g
POWER GENERATION		
Crops	1.08E-02	B
Other ecosystems	nq	-
OTHER FUEL CYCLE STAGES		
Crops	ng	B
Other ecosystems	nq	-

ng: negligible; nq: not quantified; -: not relevant.

Effects of opening corridors for pipelines on terrestrial ecosystems

This impact is thought to be negligible considering the lifetime of the power plant, although some effects were expected during the implementation phase of the pipeline. Giving the very small values that can be expected from such impact, a rough estimate of less than 0.001 mECU/kWh was considered in the framework of this study.

Ecological effects of thermal discharges in the freshwater system

The discharge of heated water in a receiving water body causes the increase in the normal temperature of its water. The consequences of this are (1) the decrease of the dissolved oxygen content of the water; (2) the increase of rates of biochemical reactions; (3) the emission of erroneous data on the physical properties of the environment to the aquatic organisms; and (4) the possible exceedance of lethal thermal thresholds for some aquatic species.

The site under analysis presents some peculiarities that can influence impact analysis, and namely the effects on sedimentation patterns downstream of the discharge point. In fact, about 1800 m downstream of the discharge point there is a large run-of-river hydropower plant with a mobile dam.

As far as sedimentation pattern changes is concerned, this impact was considered negligible because of the presence of a dam downstream of the discharge point. Thus sedimentation in the area is thought to be more affected by the decrease of river flow velocities than by the increasing settling velocity induced by the thermal effect.

The major impacts of thermal discharges from the power plant are ecological ones, with outcomes in terms of possible disturbances to the aquatic forms of life, and namely to the freshwater fish populations. This impact will be, according to the simulated scenarios, very low and probably negligible once considered the entire lifetime of the power plant. As a rough estimate a value lower than 0.001 mECU/kWh was considered for this impact.

4.4.4 Impacts of air pollutants on building materials

These impacts arise mainly from acidic deposition due to NO_x emissions from the power plant. NO_2 combine with moisture in the atmosphere and is then deposited as acid in the precipitation.

The main limitation for the quantitative evaluation of this impact (both from the physical and economic points of view) is the low quality of the existing surfaces (e.g. general buildings, houses, historic monuments) and European inventory for materials. Nevertheless, data and Exposure-Response Functions included in the EcoSense tool (see appendix III) allow for the quantification of some impacts.

Table 4.8 Summary results of damages on materials

	mECU/kWh	σ_g
POWER GENERATION		
Materials	9.60E-06	B
OTHER FUEL CYCLE STAGES		
Materials	nq	

ng: negligible; nq: not quantified; iq: only impact quantified; -: not relevant

4.4.5 Risks associated with NG transport (pipeline leaks/failures)

The storage and transport of a flammable gas over long distances (the total length of the pipelines is of about 1,870 km) introduce risks (social and ecological) that must be regarded as externalities.

From the point of view of transport safety of a flammable product by pipeline, it is particularly important to consider the potential risks of dispersion and ignition of the gas, which may result from an accidental discharge in the transportation system. Such discharge can take the form either of a massive release of the flammable gas or of a leak through a failure of fewer dimensions, followed by the formation, in the atmosphere, of a flammable cloud. Depending on the meteorological and topographic conditions, such a cloud will undergo atmospheric dispersion and, if an ignition source is reached, it can cause serious damages (depending mainly on the emitted thermal radiation and on the pressure wave caused by a possible explosion).

For the social risk, the total damage cost per year for the EU branch of the pipeline varies between 4.23E-04 and 3.73E-03 mECU/kWh for the major (600 m) and minor (200 m) distances to the pipeline, respectively. Despite the simplicity of the approach adopted and the low quality of data, the results (see table X-3 in appendix X) are presented for the worst case (highest probabilities of damages) and seems to show that, even in this case, the values of impact on human health are very small.

The regional evaluation of this impact was made considering the total length of the Maghreb-Europe pipeline, which is of 1,870 km. The simplistic approach considers that the extension of pipeline outside Portugal and Spain has similar characteristics but a lower population density in the vicinity of pipeline corridors. The final regional impact, from a physical point of view, will therefore be the result of multiplying physical damages obtained for EU (in cases/km of pipeline) by the length of the Maghreb pipeline and a factor accounting for the lower population density (50%). Given the methodological approach followed for quantifying human health impacts outside EU, the final results for this impact range between 6.01E-05 and 5.29E-04 mECU/kWh. The total results from this impact, or 2.04E-03 mECU/kWh for the best estimate, are very low and they are close to the band where they should be considered negligible.

Ecological risk assessment is the application of risk assessment to non-human organisms, populations and ecosystems. The transport of flammable gas by pipeline may produce accidental discharge, which could originate damages in ecosystems.

Due to the absence of data to permit evaluate the ecological risks from the natural gas transport, it is not possible to analyse and quantify this impact. Nevertheless, as a rough estimate, a value of 0.001 mECU/kWh was considered for this impact.

4.4.6 Aesthetic impacts

The assessment of the impact from visual intrusion is considered one of the most controversial and complex in terms of quantification. Direct assessments have been made from contingent valuation studies available for a relatively small number of cases. Values from these studies are difficult to transfer and therefore will not be applied in this case. Furthermore, taking into account that this new plant will substitute an older coal power plant, the additional impact for the power generation stage is thought to be very low, even positive.

4.4.7 Occupational health effects

Accidents are of major concern during onshore activities, drilling and gas prospecting, as well as during all the construction phase of a NG project development (e.g. construction of pipelines, power plant facilities). The quantification of these impacts is based upon historical records of accidents and other heath effects observed in similar developments. Our case study is a new project under conclusion, so there is no historical data or it is not yet compiled. As a rough assessment results from previous studies are used to provide a range of cost for this impact. The impact from occupational accidents ranges from 0.0132 to 0.0379 mECU/kWh with a mid value of 0.026 mECU/kWh.

4.4.8 Impacts of noise on human health and local amenity

Noise impacts from natural gas fuel cycle occur mainly at the electricity generation stage (power plant) and, although temporary, during the installation of the pipelines. Since pipelines often cross over wild areas or rural places (were sound pressures are often very low), the presence of noisy machinery and other point sources of noise can affect the wilderness and amenity of those areas.

In the absence of specific studies for the assessment of damage costs from noise emissions in Portugal, the monetary valuation of this impact was made by transferring the values presented in the NG fuel cycle study carried out within the ExternE project. In such study a damage cost of 0.03 mECU/kWh was suggested for this impact.

4.4.9 Land use for dumping solid waste and removed soils

The natural gas fuel cycle produces little solid wastes. The largest amount of solid wastes produced will arise during construction phase of power plant and pipelines network. The amount of soils that will be necessary to remove during the construction of the pipelines is estimated in $3.28 * 10^6$ m^3. Part of this soil can be used by other activities, most of it will introduce at the medium term small changes in the local topography, and a significant amount might be transported by water flows, causing siltation problems in water streams and reservoirs. Besides, during dry periods, there might be local air quality problems.

4.5 Summary and interpretation of the results for the NG fuel cycle

The following tables summarise the results obtained for the Portuguese NG fuel cycle.

Table 4.9 Damages of the NG fuel cycle

	mECU/kWh	σ_g
POWER GENERATION		
Public health		
Mortality*- YOLL *(VSL)*	0.20 (0.74)	B
of which TSP	1.04E-04 (4.09E-04)	
SO_2	4.47E-03 (0.022)	
NO_x	0.18 (0.71)	
NO_x *(via ozone)*	1.29E-02	
Morbidity	0.05	A-B
of which TSP, SO_2*,* NO_x	0.02	
NO_x *(via ozone)*	0.02	
Occupational and public health	6.13E-03	A
Crops	1.10E-02	B
of which SO_2	1.46E-04	
NO_x *(via ozone)*	1.08E-02	
Ecosystems	nq	
Materials	9.20E-04	B
Monuments	nq	
Noise	ng	A
Visual impacts	ng	A
Global warming		C
low and high estimates (95% confidence interval)	1.6 - 60.1	
mid 3% and mid 1% (restricted range)	7.8 - 19.9	
OTHER FUEL CYCLE STAGES		
Occupational and public health	0.081	
of which Outside EU	2.08E-04	B
Inside EU	0.08	A
Ecological effects	ng	B
Road damages	ng	A
Social risk	3.04E-03	B
Ozone on human health		
Mortality*- YOLL	ng	B
Morbidity	ng	A-B
Ozone on crops	ng	B
Global warming		C
low and high estimates (95% confidence interval)	0.03 - 1.1	
mid 3% and mid 1% (restricted range)	0.15 - 0.37	

*Yoll: years of life lost, VSL: value of statistical life.
ng: negligible; nq: not quantified; -: not relevant.

Table 4.10 Sub-total damages of the NG fuel cycle

		mECU/kWh
YOLL *(VSL)*	low	2.0 *(2.5)*
	mid 3%	**8.3** *(8.8)*
	mid 1%	**20.6** *(21.2)*
	upper	61.8 *(62.5)*

* using the illustrative restricted range for global warming impacts.

Table 4.11 Benefits of the NG fuel cycle

	mECU/kWh	σ_g
POWER GENERATION	8.89E-04	B
OTHER FUEL CYCLE STAGES	**-**	
SUBTOTAL	8.89E-04	

Table 4.12 Damages by pollutant

	ECU / t of pollutant
SO_2 *- YOLL *(VSL)*	5 271 (20 486)
NO_x *- YOLL *(VSL)*	6 562 (23 641)
PM_{10} *- YOLL *(VSL)*	6 797 (24 470)
NO_x (via ozone)	1 500
CO_2	3.8 - 139**

*Yoll= mortality impacts based on 'years of life lost' approach, VSL= impacts evaluated based on 'value of statistical life' approach.
** using the 95% confidence interval.

Estimated impacts from the NG fuel cycle are low when compared with the coal fuel cycle (see previous chapter). Atmospheric emissions at the power generation stage are small and dominated by the NO_x. The results of our assessment, without considering global warming, range between 0.32 and 0.58 mECU/kWh. Impacts from air pollutant on human health account, as for coal, for a large portion of the total impacts.

The major damages are related with global warming effects, the other relevant impacts being one or two order of magnitude lower. If effects from greenhouse gases' emissions are considered the outcome of the evaluation is in the range between 2.0 and 61.8 mECU/kWh, which makes the differences between coal and natural gas much more narrower. This is an important conclusion since for natural gas fuel cycle the GWI account for almost the totality of the external costs (84% to 99%, respectively for the low and high estimates).

5. BIOMASS FUEL CYCLE

In Portugal, there are no power plants using biomass to generate exclusively electricity. The case chosen for the implementation of the ExternE study is a cogeneration plant in a woodpulp mill. This case has been used to develop the ExternE methodology for the biomass fuel cycle. This chapter will present an updated version of this study (see CEEETA, 1994).

5.1 Definition of the fuel cycle, technologies and sites

The cogeneration plant under study is located at Figueira da Foz (Centro region of Portugal, see figure 1.4).

For this cogeneration plant, two situations concerning biomass supply have been considered for the fuel cycle analysis:

1. The real situation (case A), where the bark, a by-product resulting from the debarking process of eucalyptus roundwood in a woodpulp mill, is used for generating power and steam (cogeneration plant).

2. The possibility of using all the biomass produced from specific eucalyptus plantations in a short rotation scheme. This is a theoretical case (case B), as there are no eucalyptus plantations used only for energy purposes in Portugal.

Therefore, we will have two different situations for the stages of biomass supply and treatment.

Situation A is essentially characterised by:
- transportation of the roundwood from the tree plantation to the factory;
- storage of roundwood and feeding of the debarking drum;
- debarking of roundwood and treatment of bark;
- storage of bark;
- cogeneration;
- flue gas treatment;
- collection, transportation and treatment of ashes.

Situation B is characterised by:
- preparation of land, planting, fertilisation and maintenance of the plantation;
- felling and forwarding;
- transport of fuel;
- storage and feeding of woodchipper;
- production and storage of woodchips;

- cogeneration;
- flue gas treatment;
- collection, transportation and treatment of ashes.

A reference area (Abrantes, Tagus Valley and Rio Maior) has been defined for the fuel supply. As apart from being a region from which the company obtains much raw material, its characteristics (size of property, soil and climatic conditions) mean it will be the best area to adapt to the intensive production of biomass for energy purposes.

The main characteristics of the cogeneration plant under study are described in table hereafter for each case. Detailed characteristics of the biomass fuel cycle are presented in tables XI-1 (case A) and XI-2 (case B) of the annex XI.

Table 5.1 Technical characteristics of the biomass plant

Site	Figueira da Foz, PT	Figueira da Foz, PT
Case	A	B
Energy generation process	Cogeneration	Cogeneration
Plant size:		
- Thermal capacity	92 MWth	92 MWth
- Power generation capacity	16.8 MWe	16.8 MWe
Mean load factor	52 %	52 %
Efficiency	77 %	77 %
Operating time (h/year)	8 310	8 310
Consumption (GJ/year)	1 549 424	1 549 424
Energy generation:		
- Heat (GJ/year)	612 640	612 640
- Electricity (GWh/year)*	127.3	125.5

* Net generation = Gross electricity production - electricity consumption associated with fuel processing and energy generation.

5.2 Overview of burdens

5.2.1 Soil preparation, planting and other cultural operations

This stage is only relevant for case B. For case A, we are not going to consider the production of bark in forest. Nevertheless, as bark is now transported with woodpulp instead of the traditional debarking in forest, we have to consider the effects of this removal namely in terms of fertilisers taken away.

In situation B, all the biomass obtained from eucalyptus plantations is used for energy purpose. So, we are going to simulate such a plantation; as there are no eucalyptus plantations used only for this purpose.

The management plan of the plantation will be as follows:
Year 0 - Preparation of land.

Year 1 - Planting.
Year 3 - Maintenance (undergrowth clearance and fertilisation).
Year 6 - Harvesting (felling and forwarding).
Year 8 - Maintenance (undergrowth clearance and fertilisation).
Year 12 - Harvesting (felling and forwarding).
Year 14 - Maintenance (undergrowth clearance and fertilisation).
Year 18 - Harvesting (felling and forwarding).

Land preparation and planting

The preparation of the land basically depends on the following characteristics:

- gradient,
- existing vegetation (including stumps),
- soil type,
- size of property,
- climatic characteristics of site.

All the above operations are executed with a 140 to 165 hp track-type tractor. The extraction and removal of tree stumps is done with a rake attachment that replaces the front blade. Ripping is achieved with the tractor’s ripper. The digging of the land is carried out with a turn plough attached to the tractor.

The cost and productivity of the equipment are presented in the following table.

Planting and fertilisation are done manually by a variable number of workers. For the described conditions, we have considered the use of a group of 12 people, which will cover 2 hectares per day. Their average cost will be 19.8 ECU per person per day.

The price of the plants is 0.11 ECU per plant (including its transport). For a plantation with this objective, we have considered a planting area measuring 4x1m or one which will give a density of 2,500 plants per hectare.

The fertiliser used would be a ternary composite 1:3:1 type fertiliser. The quantity applied will be around 200 g per plant, meaning a cost of 0.05 ECU per plant.

Maintenance

Removal of the undergrowth is done mechanically using a 70 to 90 hp track-type tractor, with a disc harrow attachment. Cost per hour is 22.3 ECU and average productivity is 3 h/ha. Cost per hectare is therefore 67.1 ECU.

Fertilisation is done mechanically using a 70 to 90 hp track-type tractor, which costs 22.3 ECU per hour. Average productivity is 2 h/ha, which represents a total cost of 44.7 ECU/ha.

At this stage, the fertiliser used will be a ternary composite 4:8:3 type fertiliser. The average quantity applied will be 500 kg/ha, which corresponds to a total cost of 135.7 ECU.

Emissions from this stage are summarised in table XI-2 of the annex XI.

5.2.2 Biomass harvesting

This stage is mainly relevant for case B. For case A removal of nutrients is quantified.

Felling

Felling is carried out mechanically using a small harvester. The machine has an average productivity of 9 m^3/h, which corresponds to an average price of 7.8 ECU/m^3.

Forwarding

A forwarder is used for this operation. It has an average productivity of 16 cubic metres, which corresponds to an average price of 3.9 ECU/m^3. The equipment will also load the lorry that transports the wood, as it also has a crane.

Considering the land characteristics and the forest management type, we suppose the following average productivity levels of the plantation for three rotations as 20 m^3/ha/year, which is 120 m^3/ha/6 years or a rotation.

For this case, the emissions generated during this stage are those related with the use of manpower and equipment, the consumption of diesel and fertilisers, changes made in terms of erosion process and fire risk. Details on emissions are presented in table XI-3 of appendix XI.

5.2.3 Biomass transport

Articulated trucks (tractor and semi-trailer) with 5 or more axles and a maximum authorised gross weight of 40 t (approx. 45 m^3) per load normally transport fuel. Considering that in case A the bark represents on average 18% of the volume of eucalyptus, approximately 8.1 m^3 of bark will be transported per load. For case B all biomass transported is for energy consumption.

The price of transport depends essentially on the following factors:
- distance to the factory;
- access roads from the main road to the property;
- type of road or rail transport.

In this case, in view of the zone chosen, we will only consider road transport, with normal accessibility to properties, for a distance in the order of 100 km. The mean cost under these circumstances is 8.5 ECU/t.

In these cases, fuel transport requires manpower, equipment, consumption of diesel and road use. Emissions and other burdens for this stage are presented in table XI-3 of appendix XI.

5.2.4 Biomass treatment

Giving the different nature of the biomass between case A and B, the supply system and induced emissions are specific to each case.

In case A, the feeding system comprises:
- storage and feeding of the debarking drum - with the aid of a crane or forklift;
- debarking and bark treatment;
- bark storage.

The eucalyptus roundwood is transported to the factory where it is unloaded and piled in the wood park using a crane or forklift of between 100 and 110 hp. These machines also serve to feed the debarking line. Storage and feeding the debarking line also involves one operator per crane or forklift.

The debarking and bark treatment system comprises the following equipment: feeders, a debarker, hammer chippers, conveyor belts, a magnetic separator, a metal detector and a tripper. There are two debarking lines - one with a pre-treatment unit and debarker and another with only a debarker. The timber cut longest is normally debarked on the line with the pre-treatment unit, and the other line used for the most recently cut timber.

The pre-treatment unit, comprising rolls equipped with various types of cutting devices, tears up the bark before the pulpwood enters the debarker. The principle of debarking is the abrasive action between the logs when they roll inside the drum.

The bark from the debarkers is sent to the hammer chipper that grinds it into smaller pieces, passing them through a magnetic separator and metal detector. The bark is then transported to the tripped which distributes it along the bark store. Three workers operate the system, in two shifts. The debarking equipment needs considerable maintenance - about 8 hours a week.

The bark storage system comprises: a bark store, spiral conveyors, conveyor belts, a magnetic separator and a bark silo.

The spiral conveyors in the store make the bark fall onto the conveyor belts that lead it to the storage silos, passing through a magnetic separator. The maximum speed of the conveyors is 1.4 m/s, or approximately 5 km/h. The bark silo has a capacity of 75 m^3. The maximum feeding capacity is 120 m^3/h.

At the bottom of the bark silo are six spiral conveyors, fitted in groups of two, each set driven by a hydraulic engine. The six conveyors transport the bark in the silo to a distribution box where there is a transversal spiral conveyor, driven by an engine. This feeds a set of three vertical chutes, down which the bark falls by gravity, into the three boiler feeders.

One worker, in three shifts operates the system.

In case B, the theoretical supply system comprises:

- storage and chipper feeder,
- chipping,
- storage of woodchips.

The wood is stored and the chipper fed in a similar way to the debarking line, with the aid of a crane or a forklift. This operation involves one worker per crane or forklift.

Woodchips are produced in a chipper with helical plates and twelve blades. A U feeder feeds them, by gravity. At the entry to the chipper there is a metal detector to stop any bits of metal going in with the wood and damaging the equipment. The chipper capacity is 100 - 150 m^3/h. The woodchips produced are transported on conveyor belts to the storage unit. Three workers operate the system in two shifts.

This phase of the fuel cycle requires manpower, equipment, consumption of diesel and electricity. Table XI-3 in appendix XI presents the annual emissions for each case.

5.2.5 Power generation

The energy generation technology is the same in both cases (A and B). This stage is divided into two phases:

- steam generation,
- cogeneration of electricity and heat.

Steam is produced in an auxiliary furnace with moveable grate. The boiler is fed with fuel by gravity, with the help of spiral conveyors. The boiler has a furnace with automatic unloading, pneumatic reinjection and mechanical ash extraction. The boiler can be considered as divided into three zones:

- drying zone,
- gasification and burning zone,
- final burning zone.

In the first zone, the fuel is dried with pre-heated air. When the fuel reaches the second zone, it is completely dry. It is then heated, decomposing into volatile elements, carbon and ash. In the last zone, the complete combustion of carbon takes place. After passing through these different zones, the fuel is transformed into ash and is automatically removed.

The theoretical efficiency of the boiler (for a fuel with 55% humidity) is 85%. These operations require one worker in three shifts.

Cogeneration is carried out by a Turbine/Alternator system. The turbine speed is 7000 rpm. Steam is fed at a temperature of 450°C, with a flow rate of 140 t/h, at a pressure of 63.8 bars. The condensed steam output is at a pressure of 0.065 bars and a temperature of 25°C. The alternator has a power of 16,800 kW, and an efficiency of around 97%. One operator, in three daily shifts controls cogeneration. Emissions from this stage are synthesised in table XI-3 of the appendix XI.

5.2.6 Waste transport and disposal

The system for treatment of flue gases and ashes is the same in both cases (A and B). Flue gases are treated with the aid of electrofilters and an electrostatic precipitator. The gas dust is collected in the precipitator by electric charges. With all sectors working, efficiency of 98.5% is expected; with only one sector working the expected efficiency is 91.5%. The combustion gases are released into the atmosphere through a 93 m chimney height. This operation involves one operator, working three shifts a day.

Ashes are collected by mechanical conveyers, and then transported to a landfill site by a 10-t truck. Emissions from this stage are synthesised in table XI-3 of the appendix XI.

5.2.7 Construction and dismantling of facilities

The construction and dismantling of the energy generation plant have been considered to be identical although the latter can only be estimated hypothetically in that no data exists for this phase. The burdens for this stage are presented in table XI-3 of appendix XI and include namely the use of manpower, equipment and fuels, accident risk, noise and atmospheric emissions.

5.3 Selection of priority impacts

The following impacts are listed for a priority analysis in our study:

1. Global warming impacts.
2. Effects of air pollutants on human health.
3. Effects of air pollutants and acidic deposition on ecological receptors (agricultural crops forests and other ecosystems).
4. Effects of air pollutants on materials.
5. Impacts of fertilisers on drinking water.
6. Impacts from soil erosion.
7. Occupational and public health effects from accidents.
8. Effects of road traffic on road conservation.
9. Effects in terms of employment.

The overall approach followed for the assessment of these impacts is described in chapter 2.

Although employment effects have not been retained in the framework of the ExternE project, CEEETA's has performed such assessment in terms of employment need due to this fuel cycle. Impacts from the use of fertilisers and from soil erosion are specific to this fuel cycle. Hence, a specific methodology has been developed by CEEETA in the framework of the ExternE project (CEEETA, 1994).

5.4 Quantification of impacts and damages

Giving the characteristics of this case study, a cogeneration plant, total impacts have to be split between electricity and heat. The methodological approach followed to allocate the total impact is presented in appendix VI. For our biomass cases, and giving the exergy generated, the allocation factors are presented in the following table

Table 5.2 Allocation factors for the biomass cogeneration plant

	Case A	Case B
- Electricity	0.779	0.777
- Heat	0.221	0.223
Total exergy	1	1

5.4.1 Contribution of greenhouse gas (GHG) emissions to global warming

The emissions of GHG from the biomass fuel cycle are comparatively low when compared with fossil fuel cycles. Estimated emissions are presented in the following table for each stage of the fuel cycle. For the power generation stage, CO_2 emissions are assumed to be zero due to the previous sequestration of the carbon that is released during biomass combustion. This assumption could be considered as long as the amount of carbon stored in the biosphere is not altered due to the fuelwood removal in case A. For the case B, biomass production is dedicated to energy generation.

Table 5.3 Total emissions of GHG in terms of CO_2 equivalent for case A

Activity	Electricity	Heat	Total	
	(g/kWh)	(g/GJ)	(t/yr)	(%)
Soil preparation	na	na	na	-
Planting	na	na	na	-
Transport	9.40	554.3	1 536.5	97.1%
Biomass treatment	0.27	15.7	43.4	2.7%
Cogeneration plant operation	na	na	na	-
Transport of wastes	0.01	0.8	2.3	0.1%
Construction and dismantling	nq	nq	nq	-
Total	9.7	570.8	1 582.3	100%

na: not applicable; nq: not quantified; -: not relevant.

