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0. EXECUTIVE SUMMARY

0.1 Introduction

0.1.1 Background 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. 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. The current report is the result of the ExternE National implementation project for Italy.

The objective of the ExternE National Implementation project is to establish a comprehensive and comparable set of data on externalities of power generation for all EU member states and Norway. The tasks include the application of the ExternE methodology to the most important fuel cycles for each country as well as to update the already existing results; to aggregate these site- and technology-specific results to more general figures. For countries already involved in Joule II, these data have been applied to concrete policy questions, to indicate how these data could feed into decision and policy making processes. Other objectives were the dissemination of results in the different countries, and the creation of a network of scientific institutes familiar with the ExternE methodology, data, and their application.

The National Implementation project has generated a large set of comparable and validated results, covering more than 60 cases, for 15 countries and 11 fuel cycles. A wide range of technologies have been analysed, including fossil fuels, nuclear and renewables. Fuel cycle analyses have been carried out, determining the environmental burdens and impacts of all stages. Therefore, besides from the externalities estimated, the project offers a large database of environmental aspects of the fuel cycles studied.

An aggregation exercise has also been carried out, to extend the analysis to the whole electricity system of each of the participant countries. The exercise has proved to be very useful, although the results must be considered in most cases as a first approach, which should be carefully revised before being taken into consideration.

In spite of all the uncertainties related to the externalities assessment, the output of the project might prove to be very useful for policy-making, both at the national and EU level. The results obtained provide a good basis to start the study of the internalisation of the external costs of energy, which has been frequently cited as one of the objectives of EU energy policy. Other possibility is to use the results for comparative purposes. The site sensitivity of the externalities might encourage the application of the methodology for the optimisation of site selection processes, or for cost-benefit analysis of the introduction of cleaner technologies. The usefulness of the application for policy making has been demonstrated through the analysis of a wide variety of decision making issues carried out by those teams already involved in ExternE under Joule II.

Further work is needed, however, to remove as much uncertainties as possible of the methodology, and to improve aggregation methods for electricity systems. These improvements are required if externality values are to be used directly for policy measures, not only as background information.. The acceptability of these measures will depend on the credibility of the externality values.

The current report is to be seen as part of a larger set of publications. The results of these ExternE projects is published and made available in three different reports and publications. The current report covers the results of the national implementation for Italy, and is published by FEEM (Fondazione Eni Enrico Mattei). It contains all the details of the application of the methodology to the fuel oil, natural gas, hydro and waste incineration cycles, aggregation, and a policy case study, as an illustration of the use of these results**.** The methodology is detailed in a separate report, published by the EC.

0.1.2 The Italian National Implementation

Italy is placed in the Southern part of Europe. Its total area is some 301,000 km^2, and its population is something more than 56 million.

Approximately 80% of electric power in Italy is from thermal (primarily oil-fired) plants. Thermoelectric power generation relies heavily on heavy fuel oil (more than 60%); the contribution of solid fuels is 12 % and the one of natural gas is about 24% .

Since nuclear power has been abandoned, hydroelectric and geothermal power account for the remainder. Hydropower in particular plays a very significant role as well (17.3% of the gross national production in 1995).

It is important to note that only about one quarter of total national electricity production relies on national sources. The relative high degree of dependence from foreign sources compared to other EU member states has to be taken into account when selecting the most representative fuel cycles for the whole sector.

Considerable uncertainty exists as far as future development of power generation capacity is concerned. This uncertainty is due primarily to the ongoing privatisation process of ENEL (ENEL has the state monopoly for the import and distribution of electricity, and accounts for about 80% of production). Taking this into account and considering the present debate and the actual investment plans of the major electricity producers, it is reasonable to say that the following years will see a further development of thermoelectric capacity - mainly combined cycle (27% in terms of net power available) natural gas fired- as opposed to renewable.

Following these considerations, the Italian implementation study will focus on a CCGT gas fired power plant that will be located in Trino Vercellese (province of Vercelli - Piemonte region, northern Italy) and a base load steam turbines oil fired power plant located in Monfalcone (province of Gorizia - Friuli-Venezia Giulia region, north-eastern Italy).

As for the hydropower case study, we will refer to plants of AEM (Azienda Elettrica Municipale) of Milano, a municipal producer, located in alta Valtellina (northern Italy).

A forth fuel cycle concerning energy recovery from waste incineration is considered: an incinerator located 10 km far from the town of Milan (northern Italy) is considered in the specific case. Because of the peculiarities of this "fuel" (wastes cannot be considered a proper "economic good" specifically produced with the aim of producing electricity; they are rather a residue that remains after any consumption and production activity, and that for hygienic *reasons must be disposed of in some way*), the fuel cycle defined in this report also considers a landfill as the alternative technology for waste disposal. In the "policy case study" an application to the solid waste problem in Milan is dealt with.

0.2 Methodology

The methodology used for the assessment of the externalities of the fuel cycles selected has been the one developed within the ExternE Project (European Commission, 1995a-f). It is a bottom-up methodology, with a site-specific approach, that is, it considers the effect of an additional fuel cycle, located in a specific place.

To allow comparison to be made between different fuel cycles, it is necessary to observe the following principles:

Transparency, to show precisely how the work was done, the uncertainty associated to the results, and the extent to which the external cost of any fuel cycle have been fully quantified.

Consistency, with respect to the boundaries placed on the system in question, to allow valid comparison to be made between different fuel cycles and different types of impact within a fuel cycle.

Comprehensiveness, to consider all burdens and impacts of a fuel cycle, even though many may be not investigated in detail. For those analysed in detail, it is important that the assessment is not arbitrarily truncated.

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.

Quantification of impacts is achieved through the damage function, or impact pathway approach. This is a series of logical steps, which trace the impact from the activity that creates it to the damage it produces, independently for each impact and activity considered, as required by the marginal approach.

The underlying principle for the economic valuation is to obtain the willingness to pay of the affected individuals to avoid a negative impact, or the willingness to accept the opposite. Several methods are available for this, which will be adopted depending on the case.

0.3 Overview of the fuel cycles assessed

0.3.1 Oil fuel cycle

As for the oil fuel cycle stages, we made the hypothesis that oil is produced in northern Europe from oil fields in the North Sea. The crude oil is then transported via tankers to a coastal reference refinery located in Germany. After refining the fuel oil is loaded on tankers for long range transport to the coastal storage facility in Trieste (northern Italy) from where it is transported via pipeline to an ENEL power plant (a base load steam turbine power plant), located in Monfalcone (northern Italy).

Atmospheric emissions occur during all the stages, but they are concentrated mainly at the generation stage, arising from fuel oil combustion. Quite high emissions arise also from the fuel oil transportation stage, due to the long way (10,800 km return trip) tankers are supposed to sail from the Northern Sea to the coastal facility in Trieste. The pollutants taken into account are: SO_x, NO_x, CO, CO_2, TSP, VOC, CH_4.

As for the emission rates of the power generation plants, the law limit values, that all existing power plants will have to meet those emission values by the end of 1997.

The analysis is restricted to the following impacts, that are believed to be the most important for the oil fuel cycle (and for fossil fuel cycles in general): damages of atmospheric pollution over human health, crops and materials at the regional level; global warming at the global scale; occupational health.

Non global warming damages are quite high and the highest are those on public health (95% of the total), especially due to SO_2 emissions. Damages to other receptors are negligible.

Global warming damages span three orders of magnitude, ranging from one tenth to five times those attributed to other impact categories: this gives total damage a big uncertainty, which should be reduced by promoting further research activities in the field of global warming assessment.

Total damage, obtained using the upper limit of the mid range for global warming, is 55.8 mECU/kWh, which is comparable with the cost of electricity for the final user in Italy.

Damages given in terms of ECU per unit of emitted pollutant are quite high as they are of the order of magnitude of thousands of ECU per ton of primary pollutant emitted.

The power production plant has been located in a densely populated area of northern Italy and this explains the high damages obtained. A sensitivity analysis performed has shown that the regional damage is reduced by 70% when a less densely populated location is chosen.

0.3.2 Gas fuel cycle

Natural gas is extracted by AGIP from off-shore gas fields in Northern Adriatic Sea; it is then pumped on-shore and treated at the AGIP treatment facility of Falconara. After treatment, gas is transported by the Snam gas network to the combined cycle power plant run by ENEL located in Trino Vercellese (Piemonte region, northern Italy).

Atmospheric emissions occur during all the stages, but they are concentrated mainly at the generation stage, arising from natural gas combustion. The pollutants taken into account are: SO_x, NO_x, CO, CO_2, TSP, VOC, CH_4.

The most significant environmental issue with combined cycle power plants has been the emission of oxides of nitrogen (NO_x) as part of the production of the combustion. Since the power plant is still under construction, in this study the law limit for this kind of plants (60 mg/Nm^3) has been used for the NO_x emission rate.

The analysis is restricted to the following impacts, that are believed to be the most important for the gas fuel cycle (and for fossil fuel cycles in general): damages of atmospheric pollution over human health, crops and materials at the regional level; global warming at the global scale; occupational health; effects on the marine environment (qualitative description only).

Apart from global warming damages, the higher contribution comes from the impact on human health of nitrates generated by nitrogen oxides emissions during electricity production (95% of non global warming damage); damages to crops, materials and occupational health are much lower; damages from upstream and downstream stages are negligible (2%), even if not all the potential impacts of these activities have been quantitatively addressed.

Damages are not as low as one could expect considering the fuel and technology used (for the NO_x emission rate, the law limit for this kind of power plant has been used). One reason for this is that the area where the power plant has been located is densely populated, so that the emissions affect a great amount of people.

Total damage, considering the upper limit of the mid range of global warming damages, is 27.3 mECU/kWh, which is the same order of magnitude of average electricity production costs.

The damage per unit of pollutant emitted refers in this case only to NO_x, as emissions of other pollutants are negligible. The damage per unit of NO_x emitted is higher than in the case of the oil power plant. This id due to two reasons: first, the gas plant has been located in a more densely populated area; second, the oil power plant has been located very close to the border of the calculation grid and the impacts falling outside model domain have not been considered (this has been estimated as 10% of regional damage).

0.3.3 Hydro fuel cycle

In the hydro cycle most of the burdens concern aquatic and terrestrial ecosystems in terms of alteration of river flows, dams, etc. The impacts are very site-specific and it would be very difficult to build general dose-response functions. In addition a single impact might be caused by different causes and burdens and it is often not possible to sort out what part of the impact was caused by that burden.

Within this study, impacts are described but not quantified, and damages are estimated using an indirect method: the value of non marketed goods are estimated starting from repair and restoration costs. These include mainly costs during the operation phase of a complex hydroelectric system. It should be noticed that damage estimates obtained through this method only refer to the avoided or repaired damages, and they do not account for the full damage.

The selected hydroelectric system belongs to AEM, a municipal company serving the area of the municipality of Milano and is located in alta Valtellina, one of the biggest valleys in Lombardia region (northern Italy). The system is made up of 4 reservoirs, 7 production plants and 7 diversions.

Within this study, the attention is focused on the electricity production stage only; the main issues are therefore related to landscape, public health, plant and animal life, upstream and downstream hydrology, multiple water uses, recreational activities.

As already mentioned in the previous paragraphs, the damages caused by the impacts identified above have been estimated using the costs associated with all compensation and remediation measures, relating to the restoration of the natural situation, that have been put in place by

AEM in Valtellina. For these reasons all the costs given below have been already internalized by AEM and do not represent externalities. Nevertheless these could represent a rough estimate of externalities in other contexts where hydroelectric plants are located, but these measures have not been implemented.

The costs have been extracted from the detailed management accounting system that AEM implemented at the beginning of the 80's. Nevertheless this system does not classify the environmental costs into separated cost centres: the environmental costs are collected into overhead accounts and a cross analysis among the cost centres for their identification was necessary.

Among the three fuel cycles considered in this report, hydro is the one with the lowest external costs (the total damage calculated for the considered impacts is about 3.4 mECU/kWh), but it should be considered that they have been evaluated with a methodology completely different from the one used for fossil fuel cycles, and they probably do not account for the whole externalities.

0.3.4 Waste incineration

The process of energy recovery from waste incineration has some fundamental peculiarities that require a special care when defining it as a “fuel cycle”. In particular, it must be taken into account that unlike other fuels, wastes cannot be considered a proper “economic good”, specifically produced with a given aim (that of producing energy). They are rather a residue that remains after any consumption and production activity, and that *must be disposed of in some way*. This “mass balance constraint” about wastes imposes some modifications with respect to the traditional evaluation approach taken in most of the other fuel cycles analysed in ExternE. In particular, it requires the analysis to consider also the foregone external effects that waste disposal through an alternative technology would have caused, were the wastes not treated by the incinerator. According to that, the fuel cycle defined considers a landfill as the alternative technology for waste disposal, and subtracts the relative impact from that due to the incinerator in order to evaluate the *net* external damage of this technology.

The specific incinerator considered is located 10 km far from the town of Milan, in the western outskirt (via Silla), and treats 279000 tonnes of waste per year. The alternative treatment plant considered is a landfill of the same size located in the small town of Cerro Maggiore, 50 km North-West of Milan. As the landfill has found a strong opposition by the local communities, a specific study (an hedonic pricing model) to quantify the impact given by the amenity losses (due to odours, traffic congestion, presence of rats and flocks of birds) was considered in the evaluation of damages.

The results suggest that the incinerator is, from the environmental point of view, more damaging than the landfill, even when the adverse disamenity impact from the latter is included. The *net* external impact of the incinerator, computed as explained above, turns out to be positive, and equal to 8.9 mECU/kWh – or t0 7,5 ECU per tonne of waste disposed of.

Obviously, due to the uncertainty and to the site-specificity of the methodology, these results have to be taken with caution.

0.4 Aggregation

In order to obtain the damage of the electricity sector (in MECU/year) at the global scale, the specific damage (ECU/ton of GHG emitted) has been multiplied by emissions from the power sector taken from the Corinair emissions inventory (upstream fuel cycles emissions should ideally be added, but these are a second order correction at least for carbon dioxide).

As for damages at the regional scale , that is those due to emissions of primary pollutants from the electricity sector, these can be assessed by multiplying the specific damage for each pollutant (ECU/t) obtained with the single plant analysis by the emissions of the electricity sector. This approach assumes that the reference power plant values are transferable within the country. This is not true in the case of Italy, because the country is stretched along the north-south direction and it is surrounded by the sea. For this reason the proposed approach is based on a sensitivity analysis performed on different sites throughout the country. In order to limit the number of simulations in different locations, the Italian territory has been divided into seven sectors considered as homogeneous, according to geography, morphology and industrialization; for each of them a location has been selected and a power plant has been placed. A damage (in mECU/g) has been calculated for each pollutant and for each site. Emissions from the electricity sector were taken from CORINAIR 1990 emissions inventory as far as SO_2 and NO_x are concerned. TSP emissions have been estimated from fuel consumption for thermoelectric power generation.

The value of the total damage ranges from about 13,000 to about 16,000 MECU/y, which corresponds to about 1.4 to 1.7% of the Italian GDP of 1995.

0.5 Policy case study

Waste incineration represents one of the major alternatives for municipal solid waste disposal in western industrialised countries. Although it is still scarcely used in Italy (it only concerns about 7% in weight of the wastes yearly produced), due to its energy recovery potentialities and to the high price of waste treatment most of the local power generation utilities consider it as an attractive alternative to waste landfilling - which is now banned as a normal practice by the EU directive and by the new Italian Waste Act. In spite of its relative attractiveness on financial grounds, the welfare effects of waste incineration – in particular as regards its external costs and benefits – appear to be much more ambiguous. The strong opposition met by the construction of new plants suggests that there are considerable social costs associated with this technology, that might balance or even exceed the possible financial and economic benefits.

The analysis aims at using the results of the ExternE methodology to assess the relative advantages and disadvantages, from the environmental point of view, of two major waste treatment technologies: waste incineration and landfilling. According to the characteristic site-specificity of these results, the evaluation focuses on waste treatment in a well-defined site: the metropolitan area of Milan. The results suggest that waste incineration of municipal solid wastes is, from the environmental viewpoint, less attractive as compared to landfilling. In fact, the external cost of disposing of 1 tonne amounts to about 26.5 ECU for the former, while it is only 19 ECU for the latter (greenhouse gases effects excluded). The opposite outcome of the analysis is however obtained when considering the costs per kWh recovered from wastes: the 28 mECU/kWh of the incinerator are about 14 times lower than the corresponding external cost of energy recovery from landfill biogas. If finally the analysis considers the landfill external cost per tonne disposed of as a benefit (avoided cost) of the incineration treatment, it ends up with an external cost per kWh produced by the incinerator of some 9 mECU, which is of the same order of magnitude of the external cost of a gas-fires combined cycle plant – evaluated according to the same methodology). Therefore, when choosing the best waste treatment alternative, it becomes determinant for the local policy maker to state what is his policy priority - waste treatment in itself, or energy supply - since the choice suggested by the analysis changes radically.

0.6 Conclusions

The methodology developed within the ExternE project has been successfully applied to four case studies of energy production in Italy: two fossil fuel cycles, a hydroelectric power plant and an energy production process from waste incineration. The obtained results allow to make partial comparisons between the different fuel cycles: in particular, direct comparison can be made only between the two fossil fuel cycles, for which the same methodology has been used. As for the hydroelectric cycle, the different methodology used does not allow for comparison with the fossil fuels cycles, also because of the different role these forms of energy play within the national energy mix. Electricity production from waste deserves particular considerations because of the peculiarity of the cycle itself: the results suggest in fact that when choosing among alternatives for waste treatment, it becomes determinant for the local policy maker to state what his policy priority is - waste treatment in itself, or energy supply - since the choice suggested by the analysis changes radically.

The study has shown that externalities of fossil fuel cycles are significant as they are the same order of magnitude of the electricity production costs (in the case of oil fuel cycle they are even higher than production costs, if actual emissions are used) and could significantly affect energy policy decisions.

The high level of uncertainty affecting results, suggests that the obtained figures cannot be used directly in the economic evaluation of energy policies. This is especially true for global warming, for which results span three orders of magnitude: further research is needed in this field in order to obtain more reliable figures. Further research is necessary also in other fields, such as the impact of air pollution on human health, toward a refinement of the existing dose-response functions (mainly derived from U.S. studies) and the investigation of their transferability to the European context. Even further research is required in other fields, such as impacts on forests and ecosystems, for which other approaches than the dose-response approach should be used, and for which many physical phenomena as still far from being understood.

As a consequence of these considerations, it follows that the monetary approach should be used together with other instruments, such as multi-criteria analysis, cost-effective analysis, as a support to the decision making process. Nevertheless this study represents the most comprehensive and up to date application of the calculation of externalities of the electricity production, and can be considered as a well structured and scientifically based tool for supporting the current dialogue on how to include environmental issues into the decision making process in the energy sector.

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 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 project has continued with three major tasks: ExternE Core for the further development and updating of the methodology, ExternE National Implementation to create an EU-wide data set and ExternE-Transport for the application of the ExternE methodology to energy related impacts from transport. The current report is the result of the ExternE National implementation project for Italy.

1.1 Objectives of the project

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

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

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

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

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

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

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

1.2 Publications from the project

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

First, the current report covers the results of the national implementation for Italy, and is published by FEEM. It contains all the details of the application of the methodology to the fuel oil, natural gas, hydro and waste incineration cycles, aggregation, and a study about the role of solid waste incineration as a means of energy production and waste disposal in a large urban area, as an illustration of the use of these results. Brief details of the methodology are provided in Chapter 2 of this report and the Appendices; a more detailed review is provided in a separate report (European Commission, 1998a). A further report covers the development of estimates of global warming damages (European Commission, 1998b). The series of National Implementation Reports for the 15 countries involved are published in a third report (European Commission, 1998c).

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

This information can also be accessed through the ExternE website. It is held at the Institute for Prospective Technological Studies, and is accessible through the Internet (*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 to this report and are discussed at full length in the separate methodology publication (see above).

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

1.4 The Italian national implementation

1.4.1 Description of the country

The territory of the Italian Republic covers 301,278 km^2 (including the enclave of Campione in Switzerland and the states of the Republic of San Marino and of the Vatican City, measuring together 61 km^2). This is equal to a 35th part of Europe and slightly more than a five-hundredth of all the world's landmass. In Europe, excluding the Soviet Union, Italy's territorial extent is considerably smaller than that of France, Spain and Sweden, while only being slightly less than that of Finland, Norway and Poland.

Italy lies between the northern latitudes of 47º05'29" (m 2,837 from the Testa Gemella Occidentale/Westl. Zwillingsköpfe in the Aurine Alps on the Austrian border) and 35º39'26" (Punta Pesce Spada on the island of Lampedusa to the south of Sicily), and the eastern longitudes from Greenwich of 6º37'32" (m 3,178 from the minor peak north of the Rocca Bernauda in the northern Cottian Alps, upper Val di Susa, on the French border) and 18º31'13" (Capo d'Otranto on the Salentina Peninsula).

The territory of the Republic of Italy coincides almost precisely with the geographically defined Italian region. Its northern border corresponds with the Alpine watershed and it also physically includes the Istrian peninsula, the island of Corsica, the Swiss territories of Canton Ticino, Val Bregaglia and Val di Poschiavo and the Maltese Islands, while excluding Pantelleria and the Pelagian Islands (Lampedusa and Lampione), which emerge from the African continental platform. Altogether, the Italian physical region measures some 324,000 km^2.

Politically the territory of the Italian Republic has its northern border along the Alpine arc. This touches on France, Switzerland, Austria and Yugoslavia and is some 1,900 km long, generally following the watershed of the mountain chain except where it moves far away as in the Swiss and Yugoslavian sections. The remaining Italian territorial limits are maritime and, except for the territorial seas, they have usually been fixed with the countries concerned: Yugoslavia and Albania in the Adriatic, Greece in the Ionian, Malta, Libya and Tunisia in the Sea of Sicily, Tunisia and Algeria in the Channel of Sardinia, Spain in the Sea of Sardinia and France in the Ligurian and upper Tyrrhenian Seas.

The structure of the Italian territory differs considerably. Besides the continental section (Alps and Po-Venetian Plain), there is a long and indented peninsula that is almost completely occupied by the Apennine chain, the two large islands (Sicily and Sardinia) marking the borders of the Tyrrhenian Sea and many other minor island groups (Tuscan Archipelago, Lipari Islands, etc.). This produces long distances between the country 's extremities. In fact, along the Trieste parallel this is of some 540 km, while along that of Otranto, to the western coast of Sardinia, it is some 845 km. Finally, the greatest latitudinal distance is measured along the meridian of the Pelagian Islands for some 1,290 km.

It should also be noted that the geographical form of Italy favors the maritime. Indeed, the most inland zones of the peninsula are little more than 100 km from the sea (the peninsula's widest point, between the Argentario Promontory and Mount Conero, does not exceed 240 km) and on the two largest islands is rarely greater than 50 km. Even for continental Italy the zone furthest from the sea (the Spluga Pass in the Lombard Alps) is only just 230 km away. Finally to the land borders should be added some 7,500 km of coasts, over half of which belong just to the islands. In particular, Sicily has a perimeter of 1,115 km, Sardinia 1,336 km and the minor islands 1,734 km.

According to the last census (1991) the population of Italy was 56,778,031. With a density of 190 c./km^2, Italy is one of the most heavily populated countries in Europe after Benelux, the German Federal Republic and Great Britain. This figure, however, does not necessarily reveal the territorial distribution of population, and, in fact, of 95 provinces, only 40 have a density higher than the national average, with 70% of total population on a surface area equal to one third of the entire territory. This indicates that the territorial distribution of the population is somewhat heterogeneous. In reality, the most heavily populated areas are the Po-Veneto plains and other inland and peripherical low-lying areas (particularly Valdarno and the Campana plain) as well as the areas round the large cities (Rome) and the coastal belts. Many other areas, not necessarily mountainous or difficult to reach, are still underpopulated.

This irregular distribution appears to be a direct consequence of the strong attraction exerted over the last few decades by small and medium-sized urban centres. Almost 30% of the population of Italy is concentrated in c. 50 centres with over 100,000 inhabitants, and the overall urban population amounts to roughly two thirds of that total. The rural population which, at the beginning of the last World War, accounted for practically half the country's population, has been gradually declining with the massive increase in urbanization and drift from the countryside, influenced by the urban way of life which has leveled what were once marked differences between town and country.

Nonetheless, along with new types of community life, traditional forms of the rural community are still found, particularly where urbanization has scant influence, and these help to give the countryside its typically Italian landscapes, reflecting the classical dualism of scattered village and urban centre. The former is prevalently found in Central and Northeast Italy, where it is associated with fragmentation of farms and the mixed crop system, while the latter is generally predominant in the areas of large-scale cultivation, where farms are commonly high acreage and where environmental difficulties are accentuated, i.e. in the mountains or in areas with few resources. A direct consequence of the development of the Italian economy in the inter-war period, and particularly in the years after the Second World War, is the expansion of urban centres, whose flourishing development in the days of the Comuni and Signorie had since been considerably limited.

The extent of urbanization is now close to that of the economically advanced European countries, though there is still an imbalance in the distribution of urban centres throughout the regions, especially in the north, centre and south of the country, itself the result of varying degrees of economic development in the single regions.

Without taking into account the negative effects of the physical environment in the heart of the country as well as along the coasts, the principal clustering of urban centres is found to correspond with the areas of highest population density, i.e. the Po-Veneto plains (especially at the foot of the Alps and Apennines, in certain large inland valleys, such as the Adige Valley, and round Milan and Turin, the two great metropolises), the Arno valley and plain, the Ligurian littoral and the upper Adriatic coast (except for the Po delta), forming a fairly homogeneous continuous urban pattern. In Southern and Central Italy, the urban network appears less articulated, especially in Latium and Campania, where the metropolitan areas of Rome and Naples constitute the principal poles of aggregation. The distribution of urban centres in Puglia and Sicily, however, appears to be less irregular.

1.4.2 Overview of the national energy sector

Italy is almost entirely dependent on imports for its energy needs. The heavy reliance of the country on foreign oil and gas sources such as Libya and Algeria has made energy security and diversification of energy sources top concerns. Italy is looking to reduce its dependence on foreign oil, which accounts for over half of the primary energy demand. The government would like to increase the use of coal in power generation in order to help alleviate this dependency, a proposal which is viewed with apprehension by the country's strong environmental movement. Italy is also a strong proponent of natural gas use, particularly given the country's proximity to major gas fields in North Africa.

Tighter European standards on air quality are pushing Italy toward increasing the role of natural gas in the energy mix. Nuclear power, which was under a five-year moratorium from 1987 through 1992, does not look to figure in the short-term energy mix. Although the moratorium has expired, the government does not believe that the recommissioning of the two reactors closed in 1987 would be either economically viable or accepted by the public.

Oil

Italy’s high dependence on oil imports has made energy security an important priority. The country imports 95% of its oil, mainly from North Africa and the Persian Gulf. Libya is the biggest supplier (35% of imports).

The increasing reliance of ENEL (the state-own electricity board) on very light, sweet grades of crude oil has made this dependence even more pronounced. These low sulphur fuel oils (LSFOs) enable its power plants to meet stricter European Union regulations on air emissions. Given ENEL's plans to boost capacity significantly, it could soon become the biggest importer of LFSO if it does not diversify its energy mix or place desulfurizers on its fuel oil power plants. This could leave Italy with an even more precarious dependence on foreign oil, as LSFO demand would more than double and quickly outstrip Italian refineries capacity.

Agip’s oil and gas exploration subsidiary, Agip Spa, operates in over 20 countries to supply Italy's domestic oil demand. Significant hydrocarbon concessions exist in Libya, Tunisia, Egypt, Congo, Angola, Nigeria, United Kingdom, Norway, the United States, and China. ENI is also expected soon to open up offices in Vietnam and to begin a major move into offshore oil exploration opportunities there.

Foreign exploration and production form the core of ENI's ambitious capital spending plans. Nearly half of the proposed $18 billion the company plans to spend for the 1994-1997 period will be devoted to this activity. Agip is focusing on Libya and is also looking at future development of West Siberian oil fields and possibly Iraq's Nasariyah field.

Though Italy's domestic oil production is relatively small, exploration within the country has picked up over the last two years. The promotion of indigenous oil and gas production as a way to reduce import dependence remains an important policy objective. In March 1995, Agip's Italian exploration division announced that it was planning to spend $3.1 billion on Italian exploration and development in the next four years, a large part of which will be sunk into onshore oil fields of the Val d'Agri in the southern region of Basilicata, and the offshore Aquila oil field in the lower Adriatic Sea off Brindisi.

ENI has maintained exclusive drilling rights in two other important areas of domestic exploration, Sicily (15,000 b/d) and the Po Valley in Northwest Italy (60,000 b/d, 60% of domestic production). However, a European Union hydrocarbons licensing directive forbidding the granting of exclusive drilling rights to one company in a single geographic area will end ENI's sole concession in Sicily by January 1997. Meanwhile, the Italian government is also considering a measure that would end the group's monopoly on hydrocarbon extraction in the Po Valley.

Refineries

State-owned Agip Petroli, ENI's downstream subsidiary, is largest refiner in Italy. Through its Agip and IP retail gas chains, Agip Petroli controls roughly 30% of the domestic market, Italy's largest service station chain. The company has recently expressed interest in selling some of its refining assets in order to gain financial resources to invest abroad, particularly in Spain, Portugal, and Eastern Europe, where the company is actively pursuing new acquisitions.

Natural gas

As a result of increased domestic demand and a major campaign to boost the share of natural gas in the national energy mix (which is already second in Europe to Netherlands, a major natural gas producer), Italy's natural gas transmission and distribution infrastructure is growing rapidly. Major upgrading is taking place, especially in southern Italy and the Italian islands. Domestic exploration and production is rebounding after a slow period of several years, and Italian companies are looking both to increase gas imports from current suppliers as well as to develop new sources of gas imports.

Natural gas consumption in Italy stands at about 50 billions cubic meters per year. Agip Spa officials have projected that this level could increase by over 50% in less than five years. This would result in natural gas meeting about one third of Italy's total primary energy demand. In the electrical power sector alone, gas consumption is expected to jump to 40% of the national total from its current level of 20%. Of the gas delivered to Italian markets by Snam, 35% is produced in Italy by Agip and other companies, while 28% is imported from Algeria, 26% from Russia, and 11% from Netherlands. To boost imports, Snam is doubling throughput capacity of the trans-Mediterranean gas pipeline system and constructing a new Maghreb line for its North Africa supplies, while also increasing throughput capacity of the Trans-Austria Gasleitung (TAG) pipeline for its imports from Russia.

Agip Spa, along with British Gas plc and Russia's Gazprom, is working on gas development in Kazakhstan's Karachaganak gas/condensate field. Additionally, Agip has sought to develop the gas sector of Saudi Arabia. The company has held discussions on assisting in natural gas exploration with Saudi officials, who have so far resisted opening upstream operations to foreign companies. Also, after some delay the Italian government is moving ahead with plans to import gas from Nigeria. The project had been held up pending approval for construction of an LNG terminal in Italy.

Snam is the only gas importer and transporter in Italy, accounting for 90% of the country's gas sales. The main local distributor is Italgas, which has 34% of the market, and is 45% owned by ENI. Snam has expressed concern over proposals from Brussels to establish an internal EU gas market. The company now faces competition for the first time from British Gas plc, which recently opened up offices in Milan and is considering investing in local gas distribution companies that will soon be privatized. European Union regulations oblige national monopolies such as Snam to carry the gas of competitors and to end their exclusive exploration rights to hydrocarbon resources in areas such as the gas-rich Padana Valley in northern Italy, long the sole preserve of ENI. Suppliers, however, have maintained that this would over-extend their networks, and on this basis have denied competitors access to the system. The issue is currently being analyzed by the Italian antitrust commission.

Electric power

The Italian electricity supply industry faces an important period of restructuring. If the industry is to become competitive and more efficient with privatization, it must first satisfy certain preconditions. These include establishing the terms under which competing generators will sell their production to ENEL, deciding how new capacity will be approved, and creating a clear regulatory framework. These and other practical aspects of restructuring are currently under discussion. To date, some liberalization of the electricity industry has been achieved, notably the implementation of "Law 9", a provision which has partially deregulated independent electricity generation.

Approximately 80% of electric power in Italy is from thermal (primarily oil-fired) plants. Since nuclear power has been abandoned, hydroelectric and geothermal power account for the remainder. The government is highly supportive of renewables, and provides a program of grants and tax exemptions to support their further development. In 1993 and 1994, 729 megawatts (MW) of renewables capacity was authorized, of which over 400 MW was accounted for by hydropower. In October 1994, Italy brought into service the world's largest solar power station at Serre, in the south of the country. It is expected to generate up to 5 million kWh per year (enough to supply about 3,000 homes), and will serve as ENEL's primary research facility for photovoltaic cells.

ENEL has the state monopoly for the import and distribution of electricity, and accounts for about 80% of production. Because electricity demand has grown faster than new generation capacity, ENEL has had to rely increasingly on imports. In 1993, electricity imports accounted for a little over 10% of total consumption. In 1994, this share increased to 14%. Switzerland and France were the top two exporters to the Italian electricity market, followed by Germany.

ENEL has drawn up ambitious plans to meet the need for new capacity, which has been neglected due to the nuclear moratorium and the difficulty involved in getting permission for new construction. The utility hopes to build an additional 13.8 MW of net available capacity by 2002. This will largely come in the form of small plants constructed on or near existing sites.

Nuclear

Following the end of the moratorium on nuclear power in 1992, the Ministry of Industry set up an ad hoc committee with representatives from the Ministry of Foreign Affairs, ENEL, the environmental protection agency (ANPA), ENEA (the national agency for new technology, energy and environment), and the Italian nuclear industry to propose options for the future of the nuclear program. Two basic options were submitted to the Ministry: a renewed construction program focusing on the longer term, which would first involve a lengthy R&D commitment to safer, more advanced reactors; or a cessation of nuclear activities that would end all support for work on reactors other than handling existing waste. The government is still considering which option to pursue.

Coal

Coal consumption is dominated by power generation and coke production for steel. In 1995, coal provided about 8% of Italy's overall energy needs. Virtually all of Italy's hard coal consumption (98%) is met from imports, with the United States, Australia, and South Africa the major suppliers.

Despite the decline in coal consumption, Italy is undertaking a significant oil-to-coal conversion program as part of a growing effort to cut annual fuel oil consumption. ENEL hopes to triple coal consumption by 1998 from 1994 levels, mainly by resurrecting mothballed plants with the help of expensive flue gas desulphurization units and electrostatic filters to cut increases in carbon emissions.

Several years ago, indications had been that Italy would bring enough new coal-fired stations on-line to more than double its steam coal requirement within ten years. These projections became unrealistic, however, due to rising environmental opposition to coal use, which remains the chief obstacle to ENEL's coal plans. Until Italian environmentalists are convinced that coal can be burned cleanly, the present level of imports and consumption may rise only incrementally, despite industry plans.

1.4.3 Justification of the selection of the fuel cycles

The main criteria for the definition of the focus of the national implementation studies are: 1. the 'power generation specificity of the country' and 2. the relevance for the policy debate on new and future technologies.

The accounting framework has to be applied to the most representative fuel cycles for power generation in order to be able in a second step to aggregate the site and technology specific results to more general figures covering the externalities associated with the whole power generation system of the country and to integrate these information in energy-economy-environment models.

The accounting framework has to be implemented to fuel cycles which are currently under discussion for the renewal or extension of the power generation capacity of the country.

Both these selection criteria aim at producing research results to support the decision making process in the area of power generation.

From the above mentioned selection criteria it follows that the choice of the fuel cycles has to be based on a pragmatic approach, focusing especially on country specific issues and elements that are important for the total figure of externalities.

As one can see from the previous paragraphs, power generation capacity in Italy relies heavily on the use of traditional fossil fuels. Electricity is mainly produced with traditional thermoelectric power plants, followed by hydroelectric generation, while the contribution of geothermal plants to total electricity generation is marginal. Italy has no nuclear generation capacity. Thermoelectric power generation relies heavily on heavy fuel oil (more than 60%); the contribution of solid fuels is 12 % and the one of natural gas is about 24% .

It is important to note that only about one quarter of total national electricity production relies on national sources. The relative high degree of dependence from foreign sources compared to other EU member states has to be taken into account when selecting the most representative fuel cycles for the whole sector.

From the data of the previous paragraphs it follows that oil and natural gas are the most representative fuels used in thermoelectric production and that hydropower plays a very significant role as well (17.3% of the gross national production in 1995).

Considerable uncertainty exists as far as future development of power generation capacity is concerned. This uncertainty is due primarily to the ongoing privatization process of ENEL. Taking this into account and considering the present debate and the actual investment plans of the major electricity producers, it is reasonable to say that the following years will see a further development of thermoelectric capacity - mainly combined cycle (27% in terms of net power available) natural gas fired- as opposed to renewable.

Following these considerations, the Italian implementation study will focus on a CCGT gas fired power plant that will be located in Trino Vercellese (province of Vercelli - Piemonte region, northern Italy) and a base load steam turbines oil fired power plant located in Monfalcone (province of Gorizia - Friuli-Venezia Giulia region, north-eastern Italy). As for the hydropower case study, we will refer to plants of AEM (Azienda Elettrica Municipale of Milano), a municipal producer, located in alta Valtellina (northern Italy).

This report also contains a forth fuel cycle concerning energy recovery from waste incineration: an incinerator located 10 km far from the town of Milan (northern Italy) is considered in the specific case. Because of the peculiarities of this “fuel” (wastes cannot be considered a proper “economic good” specifically produced with the aim of producing electricity; they are rather a residue that remains after any consumption and production activity, and that for hygienic *reasons must be disposed of in some way*), the fuel cycle defined in this report also considers a landfill as the alternative technology for waste disposal. In the policy case study, presented at the end of this report, the solid waste problem in Milan - namely the closure of the landfill site and the substantial replacement of its role by a new, large incinerator equipped with energy recovery - is dealt with.

1.4.4 Other related national studies

There are only few studies related with estimate of external costs of electricity production in Italy. They did not try to compute external costs per unit of pollutant, but tried to estimate the social costs associated with electricity sector in Italy, starting from unitary damage costs transferred to previous studies.

The first one is a study, carried out by M. Agostini and A. Clò in 1993 (Agostini e Clò, 1993), that attempted an estimate of pollution damage at the national level. The study considers air pollution damage from electricity production, and is based on unitary damage costs transferred from previous works. The authors distinguish between local and global effects of air pollution. Local effects include the impact of SO_2, NO_X, TSP and CO_2 concentrations on agriculture and human health, whereas global effects include damages from acid depositions and global warming to non-cultural buildings and forests.

Dose-response functions derived from the literature are applied to estimate physical impacts on the main receptors. Dose-response coefficients for health damages are taken from Ottinger (1990). No clear reference on the source of dose-response coefficients for damage to crops is given.

As far as forest damage due to acid depositions is concerned, the physical impact has been estimated assuming that about 10% of total reported forest damage is attributable to acid rains. This is, of course, a rather strong and questionable assumption, not properly supported by bibliographic references and empirical evidence. On the basis of some national and international studies 70% of this damage is then attributed to SO_2 emissions while the remaining 30% to NO_X pollution.

Any sort of explanation is missing on the methodology followed to estimate damage to materials.

Physical damage to human health has been translated in monetary terms on the basis of a value of a statistical human life (VOSL) derived as the mean value from a sample of about 15 international studies. The resulting estimated unitary value of a human life is equal to 8.5 billions lire 1992, which include both material and moral damage (i.e. pain and suffering). Morbidity endpoints have been valued at 317.000 Lit 1992 (equal to the VOSL divided for the average life expectancy). The study does not provide any information on monetary values used to estimate economic damage to agriculture. As in the case of health impact, forest damage is valued on the basis of an average value from various international studies (i.e. 1,1-2,0 lit/gr.). Damage from CO_2 emissions is based on the cost of reforestation given in Ottinger (1990) (i.e. 20.000 lit/ton). Resulting unit value estimates for Italy are reported in Table 1.

Table 1.1 - U*nitary damage cost from air pollutants in Italy (Lit/gr.)*

Damage from:	**Local effects**	**Global effects**	**Total**	**Average range in International studies**
SO2	2,3	1,7-2,7	4,0-5,0	1,6-22,3
	1,9 (health)	1,1-2,0 (forests)		
	0,4 (agriculture)	0,6-0,7 (materials)		
		*** (monuments)		
NOx	0,7	0,8-1,3	1,5-2,0	1,7-29,5
	- (health)	0,6-1,0 (forests)		
	0,7 (agriculture)	0,2-0,3 (materials)		
		*** (monuments)		
Particulates	0,25		0,25	0,05-8,2
	0,25 (health)	0		
		0		
CO2	0	0,02	0,02	benef.- 9,2

**** Damage consistent but not quantifiable*
Source: Agostini M., Clo' A., 1993.

A more recent study is the one made by Gli Amici della Terra (Friends of the Earth Italy) (AIEE, 1997) within project EASE of DGXI. The study is focused on the quantification of the advantages of cogeneration and is in particular on externalities assessment. The costs associated with unitary pollutant emissions are taken from the literature. The study is based on the comparison between two couples of different development scenarios (reference year 1993) and takes into account the following pollutants: CO_2, NO_x, CO, VOC, SO_2, TSP.

2. METHODOLOGY

2.1 Approaches Used for Externality Analysis

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

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

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

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

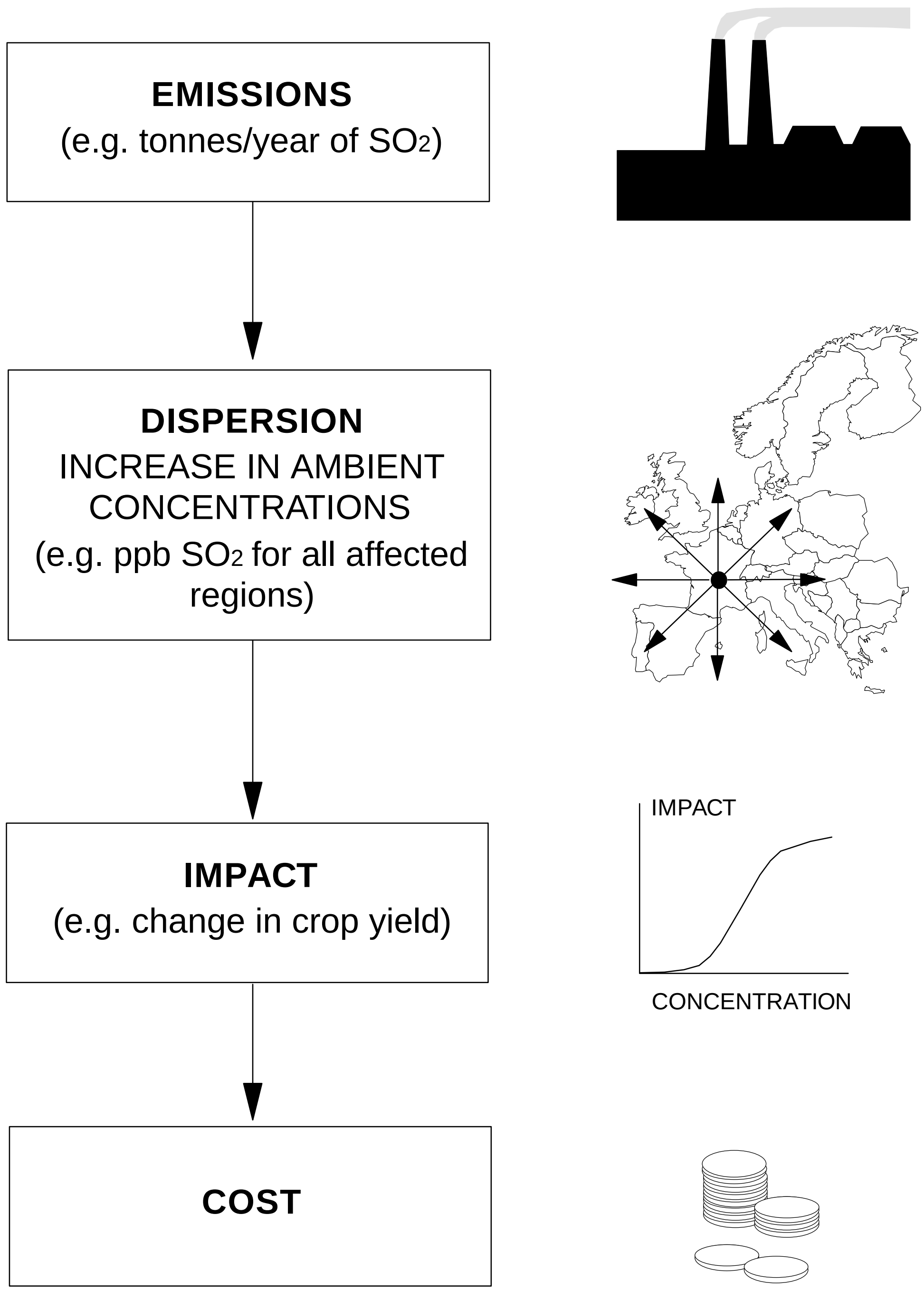

Figure 2.1 An illustration of the main steps of the impact pathways methodology applied to the consequences of pollutant emissions. Each step is analysed with detailed process models.

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

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

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

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

2.2 Guiding Principles in the Development of the ExternE Methodology

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

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

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

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

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

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

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

2.3 Defining the Boundaries of the Analysis

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

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

2.3.1 Stages of the fuel chain

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

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

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

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

2.3.2 Location of fuel chain activities

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

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

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

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

2.3.3 Identification of fuel chain technologies

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

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

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

2.3.4 Identification of fuel chain burdens

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

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

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

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

2.3.5 Identification of impacts

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

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

2.3.6 Valuation criteria

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

2.3.7 Spatial limits of the impact analysis

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

This has major implications for the analysis of the effects of air pollution in particular. It necessitates extension of the analysis to a distance of hundreds of kilometres for many air pollutants operating at the ‘regional’ scale, such as ozone, secondary particles, and SO_2. For greenhouse gases the appropriate range for the analysis is obviously global. Consideration of these ranges is in marked contrast to the standard procedure employed in environmental impact assessment which considers pollutant transport over a distance of only a few kilometres and is further restricted to primary pollutants. The importance of this issue in externalities analysis is that in many cases in the ExternE Project it has been found that regional effects of air pollutants like SO_2, NO_x and associated secondary pollutants are far greater than effects on the local scale (for examples see European Commission, 1995c). In some locations, 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 time scales that are meaningful in the context of the history of the planet. For further information, the discounting of global warming damages is discussed 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.

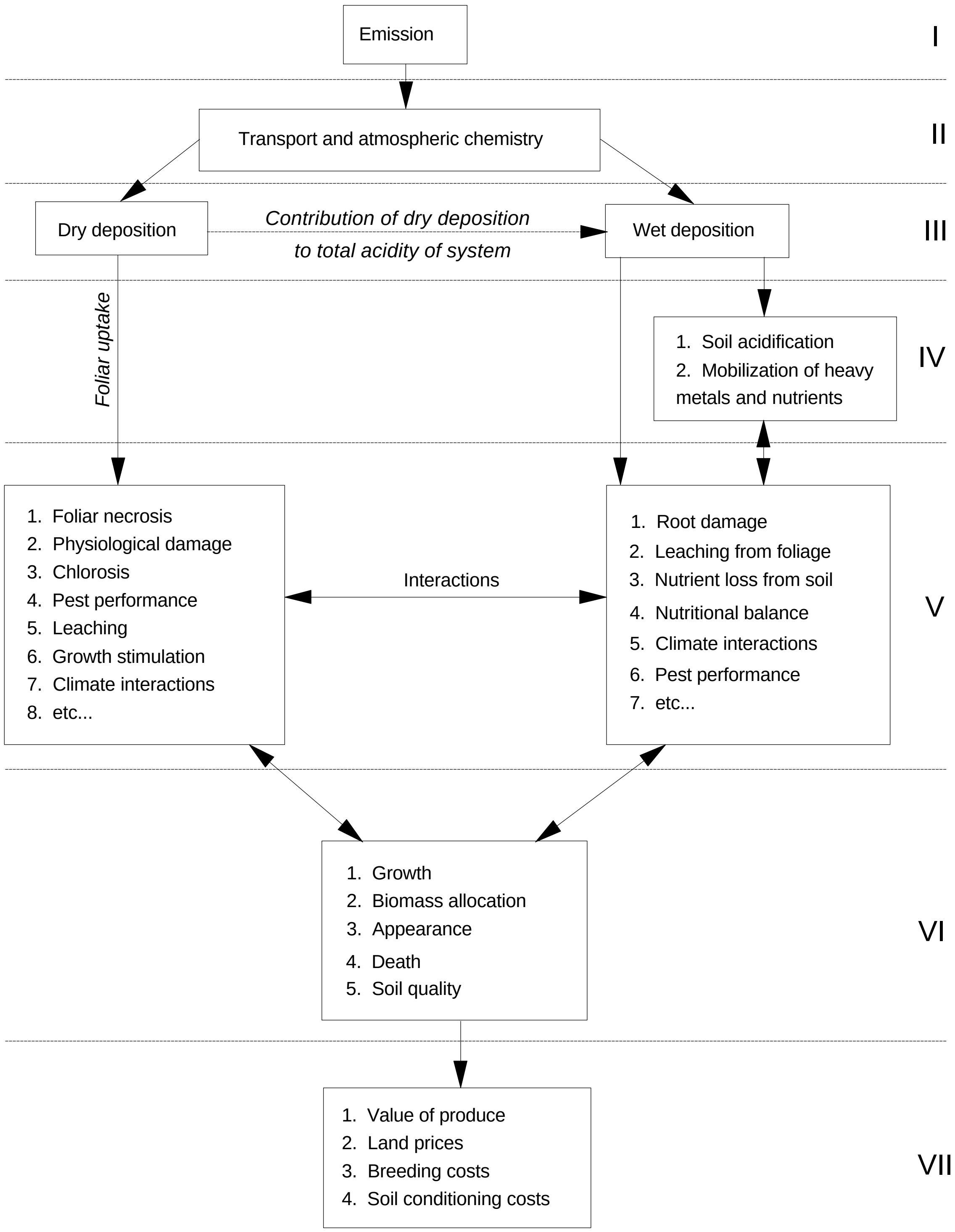

Figure 2.2 The impact pathway showing the series of linkages between emission of acidifying pollutants and ozone precursors and valuation of impacts on agricultural systems.

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

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

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

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

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

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

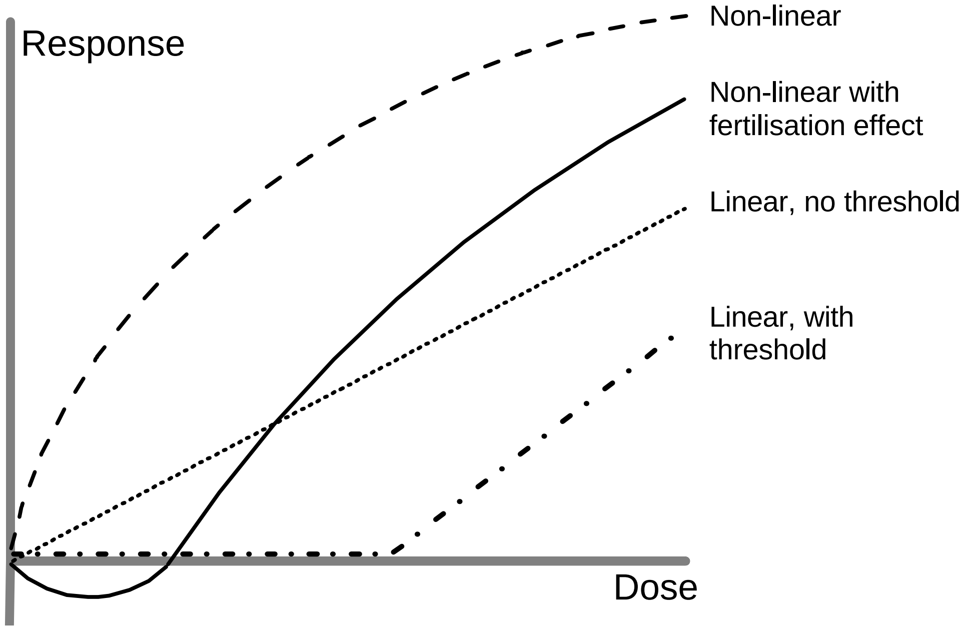

Figure 2.3 A variety of possible forms for dose-response functions.

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

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

2.4.6 Economic valuation

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

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

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

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

2.4.7 Assessment of uncertainty

Uncertainty in externality estimates arises in several ways, including:

- The variability inherent in any set of data;
- Extrapolation of data from the laboratory to the field;
- Extrapolation of exposure-response data from one geographical location to another;
- Assumptions regarding threshold conditions;
- Lack of detailed information with respect to human behaviour and tastes;
- Political and ethical issues, such as the selection of discount rate;
- The need to assume some scenario of the future for any long term impacts;

- The fact that some types of damage cannot be quantified at all.

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

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

2.5 Priority Impacts Assessed in the ExternE Project

2.5.1 Fossil technologies

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

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

8. Impacts of global warming;

9. Impacts of noise.

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

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

11. Impacts of coal mining on building and construction;

12. Resettlement necessary through lignite extraction;

13. Effects of accidental oil spills on marine life;

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

2.5.2 Nuclear technologies

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

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

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

2.5.3 Renewable technologies

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

1. Accidents affecting the public and/or workers;

2. Effects on visual amenity;

3. Effects of noise emissions on amenity;

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

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

1. Occupational health effects;

2. Employment benefits and local economic effects;

3. Impacts of transmission lines on bird populations;

4. Damages to private goods (forestry, agriculture, water supply, ferry traffic);

5. Damages to environmental goods and cultural objects.

2.5.4 Related issues

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

2.6 Summary

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

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

- Location of each stage;

- Technologies selected for each stage;

- Identified burdens;

- Identified impacts;

- Valuation criteria;

- Spatial and temporal limits of impacts.

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

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

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

3. OIL FUEL CYCLE

3.1 Definition of fuel cycle, technologies and sites

The sites chosen for the implementation of the Italian case-study on oil are listed in Table 3.1

Table 3.1 Locations of the oil fuel cycle

Stage	Site	Data source
Crude oil production	Northern sea	European Commission, 1995d
Crude oil transportation by tankers	Northern sea	European Commission, 1995d
Crude oil refining	Germany	European Commission, 1995d
Fuel oil transportation by tankers	From northern Europe to coastal storage facility in Trieste	SNAM
Transmission of oil to the power station	Oil pipeline SILONE	SNAM
Power generation	Steam turbine plant in Monfalcone (Friuli-Venezia Giulia region)	ENEL

We made the hypothesis that oil is produced in northern Europe from oil fields in the North Sea. The crude oil is then transported via tankers to a coastal reference refinery located in Germany. After refining the fuel oil is loaded on tankers for long range transport to the coastal storage facility in Trieste (northern Italy) from where it is transported via pipeline to the ENEL power plant, located in Monfalcone (northern Italy).

Figure 3-1 shows the locations of the coastal storage facility where fuel oil is discharged and the location of the oil power plant in Monfalcone; Figure 3-2 shows the stages considered in the study.