Table 5.4 Total emissions of GHG in terms of CO_2 equivalent for case B

Activity	Electricity	Heat	Total	
	(g/kWh)	(g/GJ)	(t/yr)	(%)
Soil preparation	6.2	365.3	1 003	31.7%
Planting	4.8	284.9	783	24.8%
Transport	7.0	411.6	1 131	35.8%
Biomass treatment	1.5	87.8	241	7.6%
Cogeneration plant operation	0	0	0	0%
Transport of wastes	0.0	0.9	2.3	0.1%
Construction and dismantling	nq	nq	nq	-
Total	19.6	1 150.5	3 160.4	100%

na: not applicable; nq: not quantified; - : not relevant.

For biomass fuel cycles, CO_2 emissions at the energy generation stage are not considered. The emission of other GHG is thought to be negligible. As shown from previous tables, the main relevant stages for this impact are related with biomass transport (cases A and B) and soil preparation and planting (case B). Emissions from the other stages are thought to be negligible.

Giving the damage costs established in the framework of this project (3.8-139 ECU per t of CO_2 equivalent for the conservative 95% confidence interval and 18-46 ECU per t of CO_2 equivalent for the illustrative restricted range) and the GHG emissions estimated in each case, impacts from global warming are as shown in the following tables.

Table 5.5 Damage costs from GHG emissions (case A)

	mECU/kWh	**mECU/MJ**	σ_g
POWER GENERATION			
Global warming			A
low and high estimates (95% confidence interval)	0	0	
mid 3% and mid 1% (restricted range)	0	0	
OTHER FUEL CYCLE STAGES			
Global warming			C
low and high estimates (95% confidence interval)	0.03 - 1.35	2.2E-03 - 7.9E-02	
mid 3% and mid 1% (restricted range)	0.17 - 0.44	1.0E-02 - 2.6E-02	

The σ_g column gives a label (A, B or C) for the range of uncertainty estimated for the defined damage. The label A is used for results with a high confidence (geometric standard deviation of 2.5 to 4) and the label C is associated with a low confidence in results (geometric standard deviation of 6 to 12). For more details on the uncertainty issue see appendix VIII.

Table 5.6 Damage costs from GHG emissions (case B)

	mECU/kWh	mECU/MJ	σ_g
POWER GENERATION			
Global warming			A
low and high estimates (95% confidence interval)	0	0	
mid 3% and mid 1% (restricted range)	0	0	
OTHER FUEL CYCLE STAGES			
Global warming			C
low and high estimates (95% confidence interval)	0.07 - 2.72	4.4E-03 - 0.16	
mid 3% and mid 1% (restricted range)	0.35 - 0.9	2.1E-02 - 5.3E-02	

Results for electricity generation only are about one or two orders of magnitude lower than for fossil fuel cycles (see previous chapters).

5.4.2 Impacts of air pollutants on human health

Giving the different methodological approach, impacts from primary pollutants and aerosols on human health and impacts from ozone formation will be considered separately.

Impacts of primary pollutants and aerosols on human health

Emissions of atmospheric pollutants occur at all the stages of the biomass fuel cycle. Nevertheless, the power generation stage is, in this case, the main source of these emissions. Consequently, this stage is the only process considered for the assessment of the present impact.

The methodology used to estimate the physical and economic damages from primary pollutants (particulates, SO_2 and NO_x) and aerosols (sulphates and nitrates) is supported by the computer tool EcoSense 2.0 (see appendix I). For each atmospheric pollutant considered it has been performed a physical and economic assessment for three scenarios (low, mid and high). Analytical details for human health used to assess this impact (stock at risk, exposure-response data and valuation data) are presented in appendix II. Results are presented for the mid estimate or the best estimate giving the present knowledge. For more details on these results see appendix XI.

Table 5.7 Summary results of damages on human health from primary pollutants and aerosols

	Case A		Case B		σ_g
	mECU/kWh	mECU/MJ	mECU/kWh	mECU/MJ	
Power generation					
Public health					
Mortality*- YOLL *(VSL)*	7.69 *(30.5)*	0.45 *(1.8)*	5.29 *(20.9)*	0.31 *(1.23)*	B
Morbidity	0.98	0.06	0.67	0.04	A-B
Other fuel cycle stages					
Public health	nq	nq	nq	nq	

* YOLL: years of life lost, VSL: value of statistical life. nq: not quantified.

Impacts of ozone on human health

The estimates of ozone damages on human health per tonne of precursor emission (NO_x and VOC's) suggested by Rabl (1996) range between 230 and 5750 ECU per tonne of NO_2 equivalent (NO_x emissions are NO_2 equivalent), with a mid point estimate of 1150 ECU/t of NO_2 equivalent. The following table gives the results of the ozone damage assessment for the Portuguese biomass fuel cycle (cases A and B).

Table 5.8 Summary results of damages on human health from ozone

	Case A		Case B		σ_g
	mECU/kWh	mECU/MJ	mECU/kWh	mECU/MJ	
Power generation					
Public health					
Mortality*- YOLL *(VSL)*	0.66	3.87E-02	0.66	3.91E-02	B
Morbidity	1.16	6.86E-02	1.18	6.92E-02	A-B
Other fuel cycle stages					
Mortality*- YOLL *(VSL)*	8.04E-02	4.74E-03	0.16	9.54E-03	B
Morbidity	0.14	8.39E-03	0.29	1.69E-02	A-B

* YOLL: years of life lost, VSL: value of statistical life.

5.4.3 Effects of air pollutants and acidic deposition on ecological receptors

As for effects on human health, impacts on ecological receptors (crops, forests and other ecosystems) from primary pollutants and aerosols and from ozone formation will be considered separately.

Effects of primary air pollutants and acidic deposition on ecological receptors

The methodology used to estimate the physical and economic damages from primary pollutants and aerosols is also supported by the computer tool EcoSense 2.0 (see appendix I). For each atmospheric pollutant considered it has been performed a physical and economic assessment for three scenarios (low, mid and high). Nevertheless, results are only presented for the mid estimate with a range of variation given by σ_g column. Analytical details for ecological effects are presented in appendix IV. See appendix XI for more details on the following results.

Table 5.9 Summary results of damages on ecological receptors from primary pollutants and acidic deposition

	Case A		Case B		σ_g
	mECU/kWh	mECU/MJ	mECU/kWh	mECU/MJ	
Power generation					
Crops	-1.63E-02	-9.59E-04	-1.77E-02	-1.04E-03	A-B
Other ecosystems	nq	nq	nq	nq	
Other fuel cycle stages					
Ecological effects	nq	nq	nq	nq	

nq: not quantified.

Effects of ozone on ecological receptors

As for the monetary quantification of impacts of ozone on human health we use the approach presented by Rabl (1996). In the next table are shown the results obtained. Total NO_x emissions for the biomass fuel cycle are of 290 (case A) and 322 (case B) tonnes per year respectively. The estimates of ozone damages on ecological receptors per tonne of precursor emission (NO_x and VOC's) suggested by Rabl (1996) range between 70 and 1750 ECU per tonne of NO_2 equivalent (NO_x emissions are NO_2 equivalent), with a mid point estimate of 350 ECU/t of NO_2 equivalent. The following table gives the results of the ozone damage costs for the Portuguese biomass fuel cycle.

Table 5.10 Summary results of damages on ecological receptors from ozone

	Case A		Case B		σ_g
	mECU/kWh	mECU/MJ	mECU/kWh	mECU/MJ	
Power generation					
Crops	5.54E-01	3.27E-02	5.61E-01	3.30E-02	B
Other ecosystems	nq	nq	nq	nq	
Other fuel cycle stages					
Crops	6.78E-02	4.00E-03	1.37E-01	8.05E-03	B
Other ecosystems	nq	nq	nq	nq	

nq: not quantified.

5.4.4 Effects of air pollutants on materials

The methodology used to estimate the physical and economic damages is supported by the computer tool EcoSense 2.0 (see appendix I). Exposure-response functions considered in this project are described in appendix III. This appendix includes also other analytical details. For each atmospheric pollutant considered it has been performed a physical and economic assessment for three scenarios (low, mid and high). Nevertheless, results are only presented for the mid estimate with a range of variation given by σ_g column. See appendix XI for more details on the following results.

Table 5.11 Summary results of damages on materials

	Case A		Case B		σ_g
	mECU/kWh	mECU/MJ	mECU/kWh	mECU/MJ	
Power generation					
Materials	2.59E-02	1.53E-03	2.33E-02	1.37E-03	B
Other fuel cycle stages					
Materials	nq	nq	nq	nq	

nq: not quantified.

5.4.5 Impacts of fertilisers on drinking water

This impact is only relevant for case B as for case A there is no plantation of biomass but collection of bark. Nevertheless, the assessment of this impact for case B requires the analysis of the alternative which is the situation presented in case A. In this case only the bark from tree plantations is destined to produce energy, while debarked raw material is destined to the woodpulp industry. On the contrary, in case B all the biomass is used to produce energy. Since case A is the reference case for impact estimation, the resulting impact must be the difference between impacts calculated in cases B and A, what gives an average amount of nitrate to remove from ground waters of about 316.1 kg NO_3^- yr^{-1}. As shown in the following table, the net change is positive which means that, with case B, the average amount of nitrate to remove has increased in relation with the reference case.

Table 5.12 Net physical impact on drinking water (kg NO_3^-/yr)

	Amount of NO_3^- to be removed from water
Case A	114.8
Case B	430.9
Net impact or case B - case A	**316.1**

The economic assessment is based on values from Silvander (1991). Silvander estimates the social benefit of reducing nitrate concentration in ground water to be 0.65-6.6 ECU per kg of nitrate removed. The following table shows the results of the estimated impact from fertiliser on drinking water for 3% discount rate and in terms of ECU per year, mECU per kWh of electricity generated and mECU per MJ of heat.

Table 5.13 Economic valuation of the impact on drinking water for case B

	ECU/year	mECU/kWh	mECU/MJ
Value	1 520	9.41E-03	5.53E-04

These results show that this impact is very low. But it is important to remember that this impact assessment considers as reference case a plantation of eucalyptus for pulpwood supply. For this reason, results may diverge with different reference cases.

5.4.6 Impacts from soil erosion

As for the impact from fertiliser application, this impact is only present in case B. Nevertheless, its assessment requires the analysis of case A taken as reference case. The resulting impact must be the difference between impacts calculated in cases B and A.

The net soil loss, considering the two situations, would make a difference of 0.31 t/ha/year. The methodological approach followed to assess this impact is presented in appendix VI.

Two main impacts have been addressed in our previous study (CEEETA, 1994): the impact of soil erosion on surface water quality and the impact on sediment treatment or removal.

Impact of soil erosion on surface water quality

The impact of erosion on surface water quality was assessed assuming that a percentage of the soil dragged will enter the surface water bodies increasing their turbidity. The results of the predicted increments of total suspended particulates (TSP) in surface waters and the resulting physical impacts are presented in table below.

Table 5.14 TSP concentration increments in surface waters and physical impacts of erosion on surface water quality

	Case B	Case A
Surface waters TSP concentration increments (mg/l)	30.3	21.0
Net *TSP* concentration increment (mg/l)	9.30	
Physical impact in kg of TSP/yr (*)	517.39	

(*) Net impact is defined as the impact of case B minus the impact of case A.

It was not possible to use the WTP/WTA approach for erosion impacts. There are no national or European values for this impact. Nevertheless, as a rough estimate, the impact could be value as a low impact or 0.001 mECU/kWh.

Impact of soil erosion on sediment treatment

The amount of sediment deposited in riverbeds, dams and other hydrological compartments is calculated as shown in appendix VI. The sediment treatment refers to the physical removal of sediments from those deposition sites. The following table gives the result of the net impact.

Table 5.15 Physical impact of erosion on sediment treatment

	Case B	Case A
Sediment increments (t)	9 467	6 561
Physical impact in t/yr (*)	2 906	

(*) Net impact is defined as the impact of case B minus the impact of case A.

The following table shows the results of the estimated impact on sediment treatment for 3% discount rate and in terms of ECU per year, mECU per kWh of electricity generated and mECU per MJ of heat.

Table 5.16 Economic valuation of the impact on sediment treatment for case B

	ECU/year	mECU/kWh	mECU/MJ
Value	38 045	2.36E-01	1.38E-02

These results show that this impact is low. But it is important to remember that this impact assessment considers as reference case a plantation of eucalyptus for pulpwood supply. For this reason, results may diverge with different reference cases.

5.4.7 Occupational and public health effects from accidents

Occupational and public accidents occur along the different stages of the biomass fuel cycle. Giving the level of statistical data available for Portugal, it was concluded to consider the following stages:

- Forestry (soil preparation, planting and felling and forwarding of biomass).
- Biomass transport.
- Cogeneration plant operation.
- Construction and dismantling of the facility.

The approach followed to estimate the number of injuries and fatalities due to occupational and public accidents has been described in CEEETA (1994) and European Commission (1995c). The following tables present, for each case, the results of our assessment.

Table 5.17 Occupational and public accidents for the biomass fuel cycle (case A)

Sector	Total	Damage for electricity	Damage for heat
	ECU/year	mECU/kWh	mECU/MJ
Forestry	na	na	na
Biomass transport	8.35E+05	5.11E+00	3.01E-01
Cogeneration plant operation	3.27E+03	2.00E-02	1.18E-03
Construction and dismantling of facility	1.02E+05	6.27E-01	3.69E-02
Total	9.40E+05	5.75E+00	3.39E-01

na: not applicable.

Table 5.18 Occupational and public accidents for the biomass fuel cycle (case B)

Sector	Total	Damage for electricity	Damage for heat
	ECU/year	mECU/kWh	mECU/MJ
Forestry	4.94E+03	3.06E-02	1.80E-03
Biomass transport	6.12E+05	3.79E+00	2.23E-01
Cogeneration plant operation	3.27E+03	2.02E-02	1.19E-03
Construction and dismantling of facility	7.68E+04	4.75E-01	2.80E-02
Total	6.97E+05	4.31E+00	2.54E-01

Total damages are high due essentially to a high level of mortality and injury rates in road transport. Giving the tendency observed during the last years, which shows a reduction of the number of deaths and injuries, and measures under implementation to lower these damages, total damage costs for each case should be smaller than the actual results.

5.4.8 Effects of road traffic on road conservation

Truck traffic generates a variety of emissions and impacts. One of them is the impact in terms of road wear. The methodology used for determining the impact in physical terms related with the transport of biomass is, to a certain extent, similar to that used in the US report (ORNL/RFF, 1992). However, the reduction in the lifetime of the road surface is calculated in a more pragmatic way.

The calculation of the lifetime of a road depends on the development of heavy vehicle traffic, expressed in the number of standard axle-passages (given the physical characteristics of the road). This development not being linear, the new life lifetime is deduced by approximation in time. The methodological approach followed to assess this impact has been described in CEEETA (1994). Giving the transport requirements in cases A and B, it is possible to estimate the physical impact related with road use in terms of road lifetime reduction.

The increase in traffic over and above the predicted level accelerates wear of the roads used. Therefore maintenance needed changes the resurfacing schedule, each 20 years in the cases analysed. To assess the annual cost of this reduction, the difference is calculated between the two constant annuities determined by the actual cost of maintaining the road surface. The total costs of road damages per kWh of electricity generated and per MJ of heat are presented in the following table.

Table 5.19 Impact on road conservation for each biomass case

	ECU/year		mECU/kWh		mECU/MJ	
	Case A	Case B	Case A	Case B	Case A	Case B
Value	24 242	17 580	1.48E-01	1.09E-01	8.75E-03	6.40E-03

Part of these damages costs are internalised through taxes and fees (applied to heavy vehicles, diesel oil...). So these damage costs should not be considered as externalities. The real external costs should be lower than these values.

5.4.9 Effects in terms of employment

To assess impacts in terms of employment needs, we have to distinguish between direct and indirect employment.

Direct employment is related with employment existing at the different stages of biomass fuel cycle (forestry activities, transport of biomass and ashes, operation of the cogeneration plant and construction and dismantling of the unit). Statistical data on employment have been used to estimate the direct labour required by the biomass fuel cycle. Indirect employment, or employment generated by the production of goods and services needed to build and operate the cogeneration plant, can be estimated using an input-output methodology.

The approach followed to estimate the effects on employment has been formerly described (CEEETA, 1994). This approach is summarised in appendix VI.

The following table gives an estimate of the total direct labour required for the Portuguese biomass fuel cycle.

Table 5.20 Direct labour required in cases A and B

Activities	Mean annual hours	
	Case A	Case B
1) Soil preparation	na	45 333
2) Felling and forwarding of biomass	na	34 240
3) Transport	40 834	30 051
4) Biomass treatment	11 683	26 640
5) Power plant operation	8 400	8 400
6) Transport of wastes	600	130
7) Construction and dismantling	158 400	158 400
Total working hours required per year	219 917	303 194
Number of jobs-equivalent required per year (1)	125.0	172
Number of jobs-equivalent required per TWh	764.6	1 067
Number of jobs-equivalent required per TJ	0.045	0.388

(1) 1 job-equivalent = 1760 h/year

Annual average direct labour required in each case of the biomass fuel cycle is relatively substantial and much higher than the ratio calculated for the coal fuel cycle.

In the absence of multipliers, we had to draw on Input-Output and Employment tables published by the National Institute of Statistics. These data were treated in order to extract Keynesian type employment multipliers, in other words, multipliers incorporating the effects of final household consumption. By conjugating data from mean annual increases in demand with the employment multipliers we can estimate the indirect employment required a priori by the increase in final demand. The impacts in terms of direct and indirect labour required are summarised in the following table.

Table 5.21 Direct and indirect labour required in cases A and B

	Nº of job-equivalent per year			Nº of job-equivalent per TWh			Nº of job-equivalent per TJ		
	0%	3%	10%	0%	3%	10%	0%	3%	10%
1) Case A									
- Direct labour	125	125	125	765	765	765	0.045	0.045	0.045
- Indirect labour	755	796	922	4 622	4 874	5 641	0.272	0.287	0.333
- Total labour	880	921	1 047	5 387	5 639	6 406	0.318	0.332	0.378
2) Case B									
- Direct labour	172	172	172	1 067	1 067	1 067	0.063	0.063	0.063
- Indirect labour	1 040	1 086	1 257	6 438	6 723	7 782	0.379	0.395	0.458
- Total labour	1 212	1 258	1 429	7 505	7 789	8 849	0.441	0.458	0.520

The employment required a priori by the implementation of a new energy generation unit should not be understood as job creation. So, the next step of the impact pathway approach should be the assessment of jobs created and their economic valuation. But until now, any methodology has been defined to perform this final step. This important work has to be conducted in further research development of the ExternE project.

5.5 Summary and interpretation of the results for the biomass fuel cycle

The following tables summarise the results obtained for the Portuguese biomass fuel cycle. Giving the nature of the technology (cogeneration plant), total damages were split between the electricity component and the heat one according to the exergy criteria. So, results for electricity generation are presented in mECU/kWh and results for heat are shown in mECU/MJ.

Table 5.22 Damages of the biomass fuel cycle (case A)

	mECU/kWh	mECU/MJ	σ_g
POWER GENERATION			
Public health			
Mortality*- YOLL *(VSL)*	8.34 (31.2)	0.49 (1.8)	B
of which TSP	3.17 (12.5)	0.19 (0.73)	
SO_2	0.39 (1.83)	0.02 (0.1)	
NO_x	4.12 (16.2)	0.24 (0.95)	
NO_x (via ozone)	0.66	0.04	
Morbidity	2.14	0.13	A-B
of which TSP, SO_2, NO_x	0.98	0.06	
NO_x (via ozone)	1.16	0.07	
Occupational and public health	2.00E-02	1.18E-03	A
Crops	0.56	3.29E-02	
of which SO_2	4.66E-03	2.75E-04	A
NO_x (via ozone)	0.55	3.27E-02	B
Ecosystems	nq	nq	
Materials	2.59E-02	1.53E-03	B
Monuments	nq	nq	
Noise	ng	ng	A
Visual impacts	ng	ng	A
Employment	iq	iq	
Global warming			A
low and high estimates (95% confidence interval)	0	0	
mid 3% and mid 1% (restricted range)	0	0	
OTHER FUEL CYCLE STAGES			
Occupational and public health	5.73	0.34	A
Ecological effects	ng	ng	A
Fertiliser on drinking water	na	na	
Soil erosion	na	na	
Road damages	0.15	8.75E-03	A
Employment	iq	iq	
Ozone on human health			
Mortality*- YOLL *(VSL)*	8.04E-02	4.74E-03	B
Morbidity	1.42E-01	8.39E-03	A-B
Ozone on crops	6.78E-02	4.00E-03	B
Global warming			C
low and high estimates (95% confidence interval)	0.03 - 1.35	2.2E-03 - 7.9E-02	
mid 3% and mid 1% (restricted range)	0.17 - 0.44	1.0E-02 - 2.6E-02	

* YOLL: years of life lost, VSL: value of statistical life.
ng: negligible; nq: not quantified; iq: only impact quantified; -: not relevant

Table 5.23 Sub-total damages of the biomass fuel cycle (case A)

		mECU/kWh	mECU/MJ
YOLL *(VSL)*	low	14.6 *(35.7)*	0.9 *(2.1)*
	mid 3%	**17.4 *(40.3)***	**1.0 *(2.4)***
	mid 1%	**17.7 *(40.5)***	**1.0 *(2.4)***
	upper	29.9 *(60.9)*	1.8 *(3.6)*

Table 5.24 Benefits of the biomass fuel cycle (case A)

	mECU/kWh	mECU/MJ	σ_g
POWER GENERATION	2.09E-02	1.23E-03	B
OTHER FUEL CYCLE STAGES	-	-	
SUBTOTAL	2.09E-02	1.23E-03	

Table 5.25 Damages by pollutant (case A)

	ECU / t of pollutant
SO_2 *- YOLL *(VSL)*	5 208 (21 065)
NO_x *- YOLL *(VSL)*	6 440 (23 200)
PM_{10} *- YOLL *(VSL)*	6 955 (25 054)
NO_x (via ozone)	1 500
CO_2	3.8 - 139**

* YOLL: years of life lost, VSL: value of statistical life.
** using the 95% confidence interval.

Table 5.26 Damages of the biomass fuel cycle (case B)

	mECU/kWh	mECU/MJ	σ_g
POWER GENERATION			
Public health			
Mortality*- YOLL *(VSL)*	5.95 (21.5)	0.35 (1.27)	B
of which TSP	0.98 (3.87)	0.06 (0.23)	
SO_2	0.13 (0.59)	7.51E-03 (0.03)	
NO_x	4.18 (16.4)	0.25 (0.97)	
NO_x (via ozone)	0.66	0.04	
Morbidity	1.85	0.11	A-B
of which TSP, SO_2, NO_x	0.67	0.04	
NO_x (via ozone)	1.18	0.07	
Occupational and public health	2.02E-02	1.19E-03	A
Crops	5.64E-01	3.32E-02	
of which SO_2	3.58E-03	2.01E-04	A
NO_x (via ozone)	5.61E-01	3.30E-02	B
Ecosystems	nq	nq	

	mECU/kWh	mECU/MJ	σ_g
POWER GENERATION			
Materials	2.33E-02	1.37E-03	B
Monuments	nq	nq	
Noise	ng	ng	A
Visual impacts	ng	ng	A
Employment	iq	iq	
Global warming			A
low and high estimates (95% confidence interval)	0	0	
mid 3% and mid 1% (restricted range)	0	0	
OTHER FUEL CYCLE STAGES			
Occupational and public health	4.26	0.25	A
Ecological effects	ng	ng	A
Fertiliser on drinking water	9.41E-03	5.53E-04	A
Soil erosion	2.37E-01	1.38E-02	A
Road damages	0.11	6.40E-03	A
Employment	iq	iq	
Ozone on human health			
Mortality*- YOLL *(VSL)*	0.16	9.54E-03	B
Morbidity	2.88E-01	1.69E-02	A-B
Ozone on crops	1.37E-01	8.05E-03	B
Global warming			C
low and high estimates (95% confidence interval)	0.07 - 2.72	4.37E-03 - 0.16	
mid 3% and mid 1% (restricted range)	0.35 - 0.9	2.1E-02 - 5.3E-02	

* YOLL: years of life lost, VSL: value of statistical life.
ng: negligible; nq: not quantified; iq: only impact quantified; -: not relevant

Table 5.27 Sub-total damages of the biomass fuel cycle (case B)

		mECU/kWh	mECU/MJ
YOLL *(VSL)*	low	10.9 *(24.7)*	0.6 *(1.5)*
	mid 3%	**14 *(29.6)***	**0.8 *(1.7)***
	mid 1%	**14.6 *(30.2)***	**0.9 *(1.8)***
	upper	28.9 *(53)*	1.7 *(3.1)*

Table 5.28 Benefits of the biomass fuel cycle (case B)

	mECU/kWh	mECU/MJ	σ_g
POWER GENERATION	2.13E-02	1.25E-03	B
OTHER FUEL CYCLE STAGES	-	-	
SUBTOTAL	2.13E-02	1.25E-03	

Table 5.29 Damages by pollutant (case B)

	ECU / t of pollutant
SO_2 *- YOLL *(VSL)*	5 424 (20 396)
NO_x *- YOLL *(VSL)*	6 454 (23 253)
PM_{10} *- YOLL *(VSL)*	6 954 (25 051)
NO_x (via ozone)	1 500
CO_2	3.8 - 139**

* YOLL: years of life lost, VSL: value of statistical life.
** using the 95% confidence interval.