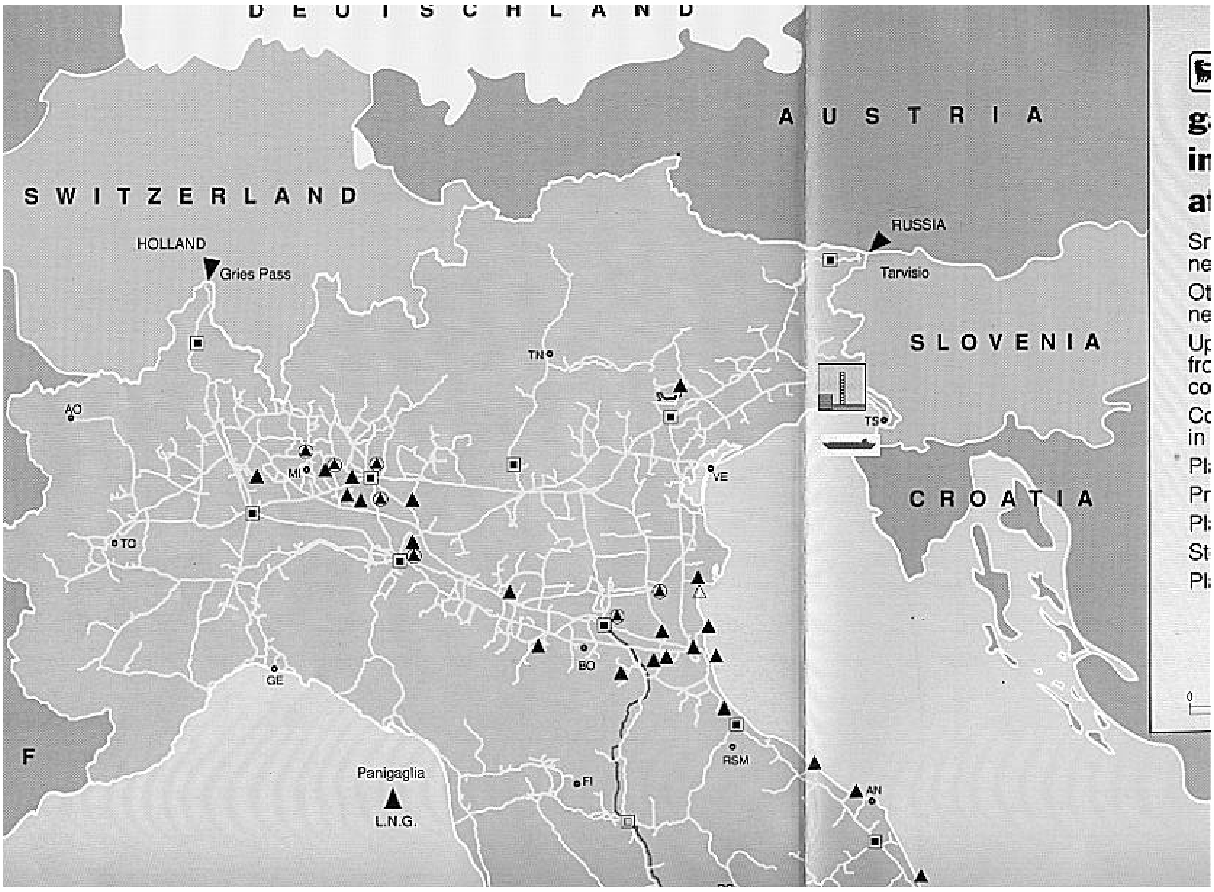

Figure 3-1 The locations for the oil fuel cycle

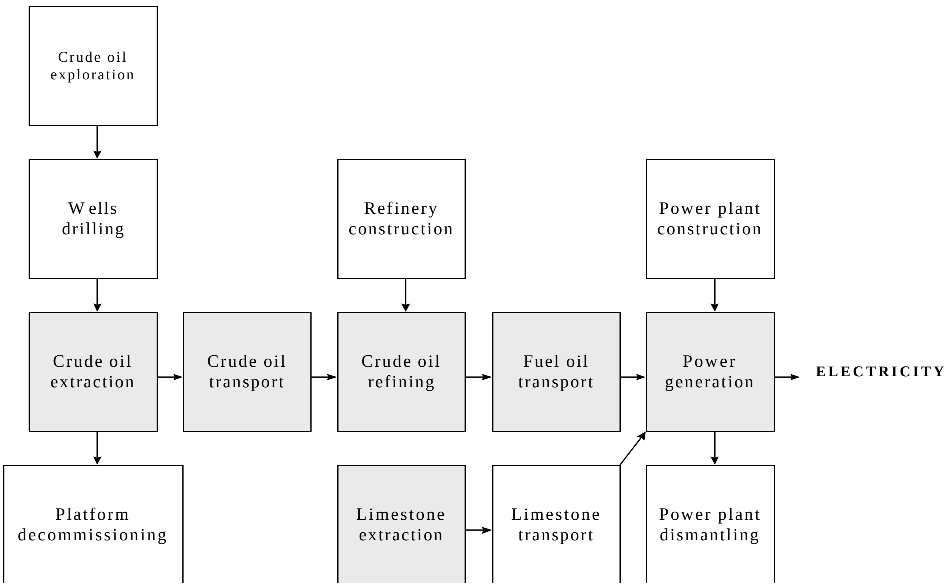

Figure 3-2 Oil fuel cycle stages (in dark the stages analysed)

3.1.1 Drilling and crude oil production

For the oil production stage we refer to a representative example concerning drilling activities of the platform OSEMBERG C described in the german report on oil (European Commission 1995d). The offshore field is located about 120 km from Bergen (Norway). Altogether 6 wells have been drilled on the platform. Two of them are producing oil, one is a gas injection well, two are water injection wells and one was drilled as a pilot well for a horizontal oil production well. While ether based drilling fluids were employed in one well, oil based drilling fluids were used in the lower section of the three wells. Produced water was treated in hydrocyclones and drain water containing oil was centrifugated. Measures have also been taken to reduce the amount of gas that is burnt off.

Crude oil is transported to the refinery by tanker along a 945 miles route.

3.1.2 Crude oil refining

The description of the reference refinery is taken from European Commission (1995d). The description is based on data of a hypothetical “German standard refinery” provided for the IKARUS project of the German Ministry for Research and Technology. This standard refinery represents average characteristics of all german refineries in the reference year 1989. The total annual output of the reference refinery is equivalent to $3.37*10^{15}$ kJ. The chosen standard refinery requires a feedstock input of $84.45*10^{6}$ t/y to produce $79.89*10^{6}$ t/y of various final products. To calculate the amount of crude oil necessary for the production of one ton of fuel oil, the input and output streams are converted to their respective energy content, leading to a refinery efficiency of 96% based on the calorific value of all the product streams. According to this efficiency, the crude oil required for the production of the fuel oil needed for the Monfalcone power plant is 671,202 t/y.

3.1.3 Fuel oil transportation to power plant

After refining, fuel oil transportation to power plant takes place via two phases: transportation by tankers from refinery to storage facility in Italy and transportation via pipeline from storage tanks to power plant. These two stages are briefly described in the following paragraphs.

Tankers

As already mentioned above, almost all of the fuel oil used in the considered power plant is imported from different countries of northern Europe, namely Sweden, Norway, The Netherlands, United Kingdom; only 5% comes from other sources. Fuel oil is transported by 40,000-60,000 tons oil tankers. The tankers dock at the SIOT terminal which is provided of two jetties oriented E-NE and have the total availability of 4 mooring points, with a draught of 16.5 meters. The tankers are docked with the poop east-oriented, so that they can easily leave the jetty in case of emergency. The Guidelines of the SIOT storage facility for accessing the terminal, say that in the port of Trieste the prevalent wind (BORA) can reach easily the speed of 80 knots (with wind gusts of 100 knots). In particular, storms from the west quadrant can suddenly occur. These storms are very difficult to forecast and they are usually not communicated by the weather forecast services. On the base of SIOT experience these storms are those that are more likely to cause the detachment of the discharge arms of the tankers. Because of this, the SIOT terminal is provided with a radar on its own for local short-term weather forecast. The Guidelines report that in case of wind speed stronger than 37 knots lasting more than 20 seconds, discharge operations are stopped.

Discharge from tankers and storage of oil in the storage facility

The fuel oil is stored in the SILONE storage facility, made up of 4 storage tanks of the capacity of 100,000 m^3, 2 tanks of the capacity of 35,000 m^3, 1 tank of the capacity of 5,000 m^3. The overall capacity is 475,000 m^3.

Pipeline

From the coastal storage facility located in Trieste (SILONE storage facility), fuel oil is transported via pipeline to the Monfalcone power plant. The SILONE pipeline, made up of 2 10 inches pipelines, is 62 km long and has a total capacity of 2.5 millions t/year. An 8 inches derivation of SILONE pipelines carries fuel oil for the use of the Monfalcone power plant.

In 1994 the SILONE pipeline transported something like 1.5 millions t of products. The maximum capacity of the stretch of pipeline that goes to the power plant is 700 ton/hour.

3.1.4 Power generation

The analysis considers the ENEL power plant located in Monfalcone (GO), northern Italy. It is a base-load steam-turbine power plant made up of 2 modules of 320 MW each operated with dense oil; the two modules are operating since 1985. Beyond these two modules, the ENEL power plant located in Monfalcone has two modules of 170 MW each, operated with coal; they date back to the 60’s and will not be considered in this case study.

As for the 2 oil-fired modules, since 1985 some interventions occurred in order to comply with the emissions standards of DM of July 1990 (concerning pollutant concentrations in flue gas from point sources of already existing plants). These interventions included various and different management actions such as change in the average quality of the fuel, changes in the process conditions and improvement of the pollution control processes. Since 1985 an increase of oil consumption occurred, together with a significant modification of the characteristics of the mix of oil used, with a higher percentage of low-sulphur-content-oil (BTZ) and a decrease of the sulphur content in the high-sulphur-content-oil (ATZ).

Technical characteristics of the power plant are summarized in Table 3.2.

Table 3.2 Technical characteristics of the reference power plant

Gross electricity capacity	640	MW
Electricity sent out	607	MW
Thermal efficiency	40	%
Full load hours per year	5000	h/y
Annual generation	3035	GWh/y
Start of commercial operation	1985	
Fuel specification		
Calorific value	40.6	GJ/t
Sulfur content	0.25	%
Fuel consumption	134	t/h
Flue gas specification		
Flue gas volume	1.7E+06	Nm^3/h
Flue gas temperature	80	°C
SO_2 concentration *	400	mg/Nm^3
NO_x concentration *	200	mg/Nm^3
TSP concentration *	50	mg/Nm^3
Emission rates		
SO_2	1.12	g/kWh
NO_x	0.56	g/kWh
TSP	0.14	g/kWh
Stack specification		
Number of stacks	2	
Stack height	150	m
Stack diameter	4.7	m

* Concentrations refer to dry flue gas with an O_2 content of 3% in volume

3.1.5 Site description

Monfalcone is located in the north-east of Italy, in the province of Gorizia, that is part of the Friuli-Venezia-Giulia region. This geographic area is characterized by the Carsic relieves in the north-eastern part of the territory and by a stretch of coast in the southern part, called Panzano Bay, in the Adriatic Sea. It is the extreme eastern part of the Friuli flooding plane, where the rivers Isonzo and Timavo run through before flowing into the Adriatic sea.

Monfalcone is the most populated town of this area: in its urban territory there is the harbour and the plane of Lisert, reclaimed many times in the past, and now main site of industrial activities, even if it conserves some places of touristic and environmental interest such as the Roman thermal baths.

At the East, Monfalcone borders on Duino, a town in the province of Trieste and the second relevant town of the Gulf of Panzano.

Population

The local area extends about 140 km^2 and includes the communes Monfalcone, Ronchi dei Legionari, Staranzano, Doberdò del Lago, Fogliano Redipuglia, San Pier d'Isonzo, Turriaco and S.Canzian d'Isonzo.

Monfalcone counts about 27,000 habitants (almost 20% of the province of Gorizia) and, together with the neighbouring communes that form the so-called "Monfalconese area", arrived to 66,178 in 1991 (about 48 % of the population of the province of Gorizia). The population density in the area is 29 c./km^2 and is particularly high in Monfalcone (1,475 c./km^2), the industrial centre of the whole zone.

Fishing

Fishing is carried out in the most part in the area of Grado (about 95% of the all activity); in the Bay of Panzano is concentrated the remaining 5%. In the last few years the quantity of fish sold and the consequent proceeds have been sensibly decreased because the local authority (Capitaneria di Porto of Grado) forbid fishing in some periods, and because of the lack of fish. The low qualitative standard level of fish and molluscs made the average price for unit lower of 2.4% and 10.7% respectively. The total and average proceeds from shellfish is quite positive even if the quantity decreases.

In the Villaggio del Pescatore, part of the territory of Duino, there is a quite relevant activity of mollusc breeding.

However, fishing does not play an important role in the economy of this area.

Flora and ecosystems

The area is characterized by the presence of two distinct natural systems: the Carso (Karst) system covering the east and the north part; the plain covering the west part.

The Carso is the typical environment of the north-east part of Italy, characterized by the presence of small forests and waste land: it is an irregular limestone region with sinks, underground streams and caverns.

Completely different is the western part of the area which is highly populated and cultivated. The area is characterized by the presence of different interconnected ecosystems: estuarines ecosystems (Isonzo and Timavo estuaries); fresh water ecosystem (Isonzo river); saltish water ecosystem; salt grassland ecosystem; forest ecosystem; grassland ecosystem; ecosystem of ruderale vegetation.

Protected natural areas

In F.V.G. the protected natural areas amount to 45,172 ha that corresponds to 5.8% of the total regional area and to 3.8 ha every inhabitant. The protected wood area is about 23.3% total protected area. In 1991 there were 8 fauna refuge and protection oasis, equal to 4,615 ha, only 1 game capture and repopulating zone and no faunistic-hunting firms.

Meteorological conditions

Meteorological data discussed below refer to a monitoring station belonging to ENEL located inside the Monfalcone power plant covering the period 1988-1995. These data were integrated with historical data coming from a meteorological and meteomarine monitoring station belonging to Istituto Talassografico of Trieste (CNR - National Research Council) located in Trieste and covering a period going from 1965 to 1994.

The analysis of meteorological data shows the classical situation of temperate climate, milded by the presence of the sea, with not very cold winters and fresh summers. Anemometric framework is the following: the area is influenced by the presence of the sea, with winds of moderate intensity coming from SE and very strong winds coming from E-NE (bora) typical of the Italian north-east border.

The meteorological situation can be summarized as follows:

- during cold seasons the dominant regime is strong winds with a constant direction coming from E-NE (BORA), with wind speeds sometimes stronger than 12.5 knots. When these winds are not blowing, a situation of wind calm occurs with a frequency of 45-50%.

- during hot seasons the dominant regime is moderate winds coming from E-SE (breeze regime), with a calm frequency of 35-40%.

- the dominant turbulence is in stable classes (E and F), typical of air layers above water surfaces, and of neutral conditions (class D), typical of cloudy conditions and of moderate winds.
- the site is influenced by the presence of the sea: the average winter temperature is 6 °C, while the summer average temperature is 23 °C. Very seldom temperatures drop below -5 °C or rise above 35 °C.

3.2 Overview of burdens

Burdens are reported in the following paragraphs grouped by type of burden: atmospheric emissions and water emissions are considered. The burdens are summarised, by fuel stage, in Appendix IX.

3.2.1 Atmospheric emissions

Atmospheric emissions occur during all the stages we accounted for, even if with different intensities. The following paragraphs report the main atmospheric emissions organized by activity. The pollutants taken into account are: SO_x, NO_x, CO, CO_2, TSP, VOC, CH_4, N_2O.

Data available on emissions to air are a combination of measurements, calculations based on simple models of combustion and other processes. Most of the important emissions result from combustion, that is the utilization of fuel oil in the power generation plant in Monfalcone. The emissions are summarized in Table 3.8.

Drilling and crude oil production

As we already mentioned, fuel oil used by the power plant in Monfalcone comes from Northern Europe countries. For this reason we took into account the emission factors reported in European Commission (1995d). In oil extraction in the North Sea 0.17 % of the calorific value of the output is used for electricity production. Further 0.23 % is used for thermal energy production. Making the hypothesis that electricity is produced from a gas turbine plant and thermal energy is produced from gas firing, the emissions from this process have been calculated based on the emission factors given in European Commission (1995d).

In oil extraction, methane is leaked by venting of associated gas, equipment leakages, well testing, well blows-out, venting of instrument and controls. Part of the petroleum gas is flared, some is lost by diffusion. The specific emissions of VOC, methane and CO_2 have been calculated using the emission factors reported in Table 3.3 (European Commission, 1995d).

Table 3.3 Direct emission factors from drilling and crude oil production

Pollutant	Emission factor (kg/TJ oil output)
CO_2	260
VOC	1.4
CH_4	2.2

Emissions are summarized in Table 3.8.

Crude oil transportation

In order to quantify airborne emissions from crude oil transportation by tanker we refer to data reported in European Commission (1995d). The emission factors of Table 3.4 have been used. The fuel demand is estimated as 0.1 kJ/t*km. Taking into account a transport distance of 1,700 km (return journey) and the crude oil requirement of the power plant, emissions per unit of electricity generation have been calculated and reported in Table 3.8.

Table 3.4 Emission factors of a tanker's diesel engine (kg/TJ_{input}).

	SO_2	NO_x	TSP	CO_2
Emission factor	1,030	990	60	79,000

Crude oil refining

In order to quantify the atmospheric emissions during this stage we refer to the hypothetical "Germany standard refinery" described in European Commission (1995d). In particular the emission factors presented in Table 3.5 have been used. The specific electricity requirement of the refining process is estimated to be 65.1 kWh per ton of feedstock input. The calculation of airborne emissions due to electricity supply is based on the emission factors of the German reference coal fired power plant (SO_2: 800 g/MWh, NO_x: 800 g/MWh, TSP: 200 g/MWh, CO_2: 900 kg/MWh). The emissions, normalized to a unit electricity output of the oil fired power plant, are reported in Table 3.8.

Table 3.5 Emission factors from the refining process

Pollutant	Thermal energy	Electricity
	kg/t feedstock	
SO_2	0.7	0.052
NO_x	0.25	0.052
TSP	0.027	0.013
NM-Hydrocarbons	0.21	-
Methane	0.01	-
CO	0.027	-
CO_2	103	58.59

Fuel oil transportation to power plant

Tankers

For this stage, the environmental indices of SNAM maritime sector reported in Table 3.6 have been used. SNAM fleet carried in 1994 17,473*10^3 t of products (80.7 % of crude oil, 17.6 % of oil products, 0.87% LPG, 0.83% LNG), used 5,070 TJ of fuel oil, 287 TJ of diesel oil, 56 TJ of natural gas, with 261,973 miles laden.

We accounted for a transport distance of about 10,800 km return trip (6,000 miles). Emissions per unit of electricity produced is reported in Table 3.8.

Pipeline

Even if the pipeline is not managed by SNAM, we took indices from *SNAM Environmental Report 1994* in order to make estimates of emissions. We made use of the coefficients reported in Table 3.7.

Table 3.6 Environmental indices in the maritime sector for the year 1994 (SNAM Environmental Report, 1994)

CO_2 emissions / t * mile laden	26.53	$t/10^6 t$*mile
NO_x emissions / t * mile laden	0.24	$t/10^6 t$*mile
SO_x emissions / t * mile laden	0.63	$t/10^6 t$*mile
TSP emissions / t * mile laden	0.019	$t/10^6 t$*mile
natural gas emissions / t * mile laden	0.03	$m^3/10^6 t$*mile
VOC emissions / t * mile laden	1.05	$t/10^6 t$*mile

Table 3.7 Environmental indices in the oil pipeline sector (Reference year = 1994)

CO_2 emissions / product transported * distance	0.4517	$t/10^6 t$*km
NO_x emissions / product transported * distance	0.571	$kg/10^6 t$*km
SO_x emissions / product transported * distance	0.104	$kg/10^6 t$*km
CO emissions / product transported * distance	1.426	$t/10^6 t$*km
TSP emissions / product transported * distance	7.1E-05	$t/10^6 t$*km
VOC emissions / product transported * distance	0.039	$kg/10^6 t$*km

Power generation

At the Monfalcone power plant there has been, during the last few years, a significant reduction of SO_2 emissions: this reduction was mainly due to the improved quality of the fuel oil, even if an increase of total consumption has occurred.

As for NO_x, the value of the emissions of this pollutant is not directly determined on the basis of the input conditions, mainly because it is strictly correlated with operating conditions. The evolution of the emissions was the result of the different actions undertaken: in particular the installation of TEA burners (ENEL-ANSALDO) into one of the two groups in 1990 sensibly reduced the amount of NO_x emitted. TEA burner is a product widely used in the industrial sector and is able to reduce NO_x in the order of 50% with respect to conventional burners. In 1995 this group was completed with the implementation of a reburning system with a reduction of NO_x values.

The emissions of TSP did not vary significantly.

As for micropollutants, they are mainly adsorbed on emitted suspended particulate. Chemical analysis of the particulate matter, showed that micropollutants (heavy metals and PAH) are detectable but their concentrations are very low. They are of the order of some hundreds of $\mu g/Nm^3$ for Vanadium and Nickel, some tens of $\mu g/Nm^3$ for Lead, Zinc and total chrome, lower than 1 $\mu g/Nm^3$ for other elements. As for PAH, compounds with 4 or more condensed rings, among which we find the most dangerous for human health, have concentrations in the emissions lower than 1 ng/Nm^3. Much higher concentrations can be found in flue gases of small combustion sources, especially solid fueled plants, and in exhausted gases coming from vehicles.

Summary of atmospheric emissions

Atmospheric emissions from the different stages of the oil cycle are summarized in Table 3.8. As one can see emissions, in terms of g/kWh, are concentrated at the power generation stage.

Table 3.8 Emissions by stage and total emissions (g/kWh)

Pollutant	**Stage**					**Total**
	Drilling and production	Crude oil transport	Refining	Fuel oil transport	Power generation	
SO_2	0.0045	0.04	0.17	0.83	1.12	2.16
NO_x	0.0034	0.04	0.067	0.32	0.56	0.99
CO	n.q.	n.q.	0.006	ng	0.084	0.090
CO_2	5.93	3.0	35.7	35.1	693.2	772.9
TSP	ng	ng	0.0088	0.025	0.14	0.17
VOC	0.013	n.q.	0.046	1.39	0.028	1.48
CH_4	0.021	ng	0.0022	ng	0.018	0.041
N_2O	n.q.	n.q.	n.q.	n.q.	0.002	0.002

ng = negligible; n.q. = not quantified

3.2.2 Emissions to water

Drilling and crude oil production

Emissions to water occur mainly during the upstream activities and in particular when oil is produced from offshore platform. As reported in European Commission (1995d), with reference to the Norwegian drilling platform, in 1992 altogether 16,300 m^3 of water based drilling fluids and 27 m^3 of ether based drilling fluids were discharged into the sea. 879 t cuttings and 1,327 m^3 fluids associated with oil based drilling fluids were brought to shore for further treatment. 126,481 m^3 of produced water, containing 3.78 t of oil (29 mg/l) were discharged to the sea. Discharged drain water amounted to 3,956 m^3 containing 0.177 t of oil (44 mg/l). The limit for oil content in discharged water was 40 mg/l. By accident 1.46 t of oil were discharged. The consumption of chemicals (drilling, production, injection and pipeline chemicals) was 10,372 t, of which 3,605 were discharged to the sea.

Crude oil transportation by tankers

During the transport of oil different discharges to the sea, both voluntary and accidental, occur. Among the voluntary discharges the most important is ballast water, that is water that is charged into tankers for static reasons. When it is no longer necessary, ballast water is discharged to the sea together with an amount of water which, in principle, should be small. In fact the pumping of ballast water into the sea should be stopped when the interface water-oil is reached. This is not always the case and sometimes large amounts of oil reach the sea. The amount of oil in ballast water must not exceed 1/15,000 (OILPOL 1954/69) of the total cargo carrying capacity. The USA National Research Council (NRC, 1985) assumed that only 50% of all crude oil tankers on long-haul-voyages meet the OILPOL 1954/69 criteria of 1/15,000. Taking an yearly transport of $1.32*10^9$ t of oil into consideration, the total oil discharged from this source would reach 37,000 t per year. According to IMCO (1981) it might be assumed that about 5% of the long-haul-voyage crude oil tankers deplete the whole content of the ballast tanks into the sea, meaning 1/250 of their total capacity, 30% discharge about 1/7,500 of their total capacity, and 15% discharge an amount of oil equal to 1/1,000 of their total capacity (European Commission, 1995d). The total quantity of oil reaching the sea by ballast water discharge in long-haul-voyage is estimated at 470,000 t per year (NRC, 1985).

Other discharges of hydrocarbons to sea come from production oils, maintenance operations, marine terminals and bunker operations, bilge oil, fuel oil sludge. We refer to European Commission (1995d) for details on the amounts discharged. According to NRC (1985) the amounts discharged are summarized in Table 3.9.

Table 3.9 Annual average discharges of hydrocarbons to the sea.

Source of discharges	**Estimated average annual discharge (t/year)**
Production oils	20,000
Maintenance	34,000
Marine terminals/ bunker operations	20,000
Bilge	7.000
Fuel oil sludge	13,000

It is clear that it is very difficult to quantify the amount of hydrocarbons discharged to the sea during tankers operation. The amount does in fact depend on human behaviour and is not specific for a certain technology. Even if some standards exist (for example for ballast water), it is estimated that the actual average amount of oil spilled is at least a factor of 10 above the standard. Thus to derive a rough estimate of the oil discharged per unit electricity generation we assume that the amount equivalent to 1/1,500 of the crude oil requirement per kWh is discharged to the sea with ballast water (European Commission, 1995d). This results in 0.14 g/kWh for the considered oil fired power plant.

As for accidental spills the Oil Spills Intelligence Report (OSIR) weekly publishes the summaries of accidental spills with more than 10,000 gallons of oil.

Power production

The Monfalcone power plant is located along the Valentinis canal, an artificial canal that takes part of the water of one of the major rivers of the area, Isonzo river. Plant cooling water is taken from the Valentinis canal: the amount of cooling water is, on an annual basis, 70,000 m^3/h. The water is discharged into another canal, the Lisert canal, with a temperature increase of about 8°C. The cooling water is also treated with a biocide, sodium hypoclorite, for biofouling control. The concentration of residual chlorine is about 0.2 mg/l (within the law limit). The chlorination is applied only during spring and summer.

3.3 Selection of priority impacts

As a list of over 200 impacts was compiled for the coal fuel cycle (European Commission, 1995c), the detailed analysis of impact pathways has to be restricted to a set of priority impacts identified by the experts of the CEC team. The impacts treated in this report are listed in Table 3.10.

Table 3.10 List of priority impacts

Description	Scale	Fuel cycle stage
global warming potential of greenhouse gas emissions	Global	All
effects of atmospheric pollution on human health	Regional	power production
effects of atmospheric pollution on materials	Regional	power production
effects of atmospheric pollution on crops	Regional	power production
occupational health and public accidents	Local	All
effects on marine environment of oil spills	Local	Exploration, drilling and production

3.4 Quantification of impacts and damages

3.4.1 Air pollution

Damages caused by atmospheric pollution to different receptors (human health, crops, materials) have been calculated using Ecosense version 2.0, which implements atmospheric pollutants transportation and diffusion at the local range using the ISCST3 model, and also chemical transformations at the regional range using the WTM (Windrose Trajectory Model). After the calculation of ground pollutant concentration, the evaluation of impacts and damages is performed implementing the appropriate exposure-response functions (ERFs). A complete list of the functions used for the evaluation is reported in Appendix VI. As for the references of the ERFs, readers can refer to Appendix II.

The model considers NO_x, SO_2 and TSP as emitted pollutants, and calculates the concentrations all over Europe of these pollutants and of some secondary pollutants (Sulfates, Nitrates, Acid deposition). As for ozone related damages, a different approach has been followed, which is described later.

Damages to public health are about 98% of all damages from atmospheric pollution (materials account for about 1.4%, and crops for about 0.4%)

Impacts of air pollution on human health

Damages caused to public health by NO_x, SO2, PM_{10}, Sulfates and Nitrates have been calculated. Different receptor categories and impacts are considered in the available ERFs. As for mortality, the number of years of life lost caused by pollution levels have been evaluated. The value for one year of life lost has been calculated assuming a discount rate of 3%.

Different calculations have been carried out using different sets of ERFs, in order to perform sensitivity analysis. The ERFs used in the base analysis and for sensitivity analysis are summarized in Appendix VI; a brief description of the different sensitivity analysis is reported in Table 3.11.

Table 3.11 List of sensitivity analysis performed for different ERF choices

Sensitivity analysis 1	Value of statistical life for acute mortality is used rather than years of life lost approach
Sensitivity analysis 2	Value of statistical life for chronic mortality is used rather than years of life lost approach
Sensitivity analysis 3	Acute mortality from SO_2 is neglected
Sensitivity analysis 4	Acute mortality from NO_x is included
Sensitivity analysis 5	Particulates are treated as $PM_{2.5}$ rather than PM_{10}
Sensitivity analysis 6	Some more morbidity exposure response functions are included
Sensitivity analysis 7	Some morbidity exposure response functions are neglected

Results for the base analysis are reported in Table 3.12, divided by receptor category, impact category, primary and secondary pollutant; results for sensitivity analysis are summarized in

Table 3.13, with absolute and percent differences. All figures refer to the regional range only, and the mid values are reported. See Appendix IX for complete results.

Table 3.12 Damages to human health - Base analysis

		Damage (mECU/kWh)
By receptor category		
Asthmatics		0.081
Elderly (above 65 years old)		0.0081
Children		0.085
Adults		16.3
Entire population		0.55
TOTAL		**17.0**
By impact category		
Mortality		15.1
	(%)	(89%)
Morbidity		1.86
	(%)	(11%)

	Damage (mECU/kWh)	
By primary pollutant	mECU/kWh	mECU/g emitted
PM_{10}	1.53	10.9
(%)	(9%)	
NO_x	4.63	8.27
(%)	(27%)	
SO_2	10.8	9.68
(%)	(64%)	
By pollutant		
PM_{10}	1.53	
(%)	(9%)	
Nitrates	4.63	
(%)	(27%)	
SO_2	0.33	
(%)	(2%)	
Sulfates	10.5	
(%)	(62%)	

Table 3.13 Damages to human health - Sensitivity analysis

	Damage (mECU/kWh)	Difference	% difference
Sensitivity analysis 1	30.6	13.6	80%
Sensitivity analysis 2	51.2	34.2	201%
Sensitivity analysis 3	16.7	-0.33	-2%
Sensitivity analysis 4	17.1	0.055	0%
Sensitivity analysis 5	18.0	1.02	6%
Sensitivity analysis 6	19.8	2.84	17%
Sensitivity analysis 7	16.6	-0.45	-3%

Impacts of air pollution on crops

The yield loss for different crops, due to SO_2 concentrations, has been calculated using the ERF from Baker *et al.* (1986); the additional lime needed to avoid the raise in ground acidity has been calculated using an ERF from CEC (1993). Furthermore, the benefit derived from nitrogen deposition has been evaluated using the ERF from Hornung (1997).

A sensitivity analysis has been performed, substituting the yield loss functions with non linear (modified) functions which account for initial fertilizer effect of SO_2.

Results are reported in Table 3.14 and Table 3.15.

Table 3.14 Damages to crops

Crop	Impact	Reference	Pollutant	Damage (mECU/kWh)
Barley	yield loss [dt]	Baker *et al.*, 1986	SO_2	0.0048
Oats	yield loss [dt]	Baker *et al.*, 1986	SO_2	0.0005
Potato	yield loss [dt]	Baker *et al.*, 1986	SO_2	0.012
Rye	yield loss [dt]	Baker *et al.*, 1986	SO_2	0.0023
Sugar beet	yield loss [dt]	Baker *et al.*, 1986	SO_2	0.020
Wheat	yield loss [dt]	Baker *et al.*, 1986	SO_2	0.023
All crops	add. fertilizer needed [kg]	Hornung, 1997	N dep.	-0.0007
	add. lime needed [kg]	CEC, 1993	Acid dep.	0.010
Total damage				**0.072**

Table 3.15 Sensitivity analysis for crops damage

		Reference		Damage (mECU/kWh)
Sensitivity analysis		Baker *et al.*, 1986	(modified)	0.0082
	Difference			-0.064
	% Difference			-89%

Impacts of air pollution on materials

The maintenance surface for different materials, due to SO_2 concentrations and acid deposition, has been calculated using the ERF from Kucera *et al.* (1995); for paint, the ERF from Haynie (1986) for carbonate has been used.

Two sensitivity analysis have been performed, substituting the ERF from Kucera *et al.* (1995) with those from Lipfert (1987, 1989) and Butlin (1992, 1993) respectively.

Results are reported in Table 3.16.

Table 3.16 Damages to materials

Material	Impact	Reference	Pollutant	Damage (mECU/kWh)
Galvanized steel	maintenance	Kucera *et al*., 1995	SO_2, acid dep.	0.034
Limestone	surface	Kucera *et al*., 1995		0.0006
Mortar		Kucera *et al*., 1995, mod.		0.0002
Natural stone		Kucera *et al*., 1995		0.0005
Paint		Haynie, 1986 (carbonate)		0.20
Rendering		Kucera *et al*., 1995, mod.		0.0092
Sandstone		Kucera *et al*., 1995		0.0008
Zinc		Kucera *et al*., 1995		0.0042
TOTAL DAMAGE				**0.25**
SENSITIVITY ANALYSIS 1		Lipfert, 1987, 1989		0.36
	Difference			0.11
	% Difference			42%
SENSITIVITY ANALYSIS 2		Butlin, 1992, 1993		0.25
	Difference			0.0018
	% Difference			1%

Ozone effects

Ozone damages have been evaluated using results of calculations carried out by Rabl and Eyre (1997). They used two photochemical dispersion models (the EMEP model for the European region and the Harwell Global Ozone model at the global range) in order to find out what is the contribution to ozone formation of different precursor emissions (i.e. emissions of VOC and NO_x).

Provided that this methodology is site-independent, the evaluation has been made for all fuel cycle stages, rather than only for the electricity production stage.

Results of the simulations are summarized in Table 3.17 to Table 3.19.

Table 3.17 Damages calculated over Europe with the EMEP model

Impact	**ECU/tNO_2**	**ECU/tVOC**
mortality	259	217
morbidity	460	385
Crop losses	200	160
Total	**919**	**762**

Table 3.18 Damages calculated with the Harwell Global Ozone model outside Europe

Impact	**ECU/tNO_2**	**ECU/tVOC**
mortality	153	29
morbidity	272	51
Crop losses	150	28
Total	**575**	**108**

Table 3.19 Damages calculated for methane

Impact	**ECU/tCH_4**
mortality	39
morbidity	71
Crop losses	24
Total	**134**

Considering the emissions reported in Table 3.8, damages reported in Table 4.21 have been calculated for the fuel cycle.

Table 3.20 Ozone damages

Impact	**Damage (mECU/kWh)**					
	NO_x		VOC		CH_4	Total
	Europe	Outside	Europe	Outside		
Energy production						
mortality	0.15	0.09	0.006	0.001	0.001	0.25
morbidity	0.26	0.15	0.011	0.001	0.001	0.42
crop losses	0.11	0.08	0.005	0.001	0.000	0.20
Other stages						
mortality	0.11	0.07	0.36	0.05	0.001	0.59
morbidity	0.20	0.12	0.64	0.09	0.002	1.05
crop losses	0.09	0.07	0.27	0.05	0.001	0.48
Total	**0.92**	**0.58**	**1.29**	**0.19**	**0.006**	**2.99**

3.4.2 Occupational health effects

As for the first fuel cycle stages (from crude oil extraction to fuel oil transportation to the power plant) the reference locations and technologies are supposed to be the same of the German oil case study (European Commission, 1995d). Therefore, the same values are used, accounting for differences in the crude oil and fuel oil demand between the two case studies. Crude oil is supposed to come from platforms in the North Sea; the refinement stage is supposed to take place on a coastal facility (so that no crude oil transportation onshore was considered), and the fuel oil transportation by tanker to the Italian power plant is added after the refinement stage (a 6,000 miles return trip is considered). Also for the extraction of limestone needed for the flue gas desulphurization during power plant operation, data from the German report have been used.

For the Italian power plant, the fuel oil requirement is $0.221*10^6$ t/TWh; the same value has been used for crude oil requirement, since the refinement conversion factor is nearly 1 on a mass basis.

Occupational health risks are classified as follows: number of deaths caused by occupational accidents and diseases, major non-fatal occupational accidents and diseases, minor non-fatal occupational accidents and diseases (European Commission, 1995d).

For the power plant construction and operation stages, data from INAIL database on Italian occupational health have been used. The database from INAIL (Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro, i.e. the Italian institute for the occupational accidents insurance) provides accidents statistics for the year 1995, divided by province, economic activity, type of accident. Aggregate data are also available for years 1993 to 1996. Therefore all calculations are referred to this time period, adjusting 1995 data for time averaging over years 1993-1996. No data about occupational diseases are available at the moment.

Accidents leading to less than three working days loss are not considered; accidents with a longer period loss are classified as follows: fatal accidents, accidents leading to permanent inability, accidents leading to temporary inability.

Crude oil extraction (offshore)

It is assumed that crude oil from the British and Norwegian oil fields in the North Sea is used in the reference power plant; therefore two values are reported for each risk category, taken from the British and the Norwegian occupational health statistics respectively.

Normal operation impacts are calculated over a five years period, while severe accidents, for which this period is too short, are treated separately.

Normal operation

Table 3.21 Occupational health impacts from crude oil extraction

Accident category	Accident rate	
	per 10^6 t	per TWh
Fatal accidents	0.037 (UK) 0.0036 (N)	0.0082 (UK) 0.0008 (N)
Major accidents/disease	0.0044 (UK) 0.69 (N)	0.0097 (UK) 0.15 (N)
Minor accidents/disease	0.39 (UK) 6.2 (N)	0.086 (UK) 1.37 (N)

Major accidents

About 0.005 deaths per 10^6 tons crude oil are caused by major accidents during crude oil extraction (European Commission, 1995d). For the Italian reference fuel cycle this means 0.0011 deaths per TWh.

Crude oil transportation (oil tanker)

Normal operation

Data provided by the German employees' compensation society are used.

Table 3.22 Occupational health impacts from crude oil transportation

Accident category	Accident rate	
	per 10^6 t	per TWh
Killed	0.16	0.035
Major accident/disease	0.94	0.21
Minor accident/disease	12.4	2.74

Major accidents

About 0.029 deaths per 10^6 tons crude oil are caused by major accidents during crude oil transportation (European Commission, 1995d). For the Italian reference fuel cycle this means 0.0064 deaths per TWh.

Crude oil refining

Table 3.23 Occupational health impacts from crude oil refining

Accident category	Accident rate	
	per 10^6 t refinery throughput	per TWh
Killed	0.010	0.0022
Major accident/disease	0.28	0.062
Minor accident/disease	10.1	2.23

Fuel oil transportation (fuel tanker)

For this stage the same figures of the crude oil transportation have been used. Moreover, since most of the accidents are related to charging and discharging stages, the distance hasn't been taken into account for the calculation.

Table 3.24 Occupational health impacts from fuel oil transportation

Accident category	Accident rate	
	per 10^6 t	per TWh
Killed	0.16	0.035
Major accident/disease	0.94	0.21
Minor accident/disease	12.4	2.74

Limestone extraction

The Italian power plant limestone requirement is 67,000 tons per year, that is about 22,100 tons per TWh. This leads to the figures reported in Table 3.25.

Table 3.25 Occupational health impacts from limestone extraction

Accident category	Accident rate	
	per 10^6 t	per TWh
Killed	0.32	0.0071
Major accident/disease	6.0	0.13
Minor accident/disease	192.5	4.25

Power plant construction and operation

For the power plant construction, it has been taken into account a mean demand of 225 workers for three years (which is 675 persons-year) for the plant construction, and about 600 workers for 30 months (which is 1,500 persons-year) for the mechanical installations.

The number of accidents (classified as fatal, major and minor) has been calculated according to INAIL 1995 statistics in building and mechanical categories, adjusted for time averaging. Based on a thirty years supposed lifetime for the power plant, which leads to a total production of about 91.1 TWh, the accident rates reported in Table 3.26 have been calculated.

Table 3.26 Occupational health impacts from power plant construction

Accident category		Accident rate		
		per person-year	total accidents	per TWh
Killed	building	0.0003	0.20	0.0022
	installation	0.0002	0.23	0.0026
Major accidents	building	0.0061	4.11	0.045
	installation	0.0034	5.13	0.056
Minor accidents	building	0.0811	54.8	0.60
	installation	0.0795	119.2	1.31

For the power plant operation, a number of employees of about 70 has been considered.

The number of accidents (classified as fatal, major and minor) has been calculated according to INAIL 1995 statistics in electricity category, adjusted for time averaging, accounting for an yearly energy production of 3.035 TWh/y. Results are reported in Table 3.27.

Table 3.27 Occupational health impacts from power plant operation

Accident category	Accident rate		
	per person-year	total accidents	per TWh
Killed	0.00007	0.005	0.0015
Major accidents	0.00087	0.061	0.020
Minor accidents	0.01668	1.17	0.38

Economic valuation

The damage costs per kWh, reported in Table 3.28, are calculated using the following monetary values:

Fatal accidents		3,100,000 ECU
Major accidents	(accidents leading to permanent inability)	95,050 ECU
Minor accidents	(accidents leading to temporary inability)	6,970 ECU

Table 3.28 Oil fuel cycle occupational health impacts

Stage description		fatal accidents and diseases	major accid. and diseases	minor accid. and diseases	total damage
Platform construction and dismantling	Cases/TWh	n.q.	n.q.	n.q.	
	mECU/kWh	n.q.	n.q.	n.q.	n.q.
Crude oil exploration	Cases/TWh	n.q.	n.q.	n.q.	
	mECU/kWh	n.q.	n.q.	n.q.	n.q.
Crude oil extraction					
normal operation	Cases/TWh	0.0008 - 0.0082	0.0097 - 0.15	0.086 - 1.37	
	mECU/kWh	0.0025 - 0.025	0.0009 - 0.015	0.0006 - 0.0096	0.0040 - 0.050
major accidents	Cases/TWh	0.0011	n.q.	n.q.	
	mECU/kWh	0.0034	n.q.	n.q.	0.0034
Crude oil transportation					
normal operation	Cases/TWh	0.035	0.21	2.74	
	mECU/kWh	0.11	0.020	0.019	0.15
major accidents	Cases/TWh	0.0064	n.q.	n.q.	
	mECU/kWh	0.020	n.q.	n.q.	0.020
Refinery construction	Cases/TWh	n.q.	n.q.	n.q.	
	mECU/kWh	n.q.	n.q.	n.q.	n.q.
Crude oil refining	Cases/TWh	0.0022	0.062	2.23	
	mECU/kWh	0.0068	0.0059	0.016	0.028
Fuel oil transportation	Cases/TWh	0.035	0.21	2.74	
	mECU/kWh	0.11	0.020	0.019	0.15
Limestone extraction	Cases/TWh	0.0071	0.13	4.25	
	mECU/kWh	0.022	0.013	0.030	0.064
Power plant construction					
building	Cases/TWh	0.0022	0.045	0.60	
	mECU/kWh	0.0068	0.0043	0.0042	0.015
installation	Cases/TWh	0.0026	0.056	1.31	
	mECU/kWh	0.0079	0.0054	0.0091	0.023

Stage description		fatal accidents and diseases	major accid. and diseases	minor accid. and diseases	total damage
Power plant operation	Cases/TWh	0.0015	0.020	0.38	
	mECU/kWh	0.0047	0.0019	0.0027	0.0093
Power plant dismantling	Cases/TWh	n.q.	n.q.	n.q.	
	mECU/kWh	n.q.	n.q.	n.q.	n.q.
TOTAL	Cases/TWh	0.095 - 0.10	0.74 - 0.88	14.3 - 15.6	
	mECU/kWh	0.29 - 0.32	0.070 - 0.084	0.10 - 0.11	**0.46 - 0.51**

3.4.3 Global Warming

Damages arising from global warming due to greenhouse gases emissions have been calculated using the aggregate figures of Table 3.29:

Table 3.29 Recommended global warming damage estimates for use in the ExternE National Implementation Study. The range given does not fully account for uncertainty.

	ECU(1995)/t
CO_2 - low - high	3.8 - 139
CO_2 - mid 3% - mid 1%	18 - 46
CH_4	520
N_2O	17,000

Considering the emissions reported in Table 3.8 the following damages have been calculated:

Table 3.30 Damages from global warming (mECU/kWh)

	Power gener.	Other stages	Total
CO_2 - low - high	2.63 - 96.4	0.30 - 11.1	2.94 - 107.4
CO_2 - mid 3% - mid 1%	12.5 - 31.9	1.44 - 3.67	13.9 - 35.6
CH_4	0.0094	0.012	0.021
N_2O	0.034	n.q.	0.034
Total - low - high	2.68 - 96.4	0.32 - 11.1	**2.99 - 107.5**
Total - mid 3% - mid 1%	12.5 - 31.9	1.45 - 3.68	**14.0 - 35.6**

3.4.4 Impacts of oil spills on marine ecosystems

In contrast to the field of air pollution, no operational transport models are available for aquatic systems. For this reason a quantitative analysis is not possible. A detailed description of effects of hydrocarbons discharges on marine environment can be found in European Commission (1995d), where physical, biological and chemical processes as well as the resulting effects on various receptors are qualitatively described. According to monitoring networks, site specific effects on soft bottom fauna within a range of several hundred meters around the installation can be observed, including a minor decrease in biodiversity and a slight increase in the number of opportunistic species.

As for the operational discharge of hydrocarbons from oil tankers, estimates suggest that world-wide several hundreds of thousands of tons are released, but a quantification of impacts is not possible. In European Commission (1995d) a first estimate of externalities is derived from world-wide statistics and damage costs from the AMOCO CADIZ and the EXXON VALDEZ accidents: these resulted in 0.031 mECU/kWh (AMOCO CADIZ) and in 0.33 mECU/kWh (EXXON VALDEZ).

3.4.5 Summary of impacts

In the following tables are summarized the damages described above:

Table 3.31 Damages of the oil fuel cycle

	mECU/kWh	**σ_g**
POWER GENERATION		
Public health		
Mortality*- YOLL *(VSL)*	15.3 *(62.9)*	B
of which TSP	*1.4 (4.9)*	
SO_2	*9.7 (43.0)*	
NO_x	*4.1 (15.0)*	
NO_x (via ozone)	*0.23*	
VOC (via ozone)	*6.9E-3*	
Morbidity	2.3	
of which TSP, SO_2, NO_x	*1.9*	*A*
NO_x (via ozone)	*0.41*	*B*
VOC (via ozone)	*0.012*	
Accidents	n.q.	A
Occupational health	9.3E-3	A
Crops	0.27	B
of which SO_2	*0.072*	
NO_x (via ozone)	*0.20*	
VOC (via ozone)	*5.3E-3*	
Ecosystems	n.q.	B
Materials	0.25	B
Noise	n.q.	
Visual impacts	n.q.	
Global warming		C
low - high	2.68 - 96.4	
mid 3% - mid 1%	12.5 - 31.9	

	mECU/kWh	σ_g
OTHER FUEL CYCLE STAGES		
Public health	1.6	B
Occupational health	0.45 - 0.50	A
Ecological effects	n.q.	B
Road damages	n.q.	A
Global warming		C
low - high	0.32 - 11.1	
mid 3% - mid 1%	1.45 - 3.68	

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

Table 3.32 Sub-total damages of the oil fuel cycle

	mECU/kWh
Non global warming: YOLL *(VSL)*	**20.2 (67.8)**
Global warming: low - high	2.99 - 107.5
Global warming: mid 3% - mid 1%	**14.0 - 35.6**

Table 3.33 Damages by pollutant

	ECU / t of pollutant
SO_2 *- YOLL *(VSL)*	9,700 *(39,400)*
NO_x *- YOLL *(VSL)*	8,300 *(27,700)*
PM_{10} *- YOLL *(VSL)*	12,300 *(35,900)*
NO_x (via ozone)	1,500
CO_2	3.8 - 139 (mid range 18 - 46)

*Yoll= mortality impacts based on 'years of life lost' approach, VSL= impacts evaluated based on 'value of statistical life' approach.

4. GAS FUEL CYCLE

Natural gas consists mainly of methane (CH_4), small quantities of heavy hydrocarbons, molecular nitrogen and carbon dioxide, in percentages which vary according to the geographical source. Natural gas requires minimum treatment since it is extracted from the subsurface at the moment in which it is transferred to the final user. It is particularly suitable for high energy efficiency processes thanks to its gaseous state and absence of combustion residues.

Because of its very low sulphur content, emissions of sulphur compounds produced by the combustion of natural gas are negligible. Furthermore, emissions of nitrogen oxides are generally lower than those produced by the combustion of coal or by other liquid fuels. Natural gas does not produce ash or dust, neither contains nor emits measurable quantities of aromatic hydrocarbons and harmful metallic compounds. The combustion of natural gas emits 25-30% less carbon dioxide (CO_2) than do oil products and 40-50% less than coal, for the same energy content.

The use of natural gas in Italy in 1994 in substitution for other fuels significantly reduced the emission into the atmosphere of polluting substances and carbon dioxide which otherwise would have been emitted.

Table 4.1 Composition of the natural gas distributed in Italy

	DOMESTIC GAS % mol.	**RUSSIAN GAS** % mol.	**DUTCH GAS** % mol.	**ALGERIAN GAS** % mol.
Methane	99.62	98.07	91.01	83.28
Ethane	0.06	0.60	3.7	7.68
Propane	0.02	0.22	0.88	2.05
Heavy hydrocarbons	0.02	0.12	0.42	1.1
Carbon dioxide	0.02	0.11	1.11	0.19
Nitrogen	0.26	0.87	2.84	5.52
Helium	-	0.01	0.04	0.18
Net calorific value (MJ/Sm^3)	33.96	34.06	34.48	36.13

4.1 Definition of fuel cycle, technologies and sites

The sites chosen for the implementation of the italian case-study on natural gas are listed in Table 4.2 and shown in Figure 4-1; Figure 4-2 shows the stages considered in this work. Natural gas is extracted from AGIP from off-shore gas fields in Northern Adriatic Sea; it is then pumped on-shore and treated at the AGIP treatment facility of Falconara. After treatment gas is transported by the Snam gas network to the combined cycle power plant run by ENEL located in Trino Vercellese.

Table 4.2 Sites for the gas cycle case study

Stage	Site	Company
Extraction and Transportation to treatment plant	Off-shore gas fields Barbara	AGIP
Treatment	Gas Reception Plant of Falconara	AGIP
Transmission of gas to the power station	Snam gas network	Snam
Power generation	CCGT in Trino Vercellese (VC - Piemonte region)	ENEL

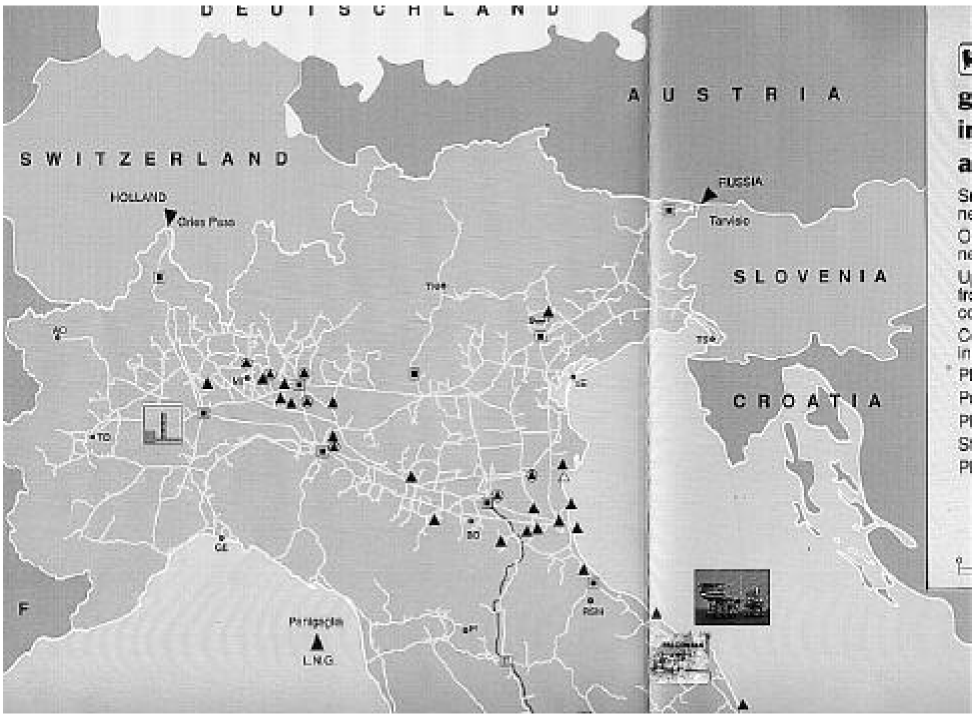

Figure 4-1 Locations of the Italian natural gas fuel cycle.

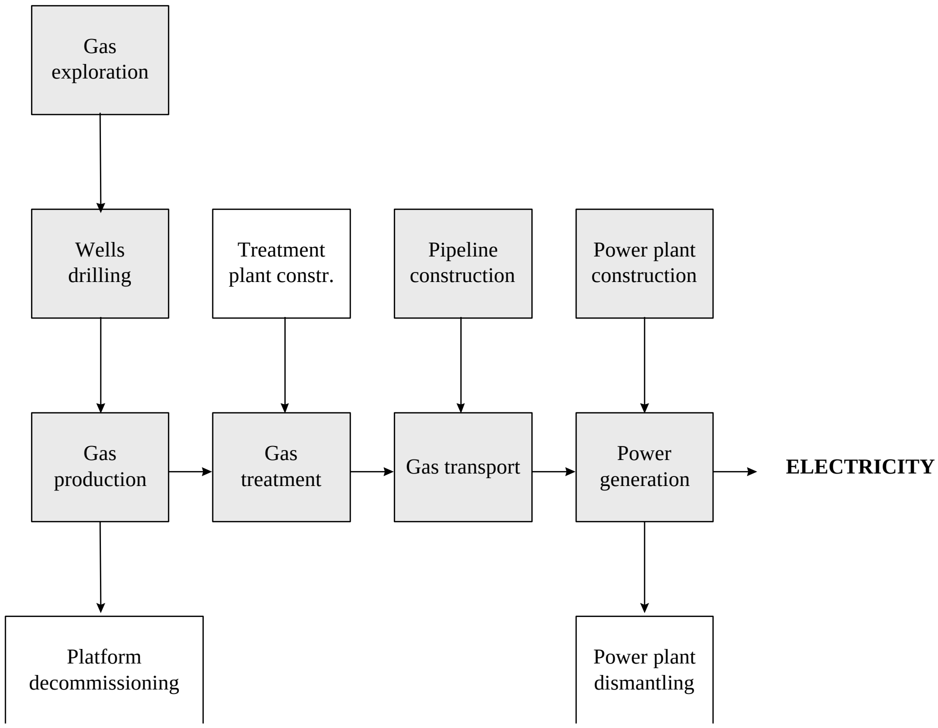

Figure 4-2 Gas fuel cycle stages (in dark the stages analysed)

4.1.1 Exploration

The exploration of hydrocarbons started in Italy in 1860 with the first drilling in the north Appennino area. The gradual development of technologies and research of the first half of the 20th century, allowed to deepen the geological knowledge of the territory and lead to the first substantial discovery in Pianura Padana (northern Italy) and in Sicily (southern Italy).