In case A, the sum of the damage costs caused by the priority impacts subject to monetary valuation reaches, for the mid estimate and excepting GWI, 17.3 mECU/kWh for the electricity and 1.02 mECU/MJ for the heat production. The main contributions to the damage cost figure arose with public health (62% of the damage cost) and occupational and public accidents (33%).

If global warming is integrated in this accounting we obtain very small increases in the results with 17.7 mECU/kWh for the electricity component and 1.02 mECU/MJ for the heat part. For the biomass fuel cycle, global warming damage costs are very small (representing less than 5% of the total damage costs for the worst scenario) since the emissions of CO_2 at the energy generation stage are not considered. That's probably the most important feature of the biomass fuel cycle in comparison with other fuel cycles studied herein.

The impacts estimated in case B result in damage costs which are slightly lower than in case A. This happens even considering the environmental costs induced by fertiliser's application and soil erosion; impacts which are not applicable in case A. The reason for such results is basically related to the sulphur content of the fuel (bark in case A), which is about three times higher than the whole average sulphur content of the biomass used in case B. Monetary valuation of the environmental damages reaches for this case 13.7 mECU/kWh for electricity generation and 0.8 mECU/MJ for heat production. If we add global warming impacts to these figures we obtain again very small higher results with values of 14.6 mECU/kWh for electricity generation and 0.9 mECU/MJ for heat.

6. HYDRO FUEL CYCLE

This chapter presents the implementation of the ExternE methodology on the hydro fuel cycle in Portugal (CEEETA, 1995b). For this analysis two hydro power plants have been selected (see figure 1.4). The two chosen cases are representative of a certain number of hydro power plants installed in Portugal. Other types of hydro power plants are also important in Portugal, like medium size capacity or run-off-river ones, but giving the study constraints, the analysis has been concentrated on the following projects:
(i) a small hydropower plant or case 1;
(ii) a large hydropower plant or case 2.

6.1 Definition of the fuel cycle, technologies and sites

6.1.1 Case 1

Lourizela small hydro development is located in a relatively uninhabited area of the Caramulo Mountain, in the Alfusqueiro River (Vouga River catchment). The dam, as well as water intake elevation is 184.2 m, being the downstream restitution made at an elevation of about 91.2 m.

The water intake carries the water from the dam into a 759 m length diversion tunnel which is followed by an open sky channel with 888 m. The total length of the diversion channel is thus 1.647 km. The hydraulic water energy needed for the transport of the water through this channel is 3.7 m, yielding to a net waterfall height of 89.2 m.

The most important hydraulic features of the development are the very low residence time of the water in the reservoir and the intermittence of the flow during the year. In dry periods the hydropower plant is inoperative because of the absence of flow.

The hydroelectric dam was built on the River Alfusqueiro, which is in the hydrographic catchment area of the River Vouga. Lourizela development is located in the district of Aveiro, in the Council of Sever do Vouga and next to the town of Talhadas.

The dam is of the drop type with a 5 metre high weir. A 759 metre long tunnel diverts the water to be used in the dam, which is followed by an 888 metre long open-air canal that terminates in a flood reservoir. The 175 metre long steel penstock allows for the water to enter the turbines installed in the building in the unit.

The development has the following technical characteristics:

- Total surface area of the basin	149.9 km^2
- Water intake level	184.2 m

- Back flow level 91.2 m
- Net fall 89.2 m
- Average water flow 6.7 m^3/s
- Ecological flow 0.25 m^3/s

Generation of electricity

Energy is produced by two groups comprising a turbine and a generator, representing an installed power of 5,200 kW whose yearly production of electric energy, on average, is of 17,860 MWh.

The groups comprise a Francis-type turbine with two wheels, a closed spiral chamber with a horizontal axis and a speed of 750 rpm, whose power for group 1 is of 3,460 kW for a water flow of 4,500 l/s and for group 2 is of 1,740 kW for a water flow of 2,250 l/s.

The generators are of the synchronous, triphasic type, with a horizontal axis, a voltage of 6,000 V and a speed of 750 rpm. In group 1 the nominal power of the generator is of 4,250 kVA and in group 2 of 2,000 kVA.

Transmission of electricity

In the transmission of electricity, which is of a distance of 13,900 metres to the public network connection point, the following criteria are to be considered:
- 6 kV generation;
- A generator-transformer unit for each group;
- 15 kV protection, measurement and metering;
- 15 kV interconnection with the receiving network;
- Automatic command and control through programmable automates so that the dam can work autonomously without resorting to permanent staff;
- Tele-information allowing for the operation of the dam to carry out by remote control.

The energy generation and transmission operations require one skilled technician working 4 hours a day, 300 days a year for the co-ordination of the dam characterised by:

- Power capacity (kW)	5 200
- Efficiency (%)	85
- Full load hours / year	4 040
- Electricity generated in average year (MWh/year)	17 860

Maintenance

The operation of the hydroelectric dam requires daily, regular and yearly maintenance actions. According to the available data, the maintenance is treated globally for the generation and transmission of electricity operations.

Daily maintenance requires 1 local technician working 4 hours a day, 240 days a year. Regular maintenance requires 1 skilled technician and 1 local technician working 8 hours a day, 16 days a year. Yearly maintenance requires 1 skilled technician and 5 local workers working 8 hours a day, 25 days a year.

6.1.2 Case 2

The analysis of this hydro cycle is merely qualitative, as the authorities responsible for the project were unable to supply figures on the construction works, power generation and transmission, costs and maintenance.

The Alto Lindoso hydroelectric station is located on the River Lima, only metres away from the Spanish border and 75% of the area of the reservoir is in Spain.

The station comprises two generator groups; each equipped with a 317 MW turbine and a 350 MVA generator. These are the most powerful generating units in Portugal, and account for 20% of the country's installed hydroelectric capacity and less than 10% of total power generating capacity in Portugal in 1991. In a year of average hydraulic conditions, the station generates 910 GWh or around 10% of total hydroelectric power generated and 3% of total power generated in Portugal for the same year.

The power generated by the station is connected to the 400 kV North-South transmission line, which extends into Spain.

Technical details:

- Total area of hydrographic basin	1 524.8 km^2
- Available storage capacity	347.8 x 10^6 m^3
- Water intake level	262 m
- Maximum net head	280.8 m
- Flow absorbed at full load	2 x 125 m^3/s
- Length of tailrace tunnel	4 926.3 m

Dam and discharges

The Alto Lindoso dam is a double curvature arch dam, with a height of 100 m and a volume of 308,500 m^3. The crown has a length of 297 m, which serves as a viaduct.

The dam has two bottom discharges with a maximum outflow capacity of 2 x 200 m^3/s. Each discharge is equipped upstream with a guard sluice and downstream with a regulator sluice with segmented flows. In the interior of each discharge gate is a pipe for the ecological water flow.

On the right bank there are two floodgates, consisting of tunnels clad with reinforced concrete with a maximum outflow of 2,700 m^3/s, 8.75 m in diameter and 238 m and 268 m long respectively. The mouth of each gate is divided into three spans with segmented sluices.

Hydraulic circuit

The hydraulic circuit has a plan length in the order of 5,340 m, and extends from the water intakes to the return outflow. Between the water intakes and the surge shaft, there is an independent circuit for each generator group that joins together downstream of the shaft, constituting the return gallery that has a length of almost 5 km.

The section between the water intakes and the surge shaft contains a fine grate at every water intake, two bulkhead gates and two sluices; the galleries and load shaft clad in reinforced concrete up to a height of 180 m and armoured, with an interior diameter of 5.1 m, up to the ball valves, the branch pipe which includes the power station and the spherical and butterfly valve chambers and the return armoured pipe lines, with a diameter of 5.75 m, downstream of the butterfly valves as far as the return shaft.

The section between the surge shaft and the return contains a surge shaft with a diameter of 21 m and a height of 65 m, fitted with an upper expansion chamber with a volume of 36,000 m^3 and a lower feeding chamber with a volume of 27,000 m^3 ; the return gallery with a length of 4,883 m and a diameter of 8.3 m and return outlet divided into two spans fitted with bulkhead gates.

Power station and valve chambers

The power station and valve chamber comprise a series of caverns located approximately 200 m below the riverbed. A gallery 1,780 m long, with branches leading to each of the chambers provides a road connection to the surface. There are communications between the interior of the power station and the valve chambers and a vertical shaft with a diameter of 6.8 m and a height of 350 m, leading to the control building and the substation.

Two generator groups are fitted in the power station. These are Francis/alternator turbines, vertical axis, each with a power of 350 MVA (317 MW in the turbine shaft). The power generated at a voltage of 18 kV is transported to the substation by shielded buses comprising a central aluminium cable inside a sleeve with a diameter of approximately 1 m. The turbines are insulated and protected upstream by a ball valve operated by two double acting auxiliary motors, and downstream by two single acting hydraulic auxiliary motors.

Control building and substation

The control building and substation are located above the power station, to which they are linked by the shaft.

The hydroelectric station is controlled in emergency or trial situations either by the central control computer installed in the control building or by the group switchboards fitted inside the underground generating station. During operation, the station is controlled from the Caniçada Telecontrol Centre, with the possibility of regulating the power of the generator groups from the National Control Centre in Lisbon.

The 18/400 kV substation occupies an area of 8,500 m^2 and is fitted with 6 single-phase transformers (3 per generator group) with unit power of 116.7 MVA and a reserve transformer. The substation buses continue in overhead lines to the switching station, 500 m away, which is an important node in the 400 kV network.

The River Lima's hydrographic basin, where is located the Alto Lindoso hydropower plant covers an area of 2525 km^2 of which 1170 km^2 belong to Portugal and the left 1355 km^2 to Spain. Inside the Portuguese border this river is 66 km long and its main tributary system comprehends the Rivers Castro Laboreiro and Vez, on the right margin and the River Vade on the left margin. The riverhead of the Lima is located at the S. Mamede mountain range, at an altitude of 950 m (Orense province - Spain). This water stream enters in Portugal near Lindoso at an altitude of 275 m and drops its stream bed level till 225 in 13 km of the way. It flows into the sea at Viana do Castelo.
According to an assessment of the hydrological availability based on figures obtained for the monthly and annual drainage taken at the hydrometric stations, we have:
- an average annual drainage from the Spanish tributary stream of $1{,}230 * 10^6 m^3$;
- at the Portuguese Lima's basin, the surface drainage system generates in Portugal an average annual figure of $1{,}190 * 10^6 m^3$;
- the average drainage of the dry semester in the Portuguese part of the Lima hydrographic basin is 17% of the overall annual drainage amount;
- the average caudal of August (dry month) in the same area is approximately 5 m^3/s.

6.2 Overview of burdens

6.2.1 Case 1

Emissions associated with construction phase

The development included the construction of concrete and metal infrastructures, as well as access and transmission infrastructures. These works required the use of work force and equipment, consumption of diesel-oil and soil occupation. Diesel-oil was consumed by lorries, cranes, etc., representing a total consumption of 173,655 kg. The diesel-oil combustion with a NCV of 43.3 GJ/t emits 0.137 t/TJ of SO_2, 73 t/TJ of CO_2, 0.4756 t/TJ of CO, 1.46 t/TJ of NO_x, 0.1664 of VOC and 0.1 t/TJ of particles into the atmosphere.

Emissions associated with generation and transmission of electricity

The operation of the dam includes generation and transmission of electricity, maintenance actions, insurance policies and the advantages for the parish. In the maintenance actions a gas-oil run vehicle is used that has a daily consumption of 0.043 kg/km, whose combustion emits into the atmosphere the values referred above.

6.2.2 Case 2

The Alto Lindoso hydroelectric power station involved the construction of concrete and metal infrastructures, new access and transmission lines. These works required the use of manpower and equipment, diesel consumption and land occupation.

The works involved around seventy suppliers, contractors and other companies and services, ranging from catering facilities for workers to civil engineering works and the supply and assembly of equipment.

The construction works involved excavations of 1,000,000 m^3, 600,000 m^3 concrete, 7,000 t steel for reinforcement, 2,500 t steel in reinforcing bars, and improvements and construction of 67 km of roads, including 11 bridges in Portugal and Spain. This development opens up this isolated region, creating connections to neighbouring districts in Portugal and Spain.

In the area affected by the reservoir and the works, 11,885 properties and 231 houses were purchased, involving 2,373 owners.

The labour force required was more than 1,000 during five years, with a peak of almost 1,500 in 1991, which required the construction of social facilities with the necessary levels of comfort for the life of the workers.

Heavy civil construction machinery was used, a concrete production works installed and one of the main equipment suppliers set up a machine workshop where it manufactured steel armouring from flat 40 mm sheets.

In direct costs and at 1993 prices, the investment amounted to 586 MECU.

The development improved communication routes and now represents an important attraction in the region, offering the potential for socio-economic development. The artificial lakes are a major attraction, and can provide other services or uses, including leisure and sports, and as a source of water for irrigation, domestic use and forest firefighting.

6.3 Selection of priority impacts

Alto Lindoso (case 2) and Lourizela (case 1) hydroelectric developments are markedly different in terms of their dimensions and hydraulic features. At this point we aim to present the selected impacts for a priority analysis retained in our implementation.

The following impacts are listed for a priority analysis in our study:

1. Global warming impacts.
2. Effects of ozone on human health and agricultural crops
3. Impacts of the hydroelectric development on aquatic and terrestrial ecosystems
4. Impacts on bird populations from operation of the transmission lines
5. Impacts of hydroelectric developments on natural erosion processes and land use
6. Effects of impoundments on water quality

7. Effects of noise on human health and amenity.
8. Impact on visual amenity.
9. Impacts of the new accesses on local accessibility
10. Impacts of the hydroelectric developments on recreational activities
11. Occupational and public health effects from accidents.
12. Effects in terms of employment.
13. Impacts from dam failure risk
14. Effects of electric and magnetic fields from transmission lines

The overall approach followed for the assessment of these impacts has been described in chapter 2. Some of these impacts have been assessed in case 1, nevertheless, given the lack of data for case 2 or of a suitable methodological approach, it has not been possible to quantify the externalities associated with this case 2.

Giving the specificity of the hydro fuel cycle, atmospheric emissions at the power generation stage are almost negligible. So impacts from air pollutants at this stage are not assessed except for GHG and ozone.

Although employment effects have not been retained in the framework of the ExternE project, CEEETA's has performed such assessment in terms of employment need due to this fuel cycle.

6.4 Quantification of impacts and damages

6.4.1 Contribution of greenhouse gas (GHG) emissions to global warming

The impacts of global warming are problematic to evaluate from the economic point of view (see appendix V). Given the lack of data on GHG emissions for case 2, the assessment of this impact will only consider the small hydro power plant or case 1 (see table hereafter).

Table 6.1 Total emissions of GHG in terms of CO_2 equivalent

Activity	g/kWh	%
Construction of the power plant	0.666	71.7%
Operation of the power plant	0.057	6.1%
Construction of the transmission lines	0.205	22.1%
Dismantling of facilities	nq	
Total	0.93	100%

The construction stage is the most important stage regarding GHG emissions with more than 93% of the total emissions. Emissions from the power generation stage are thought to be negligible in this case.

Giving the damage costs established in the framework of this project (3.8-139 ECU per t of CO_2 equivalent for the conservative 95% confidence interval and 18-46 ECU per t of CO_2 equivalent for the illustrative restricted range) and the GHG emissions estimated in this case, impacts from global warming are as shown in the following table.

Table 6.2 Damage costs from GHG emissions (case 1)

	mECU/kWh	σ_g
POWER GENERATION		
Global warming		C
low and high estimates (95% confidence interval)	2.16E-04 - 7.89E-03	
mid 3% and mid 1% (restricted range)	1.02E-03 - 2.61E-03	
OTHER FUEL CYCLE STAGES		
Global warming		C
low and high estimates (95% confidence interval)	3.31E-03 - 0.12	
mid 3% and mid 1% (restricted range)	1.57E-02 - 4.01 E-02	

The σ_g column gives a label (A, B or C) for the range of uncertainty estimated for the defined damage. The label A is used for results with a high confidence (geometric standard deviation of 2.5 to 4) and the label C is associated with a low confidence in results (geometric standard deviation of 6 to 12). For more details on the uncertainty issue see appendix VIII.

6.4.2 Impacts of ozone on human health and agricultural crops

The estimates of ozone damages on human health per tonne of precursor emission (NO_x and VOC's) suggested by Rabl (1996) range between 300 and 7500 ECU per tonne of NO_2 equivalent (NO_x emissions are NO_2 equivalent), with a mid point estimate of 1500 ECU/t of NO_2 equivalent. The following table gives the results of the ozone damage costs for the Portuguese hydro fuel cycle (case 1).

Table 6.3 Summary results of damages on human health and agricultural crops from ozone

	mECU/kWh	σ_g
CONSTRUCTION STAGE		
Public health / Mortality- YOLL	7.23E-03	B
Public health / Morbidity	1.28E-02	A-B
Ozone on crops	6.10E-03	B
OTHER FUEL CYCLE STAGES		
Public health / Mortality- YOLL	4.71E-04	B
Public health / Morbidity	8.35E-04	A-B
Ozone on crops	3.98E-04	B

6.4.3 Impacts of the hydroelectric development on aquatic and terrestrial ecosystems

In order to quantify the ecological impacts of a new hydroelectric development one should be able to predict the changes in ecological systems that such project would introduce. Such prediction is intrinsically difficult (Berkes, 1988) and the adequate treatment of the ecosystems requires a great investment on the research of the particular study cases. In the context of project such evaluation was felt not feasible, and thus a qualitative assessment of the projects from the ecological point of view was adopted.

Impacts on terrestrial biota

During dam construction, it is necessary to remove riparian vegetation and all the vegetation present in the area to be inundated. Agricultural as well as forest areas will thus be affected irreversibly in this phase of the project development. During operation, the impacts on the flora are mainly indirect. On the other hand, in the reservoir zone, and despite the fluctuations more or less pronounced in the water levels, will be created a new habitat with conditions favourable to the development of plant species adapted to the new environmental factors. Species like *Tamarix africana* and *Salix alba subsp. alba* are very common in the recent environments of Portuguese reservoirs.

The terrestrial fauna will be affected during the construction period by all the works requiring the removal of vegetation, the movement of soils, and the inundation of lands. Fauna will also be affected by the loss of local amenity due to the presence of equipment, machinery, and people. The loss of environmental quality of the habitats located in the neighbourhood of the working sites results, among other factors, from the emissions of noise and dust.

During operation, the main detrimental effects of the dam on the terrestrial fauna are still present. Thus, the impacts during operation and during construction of the dams are qualitatively coincident. The filling up of the reservoir with water produces an increase of the "barrier effect" caused by the physical presence of an obstacle to the terrestrial species unable to surmount the water plan.

Impacts on aquatic biota

Despite the variety of migratory species present in the ichthyofauna of Lima River, and which represent one of the most important sources of income to the local fishery, the fish community comprises also a considerable number of cyprinid species that, although less relevant from the piscatory point of view, are important ecological links for the community.

Other species are also represented in Lima River, but their number are considerably less important. An exception should be made for the trout that is, at least in some of the river affluents, intensively exploited by sport fishermen. Amongst the most abundant species of cyprinids present in Lima River, the species *Barbus bocagei* (barbel), *Chondrostoma polylepis* (boce), and *Leuciscus cephalus cabeda* are of major importance and have been studied in Portugal for instance by Valente e Alexandrino (1990).

6.4.4 Impacts on bird populations from operation of the transmission lines

Bird collisions with transmission lines

In many areas, birds constantly face threats through colliding with transmission lines although they are morphologically and aerodynamically fitted for airborne movement. However, the evolutionary process that gave these animals superiority in the air, has only recently been influenced by man-made constraints. Thus, there are limits to the ability of birds to cope with artificial obstacles.

A power line located between a feeding area and roosting site of wetland birds can be disastrous (e.g. Crivelli *et al.*, 1988), especially when only a short distance separates them so that the birds only have to make a short flight at the critical height.

The electrocution of birds in transmission lines

Electrocution takes place whenever a bird touches two phase conductors or a conductor and an earthed device simultaneously. This restricts the problem to power lines carrying tensions below about 130 kV, transformer and substation installations. Electrocutions may seriously affect system reliability and may have therefore major economic impacts. Hence, the electrocution problem was the first main aspect of interaction between birds and power supply on which research was carried out. In common with collisions with power lines, electrocution has biological, topographical and technical aspects although these are deeply interwoven and not easily separated.

6.4.5 Impacts of hydroelectric developments on natural erosion processes and land use

Part of this impact refers to the soil lost during construction of the dam, transmission lines, and both temporary and permanent accesses. Although temporary, it might be responsible for the loss and/or displacement of large amounts of soil. As direct consequences of the displacement of soils we have (1) the changes in stream flow characteristics, because of the settling of solids in stream beds and (2) the loss of arable soils, which can lead at a short-term to land use changes.

The quantification of erosion during construction could be made by assuming that soil is unprotected during a given time period, and by keeping the probability of occurrence of mean annual rainfall during that period. The economic valuation of this impact could be made indirectly by computing the costs associated with the loss of agricultural lands or pasturage.

The long-term effect of the presence of a dam, which constitutes a barrage to the flow, is the change in natural sediment transport patterns. The transport of sediments during floods is particularly important since, if it is disrupted, coastal areas are deprived from sediments necessary to the coastline maintenance. Receding sandy coastlines are marked by the cliffing of dunes, beach ridges, or other depositional terrain behind beaches. They occur where losses of sand from the beach have exceeded gains. In practice, most beaches show alterations of gain and loss corresponding with alternations of gentle, constructive wave action with stormy, erosive waves; with variations in rainfall and runoff influencing rates of sandy supply from rivers and eroding cliffs; with variations in the vigour of winds supplying or removing sand; or with variations in the strength and duration of longshore drifting (Bird, 1987).

Because of the uncertainties involved, the impact of the hydroelectric development on natural erosion processes and soil fertility will not be evaluated here. The assessment of impacts of a single project on a process, which operates over substantially different time, scales and spatial dimensions, if feasible, would certainly be a very difficult and ambiguous task.

6.4.6 Effects of impoundments on water quality

The impoundments necessary in most of the Portuguese hydroelectric developments can produce both beneficial and adverse effects on water quality. Two major causal agents of such effects are the detention time of the water and the stream velocity, which are both changed by the placement of a dam on a free-flowing stream.

The adverse effects of impoundments on water quality include: (1) decreased dispersion of waste discharges along the shoreline, resulting from reduced velocities, (2) reduced reaeration, caused by increased water-column depths and reduced velocities, (3) tastes and odours resulting from increased algal activity, encouraged by reduced velocity; (4) accumulation of sludge, caused by the absence of bottom scour due to increased depth and reduced velocities; and (5) a variety of impacts resulting from thermal stratification.

The Beneficial impacts of impoundments on water quality include: (1) reduced turbidity, resulting from longer detention times and lower velocities; (2) reductions in the hardness of the water from carbon dioxide produced by algae and precipitation of calcium carbonate; (3) reduced BOD, resulting from long retention times, which permit biodegradation; and (4) reduced coliform density, due to natural die-off resulting from long detention times.

The major water quality impacts of impoundments that take place downstream and are produced by reservoirs are caused by the release of hypolimnetic water. These impacts include reductions in nutrients and suspended solids concentrations, increases in iron and manganese, low dissolved oxygen concentrations and temperatures, and the presence of hydrogen sulphide. They are aggravated at peaking-power hydroelectric plants by subjecting downstream aquatic biota to wide variations in those water-quality parameters.