The evolution of the exploration cycle took place through different phases of activities, each witness of technical changes and of new knowledge in the geological field. New themes of research and the improvement of direct and indirect techniques of survey, allowed to obtain new knowledge and to overcome the limits of previous interpretations.

The improving of drilling techniques and the use of geophysics in the 40’s, gave a big impulse to the petroliferous activities, promoting the research in deeper pools in already productive areas and starting, with the introduction of reflection seismic, the drilling of wells in new areas.

The first important discovery was in Pianura Padana in 1944: in the period going from the 40’s to the 90’s, more than 5000 wells, both for exploration and production purposes, were drilled some of them even 7000 meters deep.

Geology and habitat of hydrocarbons

Mayor discoveries are located in Pianura Padana, along the Appennino on the Adriatic side, in the south Appennino and in Sicily.

The complexity of the morphology and of the geology of the Italian territory, gives origin to a large number of exploration themes that, if on the one hand stimulate the research, on the other favor the fractioning of discoveries.

Italy is above all a gas province: 80% of hydrocarbons found from 1946 is gas, only 20% is oil. The main reservoirs are distributed over an area named *"avanfossa"*, NW-SE oriented, parallel to the Appennino chain. This area contains the higher concentration of biogenic gas (76% of the total national production). The *"avanfossa"* is also a source of liquid hydrocarbons.

The biggest part of oily reservoirs is located in an area called *"avampaese"* that constitutes the soil of the Pianura Padana, of the central Adriatic zone, and, in Sicily, of the Iblei mountains area. In the *"avampaese"* the biogenic gas represents the 10% of the original stock.

The remaining area is called *"catena"*. This is made of a complex of tectonic units piled in different ways and slid over the more stable *"avampaese"*. The fields in the catena have variable reservoirs and lithology with prevalence of thermogenic gas (14%) and condensates.

Potentiality and perspective of future research

Up to now roughly 300 fields have been located, but they have limited dimensions. In fact the geo-tectonic characteristics of Italian territory does not favour the conservation and the storage of big stock of hydrocarbons.

The present original stock is about 720 millions Toe's, 600 of which are gas. The internal production is far from satisfying the need of a country where the annual consumption of hydrocarbons is 170 millions Toe's, while the availability was, in 1993, 18 millions Toe's (13,9 million t of oil and 17 billions m^3 of gas).

The target of AGIP (the company of ENI group in charge of gas exploration, production and treatment), is to maintain the supply on the internal market, which is now of 18,5 billions of m^3. To pursue this objective a concrete programme of investments is necessary in order to increase exploration and development activities, that have slowed down in the last few years because of problems connected with environmental impact and because of the non-grant of permissions.

As for gas, a big step forward is expected in the Adriatic sea area, especially after the big effort in the 3D seismic interpretation. The application of advanced technologies allowed the discovery of gas mineralization in thin layers. The Adriatic off-shore represents an area of high potentiality. By 1998 the project Alto Adriatico will permit an overall production of about 11 billions m^3 with the drilling of 75 wells.

Even the Pianura Padana represents an area with good potentialities because of the drilling of 2000 wells. The dimensions of the more recent discoveries and the concerning about environmental issues, induced AGIP to make new choices in terms of drilling criteria. For this purpose new projects have been started in order to develop a cheap drilling activity, less expensive and more environmental compatible.

As for other areas such as Sicily, the activity, stopped because of the Sicilian legislation, will have now a big increase.

Constraints and problems

Different limiting factors intervene in the hydrocarbons research process. There are basically two types of constraints: legislative and environmental.

The environmental issues are connected both with the natural situation of the Italian territory from the geological point of view and with the high density population factor.

The first limit is represented by the complexity of Italian territory: because of its recent formation, Italy is made up of structures of small dimensions. A big part of the territory is mountainous and the morphologic factor contribute to increase the cost of the research.

In the flat areas the constraints are connected with the high density of the population and of man-connected activities. From this rises the necessity to operate with dedicated and expensive techniques.

A big engagement is represented by the adoption of measures of environmental protection both on-shore and off-shore. The more and more important environmental concern has lead to the constitution of new parks and natural protected areas, very often not even included in the census, as established by local and peripheral authorities.

The Italian legislation on research and production of hydrocarbons provided for the intervention of different public authorities both during the proceedings for prospecting, research and cultivation permissions, and for the grant of permissions for the operative activities. These authorities are: Ministry of Industry, Ministry of the Environment, War Office, Home Office, Post Office Board, Ministry of Transport, Ministry of Agriculture. Furthermore different offices for each of these authorities are involved. This is the reason why very often more than one year elapses between the location of an exploration well and its construction. These factors have a big influence on costs and generate the risk of compromising the activity itself.

New difficulties and problems arise when new authorities are involved in the process when new laws come into force. This is the case of the DPR 18 April 1994, n° 526, regulating the Environmental Impact Assessment procedure for prospection, research and cultivation of hydrocarbons. Following this law, a special commission (EIA commission) is entitled to give its opinion on the basis of which the Ministry of the Environment will give its final opinion. In the case of exploration in regions with internal regulations, one need to satisfy new and usually more restrictive fulfillment.

4.1.2 Off-shore drilling activities in the Adriatic sea

Off-shore perforation operations in the Adriatic Sea are performed using Jack-Up Drilling Units. This is a barge with legs that can be lowered or raised. Having been towed into position the legs are lowered; upon contact with the seabed they lift the barge's body above the water till a safety position. Once the drilling unit is in position the well is started by drilling a hole in the seabed.

Normally the bit is cooled and lubricated by a specially formulated drilling fluid (mud) which also serves to provide a hydrostatic pressure field to balance the formation pressure and prevent borehole collapse. Furthermore, the drilling mud carries cuttings from the hole. this produces a sediment cake on the borehole wall which inhibits further fluid loss and stabilizes the nearhole region of rock. The drilling fluid are made by adding to water or to water/oil emulsions various components as viscosifiers (bentonite), whighting agents (barium sulfate), thinners (cromolignine and lignosulphonate).

In the Adriatic sea the perforation of one well 1,300 meters deep takes about 25 days, plus 5-6 more days for Jack-Up installation and removal operations.

4.1.3 Extraction and transportation to treatment plant (Barbara gas field)

The Barbara gas field lies 60 km off Ancona. The gas field is licensed to AGIP and is included in the grant A.C7.AS (100% AGIP), expiring November 2004. The gas field was discovered in the years 1971-73 when wells 1, 2bis, 3 and SW1 verified the presence of mineralization. The structural interpretation of the field is based on wells data and on the results of a more recent seismic interpretation (1990). The mineralized series includes 21 layers of peaty drifts of Pleistocene. The depth of the reservoirs varies between 1,000 and 1,300 meters. Static pressure at the bottom varies between 110.7 kg/cm^2 and 157.6 kg/cm^2. During drilling operations the overall volume of drilling fluids and solid waste (100-200 m^3 per well) is discharged into ad-hoc landfills, complying with L. 915/82 and followings decrees.

The assessment of the stock was made through a dynamic simulation with a 3D model for 2 levels, and with a single-cell model for the other levels. The sure original stock at the year 2010 was 59.86 billions of Sm^3, the remaining stock at 31/12/1993 is 40.70 billions of Sm^3 . The probable stock is 7.5 billions of Sm^3 .

The gas produced by the field is dry gas (99.4 % of methane) with traces on nitrogen and carbon dioxide.

Since June 1980 up to 1995, 102 wells were drilled: they are placed on 8 platforms (Barbara A, B, C, D, E, F, G, H): a terminal platform (Barbara T) is linked to the shore through a 24 inches sea-line. All the platforms have a 8 legs jacket, except platforms A and B that have a 4 legs jacket. Most part of the platforms are unmanned.

The current production of the field is about 12 millions Sm^3/day corresponding to 4.3 billions Sm^3/year. Gas coming from the 8 platforms is collected to the terminal platform Barbara T, where it is compressed and sent to the processing facility of Falconara through a 24 inches sea-line connecting the field to the treatment plant.

During the production phase all the effluents are collected in ad-hoc tanks and carried on shore; salty water, usually present in the field, is discharged to the sea after treatment to reduce hydrocarbons content down to 50 ppm, as prescribed by L. 886/79.

4.1.4 Gas treatment plant

The processing facility is located in the municipality of Falconara Marittima, locality Rocca Priora, in the province of Ancona. The gas coming from the gas field is processed in order to meet Snam standards for transmission. The treatment includes:

- physical separation of liquids such as water, diethylenic glycol (injected at the platform in order to avoid the formation of hydrates during transport) and traces of heavy hydrocarbons (gasoline);
- dehydration after light heating. Dehydration takes place through absorption using diethylenic glycol as absorbent.

Both gas and diethylenic glycol do not undergo any chemical modification during treatment.

The nominal capacity of the plant is 13,800 Sm^3/day. The gross production in 1995 was 4 billions Sm^3.

Taking year 1995 as reference, the consumption of gas for internal uses - including product treatment and production of electrical energy for other uses than treatment - summed up to 37.77 millions Sm^3.

4.1.5 Natural gas transportation via pipelines

The Italian gas transmission system transports natural gas from the extraction fields and from the import delivery points (former USSR, Holland and Algeria) to the large industrial or thermoelectric users and to the withdrawal points for the urban distribution networks. If necessary, the gas producers provide gas treatment before putting it in the pipeline network. More than 97% of natural gas consumed in Italy is supplied by Snam. The Snam gas supply and transport system consists of an extensive gas pipeline network, with steel pipes of diameters ranging from 100 to 1200 mm operating at pressures from 5 to 75 bar.

Compressor stations are located along the natural gas pipelines. The gas is moved along the network by centrifugal compressors, which are driven by gas turbines. The gas is compressed to different pressure levels according to transmission requirements.

There are pressure reduction plants at the interconnection nodes between natural gas pipeline branches operating at different pressures or at the connections to the single users and to the urban distribution networks.

The gas transmission system is controlled by the San Donato Milanese Dispatching Centre, through an extensive telecommunications system which transmits the operating data of the entire network.

To guarantee constant supply and to deal with the seasonal variations in demand, natural gas is stored in depleted gas fields.

The gas supply and transport system comprises 22 compressor stations, including 15 transmission stations, 1 for storage and 6 for both transmission and storage, about 500 pressure reduction plants distributed throughout the country, and a gasification plant for liquefied natural gas (LNG) imported by LNG carriers.

At the end of 1994 installed power in compressor stations was 806 MW. The total length of the Snam network at the end of 1994 was 25,919 km, divided into 11,218 km of main spine connections and 14,701 km for the transmission and large-scale distribution network. In 1994, 48.8×10^9 m^3 of natural gas were transported by the Snam network.

The reference gas transportation system

The Falconara gas treatment plant and the Trino Vercellese power plant are connected by the system of gas pipelines of Table 4.3, approximately 447 km long.

The reference pipeline is made of the most advanced steels with external coating (hot-pressed polyethylene) integrated with a system of cathodic protection to minimize any pipe corrosion.

Table 4.3 System of gas pipeline from Falconara to Trino Vercellese

Route	Length (km)	Diameter (mm)	Pressure (bar)
Falconara-Rimini	80.5	650	70
Rimini-Ravenna	52.0	650	70
Ravenna-Minerbio	50.0	750	70
Minerbio-Cortemaggiore	128.5	1,200	75
Cortemaggiore-Ripalta	32.5	1,200	75
Ripalta-Mortara	63.5	1,200	75
Mortara-Trino power plant	40.0		

The pipeline is buried along its entire length at different depths, deeper than 0.90 m, depending on nature and use of crossed lands.

The energy needed to transport the gas is provided by compressor stations suitably located along the route equipped with centrifugal compressors operated by gas turbines, that utilize the gas itself as fuel.

4.1.6 Power generation

The generation technology selected is a combined cycle gas turbine (CCGT) ENEL plant. The reference plant is a 680 MW output power station, based on 2 modules of 340 MW: each module is based on two 119 MW gas turbines and a single 109 MW steam turbine. Current standards for NO_x emissions would be met using low NO_x burners. The plant uses natural gas as primary fuel, but the ability to operate on a second fuel (light petroleum distillate or gasoil) has been incorporated in order to provide a back up in the event of interruption of gas supplies.

The plant is only partially operational at the moment. Only turbogas are in operation, while the vapour sections still have to be installed. The values for airborne emissions concerning NO_x were communicated to us by ENEL and are in accordance with measurements made in similar plants: we remind that the ultimate limits to emissions will be set by an ad-hoc decree that will be released by the Ministries of the Industry and of the Environment.

All the information reported in this section were taken from the Environmental Statement made by ENEL (ENEL/DCO, 1989).

The CCGT plant uses both gas and steam turbines. Gas turbines have three main components, the compressor, the combustion system and the power turbine which provide not only the motive force for the compressor but also drives the electrical generator. The compressor delivers atmospheric air to the combustion system where air temperature is raised to 1100°C. The energy extracted during the subsequent expansion of this high pressure and high temperature gas stream through the power turbine provides the driving force for both compressor and electrical generation.

The resulting exhaust gas stream from the power turbine has been reduced to approximately atmospheric pressure but still has a temperature higher than 500°C. These exhaust gases are used to raise steam in Heat Recovery Steam Generators (HRSGs), i.e. boilers (one for every module, that is one every two gas turbines). This steam is in turn expanded through a single conventional steam turbine to drive another generator to produce more electrical power. The steam is then condensed back into feedwater for re-use in the HRSG, forming a closed system.

In order to maximize heat recovery and hence improve overall cycle thermal efficiency, the HRSGs are designed to operate at more than one pressure. As well as producing high pressure steam at approximately 57 bars, a quantity of low pressure steam at 5.7 bars is produced.

As the reference plant is located in the north plain of Italy (Pianura Padana), no big sources of water are available. For this reason air cooled condensers are used. The cooling system is made up of two dry cooling towers (one for each module). They have a base diameter of 100 m and a top diameter of 65 meters. The height of the cooling towers is 100 m above ground level.

The thermal efficiency of the CCGT process is raised from around 30-32% of a gas turbine operating in "open cycle mode", to about 47%. The gas leaving the steam generator is dispersed at high level via two chimneys (one for each module) with outlets 100 meters above ground level. The chimneys are placed inside the cooling towers. The temperature of flue gas is 120 °C.

As already mentioned above, the plant utilizes two gas turbines for each module. This significantly reduces the risk of complete loss of output occurring through breakdown of the plant and also removes the upper limit of overall plant size. Each gas turbine is fitted with its own HRSG and the total output from the steam turbine plant approximately equals the individual ratings of each of the gas turbines. This kind of combination is referred to as "2+1 combined cycle block".

Process water supplies for boiler feed make up and for other service water requirements on site would be obtained from underground resources. Further treatment to improve the quality of water used for the HRSGs would be necessary before use. This would be carried out on site in a purpose built water treatment plant where industrial quality water would be filtered and ion exchange used to remove dissolved chemical species. Additional water would be needed to compensate for losses of steam and water. The maximum value of total water requirements of the plant is of about 1920 m^3/day. The requirement of drinking water is 48 m^3/day. The overall requirement of water can be estimated as 240,000 m^3/year.

The natural gas requirements of the plant is 77,000 m^3/h per module.

As said before the plant is able to work with light petroleum distillate or gasoil as back up fuel. In this case the fuel requirements is 60 t/h per module.

The plant would have a load factor of 6,000 hours/year at nominal capacity. The electrical energy produced would be about 4,000 GWh/year.

The technical characteristics of the reference plant are summarized in Table 4.4.

Table 4.4 Technical characteristics of the reference power plant

Gross electricity capacity	694	MW
Electricity sent out	680	MW
Thermal efficiency	46.7	%
Full load hours per year	6,000	h/y
Annual generation	4,080	GWh/y
Fuel specification		
Calorific value	8,300	kcal/m^3
Fuel consumption	154,000	m^3/h
Density	0.77	kg/Nm^3
Flue gas specification		
Flue gas volume	5.0E+06	Nm^3/h
Flue gas temperature	120	°C
NO_x concentration	60	mg/Nm^3
Emission rates		
NO_x	0.44	g/kWh
Stack specification		
Number of stacks	2	
Stack height	100	m
Stack diameter	7.3	m

The concentrations refer to a flue gas stream in standard conditions as for temperature and pressure and an excess of oxygen in the flue gas of 15%. As temperature is very high most part of nitrogen oxides is NO; the fraction of NO_2 is some percent of the total.

4.1.7 Site description

Trino is located in the North-West part of Italy, in the southern area of the province of Vercelli.

The territory is completely flat and agriculture, above all rice cultivation, is the main economic activity. The area is characterized by the presence of rivers and rural structures. The area where the electric generation plant is located is near Leri Cavour, a city at the North-West of Trino, about 10 km far away from Trino, in the extremely western part of Pianura Padana, between the hills of Monferrato at the south and the southern relieves of the Alps at the north. It is a flat zone with a gentle inclination (3% ca) where three main rivers flow through: the Po at the south, the Dora Baltea at the west and the Sesia at the east. All over the area there is a great number of canals that regulate the flow of the waters.

Meteorological conditions

The area under study is located on the left side of the Po river, the major Italian river, right in the middle of the so-called “piemontese basin”, which is a sub-climatic region of Pianura Padana. Pianura Padana is a uniform climatic region, characterized mainly by the barrier effect of the Alps: for this reason it is characterized by thermal phenomena more than by dynamical ones. The presence of hills does not change this uniformity, as only a small area of the hilly part rises above 500 m above sea level. These hills only affect the distribution of wind direction in the lowest layers, but do not affect the general aspects of climate. The climate of the area is defined as a “moderate subtype of continental climate”.

Even temperature is quite uniform over the Pianura Padana as it little develops in latitude.

In stable situations the phenomenon of fog is quite common. As atmospheric humidity can reach and maintain high values, fog can become stagnant even during long periods (several days).

Because of the presence of the Alps Pianura Padana is quiet from the meteorological point of view. This leads to a high number of wind calms: the wind regime is, over the whole valley, mainly controlled by orography and thermal unbalances.

Population

The considered territory in this report extends about 400 km^2 around the site of the generation power plant and includes the urban areas of Bianzé, Crescentino, Crova, Desana, Fontanetto Po, Lamporo, Lignana, Livorno Vercellese, Tricerro, Trino and Tronzano Vercellese. The urban areas are regularly distributed around the central-southern zone of the considered area.

There are no big urban centres: Trino is the most populated town and in 1991 counted 8,217 inhabitants, followed by Crescentino with 7,150, while the other urban centres of the area are under 5,000 inhabitants and some of them even under 1,000 inhabitants as Lamporo, Crova and Tricerro. The population density in the area considered is 87 c/km^2. It decreased about 4% compared to population density in 1981 (91 c/km^2) following the downward demographic trend.

Protected natural areas

In Piemonte the protected natural areas amount to 163,921 ha that corresponds to 6,5% of the total regional area and to 3.8 ha every 100 inhabitants. The protected wood area is about 26% the total protected area. In 1991 there were 129 faunistic - hunting firms, equal to 148,907 ha, 263 fauna refuge and protection oasis, equal to 112,017 ha and 40 game capture and re-population zones, equal to 22,750 ha. In the area around the ENEL electricity generation plant there are some protected natural areas. The “Bosco della Partecipanza” in Trino is the largest one (990 ha) and is a regional park.

4.2 Overview of burdens

Burdens are reported in the following paragraphs grouped by type of burden: atmospheric emissions, emissions to water and waste are considered. The burdens are summarised, by fuel stage, in Appendix X.

4.2.1 Atmospheric emissions

Atmospheric emissions occur during all the stages we accounted for even if with different intensities. The following paragraphs report the main atmospheric emissions organized by stage. The pollutants taken into account are: SO_x, NO_x, CO, CO_2, TSP, VOC, CH_4.

Data available on emissions to air are a combination of measurements, calculations based on simple models of combustion and other processes. Most of the important emissions result from combustion, that is the utilization of natural gas at the power generation plant.

Drilling stage

During the drilling stage emissions were computed considering the quantity of gas oil used for the functioning of generators and of all the engines on the jack-up unit and for oil-based mud production. The amount of gas oil needed was estimated as 6-7 t/day*well.

Production and treatment

During this stage emissions come mainly from fuel combustion (mainly natural gas) for energy production and from gas flaring and venting. Energy consumption is estimated as 6.8 TOE/10^6 TOE produced. Electric energy needed is 4.45 MWh/billion m^3 of gas.

The quantities of fuels used for energy production were estimated as: 5,519 m^3/billion m^3 of gas of natural gas and 5 kg/ billion m^3 of gas of gas oil. Natural gas is mainly flared and the amount of flared gas is estimated as 3,600 m^3/billion m^3 of gas.

Natural gas transport

To estimate the physical impacts of transmission of natural gas from the extraction field to the power station, average values referred to the whole Italian gas transport system have been utilized. Data reported in this paragraph are elaboration of data derived from *Snam Environmental Report, 1994*.

The most significant environmental impacts of gas transmission system are: the temporary use of the ground during the *construction of transport infrastructures*; impact of atmospheric emissions which are produced by the operation of the gas turbines installed in the compressor stations.

The route of the natural gas pipelines, which involves a 25-40 meter wide land corridor, is selected from various alternatives in the light of territory organization, environmental impact, transmission safety and technical-economic feasibility. Specifically, the company tries to avoid or to reduce passage to a minimum in areas with special natural or cultural interest, archaeological areas, geologically unstable areas and inhabited areas or those in which new housing is planned. During the construction phase, trenches to lay piping are dug using technologies which keep interference with the local environment to a minimum. Once the laying operation has been completed, reinstatement operations are carried out to restore the land to its original state.

Gas transmission requires the consumption of energy in combustion processes that produces atmospheric pollutant emissions. The energy consumption derives mainly from the gas turbines used in the compressor stations to drive centrifugal compressors which provide the pressure needed for transmission or for storage.

Atmospheric emissions are the most significant environmental impact. The use of natural gas (in gas turbines) helps to minimize the emissions of sulphur oxides, particulates, volatile organic compounds and carbon monoxide. The only pollutants emitted to a significant extent are therefore the nitrogen oxides.

Natural gas transmission activities also involve the emission into the atmosphere of greenhouse gases, such as carbon dioxide and methane, which is the main component of natural gas. The emissions of natural gas derive from the normal operation of plants and from maintenance operations or from accidental releases.

The production of waste is negligible and it is due mainly to the maintenance and operation of plants and pipelines.

Since the natural gas transmission activities require a limited use of water and the water discharges are mainly civil discharges which do not contain industrial pollutants, water supplies and water discharge are not considered among the most significant environmental data.

Table 4.5 summarizes the environmental indices for the transmission system in 1994. These indices can be used to evaluate average environmental impacts of Italian gas transmission system.

Table 4.5 Environmental indices (Reference year = 1994)

Transmission Energy Consumption / Energy transp. * avg. Gas path	$(\%/10^3$ km)	0.91
NO_x emission from transmission / Energy transp. * avg. Gas path	$(kg/10^6 m^3 * 10^3$ km)	113
CO_2 emission from transmission / energy transp. * avg. Gas path	$(ton/10^6 m^3 * 10^3$ km)	17.14
CO emission from transmission / Energy transp.*avg. Gas path	$(kg/10^6 m^3 * 10^3$ km)	42.28
VOC emission from transmission / Energy transp.*avg. Gas path	$(kg/10^6 m^3 * 10^3$ km)	1.85
SO_x emission from transmission / Energy transp.*avg. Gas path	$(kg/10^6 m^3 * 10^3$ km)	0.09
Natural gas emissions / Natural gas transported	(%)	0.10

The burdens for the case study are estimated considering average environmental indices of Italian gas transmission system (Table 4.5). Taking into account the total length of the reference pipeline (447 km) and the volume of natural gas required by Trino Vercellese power plant ($924*10^6$ m^3/year) with a net calorific value of 8,300 kcal/m^3, the emissions of gas transport from Falconara to Trino Vercellese are summarized in Table 4.6.

Table 4.6 Emissions from gas transport from Falconara to Trino Vercellese

NO_x EMISSIONS	46.67	t/y
CO_2 EMISSIONS	7078	t/y
SO_x EMISSIONS	37.17	kg/y
NATURAL GAS EMISSIONS	0.924	10^6 m^3/y

These values must be considered an indicative estimate because they are referred to the whole Italian gas transmission system and include environmental effects of stages that are not relevant for the considered case study.

A better estimate, that however will remain indicative for the case study, could be made by elaborating data reported in the Snam Environmental Report - 1994 and considering only the stage of pipeline transport of natural gas system.

Power generation

Natural gas is nominally sulphur and ash free and thus issues such as flue gas desulphurization and disposal of large quantities of ash which are associated with coal and oil fired power stations do not arise with combined cycle plants. The contribution to acid rain through emissions of sulphur based compounds is minimal.

As the combined cycle power plant is a more efficient energy converter than a coal or oil fired plant, the contribution to global warming per kWh of electricity is significantly lower.

This is further enhanced by the fact that natural gas is a hydrogen rich fuel in comparison to coal and oil. As a result the proportion of carbon dioxide in the products of combustion of a combined cycle are significantly lower than for a conventional coal or oil fired station. Only nuclear based electrical power generation offers lower carbon dioxide emissions per kWh.

The most significant environmental issue with combined cycle power plants has been the emission of oxides of nitrogen (NO_x) as part of the production of the combustion. The gas turbine has traditionally had a reputation for high levels of NO_x emission when compared with coal and oil fired boilers by virtue of the much higher air to fuel ratios used in gas turbines combustion.

Summary of atmospheric emissions

Atmospheric emissions from natural gas fuel cycle are summarized in Table 4.7. As one can see emissions, in terms of g/kWh, are concentrated at the power generation plant.

Table 4.7 Emissions from every stage and total emissions (g/kWh)

Pollutant	Stage				**Total**
	Drilling	Production and treatment	Transport	Power production	
SO_2	ng	ng	ng	ng	**ng**
NO_x	0.0031	0.010	0.011	0.44	**0.46**
CO	ng	0.0049	0.0043	0.22	**0.23**
CO_2	0.20	8.42	1.73	432.9	**443.3**
TSP	ng	ng	ng	ng	**ng**
VOC	n.q.	n.q.	ng	0.038	**0.038**
CH_4	ng	ng	0.15	0.029	**0.18**
N_2O	n.q.	n.q.	n.q.	0.003	**0.003**

4.2.2 Emissions to water and waste

Emissions to water arise at all stages of the gas fuel cycle. The greatest emissions are by far those connected with offshore upstream activities (drilling and production stages), even if, as explained below, AGIP has been implementing a zero discharge policy.

As for solid and liquid waste, the natural gas fuel cycle produces little of it. The largest contribution would arise during the construction phases of treatment and power plant.

Drilling stage

All the emissions to water occur during the drilling and the production/treatment activities. While drilling gas producing wells, large quantities and varied types of solid and liquid wastes are generated as by-products: the most typical are drilling cuttings and exhaust fluids.

The international current legislation states that is operator responsibility to take care of treatment and disposal of the generated wastes. As far as offshore activities are concerned, discharge at sea of cuttings and water-based fluids is allowed, provided that an informative technical sheet with eco-toxicological data is given to the authorizative body. AGIP, the Italian State oil company involved in gas and oil exploration and production (E&P) activities is currently transporting ashore any waste derived from drilling activities carried out on the Italian continental shelf in order to minimize environmental disturbance in such a sensitive area as the Mediterranean sea. The achievement of **zero-discharge from offshore installations** during the drilling phase requires:

- the collection of every liquid including rain water;
- the installation of easily transportable containers below equipments that generate solid wastes;
- the modification of supply vessels and the use of suitable lorries for an efficient solid and liquid waste transport;
- to find and equip treatment and landfill areas near offshore operative sites.