Changes in surface water quality are expected to occur just for the case of Alto Lindoso reservoir. In fact, given both the mean volume of water stored and the water residence time in Lourizela dam, it is believed that the impacts will be negligible for the globality of the relevant water quality parameters.

In the case of Alto Lindoso, although significant impacts are expected to occur, the application of models was felt not feasible because of the lack of information.

6.4.7 Human health and amenity impacts from noise generation

Noise has many effects upon humans, and these can be categorised in as many different ways as there are categories. One listing of noise effects would separate them into 5 categories: (i) damage to the hearing system, (ii) impairment of hearing, (iii) task performance disruptions, (iv) non-acoustic physiological effects, and (v) annoyance.

In general, the greater the intensity and the longer the duration of noise, the greater is the likelihood of the various sorts of effects. This relationship is clearest under very quiet or under very noisy conditions. The fact that several types of effects appear to be relatively monotonic, however, does not imply that the functional relationships relating magnitude of noise to magnitude of effect are the same. Indeed it is not even the case that the same parameters of the noise exposure are operative for different classes of effects (Singer & Baum, 1987).

6.4.8 Aesthetic and cultural effects of the intrusion of hydroelectric developments

During the construction phase of hydroelectric developments there are a number of negative impacts that, although temporary, may have considerable magnitude. During this phase will occur interference with the sensorial perceptions of the people who passes in the construction areas, as a result of the spatial and functional disorganisation of the affected space.

During operation some of the impacts identified during construction are eliminated. However, the impacts related to the presence of artificial elements in the landscape, as well as the impacts from changes in the terrain morphology, become definitive.

With the filling up of the reservoirs with water, the destruction of cultural, historical, or scientific landmarks can take place. Such landmarks can be lost or otherwise be simply made inaccessible. On the other hand, with the formation of a lake, the site can be also positively affected in terms of its landscape value.

6.4.9 Impacts of the new accesses on local accessibility

The accesses created by a new hydroelectric development have obviously impacts similar to those of the construction and operation of a new road. Such impacts are negative for flora, fauna, air quality, and other components of the ecosystem, and should therefore be regarded as negative externalities. However, these externalities have a limited temporal extent, since most of them occur during the construction phase and are thus temporary.

After construction, the accesses are useful not only for the transport of workers and materials to the development sites, but also to people not directly involved with the project construction and maintenance. Local people, as well as occasional visitors, can use the new accesses without having to pay for that. This represents a positive externality that is not restricted to the construction phase, and therefore has a larger temporal influence.

The construction of Alto Lindoso development has implicated the improvement of some existing roads and the construction of new ones in Portugal and in Spain. In Portugal, EDP (Electricidade de Portugal) and JAE (Junta Autónoma de Estradas) have promoted the construction (or, in a few cases, the substantial improvement) of 30 km of roads, including 4 new bridges, between Ponte da Barca and Madalena frontier post. After Madalena boundary, already in Spanish territory, it was necessary to re-establish the transport system affected by the dam. In the context of such regularisation, 24 km of major roads and 7 new bridges were constructed.

The region was benefited by a renewed international road network, more equipped in terms of accessways and closer to the Galician neighbours of Lovios and Entrimo municipalities. Yet, the road connection to Orense becomes undoubtedly facilitated.

6.4.10 Impacts of the hydroelectric developments on recreational activities

Negative impacts are expectable for small hydroelectric developments like Lourizela, where any of the new features created seems adequate for recreational utilisation. On the other hand, the presence of the artificial elements in the landscape (*e.g.* the long diversion channel in Lourizela development) are intrusive and deteriorate the conditions to nature appreciation as well as to other recreational activities.

Positive impacts are expectable in the case of large dams, where the reservoirs may constitute an attraction for nautic sports and fishing. In some cases, the negative impacts resulting from the intrusion of the artificial elements in the landscape can be comparatively negligible, and thus a significant positive externality can be produced. Alto Lindoso large dam is in this case.

However, it is always difficult to predict the direct impact on specific types of recreational activities as the result of a given development.

Alto Lindoso and Lourizela hydro developments present markedly different potentials for the outgrowth of recreational activities. In Lourizela such potential is very reduced or even negligible given the reservoir size. On the contrary, Alto Lindoso presents a completely different situation in which all the recreational capabilities could, in theory, be considered as a potential benefit to exploit from dam construction.

6.4.11 Occupational and public health effects from accidents

From preliminary assessment of accident statistics for Portugal and giving the aggregation level of the data available, it was concluded to consider the following fuel cycle stages:

- Plant operation and electricity transmission (manufacturing sector).
- Construction of the facility (construction sector).

These two stages are considered individually bellow for presenting the methodology used to assess that impact.

The approach followed to estimate the number of injuries and fatalities due to occupational and public accidents has been described in CEEETA (1995b). Ratios derived from statistical data have been considered assess the impacts induce by an additional facility. The specific monetary values used to quantify these impacts are described in European Commission (1998a).

The following table presents the results from our assessment related with case 1. Total damages are relatively small and dominated by the construction stage.

Table 6.4 Occupational and public accidents for the hydro fuel cycle (case 1)

Sector	Damage costs (mECU per kWh)		
	Fatality	Injury	Total
Plant operation	2.20E-02	nq	2.20E-02
Power plant building/dismantling	2.09E-01	nq	2.09E-01
Total	2.31E-01	nq	2.31E-01

nq: not quantified.

6.4.12 Impact in terms of employment

To assess the employment generated by the implementation of the hydropower plant, we need to distinguish between direct and indirect employment. The approach followed to estimate the effects on employment has been formerly described (CEEETA, 1994). This approach is summarised in appendix VI.

Total average annual direct employment generated by the construction of the hydropower (case 1) and the transmission lines, the operation of the facility and its maintenance is relatively small: 5.7 job-equivalents.

Table 6.5 Direct employment

Activities	Mean annual hours
1) Construction of power plant	5,738
2) Construction of the transmission lines	1,960
3) Electricity generation and transmission	2,416
Total working hours/year	9,134
Number of job-equivalents/year (1)	5.7

(1) 1 job-equivalent = 1760 h/year

The impacts in terms of direct and indirect employment can be summarised as follows.

Table 6.6 Employment need generated by the small hydro fuel cycle (case 1)

	Nº of job-equivalents per year for 3 different discount rates			**Nº of job-equivalents per TWh**		
	0 %	3 %	10 %	0 %	3 %	10 %
Direct employment	5.7	5.7	5.7	322	322	322
Indirect employment	17.2	23.4	42.9	966	1 308	2 401
Total employment	23.0	29.1	48.6	1 288	1 630	2 723

6.4.13 Impacts from dam failure risk

As already mentioned, Alto Lindoso and Lourizela hydro developments present marked differences in terms of the volume of water stored in their reservoirs. Although the dam failure risk for the small hydro can be quantitatively of the same order of magnitude than the risk failure for Alto Lindoso, it involves much less physical as well as economic consequences.

The floods in Lima and other rivers of the northern region of Portugal were analysed and updated by Rocha (1990). The historical record is not very complete and the consequences of a dam failure have never been evaluated in detail.

The Alto Lindoso dam, close to the Spanish border, retains directly the flows from Spain. Its capacity of about 348 hm^3 corresponds to about 23% of the total affluent volume, which is of about 1400 hm^3. This figures out the importance of Alto Lindoso dam in downstream flood control. In Spain, two upstream dams (Las Conchas and Las Salas) retain together only 167 hm^3, which is about 48% of Alto Lindoso reservoir capacity.

The number of fatalities, if failure occurs, cannot be known with certainty. This uncertainty should be incorporated into risk analysis by evaluating the possible number of fatalities and the probability distribution of fatalities. An additional significant problem is incorporating the non-fatal physical and emotional damages to those who survive the dam failure flood. Typically, these effects are ignored or are assumed to be a linear transformation of the number of fatalities.

6.4.14 Effects of electric and magnetic fields from transmission lines

Effects of electric fields on human health

The possible biological effects of electric fields are not well understood. Yet, it was not possible until now to link any particular human disease, or even symptom, with the exposure to electric fields, even for people living under high voltage transmission lines. Lee et al. (1979) presented one of the first reviews on this subject some years ago. The same conclusion was already pointed out in the context of the ExternE project (European Commission, 1995b&f). However, it seems clear that the uncertainty surrounding the effects of electric and magnetic fields reduce the welfare of people living, working or who have their children in kindergartens or school close to transmission lines (ENCO, 1994).

If a person contacts an earthed metallic structure two situations can occur: (i) if the person is not well isolated from the ground, his body is at the same potential of earth and therefore the contact with the metallic structure has no effect at all; (ii) if the person is isolated from earth, the charge current will pass to the person preferably across the zones of contact with less resistance. However, this current will have the same order of magnitude of that mentioned in (i).

If the person contacts a structure isolated from earth, the charge current of that structure will pass through his body. This is the case of a person that touches a car, isolated from hearth by its tyres, parked under a transmission line. In the most unfavourable situation, the charge current will be of about 0.05 mA per kV/m for a light-duty vehicle and of about 0.25 mA per kV/m for a 2 tonne truck. Assuming a threshold of risk of about 30 mA, it can be seen that such threshold value is much higher than the current expectable in the case of a 750 kV tension line. The most likely event is an unpleasant feeling that is experienced by the person when he touches the metallic structure.

Effects of magnetic fields

A steady electric charge produces an electric field only, but if it is in movement it behaves as an electric current and produces a magnetic field.

Although the actual knowledge on the effects of low intensity magnetic fields is still insufficient, they are thought to be evident only in the following situations: (1) influence over the neighbour circuits and (2) interference with the sense of orientation of some animals.

(1) The magnetic fields generated by a transmission line can produce induction effects on neighbour circuits such as other electric lines and telecommunication circuits. Such effects in general only assume significant importance when occur short-circuits in the inductor line.

(2) It is accepted that the migratory species, and namely birds, do orientate themselves during migrations with both the aid of the sun (position) and of the earth magnetic field. The finding of magnetic crystals in the head of migratory doves is an argument often presented to support this thesis. Also in the abdomen of bees and other insects such types of crystals have been found.

Radio and TV perturbations

There are two main mechanisms by which the high tension transmission lines can generate electromagnetic emissions susceptible to interfere with TV and radio reception: (1) electrical discharges, like those from crown effect and (2) micro-arches between metallic components having different electric potentials.

(1) Each discharge verified in the conductor causes an electrical impulse that originates two current waves propagating in opposite directions, starting from the point of discharge. These current waves give rise to oscillations that can be decomposed in Fourier spectrum. The frequencies contained in such spectrum range between the industrial frequency of the network (50 Hz) and about 10 MHz.

    About the oscillations of elevated wavelength (frequencies up to 3 MHz), the attenuation of their propagation across the conductors is relatively weak, and so they can be transmitted at significant distances. On the contrary, for the higher frequencies, attenuation across the conductors is much more effective and guided propagation doesn’t occur, and only a very localised electromagnetic irradiation can be observed.

    Associated with each current impulse, no matter its frequency, there is a two-field system: an electrical field (that can be picked up by an aerial) and a magnetic field. The low frequency disturbing field (< 3 MHz), at any point in the line, is thus due to the combined effect of a great number of discharges. On the other hand, the disturbances to higher frequencies are caused only by the discharges occurring close to the point of reception (say, some hundred meters around that point).

    According to this, it can be stated that interferences with the reception of emissions in frequencies higher than 10 MHz (such as TV and MF radio frequencies) are not likely to result from operation of the transmission lines.

(2) The formation of micro-arches between metallic components having different electric potentials causes emissions of high frequency electromagnetic radiations. This phenomenon verifies frequently in defective isolators and in connections with defective electrical contact.

Ozone production

The atmospheric electrical discharges due to crown effect (high-energy electrical discharges) can produce ozone and, in fewer quantities, other gases such as nitrogen oxides.

Some measurements indicate that the maximum ozone production rate is about 2 g O_3 per kWh of energy lost by crown effect. For a 750 kV transmission line operating under raining weather, the most unfavourable conditions, the ozone production would be of about 200 g per hour and per kilometre of transmission line. For the same transmission line, but under dry atmospheric conditions, ozone production would be reduced to about 20 g/h **.** km.

Measurements made at the soil level under a 750 kV transmission line show that the increase in ozone concentrations was of about 0.005 ppm(V), which is one order of magnitude less than the concentrations normally observed in the lower atmosphere.

Ions production

The electrical discharges that occur in the high tension transmission lines, particularly when crown effect verifies, produce a great number of ions (about 10^{10} per linear meter and per second). This causes very high densities of ions in the short vicinity of the conductor lines.

The biological effects of ions upon the living organisms are not well understood. However, it seems clear that the collision of ions with the external parts of organisms (e.g. skin) has exactly the same consequence as an electrical current with equivalent density. The inhalation of ions is a non-answered question that requires further research in order to prove that it can have impacts on human health or upon other organisms like birds.

Physiological effects of exposure to very low frequency electromagnetic fields

Studies on the biological action of very low frequency electromagnetic fields have been carried out since the sixties, motivated by the growing expansion of energy transport networks and by the application of working techniques that allow systems to be repaired without service interruptions. Such techniques expose the workers to electric and magnetic fields much higher than those observed at the soil level.

Such studies, which focused several biological actions caused by electromagnetic radiation, have produced controversial results, subject of criticism and doubts from many authors and authorities.

The negative health effects pointed out by the different authors include functional disturbances in the neuro-vegetative, cardiovascular and digestive systems, and the influence in the development of leukaemia and other types of cancer in children inhabiting houses exposed to very high electromagnetic fields (e.g. Rai, 1989).

6.4.15 Review of other impacts

Atmospheric emissions from dams

Depending on the water depth in the reservoirs, impoundments can be an effective source of methane emissions to the atmosphere. Such emissions depend either on the environmental conditions (abiotic factors) or on the biomass actually present in the aquatic system. Turnover rates and productivity, as well as the inputs of organic material from the river catchments, are probably the major ecological factors to be considered for an evaluation of this impact.

Alto Lindoso reservoir presents favourable conditions to methane emissions, at least in the periods of the year susceptible to the formation of a thermocline (summer). On the contrary, in Lourizela small hydro, because of its mean water depth, such emissions are very unlikely to occur.

Induced seismic activity

The presence of a great mass of water in a reservoir can, under certain circumstances, induce seismic activity. The most important aspects to consider when evaluating this impact are the geological structure of the region of implantation of a given dam, and the hydraulic charge of the reservoir. In the case of Lourizela small hydro, this impact is negligible. For Alto Lindoso case study, it may be measurable in terms of increased seismicity risk. Because of the lack of knowledge, data, and methodological approaches to evaluate this impact, it was merely pointed out in the context of this work as a possible externality to be assessed in the future.

Changes in groundwater levels

Changes in groundwater levels arise as a direct consequence of the impoundment. When reservoirs are filled up with water, this may result in a decrease in the productivity of the aquifers located downstream of the dam, compensated (or not) by an increase in their productivity in the zones upstream of the dam.

In Lourizela case study this impact is insignificant, but for Alto Lindoso it may have measurable consequences. The correct evaluation of this impact, from the physical point of view, would require information on the regime of groundwater circulation in the area of influence of the project. Such information, which is not available, should include, among other aspects, the identification of the existing connections between different aquifer levels and their depth.

6.5 Interpretation of results

The following tables summarise the results obtained for the Portuguese hydro fuel cycle. Giving the limitations above mentioned on data collection for case 2, estimated results are only presented for case 1.

Table 6.7 Damages of the hydro fuel cycle (case 1)

	mECU/kWh	σ_g
POWER GENERATION		
Public health		
Mortality- YOLL	4.71E-04	B
of which TSP	nq	-
SO_2	nq	-
NO_x	nq	-
NO_x (via ozone)	4.71E-04	B
Morbidity	8.35E-04	-
of which TSP, SO_2, NO_x	nq	
NO_x (via ozone)	8.35E-04	A-B
Occupational and public health	2.20E-02	A
Crops	3.98E-04	B
of which SO_2	nq	-
NO_x (via ozone)	3.98E-04	B
Ecosystems	nq	-
Materials	nq	-
Noise	ng	A
Visual impacts	ng	A
Employment	iq	-
Global warming		C
low and high estimates (95% confidence interval)	2.16E-04 - 7.89E-03	
mid 3% and mid 1% (restricted range)	1.02E-03 - 2.61E-03	

Table 6.7 (Cont.)

	mECU/kWh	σ_g
OTHER FUEL CYCLE STAGES		
Occupational and public health	0.21	A
Ecological effects	ng	B
Road damages	ng	A
Employment	iq	-
Ozone on human health		
Mortality- YOLL	7.23E-03	B
Morbidity	1.28E-02	A-B
Ozone on crops	6.10E-03	B
Global warming		C
low and high estimates (95% confidence interval)	3.31E-03 - 0.12	
mid 3% and mid 1% (restricted range)	1.57E-02 - 4.01E-02	

* YOLL: years of life lost, VSL: value of statistical life.
ng: negligible; nq: not quantified; iq: only impact quantified; -: not relevant.

Table 6.8 Sub-total damages of the hydro fuel cycle (case 1)

		mECU/kWh
YOLL	low	0.24
	mid 3%	**0.28**
	mid 1%	**0.3**
	upper	0.50

Table 6.9 Benefits of the hydro fuel cycle (case 1)

	mECU/kWh	σ_g
POWER GENERATION	nq	-
OTHER FUEL CYCLE STAGES	nq	-
SUBTOTAL	nq	-

Table 6.10 Damages by pollutant (case 1)

	ECU / t of pollutant
SO_2 *- YOLL	nq
NO_x *- YOLL	nq
PM_{10} *- YOLL	nq
NO_x (via ozone)	1 500
CO_2	3.8 - 139**

* YOLL: years of life lost. ** using the 95% confidence interval.

Impacts from occupational accidents are the dominant impact assessed in case 1 with about 83% of the damage cost. The other main impact in this case is related with global warming. Nevertheless, the total cost quantified or, for the mid estimate in this case, 0.28-0.3 mECU/kWh, is very small when compared with conventional fuel cycles (1 or 2 orders of magnitude higher).

7. AGGREGATION

For the development of the ExternE methodology, CEEETA has given priority to the biomass fuel cycle. This methodology has in a second phase been extended to the coal and hydro fuel cycles. In the last phase of the ExternE project, CEEETA has implemented the ExternE methodology to the natural gas fuel cycle and has updated the previous ones.

In 1995, the Portuguese electricity system was based on the following sources: coal, oil and hydropower. Given the structure of electricity generation in Portugal, the implementation of this task has required an other major development: the analysis of the oil fuel cycle. At the national level, electricity generation from biomass in 1995 is almost negligible and the use of natural gas in this sector should begin in 1998.

7.1 Description of national electricity sector

The Portuguese electricity sector is small at the EU level. With a total demand of 28 TWh in 1994, it represented less than 1.6% of the electricity consumption of the EU. In terms of electricity consumption per capita, Portugal had the lowest ratio with 2.8 MWh in 1994 (about 5 MWh/inhabitant for the EU average). But the annual increase between 1990 and 1993 was almost negligible in average for the EU (0.2% per year) when compared with 2.4% per year for Portugal.

The installed capacity in Portugal was 9 898 MW in 1995. Almost half of this, or 4 291 MW, was hydro capacity and conventional thermal plants (coal and oil) totalized 4 590 MW. The structure of electricity generation in Portugal is strongly dependent on annual hydropower generation. Considering the hydro capacity in 1995, the electricity generated could vary from 11.5 GWh, for a normal hydrological year, to less than 7 TWh for a dry year.

As for other EU countries, the Portuguese electricity sector is moving from a system dominated by one major company to a more diversified and competitive system. The new system based on recent legislation has created both a public and an independent electricity system controlled and monitored by a regulatory entity. In the public electricity system, public and private generators commit to sell electricity to the Grid Company (REN). REN buys the power at each plant’s cost and then sells it to the four regional distribution companies. In the independent electricity system, producers sell directly their electricity to independent consumers at a price including defined transmission and distribution charges.

The introduction of competition in the electricity system and the restructuring of the major company are the two main factors of changes affecting the evolution of this sector. The interaction between energy policy and environmental policy is not a priority in the short term in Portugal. Giving the low levels of emissions per capita in Portugal, the official position is that emissions limitation and environmental protection should not constrain economic growth.

7.2 Aggregation methods

The aggregation of external costs for the Portuguese electricity sector induces two major problems. The first one is related to the annual variation of electricity generated by hydropower (see figure below) and the second is related with the lack of national study on the oil fuel cycle.

Regarding the hydro component, the electricity generated in one year rarely reflects the average hydrological conditions. The base year for aggregation of impacts is 1995. As shown in the following figure, the hydropower generation for this year is not representative of mean hydrological conditions. This structure is strongly influenced by the hydrological regime. For example, the electricity generated by hydropower plants (for the same capacity installed) has almost doubled between 1992 and 1994. To avoid this problem, it has been considered a mean value for the hydrological regime. This value represents 32.4% of the total electricity generation for the reference year; the remainder is covered by thermal power generation.

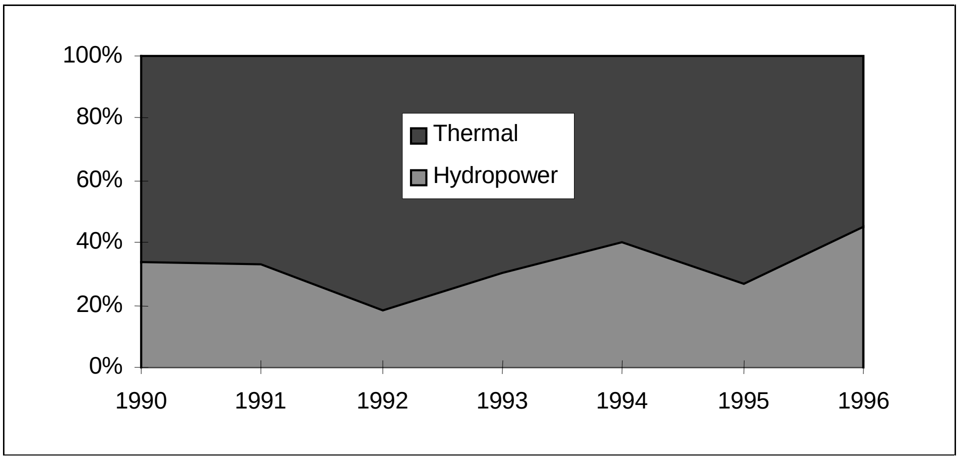

Figure 7.1 Evolution of the power generation structure

For the oil component of the system, the EcoSense software has been used to assess impacts from air pollutants (SO_2, NO_x and particulates) emitted by the main power plants. The owner (CPPE) of these power plants has provided technological and environmental data. Damages from CO_2 emissions have been calculated directly using the economic values (in ECU/t of CO_2) provided in the framework of the project and the carbon content of the respective fuel. For the other impacts, relevant data from other implementations have been used.

For the hydro and the coal fuel cycles, results from the national implementation in terms of ECU/t or mECU/kWh have been used. Giving the site and project-specific characteristics of the hydro fuel cycle, the transferability of national or international results is difficult.

Nevertheless, giving the low value of externalities that have been quantified and the range of uncertainty, the transferability of results has been considered reasonable in the framework of this task.

7.3 Results

Giving the methodological approach presented above and the hypotheses retained, the following tables summarise the results for the Portuguese electricity system. Table 8.1 gives the results in terms of external cost (mid estimate) without considering damages from global warming impacts (GWI). And table 8.2 summarises the estimates of external costs considering different ranges of damages from GWI. Tables 8.3 and 8.4 provide estimates for the overall electricity system in Portugal (continental part) respectively for 1995 and 2010.

Table 7.1 External cost (except GWI) from the Portuguese electricity system in 1995

Power plant category	Damages in mECU/kWh					Electricity generation[1]		Damages	
	SO_2	NO_x	TSP	Other	Total	GWh/yr	%	MECU/yr	%
Coal	24	14	1	10.41	49.0	13 455	43.6	658.7	69.4
Oil	30	5	1	2.34	38.8	7 426	24.0	287.8	30.3
Hydro	ng	ng	ng	0.26	0.3	10 008	32.4	2.6	0.3
Total electricity system without GWI					30.73	30 889	100	949.1	100

(1) Net production for 1995, considering an average flow regime for the last 7 years.

Considering the price of electricity for industry in 1995 or 90 mECU/kWh, the external cost (without GWI) calculated for the Portuguese electricity system (30.7 mECU/kWh) represents about 34% of this price. So, the integration of these external costs in the electricity prices would represent, in this case, an increase of 34% of the price of electricity for the industry.

The external cost (without GWI) for the society, estimated in 950 million ECU (187,000 million Escudos), represents about 1.2% of the Portuguese GDP in 1995 or around 30% of the electricity generation sector’s turnover in 1995. About 69% of this external cost is due to coal power plants and about 30% from oil units. The total damages induced by hydropower plants represents less than 1% of this total external cost.

Table 7.2 GWI from the Portuguese electricity system (per unit of electricity sent and total costs)

Power plant category	Damages from GWI in mECU/kWh			
	95% confidence interval[1]		Restricted range[2]	
	Low	High	Mid 3%	Mid 1%
Coal	3.28	120.1	15.5	39.7
Oil	3.36	122.8	15.9	40.6
Hydropower	3.53E-03	0.13	1.67E-02	4.27E-02
External costs from GWI	2.24	81.87	10.60	27.09
Power plant category	Damages in MECU/year			
	95% confidence interval[1]		Restricted range[2]	
	Low	High	Mid 3%	Mid 1%
Coal	44.2	1615.5	209.2	534.6
Oil	24.9	912.0	118.1	301.8
Hydropower	0.04	1.3	0.17	0.43
External costs from GWI	69.1	2528.8	327.5	836.9

(1) Considering values for GWI ranging from 3.8 to 139 ECU/t of CO_2.
(2) Considering values for GWI ranging from 18 to 46 ECU/t of CO_2.

Damages from GHG emissions range from 2.2 to 81.9 mECU/kWh of electricity sent to the grid. These damages are essentially due to the use of fossil fuels in the electricity sector. Aggregated GWI from the Portuguese electricity system range from 69 to 2529 millions ECU (13,600 to 500,000 millions Escudos) in 1995. These external costs represent between 0.1 and 3.2% of the Portuguese GDP in 1995 or between 2 and 82% of the electricity generation sector's turnover in 1995. For each scenario about 64% of the total cost is due to damages from coal power plants and 36% from oil units. The total external cost generated by hydropower in each valuation scenario is estimated representing less than 1% of the aggregated value.

Table 7.3 Total external costs (including GWI) for the Portuguese electricity system in 1995 (per unit of electricity sent and total costs)

Power plant category	Damages from GWI in mECU/kWh			
	95% confidence interval[1]		Restricted range[2]	
	Low	High	Mid 3%	Mid 1%
Coal	52.2	169.0	64.5	88.7
Oil	42.1	161.5	54.6	79.4
Hydropower	0.26	0.39	0.28	0.3
External costs from GWI	32.9	112.6	41.3	57.8
Power plant category	Damages in MECU/year			
	95% confidence interval[1]		Restricted range[2]	
	Low	High	Mid 3%	Mid 1%
Coal	702.9	2274.3	868.0	1193.4
Oil	312.7	1199.7	405.9	589.6
Hydropower	2.63	3.9	2.76	3.02
External costs from GWI	1018.3	3477.9	1276.6	1786.0

(1) Considering values for GWI ranging from 3.8 to 139 ECU/t of CO_2.
(2) Considering values for GWI ranging from 18 to 46 ECU/t of CO_2.

Considering the price of electricity for industry in 1995, the external costs (including GWI) calculated for the Portuguese electricity system represents between 37% and 125% of this price. So the full integration of these external costs in the electricity prices would mean, in this case, an increase ranging from 34 and 125% of the price of electricity for the industry.

Total external costs range from 33 to 113 mECU/kWh of electricity sent to the grid. These damages are essentially due to the use of fossil fuels in the electricity sector. As shown in table 8.3 above, damage costs from hydropower are 2 or 3 orders of magnitude lower than costs from fossil fuel cycles. Aggregated external costs from the Portuguese electricity system range from 1018 to 3478 millions ECU (200.6 to 685.4 10^9 Escudos) in 1995. These total external costs represent between 1.3 and 4.4% of the Portuguese GDP in 1995 or between 33 and 112% of the electricity generation sector's turnover in 1995. Damages from the coal power plants represent between 65 and 69% of this total aggregated cost and oil plants induce 30 to 35% of the total external cost. For hydropower the total external cost induced is estimated representing less than 1% of the aggregated value in all the scenarios.

Giving the recent introduction of natural gas in Portugal, the situation regarding the total external costs of the power system will be substantially altered in the medium term. External costs of electricity generation from natural gas were assessed in the Portuguese implementation of the ExternE project (see chapter 5). Giving some hypotheses on energy use in the period 1995-2010 (MIE, 1996), we can estimate the total external costs of the power system in 2010. The following table synthesises the results obtained.

Table 7.4 Estimated total external costs for the Portuguese electricity system in 2010

Power plant category	Total damages in mECU/kWh			
	95% confidence interval[1]		Restricted range[2]	
	Low	High	Mid 3%	Mid 1%
Coal	52.2	169.0	64.5	88.7
Oil	42.1	161.5	54.6	79.4
Hydropower	0.26	0.39	0.28	0.3
Natural gas	2.00	61.77	8.30	20.63
Total external cost	21.57	90.30	28.79	43.01

(1) Considering values for GWI ranging from 3.8 to 139 ECU/t of CO_2.
(2) Considering values for GWI ranging from 18 to 46 ECU/t of CO_2.

As shown in this table the total unitary costs will be reduced between 35% (for the low estimate) and 20% (for the high estimate) for a penetration of the natural gas in 2010 representing about 30% of the electricity generated in Portugal (continental part). This analysis does not include any change for the other power plants' categories. However, if the introduction of technologies reducing atmospheric emissions (namely SO_2, NO_x and particulates) was also considered for coal and oil power plants, the reduction of the total unitary costs could be larger than that.

Regarding the total external costs of the Portuguese electricity generation system, estimates show that, despite a rise of about 50% of the electricity generation during this period (1995-2010), the increase in total damages should be kept down (increase of 1.4% to 24%). Hence, the introduction of natural gas in the electricity generation sector will affect positively the situation regarding external costs.

8. POLICY CASE STUDY

8.1 Objective

The objective of this task was to used the results of the ExternE project in a policy case study to show the potential interest of these results in policy decision processes. The Portuguese implementation related to the “Policy case study” task has analysed different strategies to meet the future electricity demand in São Miguel Island (Azores archipelago).

Renewable energy sources (RES) could play an important role in the formulation of the power generation system if the large available potential of the island is significantly exploited. Given the high costs of imported fuels in islands, the competitiveness of RES is accentuated. Thus the maximisation of RES penetration could be simulated on the basis of two scenarios:

- A reference scenario (A): Minimisation of private costs for the utility.
- An alternative scenario (B): Minimisation of total costs (private and social costs) for the island and/or archipelago. This scenario considered different levels of damage cost for the GWI (low and high estimates of the restricted range).

Giving the results of this simulation, different configurations of the power generation system are presented for the years 2000, 2010 and 2020.

8.2 Implementation

To implement this case study, the following tasks were undertaken:

- Analysis of the power generation system.
- Analysis of the future electricity demand.
- Construction of a set of potential power plants for the defined scenarios.
- Assessment of external costs for the identified potential power plants using the ExternE methodology.
- Optimisation of the power generation system using an existing model for each scenario.
- Presentation of the results of the different strategies to meet the future demand.

8.3 Policy case study description

The Azores Archipelago, a volcanic formation of nine islands, is localised in the North Atlantic Ocean 1,500 km away from the European continent and 3,900 km from American continent. São Miguel is the larger island (with 747 km^2) of this archipelago (see figure 8.1 hereafter).

This island is characterised by a temperate and rainy climate with temperature varying from 10ºC to 18ºC, a maximum altitude of 1,105 m and average annual rainfall around 2,200 mm/year. The population in this island reached 125,915 inhabitants in 1993 (population density of 169 inhab./km^2).

The electricity generation sector in S. Miguel is characterised by a strong increase of the demand (6.6% per year between 1990 and 1994) reaching 195.5 GWh in 1994. Nevertheless, the electricity consumption per capita remains low with 1.3 MWh (half of the national figure and four times less than the EU ratio).

Total installed capacity in 1994 was 56.8 MW (91% oil and 9% hydro). In terms of electricity generation the oil plants provided 89% of the electricity sent to the grid and hydropower 11%. The following table lists the characteristics of the existing plants and figure 8.2 hereafter show the localisation of the main existing plants in São Miguel Island.

Table 8.1 Characteristics of the existing plants

Power plants	Unit nº	Net capacity		Outage factor	Available capacity	Full load	Energy sent	
		(kW)	(%)	(%)	(kW)	hours	(MWh)	(%)
Ponta Delgada 1	I	900		0%	900	146	131.7	
Ponta Delgada 2	IV-V	4 100		0%	4 100	745	3 055.3	
Ponta Delgada 3	VII-VIII	4 500		16.8%	3 744	1 414	5 294.0	
Foros 1	I	2 000		0%	2 000	29	58.7	
Foros 2	II	2 000		0%	2 000	34	68.8	
Caldeirao 1	I-II	15 400		12.5%	13 480	5 476	7 3819	
Caldeirao 3	III	7 700		6.6%	7 195	7 318	5 2654	
Caldeirao 4	IV	7 700		12.1%	6 767	7 287	4 9315	
Total Oil		**44 300**	92.7%		**40 186**		**184 397**	89%
Tambores	I	60		25.7%	45	6 088	271.5	
F. Redonda 2	I	300		11.6%	265	1 351	358.2	
F. Redonda 3	I	300		6.2%	281	3 246	913.2	
Nova	I	200		0.4%	199	3 076	612.5	
Tuneis	I	1 150		3.8%	1 107	8 429	9 327.6	
Canario	I	350		8.6%	320	8 005	2 559.7	
Ribeira Quente	I	750		8.1%	690	8 054	5 553.4	
Ribeira Praia	I	400		6.1%	376	8 508	3 196.3	
Total hydro		**3 510**	7.3%		**3 282**		**22 792**	11%
Total Island		**47 810**	100%		**43 468**		**207 189**	100%

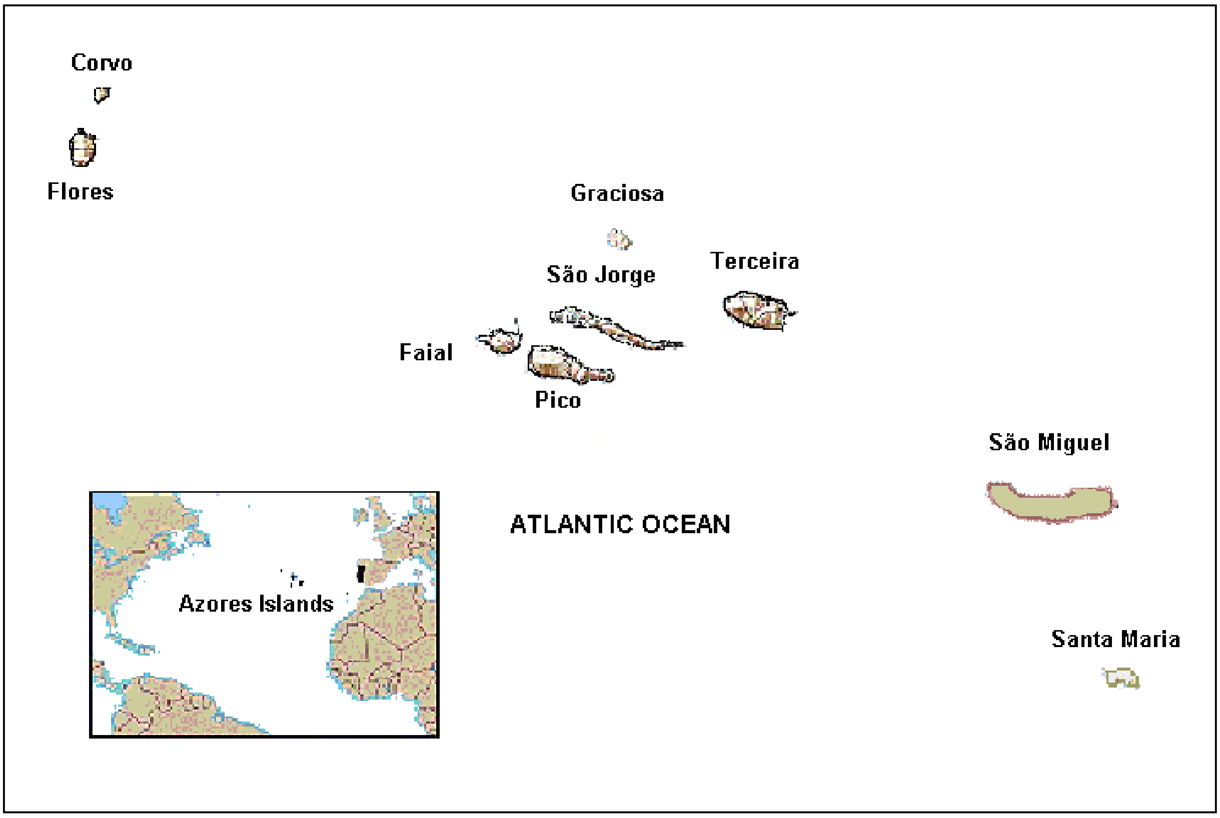

Figure 8.1 Azores archipelago

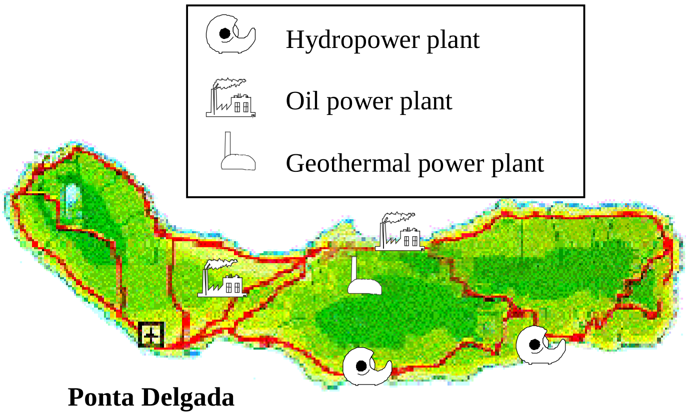

Figure 8.2 Location of the main power generation units in São Miguel Island

S. Miguel has a large potential for electricity generation from renewable energy sources (RES). The new RES, which were modelled, are geothermal, wind and biomass.

Table 8.2 Characteristics of the potential new plants

Power plant category	Unit nº	Gross capacity	Net capacity (kW)	Outage factor (%)	Full load hours	Energy sent (MWh)
Plants under construction						
Geothermal						
Pico Vermelho*	I	703	600	15%	7 446	4 468
Lagoa do Fogo*	I	12 700	10 833	15%	7 446	80 663
Potential new plants						
1) Fuel-oil						
Caldeirão5	I-VI	5 263	5 000	12%	7 709	38 544
Total fuel-oil			**30 000**			**231 264**
2) Diesel-oil						
Foros3	I-III	3 158	3 000	20%	7 008	21 024
Total diesel-oil			**9 000**			**63 072**
3) Geothermal						
Geothermal2	I-VI	6 096	5 200	15%	7 446	38 719
Total geothermal potential			**31 200**			**232 315**
4) Biomass						
Biomass	I-IV	5 556	5 000	15%	7 446	37 230
Total biomass potential			**20 000**			**148 920**
5) Wind						
Wind	I-III	4 124	4 000	15%	3 100	12 401
Total wind potential			**12 000**			**37 202**

*Considered under exploitation in 1996.

8.4 Model description

The model used can simulate the operation of electric utility systems. It can perform production cost analyses, integrated resource planning analyses and financial analyses. This model simulates the production of electricity to meet loads for one or several years. It also performs automated capacity expansion giving defined available resources. New power plants are normally introduced in the electricity system giving their capital and operating costs and existing plants are dispatched giving their marginal cost without considering their environmental impacts. This model can integrate externalities and other benefits (avoided costs) in several ways namely external costs can be added to operating costs influencing the dispatch ranking.

The following data are required or could be introduced in the model for one or more scenarios:

- description of the demand and its evolution: load curve, electricity consumption and distribution losses.
- description of the electricity generation system: plants categories and capacities, capital and operating costs, externalities and other benefits.
- operating rules: base year, simulation period, reserve margin and environmental constraints.

The generation module of this model performs a production cost simulation. It determines the least cost manner of supplying the demand for a given week, month or year. Generating units are dispatched by order of increasing operating cost.

The model also optimises the capacity expansion executing a series of production cost runs. It uses annual production cost information to determine the production and emission costs or benefits of adding additional resources. The model also calculates capital costs, fixed operation and maintenance costs and shortage costs.

8.5 Externalities

A direct assessment of externalities from the São Miguel electricity system has not been perform except for the geothermal fuel cycle, which is specific to this island (Martins *et al.*, 1996). Giving the localisation of the power plants (in a small island of the Atlantic Ocean), externalities from the electricity system are dominated by global warming impacts (GWI).

The external costs induced by GWI could be estimated for the existing and potential new plants using results from ExternE implementations, namely greenhouse gases' emissions and damages in terms of ECU per tonne of CO_2 equivalent (low and high estimates of the restricted range). Values of GWI are presented in the following table for the different energy sources that were modelled considering two alternative scenarios:

- in scenario B1 external costs are integrated in the electricity system using the low estimate for GWI or 18 ECU/t of CO_2 equivalent;
- the scenario B2 integrates external costs using the high estimate for GWI or 46 ECU/t of CO_2 equivalent.

Table 8.3 Externalities of the different fuel cycles

Cost category		External cost	
		Scenario B1	Scenario B2
1) Oil plants:	Cost (mECU/kWh)	15.9	40.6
	Cost (Esc./kWh)	3.11	7.94
2) Wind*:	Cost (ECU/kW)	0.295	0.75
	Cost (Esc./kW)	57.6	147.2
3) Hydro*:	Cost (ECU/kW)	0.057	0.147
	Cost (Esc./kW)	11.21	28.66
4) Biomass:	Cost (mECU/kWh)	0.35	0.90
	Cost (Esc./kWh)	0.07	0.18
5) Geothermal:	Cost (mECU/kWh)	14.47	36.98
	Cost (Esc./kWh)	2.83	7.23

* cost per unit of installed capacity and per operating year.

For oil, biomass and geothermal fuel cycles greenhouse gases' emissions are mainly dependent on the energy generation stage. Giving this characteristic, GHG emissions could be considered proportional to the electricity generation (see table hereafter). So, for these fuel cycles, external costs are expressed in terms of mECU/kWh (or Esc./kWh) and could be added to the fuel cost. These external costs represent in scenario B1 about 70% of the variable cost for oil plants, 1% for biomass and 105% for geothermal. For scenario B2, the external costs are higher and represent 180% of the variable cost for oil plants, 2% for biomass and 270% for geothermal. The increase for geothermal is very high due to the low level of variable cost (in the reference scenario) and, for this geothermal fuel cycle, giving the high emission of CO_2 (see table hereafter).

For wind and hydropower, GHG pollutants are dominantly emitted in the upstream stages (e.g. extraction, manufacture and production, construction and installation). In this case, GHG emissions are independent from the level of electricity generation that could vary significantly from one year to another. So, for these fuel cycles, external costs are expressed in terms of ECU/kW (or Esc./kW) and are integrated as fixed costs considering the lifetime of the defined power plant. Comparatively to the investment cost, these external costs are rather low ranging, respectively for scenario B1 and B2, from 0.3% to 0.7% for wind power and from 0.2% to 0.4% for hydropower. The following table gives the GHG emissions retained in our analysis.

Table 8.4 GHG emissions for the São Miguel Island's electricity system

Power plant category	GHG emission	
	g/kWh	t/MW*
1) Oil	883.5	-
2) Wind	-	16.38
3) Hydro	-	3.19
4) Biomass	19.6	-
5) Geothermal	803.9	-

* emission per unit of installed capacity and per operating year.

8.6 Results

In 1995, the electricity supply in São Miguel Island was mainly dependent on oil power plants (see table 9.1). Geothermal resources are important in the island and their exploitation began in 1996 with the operation of two power plants. Biomass and wind power are other options considered in our simulation.

The increase of the electricity demand is estimated to be 3.4% per year during the period 1996-2020. This moderate increase correspond more or less to a duplication of the electricity consumption during this period and give a ratio of electricity consumption per capita in 2020 equal to the national one in 1995.

Considering the minimisation of private costs for the utility as defined in scenario A, the development of the power generation system is presented in the following table.

Table 8.5 Results for scenario A (base)

Power plant category	Electricity generation					
	2000		2010		2020	
	GWh	*%*	GWh	*%*	GWh	*%*
Oil	52.8	*22.5*	19.2	*5.9*	149.3	*32.6*
Hydro	22.8	*9.7*	22.8	*7.0*	22.8	*5.0*
Biomass	0	*0*	0	*0*	26.0	*5.6*
Wind	9.1	*3.9*	27.3	*8.4*	27.4	*6.0*
Geothermal	149.7	*63.8*	257.4	*78.8*	232.4	*50.8*
Total	234.5	*100*	326.7	*100*	457.7	*100*

In this reference scenario, defined hydropower, wind and geothermal potentials are fully exploited. On the contrary, potential biomass plants remain less competitive than oil plants. Their marginal introduction in 2020 is only due to the limited number of new oil plants considered in the model.

Considering the minimisation of the total costs (private and social costs) for the utility as defined in scenario B1, the development of the power generation system is characterised in the following table.

Table 8.6 Results for scenario B1

Power plant category	Electricity generation					
	2000		2010		2020	
	GWh	*%*	GWh	*%*	GWh	*%*
Oil	52.8	*22.5*	19.2	*5.9*	149.3	*32.6*
Hydro	22.8	*9.7*	22.8	*7.0*	22.8	*5.0*
Biomass	0	*0*	0	*0*	26.0	*5.6*
Wind	9.1	*3.9*	27.3	*8.4*	27.4	*6.0*
Geothermal	149.7	*63.8*	257.4	*78.8*	232.4	*50.8*
Total	234.5	*100*	326.7	*100*	457.7	*100*

Despite the increase of variable cost for oil (70%), biomass (1%) and geothermal (105%), results from the simulation for the period 2000-2020 show that the power generation structure remain the same. Operating costs of geothermal plants are still lower than for oil plants. However, the internalisation of external costs considered in this scenario B1 is not sufficient to allow for a higher penetration of RES and namely biomass comparatively to scenario A.

Considering the minimisation of the total costs (private and social costs) for the utility as defined in scenario B2, modelling results regarding the development of the power generation system are shown in the following table.

Table 8.7 Results for scenario B2

Power plant category	Electricity generation					
	2000		2010		2020	
	GWh	*%*	GWh	*%*	GWh	*%*
Oil	11.8	*5.0*	0.1	*0.04*	69.5	*15.2*
Hydro	22.8	*9.7*	22.8	*7.0*	22.8	*5.0*
Biomass	75.0	*32.0*	149.0	*45.5*	150.0	*32.8*
Wind	9.1	*3.9*	27.3	*8.4*	27.4	*6.0*
Geothermal	115.7	*49.3*	127.8	*39.1*	187.8	*41.0*
Total	234.5	*100*	326.7	*100*	457.7	*100*

In this scenario the increase of variable cost for oil (180%), biomass (2%) and geothermal (270%) are higher than in scenario B1. These strong increase in variable costs for oil and geothermal plants make biomass competitive. In this scenario the modelling results for the period 2000-2020 show a larger penetration of renewables energy sources. Oil plants are only operating on a marginal basis with less than 1% to 15% of the electricity sent to the grid while defined hydro, wind and biomass potentials are fully exploited. Geothermal plants become less competitive than biomass ones but they remain more competitive than oil plants.

The external costs considered in this scenario B2 make all the defined RES more competitive than oil for the power generation system. So, the hypotheses considered in this scenario allow for a maximisation of RES penetration. The simple internalisation of external cost considered in scenario B2 would induce an increase in total cost of electricity ranging from 50% to 70% when compared to scenario A. However, the real impact of this internalisation could be limited if other costs (social costs or taxes) are at the same time reduced.

9. CONCLUSIONS

Despite the remaining uncertainties underlying the assessment of external costs, this project has allowed for a considerable progress in quantifying costs that are not integrated in the private cost of electricity generation. The ExternE project implemented in all the EU countries (except Luxembourg) and Norway has provided a large amount of qualitative and quantitative results that can be used directly or as background information for policy makers at national and/or international level.

Giving the approach followed in this project, the fuel cycle external costs presented in this document are more specific to Portugal and the results presented in mECU per kWh are strongly influenced by the chosen location and the analysed technology. To avoid technology discrepancies, external costs are also presented in ECU/t of pollutant emitted. Although the results are generally presented as sub-totals, some impacts remaining not quantified or not totally assessed, the figures obtained are considered significant.