Due to the limited storage availability on board and because of the complexity and high cost of the operation, AGIP radically changed its management of solid wastes, muds and washwater on platforms. Particular attention was devoted to:

- restrict at a minimum all the dilutions and the consumption of water, reusing, whenever was possible, washwater, limiting consequently the volume of liquid effluents;
- reduce the diameter of the borehole in order to minimize the amount of cuttings;
- increase the usage of recyclable oil-based fluids and improve the fluids performance by means of very efficient solid control systems;
- investigate the feasibility and make tests of cuttings injection through the anulus into suitable geological formations under the seabed.

Drilling solid wastes and liquid effluents are subjected to different operating procedures relative to their storage on the offshore platforms and their transport ashore. Final treatment processes and disposal are carried out according to environmental regulations at present in force.

Solid wastes

- Drilling cuttings are handled in appropriate, designed on purpose, bins with a capacity of 5 cubic meters. The filled bins, stored temporarily in a dedicated area at the outside edge of the platform, are loaded onto the supply vessel at least once a day;
- Onshore, a mobile crane unloads the bins on the port wharf where they are picked up by multibucket lorries to be conveyed to the disposal site.

Liquid effluents

- Exhaust or residual, not recyclable, drilling fluids and washing water are collected together on the platforms in a storage tank with a capacity of 30 cubic meters and periodically transferred via hose to the supply vessel tanks;
- On the port wharf, liquid effluents are pumped into a negative pressure drain tanktruck for their land transport and then subjected to the physico-chemical and mechanical dehydration process, which foresees the use of flocculants, demulsifiers and centrifuges or filter-presses;
- The so obtained solid waste is disposed off as the drilling cuttings, while the liquid phase undergoes to further treatment in conditioning plants.

Wastes are of three types: urban wastes, drilling muds and cuttings. The quantities of these wastes carried onshore in the case of Barbara field are summarized in Table 4.8.

Table 4.8 Quantity and type of wastes carried onshore

Urban wastes	Drilling muds	Cuttings
1,530 t	91,800 m^3	51,000 t

During the drilling phase the only discharges to sea are treated wastewater. The quantity and quality of these discharges are summarized in Table 4.9.

Table 4.9 Quantity and quality parameters of water discharged to sea

Treated waste water	BOD_5	Residual chlorine	Suspended solids
32640 m^3	50 mg/l	0.2 mg/l	100 mg/l

As for fresh water needs, they sum up to 76,500 m^3.

Production stage

The amounts reported in this paragraph accounts for the discharges and withdrawals during the production stage including offshore installations (Barbara platforms) and onshore treatment plant (Falconara treatment facility).

Freshwater needs sum up to 8.05 m^3/billion m^3 of gas.

The major emission from the E&P phases of natural gas fuel cycle is produced water, which is discharged to sea. This is water present in gas-bearing formation that becomes entrained with the gas in the flow line up to the process system. The discharge resulting from the Falconara treatment plant is 11 m^3/billion m^3 of gas (corresponding to roughly 28 m^3/day). The characteristics of the produced water is reported in Table 4.10: other analytic components of produced water, but they are not available at the moment. Their values are anyway below the limits set by the legislation in force (Law 319/76, Law 979/82).

Table 4.10 Characteristics of production water

BOD	50 mg/l
COD	120 mg/l
Total hydrocarbons	30 mg/l
Suspension matter	250 mg/l

The quantities of wastes produced during the production phase are summarized in Table 4.11.

Table 4.11 Waste from the production stage (kg/ billion m^3 of gas)

Special	122
Toxic	0.008
Used oils	4
Batteries	0.27l

Gas transport

As for the transport of natural gas, the Snam Environmental Report (Snam, 1994) reported a value of 25 kg/10^6 m^3 of total waste production/natural gas transported.

Power generation

Construction phase

The liquid effluents produced during the construction phase are mainly those connected with the presence of personnel and amount to 150 m^3/day. Rain water is conveyed through the existing water system.

Solid wastes amount to 700 kg/day.

Operation phase

The liquid effluents produced by the plant are mainly those coming from the water treatment plant and they are about 150,000 m^3/year: they are mostly made of rain water. The chemical characteristics of water collected in the terminal pool respect the limits imposed by laws in force 319/76 and 650/79.

The overall freshwater need was estimated as 240,000 m^3/year.

Even the solid emissions are those coming from the water treatment plant and are about 100 t/year with a moisture content of 30-50%.

4.2.3 Noise emissions

Noise emissions occur at all stages of the gas fuel cycle. The more relevant are those connected with upstream exploration operations (air gun surveys). During the other stages noise emissions are mainly connected with turbines operations.

Air gun seismic surveys

Air gun shootings produce low frequency and high intensity acoustic pulses in water and may affect fishery behaviour. AGIP performed a first assessment of air-gun seismic shooting on marine resources in the central Adriatic sea during summer 1995. The results are summarized in the paragraph 2.4.4 describing impacts on the marine environment.

Compression stations

During gas transmission, noise emissions come from gas turbines of compression plants. During recent measurements made at a compression station, the following noise levels were recorded: the noise level measured 1 meter away from a single turbine was 75-80 dBA; when two turbines are in operation the noise level at the border of the station (80 meters away from turbines) was in the range 50-55 dBA.

Power generation

Constructors are required to meet given standards. The acoustic level at the maximum load will be less than 51 dBA Leq at a distance of 120 m from the area where the turbines are located. This value will be respected no matter what the environmental conditions will be. Where turbines are started or stopped the acoustic level will be 54 dBA.

4.2.4 Other environmental issues at the energy production stage

Ionogenic and non-ionogenic radiations

The only radiations are the non-ionogenic radiations connected with energy transmission structures. In this case the lines of energy transmissions leaving the plant are two lines 1.5 km long. The value of electrical and magnetic fields are, in the points of maximum intensity, about 4 kV/m and 18 micro T.

Traffic

The induced traffic is represented by the private cars of people employed in the plant (120 persons). As for the supply of liquid fuel, the impact will be extremely low as fuel oil is used as back-up fuel.

Physical dimensions

The total area required would be 23 ha The station would have 2 air cooling towers 100 meters high. The 2 stacks (one for each module) are located inside the cooling towers and they are 100 meters high as well.

Transmission of electricity

The electricity will be transmitted via two lines, each 1.5 km long, connecting the plant to the national transmission network.

4.3 Selection of priority impacts

As mentioned in European Commission (1995c), well over 200 impacts have been identified for the gas fuel cycle. The analysis in this report is restricted to impacts that are believed to be the most important for the gas fuel cycle. These priority impacts are listed in the Table 4.12.

Table 4.12 List of priority impacts

Description	Scale	Fuel cycle stage
global warming potential of greenhouse gas emissions	Global	All
effects of atmospheric pollution on human health	Regional	power production
effects of atmospheric pollution on materials	Regional	power production
effects of atmospheric pollution on crops	Regional	power production
occupational and public accidents	Local	All
effects on marine environment of the Adriatic sea	Local	Exploration, drilling, production and gas treatment

The impact pathway approach was followed for all the impacts listed above with the exception of the effects on marine environment of the Adriatic sea for which the analysis was restricted to a qualitative level.

4.4 Quantification of impacts and damages

The present chapter describes and where possible quantifies the impacts and the damages coming from the different stages.

4.4.1 Air pollution

Damages caused by atmospheric pollution to different receptors (human health, crops, materials) have been calculated using Ecosense version 2.0, which implements atmospheric pollutants transportation and diffusion at the local range using the ISCST3 model, and also chemical transformations at the regional range using the WTM (Windrose Trajectory Model).

The model considers NO_x, SO_2 and TSP as emitted pollutants, and calculates the concentrations all over Europe of these pollutants and of some secondary pollutants (sulfates, nitrates, acid deposition). As for ozone related damages, results are reported in a separate section because a different approach, which is described later, has been followed.

Damages to public health are about 99% of all damages from atmospheric pollution (materials account for about 0.8%, and an even smaller percentage is attributable to crops damage, since no SO_2 is emitted by the gas power plant)

Impacts of air pollution on human health

Damages caused to public health by NO_x and nitrates have been calculated. Different receptor categories and impacts are considered in the available exposure-response functions (ERF).

Different calculations have been carried out using different sets of ERF, in order to perform sensitivity analysis. The ERF used in the base analysis and for sensitivity analysis are summarized in Appendix VI; a brief description of the different sensitivity analysis is reported in Table 4.13.

Table 4.13 List of sensitivity analysis performed for different ERF choices

Sensitivity analysis 1	Value of statistical life for acute mortality is used rather than years of life lost approach
Sensitivity analysis 2	Value of statistical life for chronic mortality is used rather than years of life lost approach
Sensitivity analysis 3	Acute mortality from NO_x is included
Sensitivity analysis 4	Some more morbidity exposure response functions are included
Sensitivity analysis 5	Some morbidity exposure response functions are neglected

Results for the base analysis are reported in Table 4.14, divided by receptor category and impact category; results for sensitivity analysis are summarized in Table 4.15, with absolute and percent differences. All figures refer to the regional range only, and the mid values are reported. See Appendix X for complete results.

Table 4.14 Damages to human health - Base analysis

	Damage (mECU/kWh)
By receptor category	
Asthmatics	0.029
Elderly (above 65 years old)	0.0029
Children	0.03
Adults	5.79
Entire population	0.078
By impact category	
Mortality	5.26
(%)	(89%)
Morbidity	0.67
(%)	(11%)
Total	**5.93**

Table 4.15 Damages to human health - Sensitivity analysis

	Damage (mECU/kWh)	Difference	% difference
Sensitivity analysis 1	7.72	1.78	30%
Sensitivity analysis 2	18.1	12.2	205%
Sensitivity analysis 3	5.98	0.04	1%
Sensitivity analysis 4	5.94	0.0062	0%
Sensitivity analysis 5	5.77	-0.16	-3%

Impacts of air pollution on crops

Since no SO_2 is emitted by the gas power plant, no yield loss due to SO_2 concentrations has been calculated. Nevertheless, NO_x emissions cause a rise in terrain acidity, so some additional lime is needed to maintain the correct ground pH value: the additional lime needed has been calculated using an ERF from CEC (1993). Furthermore, the benefit derived from nitrogen deposition has been evaluated using the ERF from Hornung (1997).

Results are reported in Table 4.16.

Table 4.16 Damages to crops

Crop	Impact	Reference	Pollutant	Damage (mECU/kWh)
All crops	add. fertilizer needed [kg]	Hornung, 1997	N dep.	-0.0005
	add. lime needed [kg]	CEC, 1993	Acid dep.	0.0017
Total damage				**0.0012**

Impacts of air pollution on materials

The maintenance surface for different materials due to acid deposition has been calculated using the ERF from Kucera *et al.* (1995); for paint, the ERF from Haynie (1986) for carbonate has been used.

Two sensitivity analysis have been performed, substituting the ERF from Kucera *et al.* (1995) with those from Lipfert (1987, 1989) and Butlin (1992, 1993) respectively.

Results are reported in Table 4.17.

Table 4.17 Damages to materials

Material	Impact	Reference	Pollutant	Damage (mECU/kWh)
Galvanized steel	maintenance	Kucera *et al*., 1995	Acid dep.	0.0043
Limestone	surface	Kucera *et al*., 1995	"	0.0001
Mortar	"	Kucera *et al*., 1995, mod.	"	0.0001
Natural stone	"	Kucera *et al*., 1995	"	0.0001
Paint	"	Haynie, 1986 (carbonate)	"	0.0406
Rendering	"	Kucera *et al*., 1995, mod.	"	0.0012
Sandstone	"	Kucera *et al*., 1995	"	0.0001
Zinc	"	Kucera *et al*., 1995	"	0.0004
Total damage				**0.047**

Material	Impact	Reference	Pollutant	Damage (mECU/kWh)
Sensitivity analysis 1		Lipfert, 1987, 1989		0.064
	Difference			0.017
	% Difference			36%
Sensitivity analysis 2		Butlin, 1992, 1993		0.047
	Difference			0.0004
	% Difference			1%

Ozone effects

Ozone damages have been evaluated using results of calculations carried out by Rabl and Eyre (1997). They used two photochemical dispersion models (the EMEP model for the European region and the Harwell Global Ozone model at the global range) in order to find out what is the contribution to ozone formation of different precursor emissions (i.e. emissions of VOC and NO_x).

Provided that this methodology is site-independent, the evaluation has been made for all fuel cycle stages, rather than only for the electricity production stage.

Results of the simulations are summarized in Table 4.18 to Table 4.20.

Table 4.18 Damages calculated over Europe with the EMEP model

Impact	ECU/tNO_2	ECU/tVOC
mortality	259	217
morbidity	460	385
crop losses	200	160
Total	**919**	**762**

Table 4.19 Damages calculated with the Harwell Global Ozone model outside Europe

Impact	ECU/tNO_2	ECU/tVOC
mortality	153	29
morbidity	272	51
crop losses	150	28
Total	**575**	**108**

Table 4.20 Damages calculated for methane

Impact	**ECU/tCH$_4$**
mortality	39
morbidity	71
Crop losses	24
Total	**134**

The factors reported in the three tables above have been combined with the emissions reported in Table 4.7, and with the annual electricity production of the reference power plant to obtain damages which are reported in Table 4.21.

Table 4.21 Ozone damages

Impact	**Damage (mECU/kWh)**					
	NO$_x$		VOC		CH$_4$	Total
	Europe	Outside	Europe	Outside		
Energy production						
mortality	0.11	0.07	0.008	0.001	0.001	0.19
morbidity	0.2	0.12	0.015	0.002	0.002	0.34
crop losses	0.09	0.07	0.006	0.001	0.001	0.17
Other stages						
mortality	0.006	0.004	0.000	0.000	0.006	0.02
morbidity	0.011	0.007	0.000	0.000	0.011	0.03
crop losses	0.005	0.004	0.000	0.000	0.004	0.01
Total	**0.43**	**0.27**	**0.029**	**0.004**	**0.025**	**0.76**

4.4.2 Occupational health effects

The database from INAIL (Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro, i.e. National institute for the occupational accidents insurance) provides accidents statistics for the year 1995, divided by province, economic activity, type of accident. More aggregated data are also available for years 1993 to 1996. Therefore all calculations are referred to this time period, adjusting 1995 data for time averaging over years 1993-1996. No data about occupational diseases are available at the moment.

Accidents leading to less than three working days loss are not considered; accidents with a longer period loss are classified as follows: fatal accidents, accidents leading to permanent inability, accidents leading to temporary inability.

According to the type of data available, different approaches have been followed for the different stages:

- as for gas production, treatment and transportation, data from AGIP and Snam about total occupational accidents in recent years have been considered, using the total amount of gas produced or transported to scale the total values and calculate the number of accidents related to the reference power plant activity; data from INAIL database have been used to account for trends over time, to separate between minor and major injuries and to calculate mean mortality values, since in the years the data were referred to no fatal accidents were reported.

- as for plant construction and operation, data about the number of workers involved in the power plant construction and operation were taken from the power plant EIS (ENEL/DCO, 1989), and they were combined with accident statistics taken from the INAIL database.

Damages from offshore exploration, platform construction and dismantling, treatment facility and pipeline construction and power plant dismantling have not been calculated. From the English gas fuel cycle report (European Commission, 1995d) it can be stated that damages from offshore exploration and pipeline construction are about one order of magnitude less than those from offshore operation; damages from offshore and treatment facility construction are the same order of magnitude as those from offshore operation; damages from power plant dismantling, decommissioning and abandonment are about one order of magnitude less than the operation related ones.

Gas production (offshore) and treatment facility operation

Normal operation

AGIP accidents statistics reported 53 and 35 non fatal accidents for years 1994 and 1995 respectively, including both oil and gas production and treatment. No fatal accidents were reported in those two years. In order to calculate the number of accidents due to gas production only, the figures have been scaled according to the annual production of oil and gas, expressed in Toe units; this led to 42 and 27 non fatal accidents for 1994 and 1995 respectively, which correspond to an annual average of 34.5 non fatal accidents. Looking at total italian accidents during years 1993 to 1996, the average number of accidents is the same as in 1994-1995, so that no adjustment is needed.

The division between minor and major non fatal accidents has been made according to the INAIL national statistics for the gas sector: about 33.5 accidents are considered as minor accidents, and 1 is regarded as major. The mean fatal accidents number has been calculated according to INAIL statistics for the electricity and gas sector: the result was 0.075 fatal accidents.

The mean annual gas production reported by AGIP for years 1994-1995 is about 18,750*10^6 m^3; according to the gas demand of the reference power plant (which is about 220*10^6 m^3 per TWh), the impact of this stage over occupational health can be calculated as number of cases per TWh. Results are reported in Table 4.22.

Major accidents

Impacts and damages from major accidents in gas exploration and production have been calculated using data from the English gas fuel cycle (European Commission, 1995d): this reported 0.09 deaths for each Mtoe of gas produced in offshore platforms. Provided that AGIP average offshore production is (corresponding to 15.804 Mtoe), and the reference power plant gas demand is about 220*10^6 m^3 per TWh, the death rate is 0.0166 deaths/TWh.

Table 4.22 Occupational health impacts from gas production and treatment

Accident category	Accident rate	
	per 10^9 m^3	per TWh
Fatal accidents		
Normal operation	0.0040	0.0009
Major accidents	0.075	0.0166
Major accidents	0.0467	0.0103
Minor accidents	1.7862	0.3930

Gas transportation via pipeline

For gas transportation, approximately the same procedure as for gas production was followed: Snam accidents statistics report 8 non fatal accidents for 1995 due to gas transportation. Looking at INAIL data, the average accidents number during years 1993 to 1996 is slightly lower than the 1995 value, so that a small adjustment is needed for averaging Snam data over time.

The division between minor and major non fatal accidents led to about 7.7 minor accidents and 0.2 major accidents, and about 0.017 death cases.

According to the amount of gas transported in 1995, which was 54,470*10^6 m^3, the impacts reported in Table 4.23 have been calculated.

Table 4.23 Occupational health impacts from gas transportation

Accident category	Accident rate	
	per 10^9 m^3	per TWh
Fatal accidents	0.0003	0.00007
Major accidents	0.0037	0.00082
Minor accidents	0.1420	0.03124

Power plant construction

The Environmental Impact Statement for the reference power plant reports a mean demand of 225 workers for three years (which is 675 persons-year) for the plant construction, and about 600 workers for 30 months (which is 1,500 persons-year) for the mechanical installations. According to INAIL 1995 statistics in building and mechanical categories, adjusted for time averaging, the number of accidents (classified as fatal, minor and major) has been calculated. Based on a thirty years lifetime supposed for the power plant, which leads to a total production of about 122.4 TWh, the accident rates reported in Table 4.24 have been calculated.

Table 4.24 Occupational health impacts from power plant construction

Accident category		Accident rate		
		per person-year	total accidents	per TWh
Fatal accidents	building	0.0003	0.20	0.0016
	installation	0.0002	0.23	0.0019
Major accidents	building	0.0061	4.11	0.0336
	installation	0.0034	5.13	0.0419
Minor accidents	building	0.0811	54.77	0.4475
	installation	0.0795	119.20	0.9739

Power plant operation

The Environmental Impact Statement for the reference power plant reports a demand of 120 employees for the operation. According to INAIL 1995 statistics in electricity category, adjusted for time averaging, the number of accidents (classified as fatal, minor and major) has been calculated. Based on an annual energy production of about 4.08 TWh, the accident rates reported in Table 4.25 have been calculated.

Table 4.25 Occupational health impacts from power plant operation

Accident category	Accident rate		
	per person-year	total accidents	per TWh
Fatal accidents	0.00007	0.008	0.0019
Major accidents	0.00087	0.105	0.0257
Minor accidents	0.01668	2.002	0.4907

Economic valuation

The damage costs per kWh, reported in Table 4.26, are calculated using the following monetary values:

Fatal accidents		3,100,000 ECU
Major accidents	(accidents leading to permanent inability)	95,050 ECU
Minor accidents	(accidents leading to temporary inability)	6,970 ECU

Table 4.26 Gas fuel cycle occupational health impacts

		fatal accidents	**major accidents**	**minor accidents**	**total damage**
Platform construction and dismantling	Cases/TWh	n.q.	n.q.	n.q.	n.q.
	mECU/kWh	n.q.	n.q.	n.q.	n.q.
Gas exploration	Cases/TWh	n.q.	n.q.	n.q.	n.q.
	mECU/kWh	n.q.	n.q.	n.q.	n.q.
Treatment facility construction	Cases/TWh	n.q.	n.q.	n.q.	n.q.
	mECU/kWh	n.q.	n.q.	n.q.	n.q.
Gas production and treatment					
normal operation	Cases/TWh	0.0009	0.0103	0.3930	
	mECU/kWh	0.0027	0.0010	0.0027	0.0065
major accidents	Cases/TWh	0.0166	n.q.	n.q.	
	mECU/kWh	0.0515	n.q.	n.q.	0.0515
Pipeline construction	Cases/TWh	n.q.	n.q.	n.q.	n.q.
	mECU/kWh	n.q.	n.q.	n.q.	n.q.
Gas transportation	Cases/TWh	0.0001	0.0008	0.0312	
	mECU/kWh	0.0003	0.0001	0.0002	0.0006

		fatal accidents	major accidents	minor accidents	total damage
Power plant construction					
building	Cases/TWh	0.0016	0.0336	0.4475	
	mECU/kWh	0.0051	0.0032	0.0031	0.0113
installation	Cases/TWh	0.0019	0.0419	0.9739	
	mECU/kWh	0.0059	0.0040	0.0068	0.0167
Power plant operation	Cases/TWh	0.0019	0.0257	0.4907	
	mECU/kWh	0.0060	0.0024	0.0034	0.0118
Power plant dismantling	Cases/TWh	n.q.	n.q.	n.q.	n.q.
	mECU/kWh	n.q.	n.q.	n.q.	n.q.
TOTAL	Cases/TWh	0.0230	0.1125	2.3363	
	mECU/kWh	0.0715	0.0107	0.0163	**0.0983**

4.4.3 Global Warming

Damages arising from global warming due to greenhouse gases emissions have been calculated using the aggregate figures of Table 4.27.

Table 4.27 Recommended global warming damage estimates for use in the ExternE National Implementation Study. The range given does not fully account for uncertainty.

	ECU(1995)/t
CO_2 - low - high	3.8 - 139
CO_2 - mid 3% - mid 1%	18 - 46
CH_4	520
N_2O	17,000

Considering the emissions reported in Table 4.7 the following damages have been calculated:

Table 4.28 Damages from global warming (mECU/kWh)

	Power gener.	Other stages	Total
CO_2 - low - high	1.65 - 60.2	0.039 - 1.44	1.68 - 61.6
CO_2 - mid 3% - mid 1%	7.79 - 19.9	0.19 - 0.48	7.98 - 20.4
CH_4	0.015	0.078	0.093
N_2O	0.051	n.q.	0.051
Total - low - high	1.71 - 60.2	0.12 - 1.52	**1.83 - 61.8**
Total - mid 3% - mid 1%	7.86 - 20.0	0.26 - 0.55	**8.12 - 20.5**

4.4.4 Impacts on the marine environment

Impacts on marine environment for the gas cycle occur only at the exploration, production and gas treatment phase. The following paragraphs list and describe the main cause-effects relationships between activities, related with the stages above, and the different components of the marine environment, with particular reference to works recently performed by AGIP in the Adriatic Sea.

Exploration stage

During summer 1995, AGIP carried out a series of investigations to test the effects of air-gun seismic shooting on main fishery resources of the Adriatic Sea (La Bella *et al*, 1996). This was the first investigation on possible interference of marine exploratory activities for sub-soil gas and oil deposits with fishery industry ever done in the Adriatic Sea and for this reason it cannot be considered exhaustive. Some investigations carried out in the North Sea and off California clearly evidenced a decrease in catches of trawlers and longliners fishing inside areas where air-gun seismic prospections were in progress (Skalski *et al*, 1992; Engas *et al*, 1993; Lokkeborg and Soldal, 1993). Other investigations evidenced an increase of total trawl catches, but a reduction in abundance of some nektonic species (Dalen *et al*, 1987).

Experiments carried out in the Adriatic Sea did not evidence any significant variation in trawl catches, nor differences in size frequency distributions recorded from capture of finfish (hake) and burrowing crustaceans (Norway lobster). If the results obtained for the North Sea have a general value, i.e. large fish are more sensitive to sound levels produced by air-gun discharge, Adriatic data might be explained by the quite different size of fish caught in the two seas. Some other results of the Adriatic survey such as the capture of large fish (Squalus acanthias) in trawl hauls made before as well as after the seismic prospection are in contrast with the hypothesis of a size selective departure of fish from the investigated area.

As for fossorian bivalves, the experiments show the same density estimates from hydraulic dredge samples collected before and after the seismic prospection and no evidence of clam mortalities. As pointed out in other studies, no evidence of mortality consequent to air-gun discharge was obtained and catchability of demersal and benthic species by active gears (trawl net and dredge) was not affected.

Some behavioural responses to high-intensity sound were observed in Clupeoids (change in vertical distribution, evidenced by echosounding), in captive sea-bass and in the gastropod *B. brandaris* (reduction of motility).

Drilling and production stage

During the gas production stage, the only potential relevant impact is the one on the marine environment resulting from offshore discharges of drill cuttings and fluids. Nevertheless, as we already remarked above, AGIP has been implementing a zero-discharge policy in order to minimize the impacts associated with this activity: for this reason the major potential impact is eliminated and transferred onshore during waste transport, treatment and disposal.

Some minor impacts are related to *the physical presence of the structures* (platforms and sealine). A research project promoted and carried out by AGIP, aimed at performing an ex-post impact analysis on two sample platforms located in the Adriatic Sea and in the Sicily Strait (Alfano *et al*, 1996), highlighted the effects of platform presence on biology and fouling and fishery. The study took also into consideration the effects of drilling cuttings and muds discharges that turned out to be the most significant impacts: we remind however that these impacts will not be considered here because AGIP has been implementing a zero-discharge policy. Neglecting this, the effect of platform presence in terms of ionic release from sacrificial anodes was highlighted, even if a direct effect of discharges on heavy metal bioaccumulation by target species was not demonstrated. As for fouling and fishery, characterization of communities settled on platform legs, abundance and biomass of resources around the platform and effects on bioaccumulation of dissolved metal ions released from sacrificial anodes, were evaluated in terms of:

- qualitative and quantitative study on macrofouling organisms;
- quantitative study on accumulation on Zn and Al on *Mytilus Galloprovincialis* as a bioindicator;
- definition of platform influence (intended as artificial reef) on fish population composition through the study of fish biomass variations versus platform distance by means of monthly bottom trawl fishing and pelagic net fishing and analysis of stomach content.

The results pointed out:

1. macrofouling characteristics are not seriously affected. In the eutrophic conditions of the Adriatic Sea, the most representative organism in the first 15 meters is *Mytilus Galloprovincialis*, with a biomass ranging from 10 to 90 kg/m2 wet weight (in relation to depth of settlement);

2. a sensible bioconcentration of Zn released by anodes in target organism *Mytilus*, that incorporates quantities of this metal variable from 1 to 3 times with respect to the control sample;

3. evidence of aggregating device function for benthic and pelagic organism, due to both hard substrata shortage in the Adriatic Sea and light attraction: the increase of biomass is restricted to platform closeness (within 50-100 meters from structures). It is important to underline the presence of some typical hard substrata species (quite rare in the offshore of the Central Adriatic Sea), detected only nearby the structures. Analysis of stomach content evidences a narrow relation between selected fish species captured around the platforms and fouling settled on structure legs.

Another potential source of impact is noise emission. During the AGIP above mentioned project, an extensive field characterization of underwater acoustic noises radiated from platforms and a literature evaluation of the radiated effects on selected marine organisms were made. In particular *in situ* measurements of acoustic and seismic noises (frequency, intensity) radiated during drilling and production phases were carried out.

The results allow the characterization of:

1. radiated noise spectra around the two reference platforms;

2. a computer model for evaluation of radiated noises emitted during the drilling and production routine operations, expressly set with data collected during the surveys;

3. possible interference/disturbance caused by drilling generated low frequencies on selected fish and crustacean species, in relation to their reproductive and social behaviors.