The implementation of the ExternE project in Portugal aimed at quantifying the external costs of energy generation, which is to say, at determining the non-internalised costs of the production of one unit of energy. That objective was pursued through the examination of a set of case studies representative of the structure of the Portuguese energy sector. In such perspective biomass, hydro, coal and natural gas fuel cycles were studied. The oil fuel cycle was not subject of such analysis, due to project implementation constraints. Despite this possible limitation, values from other case studies, undertaken in the context of ExternE accounting framework, were used for the aggregation exercise.

For the Portuguese coal fuel cycle, as illustrated by Pego case study, the total damages evaluated (excluding GWI) range between 23.1 and 40.6 mECU/kWh. Considering the mid point estimates, about 72% of the estimated results are impacts from air pollutants on human health and 26% impacts from occupational and public accidents. If global warming impacts are included in these figures, both the uncertainty and the final estimate of damage costs raise substantially, becoming the final figure in the range between 26.4 and 160.7 mECU/kWh. Considering the total estimated external costs, GWI represent between 12% and 75% of these figures.

Natural gas fuel cycle presents a rather different picture mainly in what concerns human health impacts, which are almost two orders of magnitude lower than those of coal fuel cycle. The results without considering global warming effects are low and range between 0.32 and 0.58 mECU/kWh. Impacts from air pollutant on human health account, as for coal, for a large portion of the total impacts. If effects from greenhouse gases' emissions are considered the outcome of the evaluation is in the range between 2.0 and 61.8 mECU/kWh, which makes the differences between coal and natural gas much more narrower. This is an important conclusion since for natural gas fuel cycle the GWI account for almost the totality of the external costs (84% to 99%, respectively for the low and high estimates).

As far as biomass is concerned the results refer to a cogeneration plant. In consequence, the impacts are subdivided between electricity and heat production using the exergy approach (see appendix VI). Two variants of the case study were analysed: a cogeneration plant using bark as fuel source (case A) and a cogeneration plant using biomass from short rotation forestry (case B). Impacts from each case differ mainly because of the fuel origin.

For case A, the sum of the damage costs caused by the priority impacts subject to monetary valuation ranges between 14.6 and 28.6 mECU/kWh for the electricity and between 0.86 and 1.68 mECU/MJ for the heat production at the cogeneration plant. The main contributions to the damage cost figure arose with mortality (49% of the total damage costs for the mid estimate), occupational and public health (33%) and morbidity (13%). These impacts are mainly related to air pollutant's emissions (namely particulates and NO_x) and accidents.

If global warming is included in this accounting we obtain damage cost intervals between 14.6 and 29.9 mECU/kWh for the electricity component and between 0.9 and 1.8 mECU/MJ, for the heat part. For biomass, global warming damage costs are very small (representing less than 5% of the total damage costs for the worst scenario) since the emissions of CO_2 at the energy generation stage are not considered for this fuel cycle. That's probably the most important feature of biomass fuel cycle in comparison with the other fuel cycles studied herein.

The impacts estimated in case B result in damage costs which are lower than in case A. This happens even considering the environmental costs induced by fertiliser's application and soil erosion; impacts which are not applicable in case A. The reason for such results is basically related to the fuel characteristics (bark in case A) and namely the sulphur content of the fuel which is about three times higher than the average sulphur content of the biomass used in case B. Monetary valuation of the environmental damages for this case ranges between 10.8 and 26.1 mECU/kWh for the electricity and between 0.64 and 1.54 mECU/MJ for the heat production. If we add global warming impacts to these figures we obtain again a slightly higher result with damage cost intervals ranging from 10.9 and 28.9 mECU/kWh for electricity generation and between 0.64 and 1.7 mECU/MJ for heat.

With respect to the hydro fuel cycle the results are only available for case 1 (small hydro development). The authorities in charge of the project referred to as case 2 (Alto Lindoso large hydro development) were unable to provide us with the necessary data to implement the ExternE methodology. Thus, quantitative results have only been obtained in case 1.

The analysis of the hydro fuel cycle has shown that ecological impacts were of major importance for the evaluation of the externalities of hydro developments. Differently of what we may notice in other fuel cycles where the relative weight of local ecological impacts is assumed rather small when compared to that of other categories of impacts, for hydro developments, and namely for the large ones, that assumption definitely doesn't verifies. Since local ecological impacts were not quantified from the monetary point of view, it should be kept in mind that the monetary results presented below could represent the quantification of a small fraction of the whole figure of damage costs. Benefits from the existence of a lake and from the construction of new infrastructures have not been assessed. For the Portuguese context, these positive externalities could reach a significant figure. This is an important area for further research.

For case 1, Lourizela small hydro, it was found a damage cost of about 0.3 mECU/kWh (excluding GWI), value that becomes in the range between 0.24 and 0.37 mECU/kWh. The major contribution to this figure are the occupational health impacts, accounting for 62% to 98% of the total damage costs excluding GWI. If global warming impacts are included the total figures range from 0.24 to 0.5 mECU/kWh. As for the biomass fuel cycle, GWI are less relevant with values representing between 1.5% and 26% of the total damages.

As it was expected, the results from our case studies show that renewable fuel cycles are less harmful than fossil fuel cycles. An other important conclusion of the implementation of the ExternE project is that the introduction of some conventional technologies to reduce atmospheric emissions (namely SO_2, NO_x and particulates) would be, in the Portuguese context, completely compensated by a reduction in total damages related to these pollutants.

As far as aggregation is concerned, the uncertainties burdening the assessment of externalities for individual cases may rise at the whole electricity system. The transferability of values taken from specific cases might not be reasonable. However, the results from the aggregation exercise are a first exhaustive attempt to quantify the effects of political and economic choices regarding electricity generation.

The implementation of this task for the whole electricity system in Portugal (continental part) gives estimates ranging between 32.9 and 112.6 mECU per kWh (considering the 95% confidence interval for GWI) and between 41.3 and 57.8 mECU per kWh (considering the restricted range for GWI). These external costs are high. For comparison, the indicative electricity price for an industrial consumer was of about 90 mECU/kWh in 1995. Considering the total electricity generation in 1995, the Portuguese electricity system would be responsible for an external cost that, given the present state of our knowledge, range between 1.0 and 3.5 GECU (200 to 685 10^9 Escudos). These values represent between 1.3% and 4.4% of the Portuguese GDP or 33% to 112% of the electricity sector’s turnover in 1995.

The introduction of natural gas in the electricity generation sector will affect positively the situation. Considering only some hypotheses on NG penetration and electricity consumption for 2010, the unitary external cost of the Portuguese electricity generation system might be reduced in 20% to 35% during the period 1995-2010 and the increase of the total external cost should be contained.

The major conclusion of this study may be that, in spite of the uncertainties underlying the analysis, a large set of externalities for electricity generation has been generated, and therefore, a first attempt towards the integration of environmental aspects into energy policy may be carried out. The fact that this study has been implemented at an European level implies that the Portuguese results may be compared with those from other EU countries, thus illustrating the site-specificity of the externalities assessed.

Regarding the figures obtained for external costs, it has to be noted that, although the results are considered sub-totals (some impacts were not quantified) these figures are already significant, specially if global warming damages are taken into account. For example, and considering the restricted range for global warming impacts, the coal fuel cycle assessed show external costs of around 50 mECU/kWh, or about the same magnitude as the private costs. Natural gas, which is considered as a clean fuel, shows external costs around 10 mECU/kWh, what is also significant but considerably lower than those for coal and oil.

In general, it may be said that fossil fuels have significant external costs, while renewable energies have very small ones, namely for hydropower with less than 1 mECU/kWh. Nevertheless, biomass fuel cycles (old technologies) could induce some significant damages with external costs around 15 mECU/kWh.

When it comes to the aggregation of the damages for the whole electricity sector, the figures obtained, although still preliminary, show significant values, between 1% and 2% of the Portuguese GDP (1995). Therefore, it might be concluded that the external costs of some fuel chains are high enough to affect energy policy decisions. However, here it has to be reminded that the methodology has still a large number of uncertainties.

Several aspects should be improved, mainly the estimation of global warming damages. Atmospheric dispersion models, which, at least for some countries, should account for the complex topographic conditions are also a controversial aspect. An important issue which should also be studied is the relationship between atmospheric pollution and chronic mortality, and the valuation of the deaths produced by atmospheric pollution.

Regarding global warming damages, its range of estimated results is so broad that it dominates the results for fossil fuel chains. This produces that, when the mid or high estimate for global warming damages is considered, fossil fuels cannot compete with renewables. Therefore, these estimates for global warming benefit to a large extent these energy sources.

Considering that chronic mortality is, by large, the major externality, besides from global warming damages, of fossil fuel chains, the fact that there is only one exposure-response function for its estimation, and that this function comes from the US, without being checked in Europe, adds a lot of uncertainty to the final results.

The valuation of human life is also a significant factor affecting the results, as it determines the human health externality, which, as said before, is the major one. Controversy still exists around this issue, and, in spite of the modifications introduced in the valuation of life by the Core Project, the values assigned are still contested outside the project.

All these uncertainties affect the individual fuel chains examined. For the aggregation of results to the whole electricity sector, more problems arise, such as the transferability of results from one site to another, or the accounting of effects for which there is a threshold. Indeed, differences in the damages per tonne of pollutant emitted between different sites are quite large, so the direct transfer of results from one site to another is not reasonable. In the case of hydro, this transferability is even more difficult.

Hence, it is recommended to use the results provided by this report only as background information. This background information might be very useful for establishing economic incentives, such as environmental taxes, or subsidies for renewable energies, or for energy planning measures.

Although further research is required to refine the methodology, and thus, to produce more precise results, reducing the range of existing uncertainties, this report is the first comprehensive attempt to estimate the externalities of electricity generation in the Portugal as well as in the other EU countries. The ExternE Project has succeeded in quantifying externalities and their associated uncertainties in more detail than any previous study. The uncertainties are rather large, but they are more a reflection of the existing knowledge than the result of the methodology used. The ExternE outcomes therefore provide the information that policy makers need to make informed decisions about energy/environment issues, enabling them to balance the risks of not taking action against the costs of doing so.

This fact has already been accepted by the scientific community, and is starting to get attention from the industry and policy makers, due to the dissemination activities carried out within the project.

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11. ACRONYMS

μ	micron
σ_g	range for uncertainty
BOD	Biochemical Oxygen Demand
C	carbon
CCGT	combined cycle gas turbine
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
d	day
EC	European Commission
ECU	European Currency Unit
ESP	electrostatic precipitator
EU	European Union
FGD	flue gas desulphurisation
g	gram
GDP	Gross Domestic Product
GECU	giga ECU
GHG	Greenhouse gas
GJ	gigajoule
GWh	gigawatt-hour
GWI	Global Warming Impacts
h	hour
ha	hectare
hp	horse-power
IPCC	Intergovernmental Panel on Climate Change
IPTS	Institute for Prospective Technological Studies
J	joule
kg	kilogram
ktoe	kilotoe
km	kilometre
kV	kilovolt
kVA	kilovolt-ampere
kW	kilowatt
kWh	kilowatt-hour
l	litre
LCA	Life Cycle Analysis
m	metre
mECU	milli ECU

MECU	mega ECU
meq	milli equivalents
mg	milligram
MJ	megajoule
mm	millimetre
Mt	million tonne
MVA	megavolt-ampere
MW	megawatt
N	nitrogen
N_2O	nitrous oxide
NCV	Net Calorific Value
NG	natural gas
NO_2	nitrogen dioxide
NOx	nitrogen oxide
O_3	ozone
PM	Particulate Matter
PM10	Particulates under 10 microns
ppb	parts per billion
ppbv	parts per billion in volume
ppm	parts per million
ppmv	parts per million in volume
RES	Renewable Energy Sources
rpm	rotation per minute
s	second
S	sulphur
SO_2	sulphur dioxide
SO_x	sulphur oxide
t	tonne
TJ	tera Joule
toe	tonne oil equivalent
TSP	total suspended particulates
V	volt
VOC	volatile organic compounds
VSL	value of statistical life
WTA	willingness to accept
WTP	willingness to pay
YOLL	years of life lost
yr	year

APPENDICES

APPENDICES

I. APPENDIX IX: DEFINITION OF THE COAL FUEL CYCLE, DATA AND RESULTS

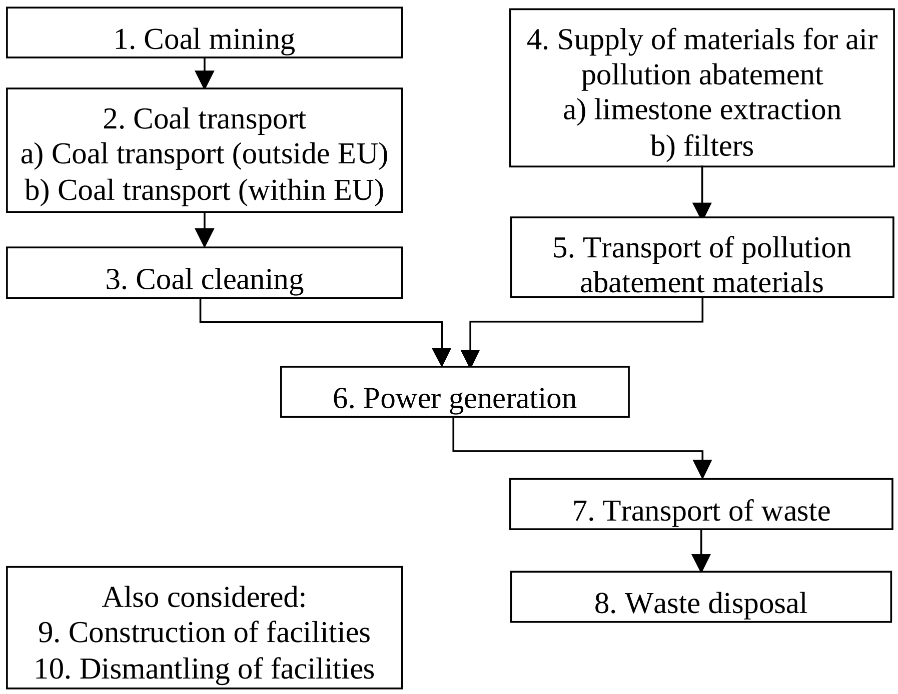

Figure I.1 Coal fuel cycle

Table I.1 Coal fuel cycle characteristics

Stage	Parameter	Quantity/Characteristic	Source of data, comments
1. Coal mining	Location(s)	Outside EU: South Africa, Colombia and USA	DGE (1996)
	Type of mine	Underground/Open mine	
	Calorific value of coal	24 GJ/Mg	EDP (1986)
	Mine air quality control	-	x - no data
	Control of mine methane emissions	-	x - no data
	Mine waste disposal site	-	x - no data
	Composition of coal		
	water	10 %	EDP (1986)
	ash	14%	EDP (1986)
	carbon	65%	EDP (1986)
	oxygen	3.8%	EDP (1986)
	hydrogen	4.3%	EDP (1986)
	sulphur	1%	EDP (1986)
	nitrogen	1.7%	EDP (1986)
	chlorine	0.15%	EDP (1986)
	phosphorous	0.05%	EDP (1986)
2. Coal transport	Distance to power station	7 300 km	CEEETA (95)
	Mode of transport	Ship - 96%	CEEETA (95)
		Rail - 4%	EDP (1986)
	Number of loads:		
	ship	20/yr	CEEETA (95)
	rail	1 620/yr	CEEETA (95)
3. Coal cleaning	Processes adopted	-	x - no data
	Waste streams	-	x - no data
4. Extraction, production of pollution abatement materials			
4a. Limestone	Location	up to 150 km	CEEETA (95)
	Annual production	-	x - no data
4b, c. NH_3, bag filters	Not applicable	-	
5. Transport of pollution abatement materials			
5a. Limestone	Distance to power station	up to 150 km	CEEETA (95)
	Mode of transport	Road	CEEETA (95)
	Number of loads	2 300/yr	CEEETA (95)
5b, c. NH_3, bag filters	Not applicable	-	
6. Power generation	Fuel	coal	EDP (1986)
	Type of plant	pulverised fuel	EDP (1986)
	Location	Pego, PT	EDP (1986)
	Power generation		
	gross	1 200 MW	EDP (1986)
	sent out	1 092 MW	EDP (1986)
	Efficiency	37.4%	EDP (1986)
	Load factor	65%	EDP (1986)

Table IX.1 (Cont.)

Stage	Parameter	Quantity/Characteristic	Source of data, comments
	Lifetime	25 yr	EDP (1986)
	Pollution control		
	ESPs	99.5 % effective	EDP (1986)
	low NO_x burners	-	x - no data
	FGD	90 % effective	CEEETA (95)
	recirculation of cooling water	98.4 % effective	EDP (1986)
	waste water	-	x - no data
	Stack parameters		
	height	2 x 220 m	EDP (1986)
	diameter	2 x 4.8 m	EDP (1986)
	flue gas volume	4 707 000 Nm^3	EDP (1986)
	flue gas temperature	413.2ºK	EDP (1986)
	Material demands		
	coal	2 492.6 Gg/yr	EDP (1986)
	fuel oil	-	x - no data
	limestone	62.8 Gg/yr	CEEETA (95)
	water	35 940 m^3/day	EDP (1986)
Transmission	Length of new lines	-	x - no data
7. Transport of waste	Site	Various	CEEETA (95)
	Distance to power station	up to 150 km	CEEETA (95)
	Mode of transport	Rail and road	CEEETA (95)
	Number of loads:		
	train	181/yr	CEEETA (95)
	truck	7 359/yr	CEEETA (95)
8. Waste disposal	Type of facility	Landfill and cement industry	CEEETA (95)
9. Construction of facilities			
coal mine	Materials needed	negligible	CEEETA (95)
limestone quarry	Materials needed	negligible	CEEETA (95)
power station	Construction materials		
	concrete	304 400 t	CEEETA (95)
	steel	109 600 t	CEEETA (95)
	other	3 800 t	CEEETA (95)
transmission lines	Materials needed	-	x - no data
10. Demolition of facilities			
	Waste arising		
	Metals	109 600 t	CEEETA (95)
	Aggregates	308 200 t	CEEETA (95)

Table I.2 Inventory of burdens from the coal fuel cycle

Stage	Burden	Quantity	Source of data	Impact assessed?
1. Coal mining outside EU				
	Occupational health			
	accidents - fatal	7.0 /Mt coal	EC, 1997	✓
	accidents - major injury	180 /Mt coal	EC, 1997	✓
	accidents - minor injury	1 775 /Mt coal	EC, 1997	✓
	noise levels	not quantified		x – no data
	exposure to physical stress	not quantified		x – no data
	radon levels in mines	not quantified		x – no data
	levels of other air pollutants in mines	not quantified		x – no data
	Air emissions			
	CO_2	41 906 t/yr	EC, 1997	✓
	CH_4	935.7 t/yr	EC, 1997	✓
	SO_2	40.9 t/yr	EC, 1997	x - negligible
	NO_x	1 116.7t/yr	EC, 1997	Partially
	PM_{10}	not quantified		x - no data
	Other burdens			x - no data
	mine drainage	not quantified		x
	solid wastes	not quantified		x
	subsidence	not quantified		x
	noise	not quantified		x
2. Coal transport outside EU				
	Occupational and public health			x – no data
	accidents - fatal	not quantified		x
	accidents - major injury	not quantified		x
	accidents - minor injury	not quantified		x
	Air emissions			
	CO_2	127 000 t/yr	Ministry of	✓
	CH_4	17 448 t/yr	Health	✓
	SO_2	3 803.7 t/yr	and	x - negligible
	NO_x	296.6 t/yr	Environmental	Partially
	PM_{10} - combustion	174.5 t/yr	Protection	x - negligible
	PM_{10} - fugitive dust	-	(80)	x - no data
	Other burdens			
	noise	-		x - no data
Coal transport within EU				
	Occupational and public health	7 800 h/yr	CEEETA (1995a)	✓
	Air emissions		CEEETA (1995a)	
	CO_2	26 350 t/yr		✓
	SO_2	49.1 t/yr		x - negligible
	NO_x	285 t/yr		Partially
	CO	174.2 t/yr		x - negligible
	VOC's	60.9 t/yr		Partially
	PM	36.6 t/yr		x - negligible

Table IX.2 (Cont.)

Stage	Burden	Quantity	Source of data	Impact assessed?
	Other burdens			
	noise			x - no data
	burden on infrastructure			x - no data
3. Coal cleaning				x - no data
4. Extraction, production of pollution abatement materials				
4a. Limestone				
	Occupational health			x - no data
	Air emissions			x - no data
	Emissions to water			
	suspended solids			x - no data
	Other burdens			
	noise			x - no data
4b, c. NH_3, bag filters		Not applicable		
5. Transport of pollution abatement materials				
5a. Limestone				
	Occupational and public health	6 978 h/yr	CEEETA (1995a)	✓
	Air emissions		CEEETA (1995a)	
	CO_2	231.0 t/yr		✓
	SO_2	0.44 t/yr		x - negligible
	NO_x	4.69 t/yr		Partially
	CO	1.52 t/yr		x - negligible
	VOC’s	0.53 t/yr		Partially
	particulates	0.32 t/yr		x - negligible
	Other burdens			
	Noise			x - no data
	Road use	348 890 km/yr	CEEETA (1995a)	✓
5b, c. NH_3, bag filters		Not applicable		
6. Power generation				
	Occupational health	466 275 h/yr	CEEETA (1995a)	✓
	Air emissions			
	CO_2	4 292 600 t/yr	CEEETA (1995a)	✓
	N_2O			x - no data
	CH_4			x - no data
	SO_2	4 260 t/yr	EDP (1986)	✓
	NO_x	11 300 t/yr	EDP (1986)	✓
	particulates	1 400 t/yr	EDP (1986)	✓
	trace elements			x - no data
	evaporated water from cooling system	13 118 980 m^3/yr	EDP (1986)	x - no data
	Noise emissions			x - no data
	Solid waste production			
	PFA	279 170 t/yr	EDP (1986)	x - negligible
	FBA	69 790 t/yr	EDP (1986)	x - negligible
	gypsum	104 460 t/yr	CEEETA (1995a)	x - negligible
	FGD sludge			x - no data
	silt from cooling towers			x - no data

Table IX.2 (Cont.)

Stage	Burden	Quantity	Source of data	Impact assessed?
	Water abstraction	26 554 320 m^3/yr	EDP (1986)	x - no data
	Emissions to water from			
	cooling system	11 479 104 m^3/yr	EDP (1986)	x - negligible
	temperature of cooling water on return	16-25ºC	EDP (1986)	✓
	chloride			x - no data
	FGD plant	2 049 840 m^3/yr	CEEETA (1995a)	x - negligible
Transmission	No additional burdens			
7. Transport of waste				
7a. Transport of gypsium				
	Occupational and Public health	16 235 h/yr	CEEETA (1995a)	✓
	Air emissions		CEEETA (1995a)	
	CO_2	376.3 t/yr		✓
	SO_2	0.71 t/yr		x - negligible
	NO_x	7.63 t/yr		Partially
	CO	2.49 t/yr		x - negligible
	VOC's	0.87 t/yr		Partially
	particulates	0.52 t/yr		x - negligible
	Other burdens			
	Noise			x - no data
	Road use	811 775 km/yr	CEEETA (1995a)	
7b. Transport of bottom ash				
	Occupational and Public health	1 745 h/yr	CEEETA (1995a)	✓
	Air emissions		CEEETA (1995a)	
	CO_2	3.24 t/yr		✓
	SO_2	0.006 t/yr		x - negligible
	NO_x	0.065 t/yr		Partially
	CO	0.021 t/yr		x - negligible
	VOC's	0.007 t/yr		Partially
	particulates	0.005 t/yr		x - negligible
	Other burdens			
	Noise			x - no data
	Road use	6 980 km/yr	CEEETA (1995a)	
7c. Transport of fly ash				
	Occupational and public health	544 h/yr	CEEETA (1995a)	✓
	Air emissions		CEEETA (1995a)	
	CO_2	1 952 t/yr		✓
	SO_2	3.63 t/yr		x - negligible
	NO_x	21.14 t/yr		Partially
	CO	12.90 t/yr		x - negligible
	VOC's	4.51 t/yr		Partially
	particulates	2.71 t/yr		x - negligible
	Other burdens			
	Noise			x - no data
8. Waste disposal				x - no data

Table IX.2 (Cont.)