Gas treatment stage

The only significant impact is the one deriving from the immission of produced water that may cause an impact on coastal environment. The discharge of produced water resulting from the Falconara treatment plant is 11 m^3/billion m^3 of gas and its composition is reported in Table 4.10. This corresponds to a rate of discharge of roughly 28 m^3/day.

Produced water discharge is related to chronic immission of small quantities of heavy metals, hydrocarbons, nutrients and suspension matter. This may cause an impact on benthic species, an alteration of chemical, physical and biological parameters of water column and of sediments, an accumulation of toxic substances in organisms. Attributing the impact to produced water discharge is however very difficult, because of the lack of emission data, dose-response functions and population distribution. Furthermore the prediction of environmental effects is chemically complex, analyses are few and different site produce different effluents, the environment is different and the transfer of results is difficult.

Platform reutilisation

AGIP performed a feasibility study for the characterization, among various platform reutilisation possibilities, of those with less environmental impact and better cost-benefit ratio. In particular, a field study on existing structures maintained *in situ* as mariculture logistic support and on the use of a platform structure or parts of it as artificial fishing reef was carried out. The results of the study made on an existing platform wreck in the North Adriatic area, pointed out that:

1. collected data of communities settled on the platform wreck are similar to those recorded on artificial concrete reefs located in other areas of the Adriatic Sea; furthermore platform wreck offers a suitable substratum for eggs settlement and carries out an aggregating device function for benthic and pelagic organisms;

2. a large wreck surface was covered by organisms with high commercial value (mussels and oysters) with a biomass varying in the range 10 to 90 kg/m^2 wet weight, according to settlement depth;

3. platforms steel structures offer very high resistance to sea water effects (corrosion, strong currents, etc.) and could carry out the function of artificial reef for many years with a minimum environmental impact;

4. platform structures maintained *in situ* could be well utilized for logistic support in a quite large offshore cage mariculture plant.

The cause-effects relationships identified in the above mentioned project are summarized in Table 4.29, where the main perturbations on the environment and the related target indicators are reported.

Summary of impacts on the marine environment

Table 4.29 Cause-effects relationships between exploitation activities and environmental indicators.

Exploitation activity	Perturbations	Environmental indicators
Air gun seismic surveys	• Low frequency and high intensity acoustic pulses noise production in water	• School of pelagic fish and benthic molluscs
Platform and sealine installation	• Sea bottom reworking with temporary benthic organisms burial phenomena and local modification of granulometric distribution	• Sessile benthic species; ecological indexes • Granulometric parameters
Wells drilling	• Temporary landscape alteration • Continuous emissions of low and medium frequency radiated noise in water • Engines cooling water disposal	• Noise spectra in water • Sessile benthic species; ecological indexes • Toxic substances accumulation in target organisms • Granulometric parameters • Physical, chemical and biological parameters in water and sediment
Physical presence of structures (platform and sealine)	• Landscape alteration • Sediment resuspension and erosion phenomena nearby the structures • Vertical granulometric distribution alteration due to the trench excavation (sealine) • Dissolved metal ions released from anticorrosion system (sacrificial anodes	• Sessile benthic species; ecological indexes • Granulometric parameters • Toxic substances accumulation in target organisms • Chemical parameters in water and sediments

Exploitation activity	Perturbations	Environmental indicators
	• Pelagic biomass attraction effect due to food, shelter and settling surface availability for sessile and vagile organisms	
Exploitation-related routine activities	• Production of waters discharges to sea with chronic immissions of small quantities of hydrocarbons, nutrients suspension matter • Chronic immission of small quantities of hydrocarbons and heavy metals due to related naval traffic	• Sessile benthic species; ecological indexes • Granulometric parameters • Physical, chemical and biological parameters in water and sediment

A critical analysis of the obtained results indicates that, although the italian offshore upstream activities topology is similar to those performed in other countries, some peculiar aspects reduce consistently the interactions between platforms and marine environment. They are:

1. Small sized fields;

2. The low depth of platform locations (they are in fact almost totally located in the high and central Adriatic Sea, where bottoms do not overtake 30 meters depth);

3. The policy, adopted since 1987, to dispose into the sea exclusively production waters and to ship ashore both cuttings and drilling muds;

4. The use of steel platforms simply structured, automated and safe.

On the other hand some evidence resulted from both experimental and bibliographic approaches, that in sensitive environments like the Adriatic Sea, even limited perturbations can give rise to an alteration of the weak balance which regulates the ecosystem over both the short and long term.

4.4.5 Summary of damages

In the following tables are summarized the damages described above:

Table 4.30 Damages of the gas fuel cycle

	mECU/kWh	**σ_g**
POWER GENERATION		
Public health		
Mortality*- YOLL *(VSL)*	5.5 *(21.1)*	B
of which TSP	*ng*	
SO_2	*ng*	
NO_x	*5.3 (21.1)*	
NO_x (via ozone)	*0.18*	
VOC (via ozone)	*9.4E-3*	
Morbidity	0.99	
of which TSP, SO_2, NO_x	*0.67*	A
NO_x (via ozone)	*0.32*	B
VOC (via ozone)	*0.017*	
Accidents	n.q.	A
Occupational health	0.012	A
Major accidents	n.q.	
Crops	0.15	B
of which SO_2	*1.2E-3*	
NO_x (via ozone)	*0.15*	
VOC (via ozone)	*7.2E-3*	
Ecosystems	n.q.	B
Materials	0.047	B
Noise	n.q.	
Visual impacts	n.q.	
Global warming		C
low - high	1.71 - 60.2	
mid 3% - mid 1%	7.86 - 20.0	

	mECU/kWh	σ_g
OTHER FUEL CYCLE STAGES		
Public health	0.058	B
Occupational health	0.087	A
Ecological effects	n.q.	B
Road damages	n.q.	A
Global warming		C
low - high	0.12 - 1.52	
mid 3% - mid 1%	0.26 - 0.55	

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

Table 4.31 Sub-total damages of the gas fuel cycle

	mECU/kWh
Non global warming: YOLL *(VSL)*	**6.84 (22.4)**
Global warming: low - high	1.83 - 61.8
Global warming: mid 3% - mid 1%	**8.12 - 20.5**

Table 4.32 Damages by pollutant

Pollutant	**ECU / t of pollutant**
SO_2 *- YOLL *(VSL)*	-
NO_x *- YOLL *(VSL)*	13,500 *(49,400)*
PM_{10} *- YOLL *(VSL)*	-
NO_x (via ozone)	1,500
CO_2	3.8 - 139 (mid range 18 - 46)

*YOLL= mortality impacts based on ‘years of life lost’ approach; VSL= impacts evaluated based on ‘value of statistical life’ approach.

5. HYDRO FUEL CYCLE

The hydro fuel cycle is very different from the fossil fuel cycles, where the burdens are dominated by atmospheric emissions and impacts and damages can be estimated from general dose- and exposure-response functions. In the hydro cycle most of the burdens are not related to atmospheric emissions, but concern aquatic and terrestrial ecosystems in terms of alteration of river flows, dams, etc. The impacts are very site-specific and it would be very difficult to build general dose-response functions. In addition a single impact might be caused by different causes and burdens and it is often not possible to sort out what part of the impact was caused by that burden.

As already remarked, most of the hydroelectric plants in Italy were built before 1960 (at the moment only one hydroelectric plant is under construction, but no data were available when this report was prepared). The construction of dams and main power plants date back to a period where the technical and economical evaluation of investments was made with reference to conventional evaluation parameters, without considering the set of techniques that have been more recently used, which take into account also issues related to environment, landscape, social and cultural contexts, safety of territory. For these reasons, it was not possible, with the limited resources available within the current project, to implement an approach similar to the one used in studies made for other countries (European Commission, 1995b). Within this study, impacts are described but not quantified, and damages are estimated using an indirect method: the value of non marketed goods are estimated starting from repair and restoration costs. These include mainly costs during the operation phase of a complex hydroelectric system.

It should be noticed that damage estimates obtained through this method only refer to the avoided or repaired damages (AC). In other words, the damages which are not repaired or avoided - because they are considered marginal, too expensive or irreversible, are not taken into account. Ideally one should estimate the Total Damage Costs (DC_{Tot}) by summing the avoided or repaired damages (AC) to the estimate of the 'residual' damage (DC_r) obtained through direct or indirect methods:

Estimated Damage Cost	*Methodology*	
Damage Cost (residual)	a) direct + indirect methods	DC_r
Repair and Restoration Costs	b) avoidance and/or repairing costs	AC
Total Damage Costs	combination of a) and b)	$DC_{Tot}=DC_r+AC$

Provided that the power system is situated in a national park, the value of damages for landscape, ecosystems and visual intrusion is probably higher than the repair costs methodology will show.

The selected hydroelectric system belongs to AEM, a municipal company serving the area of the municipality of Milano and is located in Valtellina, northern Italy.

5.1 Description of technologies and site

The selected hydroelectric system of AEM is located in alta Valtellina, one of the biggest valleys in Lombardia region (northern Italy): the valley includes the Adda river, the major affluent of the Po river on its left side, from its springs to lake of Como.

The system is based on 8 hydroelectric power plants located along the upper stretch of the Adda river: they use the waters of Adda river itself, for a total area of 885.5 km^2, between 2000 and 4000 meters of altitude, and the highest part of the basin of the river Spoel for a total area of 105 km^2. The AEM hydroelectric system in Valtellina has an installed power of 682.05 MVA and produces, on average, 1.8 TWh/y of electricity using an overall hydraulic head of 1800 meters over a few km. The first plant was put in operation in 1910, the same year when AEM was founded, at Grosotto, the last one started its operation in 1986 (at over 2000 meters of altitude). The system (Figure 5-1) is made up of 4 reservoirs, 7 production plants (Table 5.1) and 7 diversions.

The 8 power plants can be grouped as follows:

- a first group, including Premadio, Grosio, Lovero and Stazzona, which represents the main hydraulic system, are connected in cascade: the system is regulated on annual basis using the water collected by the two main reservoirs Cancano and S. Giacomo, on daily basis using the waters of reservoirs Val Grosina and Sernio

- a second group, including Grosotto, Boscaccia Nuova, Fraele that can be considered as old plants only partially operating, that must be dismantled or refurbished

- a third group, including plant Braulio that was built for the optimization of the existing diversion system.

The technical characteristics of the production plants are reported in Table 5.1.

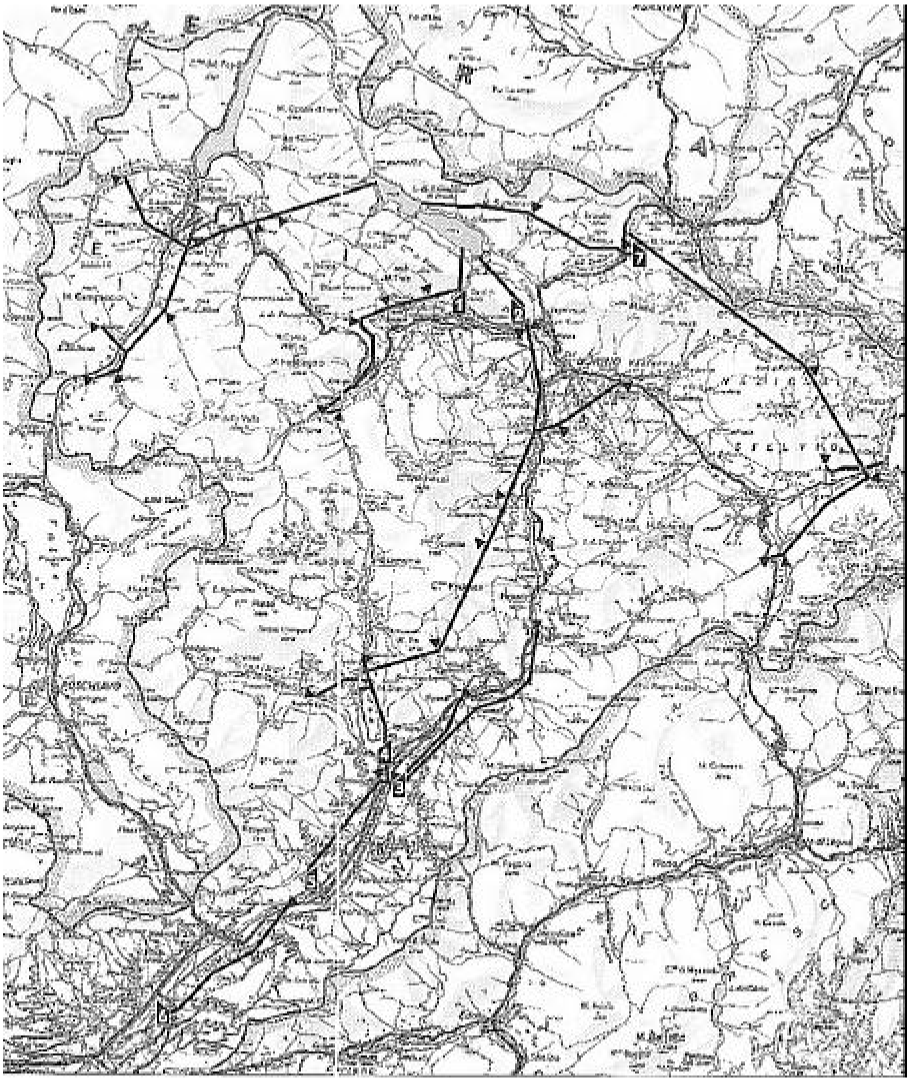

Figure 5-1 Plan view of the hydroelectric system of AEM in alta Valtellina

Table 5.1 Characteristics of the production plants

Plant	Height (m s.l.m.)	Basin (km2)	Average head (m)	Forced pipe (n D(m))	Turbine (n)	Tours/min (aver)	Maximum flow rate (m3/s)	Installed power (MVA)
Braulio	1.986,17	108,3	133,83	1 2,05	1 Pelton 2 Francis	600	16,00	21
Fraele	1.330,75	73,3	520,70	1*1,80	2 Pelton	600	7,50	35
Premadio	1.223,00	361,0	646,70	1 2,60/2,30	2x2 Pelton	300	25,20	160

Plant	Height (m s.l.m.)	Basin (km2)	Average head (m)	Forced pipe (n D(m))	Turbine (n)	Tours/min (aver)	Maximum flow rate (m3/s)	Installed power (MVA)
Grosio	609,00	712,0	588,20	2 3,20/2,90	3 Pelton	333	60,00	345
Grosotto	603,35	124,0	320,05	3 1,50/1,10	3 Pelton	375	10,80	42
Boscaccia Nuova	607,50	38,7	208,40	1 0,90/0,80	1 Pelton	500	2,25	5
Lovero	497,00	919,0	107,25	1 3,50	2 Francis	375	58,00	44
Stazzona	388,71	990,5	88,73	1 3,20	2 Francis	375	38,00	44

AEM hydroelectric system is organized into 5 different levels, so that the hydraulic head between a level and the following one is fully exploited (Figure 5-2).

At the first level (above 1986 meters), the waters coming from snow melt are collected into the reservoirs of Cancano and S. Giacomo, which constitute the storage for the whole system (Figure 5-4). The two basins have an overall capacity of 187 millions of cubic meters (surface 5 km^2) and act as regulation reservoirs. At the same level there are 3 diversions that collect the water of several streams into the reservoirs, and the plant of **Braulio-7 (19 MW)** the last one that was put into operation in 1986.

At the second level we find one of the main production plants **(Premadio-2, 142 MW)** and the third reservoir (Valgrosina - 1.2 million of cubic meters - area 0.075 km^2 - Figure 5-3).

At the third level we find the production plant of **Grosio-4 (321 MW**, the biggest one) that represents the heart of the whole system: it controls the efficiency of the system, regulates the production on the basis of the demand, monitors precipitation, manages the whole hydraulic system governing all the flows diverted from each stream.

At the fourth level, water coming out from Grosio plant enters the plant of **Lovero (44 MW)** with a hydraulic head of 100 meters.

At the fifth level, a diversion takes the water from the reservoir of Sernio - 4 (0.7 million of cubic meters - area 0.33 km^2) to the last plant **Stazzona (32 MW)**.

The two remaining plants **Fraele (24 MW)** and **Grosotto (24 MW)** are out of this scheme of functioning. Fraele, works only when the water level into the main reservoir (that collects also the waters of Viola river) exceeds the level of the canal leading to the plant of Fraele. This plant will be dismantled after the construction of a new diversion that, starting from above 1900 meters of altitude, will convey the waters of Viola into the main reservoir throughout the whole year. The plant of Grosotto, the most ancient one, is now out of service after the flood of 1987 that caused severe damages to the inlet system.

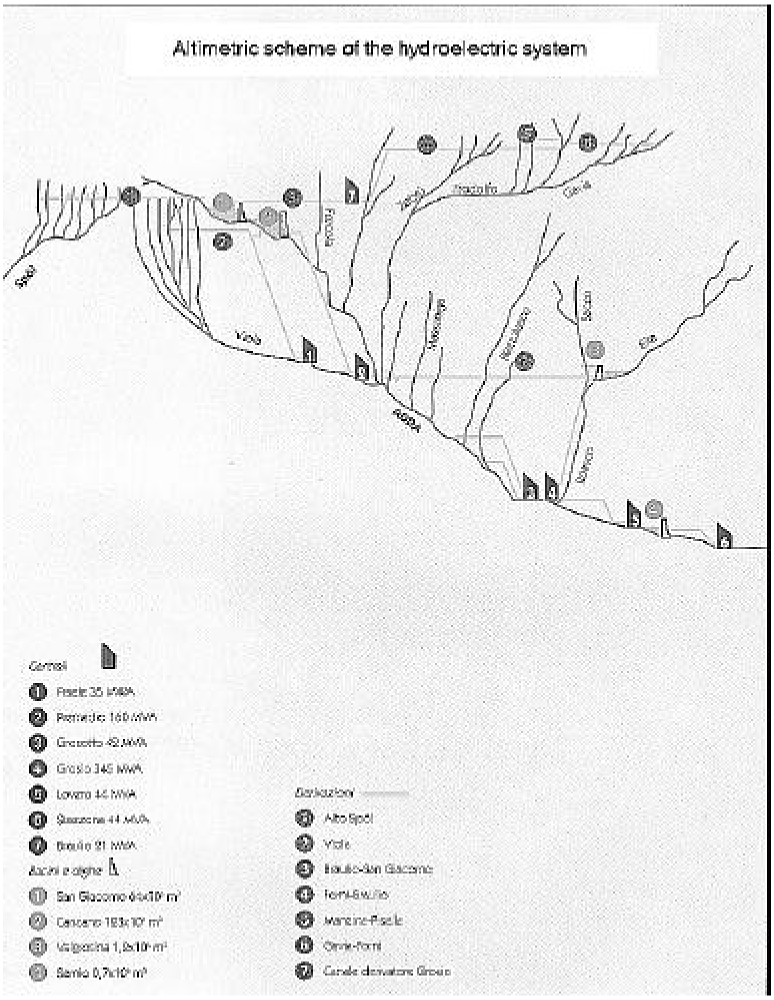

Figure 5-2 Altimetric scheme of AEM plants in alta Valtellina

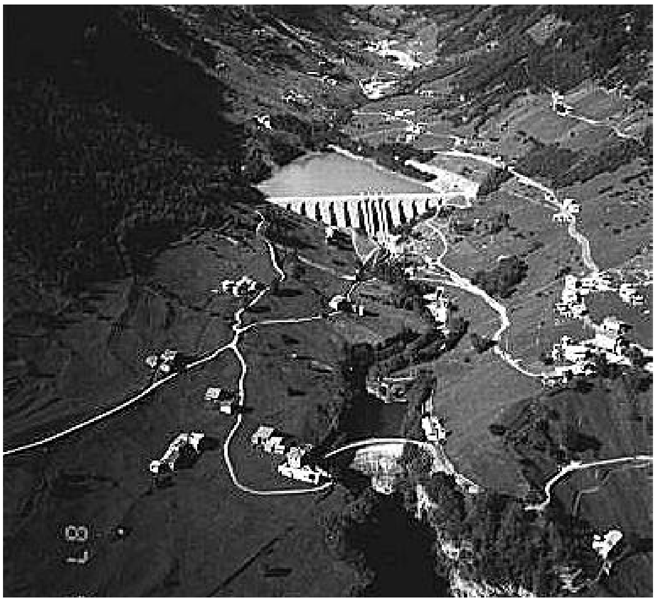

Figure 5-3 Dam of Valgrosina (1.2 million of cubic meters)

Figure 5-4 Dams of Cancano and San Giacomo (187 millions of cubic meters)

5.1.1 Local environment

The Valtellina valley was characterized, until the fifties, by a rural economy and had a very little developed road system and very little commercial and cultural exchanges. In the fifties, with the construction of AEM plants a rapid development of road system occurred, and, in the sixties, local economy shifted towards an economy based on tourism, mainly from the close municipality of Milano. The increased touristic attraction of the area, aroused a great attention toward the presence of the hydroelectric plants that were seen as elements of degradation of the environment in general and of water quality in particular. This situation was worsened with the changed legislative context, which increased the costs associated with environmental issues, causing sometimes limitations to the production.

The system is within the national park of Stelvio. Established by a national law in 1935, the park covers an area of 134,619 ha, 61,824 of which in Lombardia region, between 644 and 3,905 meters above sea level. The territory is mountainous, in the heart of central Italian Alps. From the geological point of view the territory is made up of two different units: a crystal system of metamorphic origin and limestone-dolomitic rocks, and an igneous rocks, of very little extension. Over 25,000 ha of the park are covered with larch and spruce from valley bottom to 1,800 meters. The flora is very rich and includes about 2,500 species, 1,500 of which of lichens and moss. The fauna is represented by deers, roedeer, chamois and steinbock. Several species of birds, both migratory and non-migratory, spend the winter period in the park. The park also includes important touristic centres such as S. Caterina di Valfurva, Passo dello Stelvio, Solda. All new settlements must obtain the permit from park authority.

5.2 Selection of priority impacts

The environmental problems generated on the Italian territory by the presence of hydroelectric plants, and in particular of regulation dams, are those typical of environmental contexts characterized by high levels of urbanization, rather delicate hydrologic situations, slope stability problems, multiple and conflictual use of water.

Within this study, the attention is focused on the **electricity production stage only**.

Also impacts related to construction of dams and infrastructures involves externalities: these include population resettlement, land losses, temporary worsening of water quality, emissions to air from construction activities, aesthetic and noise annoyance for people living in the area. Some of these impacts may be significant, but would probably be quite small if compared with more permanent externalities associated with operation. Furthermore, these impacts would probably not be significant for the selected case: the main reason for this is the fact that construction dates back to 40 years ago and at that time the area selected for the construction of the hydroelectric system was unexplored and scarcely populated. The impact on forestry due to land loss is likely to be quite small since the main reservoirs, which subtracted more than 90% of total land lost, were built above 2.000 meters above sea level in a context of alpine desert. As for the other reservoirs only the dam of Valgrosina involved the loss of a small portion of wood-land (fir).

Also other impacts of the construction phase, such as secondary effects of emissions from production of the construction materials will not be considered since previous studies showed that they turned out to be very small (European Commission, 1995b).

For these reasons, the only impact that will be cosidered for other stages than operation will be the occupational health impact of plant construction.

Focusing our attention to the **generation phase**, the main issues are therefore related to landscape, public health, plant and animal life, upstream and downstream hydrology, multiple water uses, recreational activities.

With particular reference to the selected hydroelectric system, the environmental issues/impacts identified are listed and briefly commented below.

Impacts on water quality: a high organic load in surface water bodies causes the proliferation of algae, gives rise to a general deterioration of water quality and could generate particularly critical seasonal situations. It is not sure that these phenomena are related to the presence of the hydroelectric system, even if someone made the hypothesis that these facts are related to a decreased depuration capacity of water bodies caused by the diversions of the hydroelectric system. More specific studies showed that these pollution episodes are more related to the increased organic load deriving from the development of the area for residential and touristic purposes than to the operation of the AEM system.

Impacts on downstream hydrology. It is sure that the presence of dams and diversions modify the natural regime of the river (river Adda in this particular case): these modifications do not necessarily imply negative impacts since water flow regulation can convert seasonal rivers into perennial waterways, reduce flooding and improve drinking and irrigation water quality; on the other hand, changes in downstream hydrology can impair ecosystems dependent on seasonal flooding, including areas that may be important for fisheries (floodplains, lagoons).

Strictly connected with the modifications on river hydrology are the **impacts on river ecosystem**. The change, usually the decrease, of water level downstream a reservoir may have impacts on plants and fish contents. In order to preserve river flora and fauna, a minimal flow downstream water diversions must be guaranteed. This is not always the case, and it is not rare to see completely dried out rivers. In addition to these, other impacts on fish populations come from the alteration of river continuity (due to the presence of structures), that prevent fish from swimming upstream for reproduction purposes.

Also connected with modified hydrology are the **impacts on river morphology**: erosion upstream the reservoirs leads to sedimentation or land slip which can impair storage. The water released by the reservoir does not contain solid matters and increases erosivity downstream. Furthermore the periodic releases of solid matter accumulated in the reservoirs can cause changes in river sedimentation and generate a deterioration of downstream river quality and an alteration of river flora and fauna. Recent studies and interview have shown that the trap of sediments into AEM alpine reservoirs can be considered negligible, with the exception of the reservoir of Val Grosina where sediments are originated by a particular geological situation characterized by the presence of a consistent detrital layer over the bedrock.

Among the social aspects the **impacts on recreational activities** could be significant: these include all the impacts on activities such as canoeing and fishing. It is however clear that touristic development of the area was in part fostered by hydroelectric system and related infrastructures (road system). For this reason the operation of the system could, in principle, be considered as neutral with respect to recreational activities. Other social aspects are those related with i**mpacts on landscape**: these concern in particular the landfills where the materials coming from construction sites are stored. These landfills, usually located at high altitudes, are extremely visible within the alpine landscape and in some cases turned out to be unstable because of changes in local geomorphological and hydrologic conditions.

As for the **impacts on local employment and economy**, the construction and the operation of hydroelectric systems in Valtellina radically modified the economy of the valley by the development of the road system and the creation of direct and indirect job opportunities. These are for sure positive impacts, but the information available and the fact that the constructions date back to the fifties does not allow us to estimate this benefit.

The last but not least category includes the impacts of construction and operation on **occupational health**. This is dealt with in the usual way; as no precise data were available from construction of AEM system in Valtellina, data about the number of workers needed for the construction and operation have been derived from the Greek report for Hydro fuel cycle, accounting for the different dimension of the electricity production system. The obtained values have been combined with data from the INAIL (Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro, i.e. the Italian institute for the occupational accidents insurance) database, in order to calculate the number of accidents. The database from INAIL provides accidents statistics for the year 1995, divided by province, economic activity, type of accident. Aggregate data are also available for years 1993 to 1996. Therefore all calculations are referred to this time period, adjusting 1995 data for time averaging over years 1993-1996. No data about occupational diseases are available at the moment.

5.3 Quantification of damages

As already mentioned in the previous paragraphs, the damages caused by the impacts identified above have been estimated using the costs associated with all compensation and remediation measures, relating to the restoration of the natural situation, that have been put in place by AEM in Valtellina. For these reasons all the costs given below have been already internalized by AEM and do not represent externalities. Nevertheless these could represent a rough estimate of externalities in other contexts where hydroelectric plants are located, but these measures have not been implemented.

The costs have been extracted from the detailed management accounting system that AEM implemented at the beginning of the 80’s. Nevertheless this system follows the standard accounting methodologies which do not classify the environmental costs into separated cost centres: the environmental costs are collected into overhead accounts and a cross analysis among the cost centres for their identification was necessary. In particular the environmental costs are allocated to overhead accounts such as labour costs, plant costs, restoring costs, and other overhead accounts of the company. Therefore the evaluation of the operating environmental costs comes from a cross analysis among the cost centres and, where this is not possible, from a reliable valuation of the environmental share of the overhead cost. The considered costs refer to the period 1989-1996 and are annual average costs.