Stage	Burden	Quantity	Source of data	Impact assessed?
9. Construction				
	Occupational health	1 253 h/yr	CEEETA (1995a)	✓
	Air emissions from materials production			x - no data
	Air emissions from materials transport		CEEETA (1995a)	
	CO_2	70.3 t/yr		✓
	SO_2	0.13 t/yr		x - negligible
	NO_x	1.43 t/yr		Partially
	CO	0.47 t/yr		x - negligible
	VOC's	0.16 t/yr		Partially
	PM10 - combustion	0.10 t/yr		x - negligible
	PM10 - fugitive dust	-		x - no data
	Other burdens			
	Noise			x - no data
	Visual intrusion			x - no data
	Road use	106 230 km	CEEETA (1995a)	
10. Dismantling				
	Occupational health	1 253 h/yr	CEEETA (1995a)	✓
	Air emissions from materials transport		CEEETA (1995a)	
	CO_2	70.3 t/yr		✓
	SO_2	0.13 t/yr		x - negligible
	NO_x	1.43 t/yr		Partially
	CO	0.47 t/yr		x - negligible
	VOC's	0.16 t/yr		Partially
	PM10 - combustion	0.10 t/yr		x - negligible
	PM10 - fugitive dust	-		x - no data
	Other burdens			
	Noise			x - no data
	Visual intrusion			x - no data
	Road use	106 230 km	CEEETA (1995a)	✓

Table I.3 Impacts and damages from the coal fuel cycle

Impact category	Impact		Damages		σ_g,
	units	Number/TWh	mECU/kWh	ECU/t_{poll}	range
Air pollution					
6. Power generation					
Primary PM_{10}					
Mortality	YOLL	15.0	1.28	4 937	B
	deaths	1.62	5.02	19 421	B
Morbidity	cases	931.6	0.16	629	A-B
NO_x					
via nitrates					
Mortality	YOLL	118.2	10.03	5 301	B?
	deaths	12.7	39.47	20 857	B?
Morbidity	cases	7 317	1.28	675	A-B
via O_3	na	nq			
Mortality	YOLL	nq	0.75	415	B
	deaths	nq	nq	nq	B
Morbidity	cases	nq	1.34	735	A-B
Effects on crop production	t	nq	0.64	350	B
via acidity					
Relative exceedance weighted areas in which critical loads of acidity are already exceeded	na	nq	nq	nq	
Effects on crop production	t	nq	nq	nq	
via nitrogen deposition					
Relative exceedance weighted areas in which critical loads of nutrient nitrogen are already exceeded	na	nq	nq	nq	
add. fertil. needed	kg	-129 500	-5.58E-02	-29.5	B
SO_2					
via SO_2					
Mortality	YOLL	0.56	0.09	110	B
	deaths	0.75	2.32	2 926	B
Morbidity	cases	0.21	1.69E-03	2	A
Materials damage	m^2	5 624	8.89E-02	112	B
Effects on crop yield	t	1 200	9.28E-03	12	A
via sulfates					
Mortality	YOLL	39.4	3.34	4 205	B
	deaths	4.2	13.15	16 558	B
Morbidity	cases	2 435	0.41	519	A-B
via acidity					
Relative exceedance weighted areas in which critical loads of acidity are already exceeded	na	nq	nq	nq	
Effects on crop production	t	nq	nq	nq	
Additional lime needed	kg	797 900	1.37E-02	n.a.	A

Table IX.3 (Cont.)

Impact category	Impact		Damages		σ_g,
	units	Number/TWh	Mecu/kWh	ECU/t_{poll}	range
Greenhouse gas emissions	na	nq	13.9 - 35.4	18 - 46	C
Global warming via CO_2	na	nq	nq	nq	
Global warming via N_2O	na	nq	nq	nq	
Global warming via CH_4	na	nq	nq	nq	
Other stages					
Primary PM_{10}	na	nq	nq	nq	
NO_x					
via nitrates	na	nq	nq	nq	
via O_3	na	nq			
Mortality	YOLL	nq	0.12	415	B
	deaths	nq	nq	nq	B
Morbidity	cases	nq	0.20	735	A-B
Effects on crop production	t	nq	9.77E-02	350	B
via acidity	na	nq	nq	nq	
via nitrogen deposition	na	nq	nq	nq	
SO_2	na	nq	nq	nq	
Greenhouse gas emissions	na	nq	1.7 - 4.3	18 - 46	C
Global warming via CO_2	na	nq	nq	nq	
Global warming via N_2O	na	nq	nq	nq	
Global warming via CH_4	na	nq	nq	nq	
Effects of thermal discharges in the aquatic environment					
6. Power generation	na	na	0.001	na	A
Effects of noise on human health and amenity					
All stages	na	na	0.03	na	A
Impacts on visual amenity					
All stages	na	na	0.001	na	A
Road damage from transportation					
Transportation stages	na	na	2.22E-03	na	A
Occupational and public accidents					
1. Coal extraction (outside EU)					
Fatalities	deaths	0.45	0.77	na	B
Major injuries	cases	11.6	0.60	na	B
Minor injuries	cases	114.4	0.43	na	B
2a. Coal transport (outside EU)	cases	nq	nq	na	
2b. Coal transport (within EU)					
Fatalities	deaths	1.54	4.84	na	A
Major injuries	cases	0.15	1.38E-02	na	A
Minor injuries	cases	1.97	1.38E-02	na	A

Table IX.3 (Cont.)

Impact category	Impact		Damages		σ_g,
	units	Number/TWh	Mecu/kWh	ECU/t_{poll}	range
Other stages					
Fatalities	deaths	0.05	0.15	na	A
Major injuries	cases	0.57	5.44E-02	na	A
Minor injuries	cases	3.41	2.38E-02	na	A
Employment effects					
All stages	job-equivalent	5 431	nq	na	A

ng: negligible; nq: not quantified; na: not applicable; - : not relevant

II. APPENDIX X: DEFINITION OF THE NG FUEL CYCLE, DATA AND RESULTS

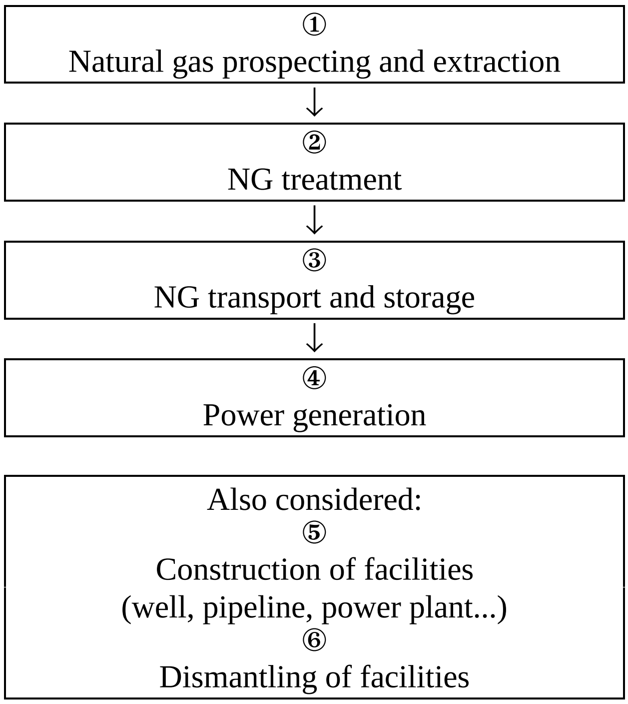

Figure II.1 Natural gas fuel cycle

Table II.1 Natural gas fuel cycle characteristics

Stage	Parameter	Quantity/Characteristic	Source of data, comments
1. NG prospecting and extraction	Location	Hassi R´Mel, Algeria	EDP (1992)
	Gas field production	37 Mm^3/day	SEDIGAS (1991)
	Calorific value of NG	37-45 MJ/Nm^3	EDP (1992)
	Composition of NG		EDP (1992)
	Methane	85-96 %	
	Ethane	3-4 %	
	Propane	0-3 %	
	Butane	0-1.4 %	
	Pentane	0-0.2 %	
	Nitrogen	0.2-3 %	
	Carbon dioxide	10-1 %	
	Carbon monoxide	<3.5 %	
	Hydrosulphuric acid	<1.5 %	
	Ammonia	<15 %	
2. NG treatment			x - no data
3. NG transport	Distance to power station	1 870 km	EDP (1992)
	Mode of transport	Pipeline	EDP (1992)
	Gas volume transported	$2.5x10^9$ Nm^3/yr	EDP (1992)
	NG leakage	0.03-0.5 %	EC (1995)
	Compressor stations	1	ENAGAS (1996)
	location	Tanger, Algeria	
	capacity	25 MW	
	NG consumption	3 500 m^3/h	
4. Power generation	Fuel	Natural gas	EDP (1992)
	Type of plant	Combined cycle gas turbine	EDP (1992)
	Location	Tapada do Outeiro, PT	EDP (1992)
	Power generation		
	gross	1 000 MW	EDP (1992)
	sent out	918 MW	EDP (1992)
	Efficiency	48 %	EDP (1992)
	Full load hours	7 530 h/yr	EDP (1992)
	Lifetime	25 yr	EDP (1992)
	Pollution control		
	low NO_x burners	-	EDP (1992)
	Stack parameters		
	number of stacks	4	EDP (1992)
	height	40 m	EDP (1992)
	diameter	6 m	EDP (1992)
	NG consumption	$1.378x10^9$ Nm^3/yr	EDP (1992)

Table X.1 (Cont.)

Stage	Parameter	Quantity/Characteristic	Source of data, comments
	Flue gas characteristics		
	volume	1 379 000 Nm^3/h	EDP (1992)
	temperature	367.2ºK	EDP (1992)
	CO_2	428 g/kWh	CEEETA (97)
	SO_2	0.75 mg/Nm^3	EDP (1992)
	NO_x	20.6 mg/Nm^3	EDP (1992)
	PM_{10}	0.0115 mg/Nm^3	EDP (1992)
	VOC's	1.31 mg/Nm^3	EDP (1992)
	Liquid effluents		
	water pre-treatment	40 m^3/day	EDP (1992)
	demineralisation effluent	10 m^3/day	EDP (1992)
	boiler purge	3 kg/s	EDP (1992)
	oil effluent	3 kg/s	EDP (1992)
	domestic effluent	0.06 kg/s	EDP (1992)
Transmission	Length of new lines	-	x - no data
5. Construction of facilities			
extraction	Materials needed	negligible	CEEETA (97)
transport	Materials needed		CEEETA (97)
	steel	600 000 Mg	ENAGAS (1996)
	other	negligible	x - no data
power station	Construction materials		EC (1995d)
	concrete	20 000 Mg	
	steel	6 000 Mg	
	other	20 000 Mg	
transmission lines	Materials needed	-	x - no data
6. Demolition of facilities			
	Waste arising		CEEETA (97)
	metals	6 000 Mg	
	aggregates	40 000 Mg	

Table II.2 Inventory of burdens from the natural gas fuel cycle

Stage	Burden	Quantity	Source of data	Impact assessed?
1. Natural gas prospecting and extraction				
	Occupational health			
	accidents - fatal	-		x - no data
	accidents - major injury	-		x - no data
	accidents - minor injury	-		x - no data
	Air emissions			
	CO_2	-		x - no data
	CH_4	-		x - no data
	SO_2	-		x - no data
	NO_x	-		x - no data
	particulates	-		x - no data
	VOC's	-		x - no data
	Wastewater emissions			
	produced water	525.5 barrels / 10^6 m^3	ORNL & RFF (1993)	✓
	drilling wastes	6.774 or 8.254 barrels/well		✓
	spent completion and workover fluids	-		x - no data
	wastewater from well treatment	-		x - no data
	deck drainage	-		x - no data
	sanitary wastes	-		x - no data
	Other burdens			
	solid wastes	-		x - no data
	sand	17 barrels/10^6 m^3	ORNL & RFF (1993)	✓
	nature conservation disruption	-		x - no data
	groundwater contamination	-		x - no data
	subsidence	-		x - no data
2. NG treatment				
	Occupational health			
	accidents - fatal	6.9E-05 case/TWh	EC (1995d)	✓
	accidents - major injury	0.0025 case/TWh	EC (1995d)	✓
	accidents - minor injury	0.026 case/TWh	EC (1995d)	✓
	noise levels			x - no data
	exposure to physical stress			x - no data
	Air emissions			
	CO_2	3 334 Mg/yr	EC (1995d)	✓
	CH_4	816 Mg/yr	EC (1995d)	✓
	SO_2	-		x - no data
	NO_x	-		x - no data
	particulates	-		x - no data
	VOC	-		x - no data
	Hydrocarbons	-		x - no data

Table X.2 (Cont.)

Stage	Burden	Quantity	Source of data	Impact assessed?
	Solid wastes			
	sand and salts	-		x - no data
	storage tank bottoms	-		x - no data
3. Natural gas transport (outside EU)				
	Occupational health	-		x - negligible
	Public health			
	accident risk	0.0014 case/TWh	CEEETA (97)	✓
	Air emissions			
	CO_2	26 153 Mg/yr	EC (1995b)	✓
	SO_2	-		x - no data
	NO_x	0.04 Mg/yr	CIEMAT (97)	x - negligible
	CH4 (mid value)	222 Mg/yr	EC (1995d)	✓
	Other burdens	-		x - no data
3. Natural gas transport (EU)				
	Occupational health	-		x - negligible
	Public health			
	accident risk	0.0026 case/TWh	CEEETA (97)	✓
	Air emissions			
	CO_2	27 Mg/yr	EC (1995d)	✓
	SO_2	-		x - no data
	NO_x	-		x - no data
	CH4 (mid value)	206 Mg/yr	EC (1995d)	✓
	Solid wastes	-		x - no data
	Other burdens			
	noise	-		x - no data
	nature conservation disruption	-		x - no data
	landscape interference	-		x - no data
	road traffic perturbation	-		x - no data
4. Power and electricity generation				
	Occupational health		EC (1995d)	
	accidents - fatal	0.00067 case/TWh		✓
	accidents - major injury	0.024 case/TWh		✓
	accidents - minor injury	0.25 case/TWh		✓
	Public health			x - no data
	Air emissions			
	CO_2	2 961 Gg/yr	CEEETA (97)	✓
	SO_2	7.8 Mg/yr	EDP (1992)	✓
	NO_x	214 Mg/yr	EDP (1992)	✓
	N_2O	89.9 Mg/yr	EC (1995d)	✓
	particulates	0.12 Mg/yr	EDP (1992)	✓
	VOC's	13.6 Mg/yr	EC (1995d)	✓
	Waste water emissions			
	cooling water	17 m^3/s	EDP (1992)	✓
	sewage/household facilities	0.06 kg/s	EDP (1992)	✓

Table X.2 (Cont.)

Stage	Burden	Quantity	Source of data	Impact assessed?
	Solid wastes	-		x - no data
	Other burdens	-		x - no data
5. Construction of facilities				
Extraction and treatment				
	Occupational health	-		x - no data
	Air emissions	-		x - negligible
Transport (pipeline)				
	Occupational health		EC (1995d)	
	accidents - fatal	0.0088 case/TWh		✓
	accidents - major injury	0.267 case/TWh		✓
	accidents - minor injury	1.31 case/TWh		✓
	Air emissions	-		x - negligible
	Other burdens	-		x - no data
Power plant				
	Occupational health		EC (1995d)	
	accidents - fatal	0.0025 case/TWh		✓
	accidents - major injury	0.078 case/TWh		✓
	accidents - minor injury	0.37 case/TWh		✓
	Air emissions	-		x - negligible
	Other burdens	-		x - no data
6. Dismantling of facilities				
Power plant				
	Occupational health		EC (1995d)	
	accidents - fatal	1.30E-05 case/TWh		✓
	accidents - major injury	0.0039 case/TWh		✓
	accidents - minor injury	0.018 case/TWh		✓
	Air emissions	-		x - negligible
	Other burdens	-		x - no data

Table II.3 Impacts and damages from the natural gas fuel cycle

Impact category	Impact		Damages		σ_g,
	units	**number/kWh**	**mECU/kWh**	**ECU/t_{poll}**	**range**
Air pollution					
4. Power generation					
Primary PM_{10}					
Mortality	YOLL	1.23E-03	1.04E-04	6 030	B
	deaths	1.32E-04	4.09E-04	23 703	B
Morbidity	cases	7.59E-02	1.33E-05	767	A-B
NO_x					
via nitrates					
Mortality	YOLL	2.12	0.18	5 823	B?
	deaths	0.23	0.71	22 901	B?
Morbidity	cases	131.5	2.29E-02	741	A-B
via O_3					
Mortality	YOLL	nq	1.29E-02	415	B
	deaths	nq	nq	-	B
Morbidity	cases	nq	0.02	735	A-B
Effects on crop yield	t	nq	1.08E-02	350	B
via acidity					
Relative exceedance weighted areas in which critical loads of acidity are already exceeded	na	nq	nq	nq	
Effects on crop production	t	nq	nq	nq	
via nitrogen deposition					
Relative exceedance weighted areas in which critical loads of nutrient nitrogen are already exceeded	na	nq	nq	nq	
add. fertil. needed	kg	-2 063	-8.89E-04	-28.7	B
SO_2					
via SO_2					
Mortality	YOLL	1.14E-03	1.76E-04	156	B
	deaths	1.51E-03	4.69E-03	4 164	B
Morbidity	cases	4.34E-04	3.41E-06	3.0	A
Materials damage	m^2	74.7	9.60E-06	8.5	B
Effects on crop yield	t	1.6	1.20E-05	10.6	A
via sulfates					
Mortality	YOLL	5.06E-02	4.30E-03	3 814	B
	deaths	5.46E-03	1.69E-02	15 021	B
Morbidity	cases	3.1	5.31E-04	471	A-B
via acidity					
Relative exceedance weighted areas in which critical loads of acidity are already exceeded	na	nq	nq	nq	
Effects on crop production	t	nq	nq	nq	
Additional lime needed	kg	7 803	1.34E-04	na	A

Table X.3 (Cont.)

Impact category	Impact		Damages		σ_g, range
	units	number/kWh	mECU/kWh	ECU/t_{poll}	
Greenhouse gas emissions	na	nq	7.8 - 19.9	18 - 46	C
Global warming via CO_2	na	nq	nq	18 - 46	
Global warming via N_2O	na	nq	nq	nq	
Global warming via CH_4	na	nq	nq	nq	
Other stages					
Primary PM_{10}	na	nq	nq	nq	
NO_x					
via nitrates	na	nq	nq	nq	
via O_3	na	nq	ng	1 500	
via acidity	na	nq	nq	nq	
via nitrogen deposition	na	nq	nq	nq	
SO_2	na	nq	nq	nq	
Greenhouse gas emissions	na	nq	0.15 - 0.37	18 - 46	C
Global warming via CO_2	na	nq	nq	18 - 46	
Global warming via N_2O	na	nq	nq	nq	
Global warming via CH_4	na	nq	nq	nq	
Effects of pipelines installation on terrestrial ecosystems					
3.Transport	na	na	0.001	na	A
Ecological effects of thermal discharges upon freshwater ecology					
4. Power generation	na	na	0.001	na	A
Risk associated with NG transport					
3.Transport					
Social risk (outside EU)	cases	7.89E-03	2.54E-04	na	B
Social risk (EU)	cases	1.81E-02	1.79E-03	na	B
Ecological risk	na	na	0.001	na	B
Aesthetic impacts	na	na	nq	na	
Land use for dumping solid wastes and removed soil					
3.Transport	na	na	nq	na	
Occupational health effects					
All stages					
Fatalities	deaths	0.012	1.36E-02	na	A
Major injuries	cases	0.38	3.55E-02	na	A
Minor injuries	cases	1.97	3.77E-02	na	A
Impact noise on human health and local amenity					
All stages	na	na	0.03	na	A

ng: negligible; nq: not quantified; na: not applicable; - : not relevant

III. APPENDIX XI: DEFINITION OF THE BIOMASS FUEL CYCLE, DATA AND RESULTS

① Soil preparation, planting and other cultural operations (fertilisation, removal of vegetation...)

↓

② Felling and forwarding

↓

③ Biomass transport

↓

④ Biomass treatment (storage, chipping...)

↓

⑤ Energy generation

↓

⑥ Waste transport

↓

⑦ Ash disposal

Also considered:
⑧ Construction of facilities
⑨ Dismantling of facilities

Figure III.1 Biomass fuel cycle

Table III.1 Biomass fuel cycle characteristics (case A)

Stage	Parameter	Quantity / Characteristic	Source of data
1. Soil preparation, planting and other cultural operations		na	
2. Felling and forwarding of biomass		na	
3. Biomass transport			CEEETA (94)
	Distance to power station	up to 100 km	
	Mode of transport	100% road	
	Number of loads	45 372/yr	
	Quantity transported	155 560 t/yr	
	Characteristics of biomass	Pulpwood with bark	
4. Biomass treatment			CEEETA (94)
	Process adopted	Mechanical debarking	
	Storage capacity	2 weeks of energy consumption	
5. Energy generation			CEEETA (94)
	Fuel	Bark	
	Type of plant	Cogeneration unit	
	Location	Figueira da Foz, PT	
	Power generation capacity:		
	boiler	92 MWth	
	electric	16.8 MWe	
	Efficiency	77%	
	Full load hours	4 321 h/yr	
	Energy sent out:		
	thermal	612 600 GJ/yr	
	electric	127.3 GWh/yr	
	Lifetime	10 yr	
	Pollution control:		
	ESP	91.5% effective	
	Plant characteristics:		
	land area required	-	x – no data
	height of stack	93 m	
	diameter of stack	4.3 m	
	Consumables:		
	bark	155 560 t/yr	
	other	-	x – no data
	Other characteristics:		
	flue gas temperature	443ºK	
	flue gas volume	83 941 Nm^3/h	
6. Transport of waste			CEEETA (94)
	Type of waste	Ashes	
	Distance to plant	4 km	
	Mode of transport	100% road	
	Number of loads	436/yr	
	Quantity transported	4 358 t/yr	
7. Waste disposal			CEEETA (94)
	Type of facility	Landfill	
	Site	Figueira da Foz, PT	
8. Construction	Energy generation unit	-	x – no data
9. Dismantling	Energy generation unit	-	x – no data

Table III.2 Biomass fuel cycle characteristics (case B)

Stage	Parameter	Quantity / Characteristic	Source of data
1. Soil preparation, planting and other cultural operations			CEEETA (94)
	Location of the plantation	Vale do Tejo region, PT	
	Type of plantation	Short rotation forestry	
	Species	Eucalyptus	
	Number of rotations	3 each 6 years	
	Total area required	9 600 ha	
	Productivity	9 odt/ha/yr	
	Plantation density	2 500 plants/ha	
2. Felling and forwarding of biomass			CEEETA (94)
	Mode of operation	Mechanical	
	Equipment productivity:		
	harvester	9 m^3/h	
	forwarder	12 h/ha	
	Number of ha treated	1 600 ha/yr	
3. Biomass transport			CEEETA (94)
	Distance to power station	up to 100 km	
	Mode of transport	100% road	
	Number of loads	6 010/yr	
	Quantity transported	86 360 t/yr	
	Characteristics of biomass transported	Roundwood	
4. Biomass treatment			CEEETA (94)
	Process adopted	Chipping	
	Storage capacity	2 weeks of energy consumption	
5. Energy generation			CEEETA (94)
	Fuel	Wood chips	
	Type of plant	Cogeneration unit	
	Location	Figueira da Foz, PT	
	Power generation capacity:		
	boiler	92 MWth	
	electric	16.8 Mwe	
	Efficiency	77%	
	Full load hours	4 321 h/yr	
	Energy sent out:		
	thermal	612 600 GJ/yr	
	electric	125.5 GWh/yr	
	Lifetime	10 yr	
	Pollution control:		
	ESP	91.5% effective	
	Plant characteristics:		
	land area required	-	x – no data
	height of stack	93 m	
	diameter of stack	4.3 m	
	Consumables:		
	wood chips	240 410 t/yr	
	other	-	x – no data

Table XI.2 (Cont.)

Stage	Parameter	Quantity / Characteristic	Source of data
	Other characteristics:		
	flue gas temperature	443 ºK	
	flue gas volume	83 941 Nm^3/h	
6. Transport of waste			CEEETA (94)
	Type of waste	Ashes	
	Distance to energy generation unit	4 km	
	Mode of transport	100% road	
	Number of loads	177/yr	
	Quantity transported	1 768 t/yr	
7. Waste disposal			CEEETA (94)
	Type of facility	Landfill	
	Site	Figueira da Foz, PT	
8. Construction			
	Energy generation unit	-	x – no data
9. Dismantling			
	Energy generation unit	-	x – no data

Table III.3 Inventory of burdens from the biomass fuel cycle

Stage / Burden	Unit	Quantity		Source of data	Impact assessed?
		Case A	Case B		
1. Soil preparation, planting and other cultural operations		na		CEEETA (94)	
Occupational health	h/yr	-	96 533		✓
Air emissions					
CO_2	t/yr	-	1 003.4		✓
CO	t/yr	-	6.5		-
SO_2	t/yr	-	130.6		-
NO_x	t/yr	-	20.1		partially
particulates	t/yr	-	1.4		-
VOC	t/yr	-	2.3		partially
Emissions to soil					
Nutrients					
nitrogen	t/yr	-	139		-
phosphorus	t/yr	-	312		-
potassium	t/yr	-	115		-
pesticides	t/yr	-	na		-
others			nq		x – no data
Other burdens					
fire risk	GJ/yr	-	1 549 424		x – no data
noise	dB	-	nq		x – no data
visual intrusion		-	nq		x – no data
soil loss	t/yr	-	10 189		partially

Table XI.3 (Cont.)

Stage / Burden	**Unit**	**Quantity**		**Source of data**	**Impact assessed?**
		Case A	**Case B**		
2. Biomass harvesting				CEEETA (94)	
Occupational health	h/yr	na	34 240		
Air emissions		na			
CO_2	t/yr	-	782.7		✓
CO	t/yr	-	5.10		-
SO_2	t/yr	-	1.47		-
NO_x	t/yr	-	15.65		partially
particulates	t/yr	-	1.07		-
VOC	t/yr	-	1.78		partially
Removal of nutrients					
nitrogen	t/yr	337	95.0		-
phosphorus	t/yr	379	30.2		-
potassium	t/yr	438	77.7		-
calcium	t/yr	1 043	34.5		-
magnesium	t/yr	353	17.3		-
Other burdens					
noise	dB	na	nq		x – no data
visual intrusion		na	nq		x – no data
3. Biomass transport				CEEETA (94)	
Occupational and public health	h/yr	40 834	30 051		
Air emissions					
CO_2	t/yr	1 536.5	1 130.8		✓
CO	t/yr	10.0	7.4		-
SO_2	t/yr	2.9	2.1		-
NO_x	t/yr	30.7	22.6		partially
particulates	t/yr	2.1	1.5		-
VOC	t/yr	3.5	2.6		partially
Other burdens					
noise	dB	nq	nq		
road use	km/yr	1 633 380	1 202 054		✓
4. Biomass treatment				CEEETA (94)	
Occupational and public health	h/yr	11 683	26 640		✓
Air emissions					
CO_2	t/yr	43.4	241.2		✓
CO	t/yr	0.283	1.572		
SO_2	t/yr	0.081	0.453		
NO_x	t/yr	0.868	4.825		partially
particulates	t/yr	0.059	0.330		
VOC	t/yr	0.099	0.550		partially
Other burdens					
noise	dB	nq	nq		
fire risk	Gj/yr	59 430	59 430		

Table XI.3 (Cont.)

Stage / Burden	Unit	Quantity		Source of data	Impact assessed?
		Case A	Case B		
5. Energy generation				CEEETA (94)	
Occupational accidents	h/yr	8 400	8 400		✓
Air emissions					
CO_2	t/yr	141 240	141 245		✓
CO	t/yr	945.1	945.1		-
SO_2	t/yr	14.8	5.0		-
NO_x	t/yr	258.8	258.8		partially
particulates	t/yr	84.0	84.0		-
VOC	t/yr	157.3	157.3		partially
Solid waste emissions					
PFA (pulverised fly ash)	t/yr	904	904		-
FBA (furnace bottom ash)	t/yr	3 454	864		-
Other burdens					
noise	dB	nq	nq		x – no data
6. Removal and transport of waste				CEEETA (94)	
Occupational and public health	h/yr	218	88		✓
Air emissions					
CO_2	t/yr	2.343	0.950		✓
SO_2	t/yr	0.004	0.002		-
NO_x	t/yr	0.047	0.019		partially
CO	t/yr	0.015	0.006		-
VOC	t/yr	0.005	0.002		partially
particulates	t/yr	0.003	0.001		-
Other burdens					
noise	dB	nq	nq		
road use	km/yr	3 487	1 414		✓
7. Waste disposal				CEEETA (94)	
Ash composition					
nitrogen	t/yr	17.4	4.9		-
phosphorus	t/yr	19.6	1.6		-
potassium	t/yr	22.7	4.9		-
calcium	t/yr	54.0	4.1		-
magnesium	t/yr	18.3	1.9		-
8. Construction				CEEETA (94)	
Occupational and public health	h/yr	79 200	79 200		✓
Air emissions		nq	nq		x – no data
Other burdens					
noise	dB	nq	nq		x – no data
road use	km/yr	nq	nq		x – no data
visual intrusion		nq	nq		x – no data
9. Dismantling					
Occupational and public health	h/yr	79 200	79 200	CEEETA (94)	
Air emissions		nq	nq		x – no data
Other burdens					
noise	dB	nq	nq		x – no data
road use	km/yr	nq	nq		x – no data
visual intrusion		nq	nq		x – no data

Table III.4 Impacts and damages from the biomass fuel cycle (case A)

Impact category	Impact - units	Impact - number/TWh	Damages		Impacts - number/TJ	Damages		σ_g, range
			mECU/kWhe	ECU/tpoll		mECU/MJ	ECU/tpoll	
Air pollution								
6. Power generation								
Primary PM10								
Mortality	YOLL	37.37	3.17	4 806	2.20E-03	1.87E-01	1 364	B
	deaths	4.02	12.47	18 905	2.37E-04	7.35E-01	5 363	B
Morbidity	cases	2 312	0.40	612	0.13	2.38E-02	174	A-B
Nox								
via nitrates								
Mortality	YOLL	48.5	4.12	4 451	2.86E-03	2.43E-01	1 263	B?
	deaths	5.2	16.20	17 507	3.08E-04	9.55E-01	4 967	B?
Morbidity	cases	3 004	0.52	567	0.17	3.09E-02	161	A-B
via O3								
Mortality	YOLL	na	0.66	415	na	0.04	415	B
Morbidity	cases	na	1.16	735	na	0.07	735	A-B
Effects on crop yield	t	na	0.55	350	na	3.27E-02	350	B
via acidity								
Relative exceedance weighted areas in which critical loads of acidity are already exceeded		na	na	na	na	na	na	
Effects on crop yield	t	na	na	na	na	na	na	
via nitrogen deposition								
Relative exceedance weighted areas in which critical loads of nutrient nitrogen are already exceeded								
Add. fertilizer needed	kg	-48 530	-2.09E-02	-22.61	-2.9	-1.23E-03	-6.42	B
SO2								
via SO2								
Mortality	YOLL	7.67E-02	1.19E-02	12.8	4.52E-06	7.00E-04	28.9	B
	deaths	0.10	3.17E-01	342.6	6.03E-06	1.87E-02	772.9	B
Morbidity	cases	2.93E-02	2.31E-04	0.2	1.73E-06	1.36E-05	0.56	A

Table XI.4 (Cont.)

Impact category	Impact - units	Impact - number/TWh	Damages mECU/kWhe	Damages ECU/tpoll	Impacts - number/TJ	Damages mECU/MJ	Damages ECU/tpoll	σ_g, range
Materials damage	m^2	1 802	2.59E-02	28.0	0.10	1.53E-03	63.1	B
Effects on crop yield	t	140	1.08E-03	1.2	8.25E-03	6.36E-05	2.6	A
via sulfates								
Mortality	YOLL	4.54	3.85E-01	416.5	2.68E-04	2.27E-02	940	B
	deaths	0.49	1.52E+00	1640.2	2.89E-05	8.95E-02	3 700	B
Morbidity	cases	280.9	4.76E-02	51.4	1.66E-02	2.81E-03	116	A-B
via acidity								
Relative exceedance weighted areas in which critical loads of acidity are already exceeded		na	na	na	na	na	na	
Effects on crop yield	t	na	na	na	na	na	na	
Add. lime needed	kg	208 975	3.58E-03	n.a.	12.3	2.11E-04	n.a.	A
Greenhouse gas emissions								
Global warming via CO_2	na	nq	0	18 - 46	nq	0	18 - 46	C
Global warming via N_2O	na	nq	0	nq	nq	0	nq	
Global warming via CH_4	na	nq	0	nq	nq	0	nq	
Other stages								
Primary PM_{10}	n.a.	nq	nq	nq	nq	nq	nq	
NO_x								
via nitrates	na	nq	nq	nq	nq	nq	nq	
via O_3								
Mortality	YOLL	na	8.04E-02	415	na	4.74E-03	415	B
Morbidity	cases	na	1.42	735	na	8.39E-03	735	A-B
Effects on crop yield	t	na	6.78E-02	350	na	4.00E-03	350	B
via acidity	na	nq	nq	nq	nq	nq	nq	
via nitrogen deposition	na	nq	nq	nq	nq	nq	nq	
SO_2	na	nq	nq	nq	nq	nq	nq	
Greenhouse gas emissions	na	nq	0.17 - 0.44	18 - 46	nq	0.01 - 0.02	18 - 46	C
Global warming via CO_2	na	nq	nq	18 - 46	nq	nq	18 - 46	
Global warming via N_2O	na	nq	nq	nq	nq	nq	nq	
Global warming via CH_4	na	nq	nq	nq	nq	nq	nq	

Table XI.4 (Cont.)

Impact category	Impact - units	Impact - number/TWh	Damages mECU/kWhe	Damages ECU/tpoll	Impacts - number/TJ	Damages mECU/MJ	Damages ECU/tpoll	σ_g, range
Effects of noise on human health and amenity								
All stages	na	na	0.03	na	na	na	na	A
Impacts on visual amenity								
All stages	na	na	0.001	na	na	na	na	A
Road damage from transport								
Transport stages	na	na	1.48E-01	na	na	8.75E-03	na	A
Occupational and public accidents								
Power generation stage								
Fatalities	deaths	0.006	2.00E-02	na	3.75E-07	1.18E-03	na	A
Injuries	cases	nq	nq	na	nq	nq	na	
Other stages								
Fatalities	deaths	1.520	4.77	na	8.96E-05	2.81E-01	na	A
Injuries	cases	35.47	9.62E-01	na	2.09E-03	5.67E-02	na	A
Employment effects								
All stages	job-equivalent	5 640	nq	na	3.32E-07	nq	na	A

ng: negligible; nq: not quantified; na: not applicable; - : not relevant

Table III.5 Impacts and damages from the biomass fuel cycle (case B)

Impact category	Impact - units	Impact - number/TWh	Damages		Impacts - number/TJ	Damages		σ_g, range
			mECU/kWhe	ECU/tpoll		mECU/MJ	ECU/tpoll	
Air pollution								
6. Power generation								
Primary PM10								
Mortality	YOLL	11.6	0.98	4 793	6.81E-04	5.78E-02	1 376	B
	deaths	1.25	3.87	18 854	7.34E-05	2.27E-01	5 411	B
Morbidity	cases	717.2	0.13	610	4.22E-02	7.36E-03	175	A-B
NOx								
via nitrates								
Mortality	YOLL	49.2	4.18	4 449	2.89E-03	2.46E-01	1 277	B?
	deaths	5.30	16.43	17 503	3.12E-04	9.66E-01	5 023	B?
Morbidity	cases	3 045	0.53	566	1.79E-01	3.12E-02	163	A-B
via O3								
Mortality	YOLL	na	0.66	415	na	0.04	415	B
Morbidity	cases	na	1.85	735	na	0.11	735	A-B
Effects on crop yield	t	na	6.72E-01	350	na	3.95E-02	350	B
via acidity								
Relative exceedance weighted areas in which critical loads of acidity are already exceeded		na	na	na	na	na	na	
Effects on crop yield	t	na	na	na	na	na	na	
via nitrogen deposition								
Relative exceedance weighted areas in which critical loads of nutrient nitrogen are already exceeded								
Add. fertilizer needed	kg	-49378	-2.13E-02	-22.7	-2.9	-1.25E-03	-6.51	B
SO2								
via SO2								
Mortality	YOLL	2.41E-02	3.73E-03	4.0	1.42E-06	2.19E-04	27.1	B
	deaths	3.21E-02	9.96E-02	106.1	1.89E-06	5.86E-03	722.6	B
Morbidity	cases	9.21E-03	7.24E-05	0.1	5.41E-07	4.26E-06	0.53	A

Table XI.5 (Cont.)

Impact category	Impact - units	Impact - number/TWh	Damages mECU/kWhe	Damages ECU/tpoll	Impacts - number/TJ	Damages mECU/MJ	Damages ECU/tpoll	σ_g, range
Materials damage	m^2	1 655	2.33E-02	24.8	9.73E-02	1.37E-03	168.8	B
Effects on crop yield	t	45.4	3.49E-04	0.4	2.67E-03	2.05E-05	2.5	A
via sulfates								
Mortality	YOLL	1.46	1.24E-01	132.1	8.59E-05	7.29E-03	900	B
	deaths	1.58E-01	4.88E-01	520.3	9.26E-06	2.87E-02	3 543	B
Morbidity	cases	90.39	1.53E-02	16.3	5.31E-03	9.00E-04	111	A-B
via acidity								
Relative exceedance weighted areas in which critical loads of acidity are already exceeded		na	na	na	na	na	na	
Effects on crop yield	t	na	na	na	na	na	na	
Add. lime needed	kg	188 212	3.23E-03	n.a.	11.1	1.90E-04	n.a.	A
Greenhouse gas emissions								
Global warming via CO_2	na	nq	0	18 - 46	nq	0	18 - 46	C
Global warming via N_2O	na	nq	0	nq	nq	0	nq	
Global warming via CH_4	na	nq	0	nq	nq	0	nq	
Other stages								
Primary PM_{10}	na	nq	nq	nq	nq	nq	nq	
NO_x								
via nitrates	na	nq	nq	nq	nq	nq	nq	
via O_3								
Mortality	YOLL	na	0.16	415	na	9.54E-03	415	B
Morbidity	cases	na	0.29	735	na	1.69E-02	735	A-B
Effects on crop yield	t	na	0.14	350	na	8.05E-03	350	B
via acidity	na	nq	nq	nq	nq	nq	nq	
via nitrogen deposition	na	nq	nq	nq	nq	nq	nq	
SO_2	na	nq	nq	nq	nq	nq	nq	
Greenhouse gas emissions	na	nq	0.35 - 0.9	18 - 46	nq	0.02 - 0.05	18 - 46	C
Global warming via CO_2	na	nq	nq	18 - 46	nq	nq	18 - 46	
Global warming via N_2O	na	nq	nq	nq	nq	nq	nq	
Global warming via CH_4	na	nq	nq	nq	nq	nq	nq	

Table XI.5 (Cont.)

Impact category	Impact - units	Impact - number/TWh	Damages mECU/kWhe	Damages ECU/tpoll	Impacts - number/TJ	Damages mECU/MJ	Damages ECU/tpoll	σ_g, range
Fertiliser on drinking water								
1. Soil preparation, planting and other	na	na	9.41E-03	na	na	5.53E-04	na	A
Soil erosion								
Stages 1 and 2	na	na	2.37E-01	na	na	1.38E-02	na	A
Effects of noise on human health and amenity								
All stages	na	na	0.03	na	na	na	na	A
Impacts on visual amenity								
All stages	na	na	0.001	na	na	na	na	A
Road damage from transport								
Transport stages	na	na	1.09E-01	na	na	6.40E-03	na	A
Occupational and public accidents								
Power generation stage								
Fatalities	deaths	0.006	2.02E-02	na	3.79E-07	1.19E-03	na	A
Injuries	cases	nq	nq	na	nq	nq	na	
Other stages								
Fatalities	deaths	1.13	3.55	na	6.65E-05	2.09E-01	na	A
Injuries	cases	26.3	7.13E-01	na	1.55E-03	4.19E-02	na	A
Employment effects								
All stages	job-equivalent	7 789	nq	na	4.58E-07	nq	na	A

ng: negligible; nq: not quantified; na: not applicable; - : not relevant

IV. APPENDIX XII: DEFINITION OF THE HYDRO FUEL CYCLE, DATA AND RESULTS

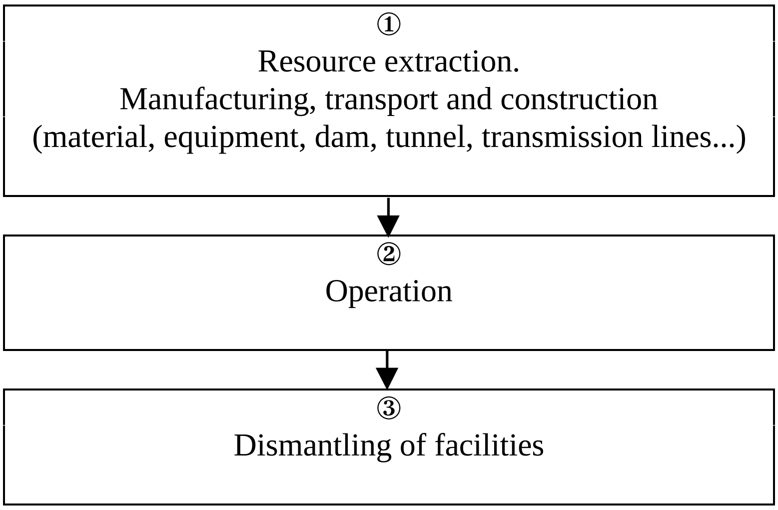

Figure IV.1 Hydro fuel cycle

Table IV.1 Hydro fuel cycle characteristics: Case 1

Stage	Parameter	Quantity / Characteristic	Source of data
1. Construction			GENERG (95)
Dam, tunnel and	Location of the hydro power plant	Lourizela, Centro Region, PT	
other infrastructures	Total surface area of the basin	149 km^2	
and equipment	Water intake level	184.2 m	
	Back flow level	91.2 m	
	Net fall	89.2 m	
	Average water flow	6.7 m^3/s	
	Ecological flow	0.25 m^3/s	
	Dam height	5 m	
	Tunnel length	759 m	
	Open-air canal length	888 m	
	Flood reservoir capacity	300 m^3	
	Penstock length	175 m	
	Turbine:		
	type	Francis	
	speed	750 rpm	

Table XII.1 (Cont.)

Stage	Parameter	Quantity / Characteristic	Source of data
	Generator		
	type	synchronous, triphasic type	
	number of generators	2	
	nominal power	6 250 kVA	
	Material needed		
	steel	-	x - no data
	concrete	-	x - no data
	other	-	x - no data
	Lifetime of the development	40 years	
Transmission lines	Distance to the network	13.9 km	
	Line voltage	15 kV	
	Lifetime	20 years	
2. Operation			GENERG (95)
	Mode of operation	hydraulic	
	Command and control mode	automatic	
	Power capacity	5 200 kW	
	Electricity generated in average	17 860 MWh/year	
	Full load hours	4 040 / year	
3. Dismantling			
	Energy generation unit		
	steel	-	x - no data
	construction materials	-	x - no data
	other	-	x - no data

Table IV.2 Hydro fuel cycle characteristics: Case 2

Stage	Parameter	Quantity / Characteristic	Source of data
1. Construction			EDP (93)
Dam, tunnel and other infrastructures and equipment	Location of the hydro power plant	North region, PT	
	Total area of hydrographic basin	1 524.8 km^2	
	Available storage capacity	347.8 x 10^6 m^3	
	Water intake level	262 m	
	Maximum net head	280.8 m	
	Flow absorbed at full load	2 x 125 m^3/s	
	Length of tailrace tunnel	4 926.3 m	
	Dam:		
	height	110 m	
	crown length	297 m	
	Turbine:		
	type	Francis	
	speed	214.3 rpm	
	Generator		
	type	-	x - no data
	number of generators	2	
	nominal power	2 x 350 MVA	

Table XII.2 (Cont.)

Stage	Parameter	Quantity / Characteristic	Source of data
	Material needed		
	steel	14 070 t	
	concrete	742 600 m^3	
	other	-	x - no data
	Lifetime of the development	40 years	
Transmission lines	Distance to the network	57.7 km	
	Line voltage	400 kV	
	Lifetime	20 years	
2. Operation			EDP (93)
	Mode of operation	Hydraulic	
	Power capacity	2 x 317 MW	
	Electricity generated in average	910 GWh/year	
	Electricity generated in dry year	533 GWh/year	
3. Dismantling			
	Energy generation unit		
	steel	-	x - no data
	construction materials	-	x - no data
	other	-	x - no data

Table IV.3 Inventory of burdens from the hydro fuel cycle

Stage / Burden	Unit	Quantity		Source of data	Impact assessed?
		Case 1	Case 2		
1. Construction of dam, tunnel and other infrastructures and equipment				CEEETA (95b)	
Occupational health	h	229 500	nq		✓
Air emissions					
CO_2	t	475.7	-		✓
CO	t	3.1	-		-
SO_2	t	0.9	-		-
NO_x	t	9.5	-		partially
particulates	t	0.6	-		-
VOC	t	1.1	-		partially
Emissions to soil	t	-	-		x - no data
Emissions to water	m^3	-	-		x - no data
Other burdens					
noise	dB	-	-		x – no data
visual intrusion		-	-		x – no data
soil loss	t	-	-		x – no data
Road use	km	1 011 500	-		x – no data
Labour required (direct)	h	229 500	-		not valued
Labour required (indirect)	ECU	2 912 500	-		not valued
Transmission lines				CEEETA (95b)	
Occupational health	h	39 200	-		

Table XII.3 (Cont.)

Stage / Burden	Unit	Quantity Case 1	Case 2	Source of data	Impact assessed?
Air emissions		na			
CO_2	t	73.4	-		✓
CO	t	0.5	-		-
SO_2	t	0.1	-		-
NO_x	t	1.5	-		partially
particulates	t	0.1	-		-
VOC	t	0.2	-		partially
Road use	km	156 000	-		x – no data
Labour required (direct)	h	39 200	-		not valued
Labour required (indirect)	ECU	396 150	-		not valued
Other burdens					
noise	dB	-	-		x – no data
visual intrusion		-	-		x – no data
2. Operation				CEEETA (95b)	
Occupational and public health	h/yr	2 416	-		
Air emissions					
CO_2	t/yr	1.0	-		✓
CO	t/yr	ng	-		-
SO_2	t/yr	ng	-		-
NO_x	t/yr	ng	-		partially
particulates	t/yr	ng	-		-
VOC	t/yr	ng	-		partially
Other burdens					
noise	dB	-	-		x – no data
visual intrusion		-	-		x – no data
Road use	km/yr	7 550	-		x – no data
Labour required (direct)	h/yr	2 416	-		not valued
Labour required (indirect)	ECU/yr	89 400	-		not valued
3. Dismantling					
Occupational and public health		-	-		x – no data
Air emissions		-	-		x – no data
Other burdens		-	-		x – no data

Table IV.4 Impacts and damages from the hydro fuel cycle: Case 1

Impact category	Impact units	number/TWh	Damages mECU/kWh	ECU/t_{poll}
Air pollution				
All stages				
Air pollutants on human health				
Mortality	YOLL	na	7.70E-03	na
Morbidity	Cases	na	1.36E-02	na
Air pollutants on crops	t	na	6.50E-03	na
Air pollutants on materials	m^2	nq	nq	
Air pollutants on ecosystems		nq	nq	

Table XII.4 (Cont.)

Impact category	**Impact**		**Damages**	
	units	**number/TWh**	**mECU/kWh**	**ECU/t_{poll}**
Greenhouse gas emissions		nq	3.53E-03 / 1.29E-01	3.8 - 139
Occupational and public health effects				
Construction				
Fatalities	deaths	6.65E-02	2.09E-01	
Injuries	cases	nq	nq	
Operation				
Fatalities	deaths	7.01E-03	2.20E-02	
Injuries	cases	nq	nq	
Impact from noise				
All stages	-	nq	nq	
Impacts of the hydroelectric development on aquatic and terrestrial ecosystems				
All stages		nq	nq	
Impact on bird population from transmission lines				
Operation	-	nq	nq	
Impacts of hydroelectric developments on natural erosion processes and land use				
All stages	-	nq	nq	
Effects on water quality				
All stages	-	nq	nq	
Impacts from visual intrusion				
All stages	-	nq	nq	
Impacts from new access infrastructures				
Construction	-	nq	nq	
Impacts on recreational activities				
Construction	-	nq	nq	
Impacts from dam failure risk				
All stages	-	nq	nq	
Effects of electric and magnetic fields				
Operation of transmission lines	-	nq	nq	
Road use				
All stages	-	nq	nq	
Employment (3 % disc. rate)				
All stages	Nº of jobs eq. per year	1 630	iq	

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