This procedure was followed for all the selected impacts, with the exception of impacts of construction and operation on occupational health, for which a standard procedure based on statistical data was used. The impact on local economy and employment was not quantified, even if evidence show that it might be significant and positive (benefit).

The selected impacts have been grouped into two main categories: impacts on ecology and impact on society. The computed damages - in mECU/kWh - for each impact are listed and commented below.

5.3.1 Impacts on ecology

These include:

Impacts on water quality: this damage was estimated as the costs associated with all those interventions aimed at improving current situations, at avoiding potential critical situations and/or conflicts on water use. These costs include issues related to both water quality in general and water quality for drinking purposes. The damage is estimated as 0.069 mECU/kWh.

Impacts on downstream hydrology: this damage is estimated as the costs related to water releases and to the construction of links in order to satisfy water needs for irrigation purposes. The damage is estimated as 0.086 mECU/kWh.

Impacts on river ecosystem: the costs used to estimate this damage are those related to fish restocking, construction of water ways to allow fish to swim upstream for reproduction purposes, release of a minimal flow. In the case of AEM Valtellina hydroelectric system, the minimal flow was set to the value of 1.6 l/s per square km. The damage is estimated as 2.478 mECU/kWh and is by far the largest value.

Impacts on river morphology: the damage caused by these impacts have been estimated on the basis of the costs for the removal of solid matters from reservoirs without the discharge into the downstream stretch of the river. The damage was estimated as 0.095 mECU/kWh.

5.3.2 Impacts on society

These include:

Impacts on recreational activities: the costs used to estimate this damage are those related to particular situations and events where AEM had to open gates in order to guarantee a specific flow, or had to make a specific fish restocking for fish competitions. This damage is estimated as 0.046 mECU/kWh;

Impacts on landscape: the damage due to this impact is estimated as the costs accounted for construction sites removal and turfing of landfills. The damage is estimated as 0.067 mECU/kWh.

Impacts of construction and operation on local employment and economy; this is for sure a positive impact: in fact, at the moment AEM started its operations in Valtellina, the valley was characterized by a rural economy and had a very little developed road system and very little commercial and cultural exchanges. With the construction of AEM plants a rapid development of road system occurred, and, in the sixties, local economy shifted towards an economy based on tourism, mainly from the close municipality of Milano.

Impacts on occupational health: power plant construction

The workers demand for the dams and plants construction has been estimated as 12,500 persons/year; the number of accidents (classified as fatal, minor and major) has been calculated according to INAIL 1995 statistics in constructions category, adjusted for time averaging. Based on a fifty years lifetime supposed for the generation system, which leads to a total production of about 90 TWh, the accident rates reported in Table 5.2 have been calculated.

Table 5.2 Occupational health impacts from construction

Accident category	Accident rate		
	per person-year	total accidents	per TWh
Fatal accidents	0.0003	3.22	0.0022
Major accidents	0.0051	63.89	0.0452
Minor accidents	0.0801	1,001	11.125

Impacts on occupational health: power plant operation

For the system operation about 140 workers are needed.

According to INAIL 1995 statistics in electricity category, adjusted for time averaging, the number of accidents (classified as fatal, minor and major) has been calculated. Based on an annual energy production of about 1.8 TWh, the accident rates reported in Table 5.3 have been calculated.

Table 5.3 Occupational health impacts from system operation

Accident category	Accident rate		
	per person-year	total accidents	per TWh
Fatal accidents	0.00007	0.009	0.0051
Major accidents	0.00087	0.122	0.0680
Minor accidents	0.01668	2.336	1.2976

The damage costs per kWh, reported in Table 5.4, are calculated using the following monetary values:

Fatal accidents		3,100,000 ECU
Major injury	(accidents leading to permanent inability)	95,050 ECU
Minor injury	(accidents leading to temporary inability)	6,970 ECU

Table 5.4 Hydro fuel cycle occupational health impacts

Stage		**fatal accidents**	**major accidents**	**minor accidents**	**total damage**
System construction	Cases/TWh	0.0358	0.7099	11.1246	
	mECU/kWh	0.1108	0.0675	0.0775	0.2560
System operation	Cases/TWh	0.0051	0.0680	1.2976	
	mECU/kWh	0.0159	0.0065	0.0090	0.0313
System dismantling	Cases/TWh	n.q.	n.q.	n.q.	
	mECU/kWh	n.q.	n.q.	n.q.	n.q.
TOTAL	Cases/TWh	0.0409	0.7779	12.4222	
	mECU/kWh	0.1267	0.0739	0.0866	**0.2873**

5.3.3 Summary of results

Table 5.5 summarises the results of the analysis, presenting the valuation estimates for the different priority impacts. As it has been noticed at the beginning of this chapter, the real damage values are probably higher.

Table 5.5 Damages and benefits of the hydroelectric fuel cycle for the AEM hydroelectric system in Valtellina

Stage/Impact category	Damage (mECU/kWh)
Electricity generation	
Construction	
Recreation	ng
Agriculture	ng
Forestry	ng
Commercial fisheries	ng
Ecosystems	n.q.
Cultural objects	n.q.
Occupational health	0.25
Public health	n.q.
Aestethics	n.q.
Operation	
Recreation	0.046
Agriculture (downstream hydrology)	0.086
Forestry	ng
Commercial fisheries	n.q.
Cultural objects	n.q.
Occupational health	0.031
Public health (water quality)	0.069
Ecosystems (fisheries included)	2.737
River morphology	0.095
Aestethics	0.067
Dismantling	n.q.
Transmission	
Construction	n.q.
Operation	n.q.
Dismantling	n.q.

n.q. = not quantified; ng= negligible

6. WASTE INCINERATION

6.1 Definition of the waste incineration cycle, site and technology

6.1.1 The waste disposal constraint and its consequences

As such, energy production by municipal solid waste (MSW) incineration or from landfill biogas may well be regarded as a fuel cycle. Indeed, much of the external impact closely resembles that of fossil fuels, although emissions differ quantitatively and some priority impacts are peculiar. As a consequence, it will be possible to some extent to exploit and adapt the same methodologies and tools that were developed within the ExternE framework for other fuel cycles (notably coal), in particular as regards the “power generation” stage of the fuel cycle. However, there are some peculiarities concerning any technology related to the waste treatment that suggest a different definition of this “fuel cycle” as compared to the approach taken with the other fuels analysed within the ExternE program.

The fundamental peculiarity of these cycles that must be recalled derives from the basic fact that solid wastes are not an economic good, like coal, which is *produced* to be used as an input in the power generation process. They are rather an unessential residue that remains after the completion of any production and consumption activity, and that *must be always disposed of in some way*. Two main consequences derive from these peculiarity, as concerns the definition of the waste incineration fuel cycle. First of all, the evaluation of environmental burdens and their impacts must always be compared with an alternative waste disposal benchmark, so that this "mass constraint" concerning waste disposal is respected. This means that any technology leading to energy recovery form wastes involves important external *benefits,* as well as costs, that would derive from the displaced alternative way of disposing of MSW. Secondly, the processes of waste collection and waste transport to the treatment plant cannot properly be considered as a part of the fuel cycle analysed. In fact, it would be difficult to claim that MSW are transported out of the place of origin *only because* of the need to produce energy from them. The first aim of their transport is rather the need to dispose them of.

According to these statements, the waste incineration fuel cycle analysed has been defined as energy production from a MSW incinerator *against* the alternative waste disposal facility consisting of a landfill with biogas recovery and energy production. Each of the two processes has been analysed using the usual ExternE approach, opportunely adapted to the evaluation problems peculiar to each technology. Once the impacts have been quantified both in terms of costs per kWh produced and costs per tonne of waste disposed of, the analysis has then considered the impact due to the landfill as an avoided cost - i.e. a benefit - of the incineration process.

The "technology" outlined consist therefore of several stages that are listed below; each stage involving externalities that are denoted by symbols in brackets:

- an incineration plant with electricity production (INC);
- a landfill site for incineration residuals (ASH);
- these combined plants allow society to avoid the (external effects of a) landfill site (LFL)
- the landfill biogas is collected and burned, with energy recovery (COL);
- part of the gas cannot however be collected, hence it is dispersed (DIS)

The *net* impact of the waste incineration fuel cycle may be computed in two different ways. A first approach consists of analysing both technologies primarily as *waste disposal* processes. From this viewpoint, the analysis has first of all to estimate their environmental externalities *per unit of waste disposed*; then it has to compute the net external cost by subtracting the landfill's externalities from those due to the incineration process; finally, it has to translate the net cost calculated per unit of waste disposed in a net external cost *per kWh generated*. An alternative way of considering the problem is that of considering both technologies primarily *as an electricity generation* process. According to this perspective, the analysis would have first to quantify the external impact of both processes in terms of cost *per kWh generated*; then it would have to compute the *net* cost of electricity generation by the incineration plant, taking into account the foregone amount of electricity that would have been generated by the landfill. Our analysis will be based on the first approach described.

If we take into account the transport of waste to the treatment plant as well, we may summarize the overall impact coming from the mass burning process as:

$$INC(W) = TRASP(W) + POW(W) + TRASP(ASH) + ASH(W) \quad (1)$$

where

W is the amount of MSW treated;

TRASP stands for the impact due to the transport stage of the treatment;

POW(W) is the impact due to the the power generation stage;

ASH(W) is the damage caused by solid residual disposal (in a landfill), and

TRASP(ASH) indicates the additional impact brought about by the transport of solid residuals of incineration (ashes and slug) to the closest landfill.

The same amount W disposed of through landfill would lead to the following external impact:

LFL (W) = TRASP(W) + LEACH (W)+ COL(W) + DIS(W),
(2)

where LEACH(W) is the damage due to the possible leaching of pollutants contained in the waste, and the variables TRASP, COL and DIS have been explained above.

For reasons discussed below in details (paragraph 6.2), it is reasonable to assume that impacts of MSW disposal in a landfill site are not very different from those concerning the disposal of incineration residuals, with the exception of the biogas production which is either burned or dispersed. So, it can be assumed that, approximately, LEACH(W) = ASH(W). If this equality holds, it looks obvious from (1) and (2) that, when computing the *net* impact, we can neglect the externalities coming from ashes disposal and waste transport to the treatment plant. The statement about transport, however, only holds if the distance between the origin of wastes and the two alternative treatment technologies is the same. Unfortunately, this hypothesis is rarely veryfied in reality, especially when considering waste coming from large and densely populated towns as Milan. In fact, since landfill sites need much larger areas than the incinerator plants, the formers are usually located at a higher distance from the town where wastes are originated. This is why, although we hold that waste transport cannot properly be considered as part of the “waste incineration cycle”, the *differential* impact of transports due to the longer distance of the landfill sites is worth being considered. Obviously, to get the differential damage, the analysis has first to quantify the external costs of transport *per se*, for each technology. The information on these transport impacts and damages per se is reported in paragraph 6.3 (and in the appendix XI, for the incinerator). The reader should however keep in mind, when looking at these results, that according to our fuel cycle definition the most relevant data are those referred to the differential impact rather than those computed in “absolute” terms. These data will be presented and interpreted in the final paragraph.

6.1.2 Definition of the incinerator and landfills locations and technology

The incinerator considered is a new plant, which has not yet been completed. It is located in the western part of the outskirts of Milan, about 10 km far from the storage where waste collected in the town are provisionally disposed before their transport to the treatment plants. Since at the moment there are not “real” emissions from the plant, our analysis has been based on the data provided by AMSA (the local public utility responsible for waste collection and treatment) concerning the future performances of the plant.

The planned plant consists of a grate-type furnace, with secondary combustion chamber and energy recovery. It has a selective non-catalytic reduction (SNCR) emission control system with ammonia injection in secondary combustion chamber and dry-type tail-end system with final bag-house filters for removal of acid gases, particulate matters and toxic micro-pollutants through addiction of hydrated lime and activated carbon.

The waste treated comes from the town of Milan, where separate collection for glass, paper, plastic, cans and organic matter has been introduced since about one year. The average waste calorific power -after separate collection- is around 15000 kJ/kg.

As the alternative location for the waste treatment, the analysis has considered the Landfill of Cerro Maggiore, a small town situated North-West fo Milan, 50 km far from the provisional waste deposit mentioned above. The landfill is provided with facilities for biogas recovery and with a small power plant (Otto-cycle engine) to generate electricity from the gas collected The landfill site has recently incurred a very strong opposition from the local community, and has consequently been closed. It remains, however, highly representative of a typical landfill site dedicated to the waste coming from a large town, and for this reason has been taken as a benchmark for the evaluation of the net external costs of incineration.

For what concerns the transport technologies, in both cases the totality of waste is conveyed to the treatment facility through an heavy duty diesel vehicle, with a capacity of about 15 tonnes per trip. The same transport technology is used as concerns the disposal of solid residuals remaining after the incineration combustion. As the specification of a transport technology requires also details about the driving cycle, as the ExternE – Transport project (1997) has recently illustrated, it has to be added that the analysis considers a lorry going at an average speed of 40 km/h, which is quite typical for streets passing through densely populated areas.

6.2 Overview of burdens and choice of priority impacts

Power generation and waste transport are likely to represent the fuel cycle's stages showing the most considerable impacts, due in both cases to their atmospheric pollution emissions. The impact is expected to be relatively high, and locally significant, because of the high population density in the area considered (the average density within the municipality borders of Milan is of about 8000 inhabitants per squared km; it is obviously lower when considering the further area where the landfill of Cerro Maggiore is located, but it still remains at a level close to 1900 inhabitants per squared km).

Looking at **Table 6.1** (more details can be found in Appendix XI), the contribution of the power generation stage to the overall amount of burdens appears to be overwhelming as compared to that of waste and solid residues (ashes) transport. However, the data presented in this form can be misleading for the reader. In fact, as it will be shown in paragraph "6.3", the amount of damage (in monetary terms) caused *per ton of pollutant* emitted is considerably higher for transport than for the incinerator technology. This is basically due to two main reasons: the height of the emission sources, and the corresponding dispersion pattern of the pollutants. Indeed, contrary to what happens with the incinerator's stack, in the transport case each pollutant is emitted directly at the ground level; moreover, after the emission it remains at rather high concentrations up to quite a short distance (an order of magnitude of 1 km) from the street - where, as concerns urban area, there is a very high number of residents – and then falls sharply to negligible concentration levels.

Table 6.1 Yearly atmospheric emissions of the incineration fuel cycle

Stage	**Emissions (t/yr)**		
	TSP	SOx	NOx
Waste transport	0.15	0.03	1.38
Power generation	5.58	93	372
Ashes transport	0.09	0.02	0.83
Total	*5.82*	*93.05*	*374.21*

The *quality* of atmospheric emissions as regards the incinerator is quite similar to that considered for the coal and lignite fuel cycles. However, there are some relevant peculiarities for what concerns micro-pollutants emissions. The incinerators have been historically seen with hostility because of their possible carcinogenic emissions of dioxins and furans. In spite of this common belief, previous studies (IEFE 1995) on the environmental impact of the municipal solid waste incinerators have shown that, where legal emission standards are fulfilled, their expected damage is negligible as compared to that of the major macro-pollutants: TSP, SOx and NOx. Moreover, the studies have also suggested that, among carcinogenic pollutants emitted by this technology, some heavy metals (e.g. cadmium) cause a much higher risk for human health than that due to dioxins.

The other peculiarities of the waste incineration fuel cycle worth being mentioned involve less easily measurable burdens and impacts. Typically, this kind of technology is strongly opposed by local communities for three main reasons. Firstly, because any waste treatment plant involves an additional, considerable amount of traffic in the surrounding area, which causes noise, additional pollution, congestion, and spreads waste odours around. Secondly, the plant itself is – in particular as regards the landfills – is a major source of unpleasant odours, and usually attracts rats, flocks of birds and various insects – worsening the general hygienic conditions of the area. Finally, the plant may also have a negative visual impact, possibly leading to a decrease in the property values of the surrounding buildings. As it will be better explained in the policy case report, these impacts seem to be high as regards the landfill sites, while they are likely to be less important – although still worth being analysed - for incinerators. Indeed, it must be emphasised that an extreme caution has to be taken when trying to generalise any conclusion taken from a single, site-specific study. The impacts mentioned are, in fact, heavily dependent on local environmental, economic and social conditions that may considerably vary from site to site.

A final specific burden concerning both the alternative waste treatment technologies analysed is that of leachates. The problem of persistant pollutants leaching affects not only the landfill, but also the incinerator, as the solid residues of mass burning are ultimately conveyed to a landfill site, and are therefore possibly responsible for the deriving leachates. Now, while both kinds of leaching (that directly coming from the waste disposed in the landfill, or that caused by the solid residues from the incineration) may be quite serious, the impact *of their difference* is probably much smaller. A large part of the impact derives from contamination of soil and groundwater by heavy metals; but that would happen both in MSW landfill or in a plant for disposal of incineration residuals. In fact, most of heavy metals are confined into the landfill site anyway (as ashes trapped in the electrostatic precipitator, or dispersed in the untreated MSW). There might be some differences as regards the soil contamination impact of the two different leaching sources. These differences are however likely to be less relevant as compared to the those summarised in the previous paragraphs, and hardly worth pursuing if we consider the large difficulties involved therein. Thus, with reference to equations (1) and (2) of paragraph 6.1.1 we assume:

ASH(W) – LEACH(W) $\rightarrow$ negligible.

Therefore, we will not consider this impact when comparing the two technologies.

6.3 Quantification of impacts and damages

The damages of both energy recovery technologies analysed, i.e. the incinerator and the landfill with biogas recovery, are reported separately in **Table 6.3** and in **Table 6.4** as if they were “stand-alone” technologies, giving the damage in terms of mECU/kWh generated. Although this reporting format gives some useful information, and makes possible a comparison with other, more traditional fuel cycles analysed within the ExternE program, we do not consider these results as the most significant to evaluate the fuel cycle as we have defined it. In particular, it seems to be not sensible to analyse the landfill as a technology for energy production per se, without taking into account what is its first traditional aim – i.e. that of waste disposing. For instance, the particular viewpoint represented by **Table 6.4** seems to suggest in fact that it is not worth transporting waste to the landfill in order to produce energy, as the external damage of this stage alone turns out to be at least an order of magnitude higher than that of power generation. The conclusion can obviously change if we admit that the landfill already exists and operates for other purposes, giving electricity production as an *additional* output of its process.

Few results illustrated in the tables below are worth being underlined and commented. Leaving aside for a moment the damage caused by global warming, results show that public health, and in particular mortality, explains most of the total damage for the incinerator case. The same consideration does not hold true for the landfill case, where the “amenities” impact accounts for about 70% of the total (greenhouse gases excluded).

Moreover, the results confirm, once again, what was found in the previous study on the incinerator as regards the damage due to micro-pollutants (heavy metals and dioxins): their external cost, computed in mECU/kWh according to the ExternE methodology, turns out to be negligible as compared to the impact caused by primary and secondary macro-pollutants.

Table 6.2 Damage per tonne of pollutant emitted (in ECU/t)

Stage	**Pollutant damage (ECU/t)**		
	TSP	**NOx (nitrates)**	**SOx (sulphates)**
Incinerator power gen.	50506	13244	10173
Transport	3974280	nq	nq

In addition to that, both tables show how relevant the "transport" stage can be for the fuel cycles analysed. The relevance of this stage will remain considerable even when considering the *differential* impact between the two waste treatment technologies (see **Table 6.5**). As shown in **Table 6.2**, this relevance is more properly underlined when looking at the extraordinarily high data obtained *per unit of pollutant emitted*. According to the results recently found by the ExternE – Transport project, the vast majority of the impact coming from transports falls in a local area – where "local" is referred to a smaller region than the traditional 100 x 100 squared km considered in Ecosense. This means that the result shown below is particularly site-specific, and is heavily influenced by the high population density of the area where waste transports occur. The *local* effects of sulphates and nitrates were not quantified in the ExternE project mentioned, since this analysis requires particularly complex models. It would be on the other hand misleading to report in the table the regional damage only, as quantified by Ecosense, since this accounts for less than 10% of the overall damage. This is why these results were not reported in the table.

Table 6.3 Damages of energy recovery from waste incineration (facility of Milano – Silla)

	mECU/kWh	σ_g
POWER GENERATION		
Public health	26.5	
Mortality*- YOLL *(VSL)*	22.5 (80.6)	B
of which TSP	*0.9 (3.4)*	
SO_2	*3.4 (12.5)*	
NO_x	*17.6 (64.7)*	
NO_x *(via ozone)*	*0.66*	
Morbidity	4.0	
of which TSP, SO_2*,* NO_x	*2.9*	A
NO_x *(via ozone)*	*1.17*	B
Cancer		
Cd	0.026	
PCDD/DF	ng	
Accidents	ng	A

Waste incineration		
Occupational health	nq	A
Major accidents	-	-
Crops	0.56	B
of which SO_2	*0.002*	
NO_x (via ozone)	*0.56*	
Ecosystems	ng	B
Materials	0.25	B
Monuments	nq	
Noise	nq	
Amenity losses	nq	
Global warming		C
(Mid range)		
low	22.3	
upper	57.0	

OTHER FUEL CYCLE STAGES		
Public health	1.65	A-B
Outside EU	-	
Inside EU	*1.65*	
Road accidents	0.25	A
Occupational health	0.47	A
Outside EU	*nq*	
Inside EU	*0.47*	
Ecological effects	ng	B

Road damages		ng	A
Global warming			C
(Mid range)			
	low	0.013	
	mid	0.033	

*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 6.4 Damages of energy recovery from landfill biogas (facility of Cerro Maggiore)

	mECU/kWh	σ_g
POWER GENERATION		
Public health	5.3	
Mortality*- YOLL *(VSL)*	4.5	B
of which TSP	*0*	
SO_2	*0.9*	
NO_x	*3.5*	
NO_x (via ozone)	*0.1*	
Morbidity	0.8	
of which TSP, SO_2, NO_x	*0.6*	A
NO_x (via ozone)	*0.2*	B
Cancer *benzene*	*ng*	
Accidents	nq	A
Occupational health	nq	A
Major accidents (nuclear)	-	
Crops	0.1	B
of which SO_2	*0.001*	
NO_x (via ozone)	*0.1*	
Ecosystems	iq	B
Materials	0.05	B
Noise	nq	
Amenity losses	275	B

Global warming				C
(Mid range)				
	CO2			
		low	78.7	
		upper	201.2	
	CH4		191	
OTHER FUEL CYCLE STAGES				
Public health			95.8	A-B
	Outside EU		-	
	Inside EU		*95.8*	
Road accidents			*14.2*	
			-	
Occupational health			2.9	A
	Outside EU		-	
	Inside EU		nq	
Ecological effects			ng	B
Road damages			ng	A
Global warming				C
(Mid range)				
		low	0.74	
		mid	1.89	

6.4 Summary and interpretation of results

The final step that has to be completed, to interpret our results according to the fuel cycle definition given in the first paragraph, is that of comparing the two technologies – incinerator and landfill – *as waste disposal processes*, giving data in terms of economic value per unit of waste disposed and computing only in a second stage the *net* external impact of the incinerator for what concerns both waste disposal and energy generation. This comparison is made in **Table 6.5**, where all categories of damage estimated are couched in terms of external cost per tonne of waste.

Let us leave aside the greenhouse gases effect, whose uncertainty appears to be much higher as compared to the other damages. The table suggests that, including the evaluation of the *differential* transport costs (which is 3.41 ECU/t in favour of the incinerator) and that of the amenity losses for the landfill, waste treatment through incineration causes still a higher external damage: 26.4 ECU/t versus 18.9 for the latter technology. The conclusion does not change even if we include the global warming effect (taking the upper value of the mid range given for CO2 as a reference point; for CH4, we took the FUND value of 520 ECU/t). In this case, the comparison gives 76.4 ECU/t against 37.7 for the landfill. Looking at the results obtained, the incinerator seems thus to be the most polluting technology. It has to be emphasised, however, that this conclusion has to be taken with much caution. In fact, first of all the evaluations presented have a certain degree of uncertainty. Moreover, the conclusion might change significantly by taking different viewpoints - e.g., if we wanted to consider also the displaced effects resulting from another, different fuel cycle that produces the same amount of energy recovered by the incinerator.

Considering the first comparison mentioned above, we have that the disposal of one tonne of waste by mass burning causes a damage of 26.4 ECU *less* the displaced effect of 18.9 ECU that would have been caused by the alternative disposal: therefore, a *net damage* of 7.5 ECU/t. According to the technology specification of the incinerator analysed (see Appendix XI) this turns out to be the external cost faced to generate 888 kWh. However, we have to take also into account another displaced effect, which is the amount of energy that would have been generated by the utilisation of the biogas recovered from one tonne of waste disposed in the landfill: 48 kWh. The *net* energy production per ton of waste disposed of becomes therefore 840 kWh. With this number, it is finally possible to compute the net external cost *per kWh generated* by the waste incineration fuel cycle, as defined in section 6.1.1: it amounts to 8.9 mECU/kWh. This result is almost three times lower as compared to that obtained considering waste incineration as a technology per se, aimed at energy generation.

Table 6.5 Damages and avoided costs (*per tonne*) of the waste incineration fuel cycle

		MSW Incinerator	**Landfill**
		ECU/t	**ECU/t**
POWER GENERATION			
Public health (mortality and morbidity)		23.69	0.26
	TSP	*1.01*	*0*
	SO_2	*3.39*	*0.05*
	NO_x	*17.65*	*0.19*
	NO_x (via ozone)	*1.62*	*0.02*
	Cd-PCDD/F	0.02	-
	Benzene	-	7.3E-05
Crops		0.49	0.005
Ecosystems		nq	nq
Materials		0.22	0.012
	Monuments	*nq*	*nq*
Noise		nq	nq
Visual impacts		nq	13.2
Global warming			
(Mid range)			
	CO_2		
	low	19.8	3.8
	mid	50.6	9.6

	CH_4	-	9.2
OTHER FUEL CYCLE STAGES			
Public health		1.46	4.60
	TSP	*1.44*	*4.55*
	DME	*0.013*	*0.041*
	SOx	0.003	0.011
Road accidents		0.14	0.68
Occupational health		0.41	0.14
Ecological effects		ng	ng
Road damages		nq	nq
Global warming			
	low	0.011	0.04
	mid	0.029	0.09

*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

7. AGGREGATION

7.1 Comparison of the fuel cycles

The comparison between fuel cycles will be limited to fossil fuels only, because the hydro fuel cycle has different characteristics and a different methodology has been used to calculate external costs.

The results of the two fossil fuel cycles are summarized in Table 7.1. The oil fuel cycle has the higher costs, mostly because of higher emission factors at the power generation stage for all the considered pollutants.

Table 7.1 Comparison between the damages of the two fossil fuel cycles

	mECU/kWh	
	Gas fuel cycle	**Oil fuel cycle**
POWER GENERATION		
Public health		
Mortality*- YOLL	5.5	15.3
of which TSP	*ng*	*1.4*
SO_2	*ng*	*9.7*
NO_x	*5.3*	*4.1*
NO_x *(via ozone)*	*0.18*	*0.23*
Morbidity	0.99	2.3
of which TSP, SO_2, NO_x	*0.67*	*1.9*
NO_x *(via ozone)*	*0.32*	*0.41*
Occupational health	0.012	9.3E-3
Crops	0.15	0.27
of which SO_2	*1.2E-3*	*0.072*
NO_x *(via ozone)*	*0.15*	*0.20*
Materials	0.047	0.25
Global warming (Mid range)	7.86 - 20.0	12.5 - 31.9

	mECU/kWh	
	Gas fuel cycle	**Oil fuel cycle**
OTHER FUEL CYCLE STAGES		
Public health	0.058	1.6
Occupational health	0.087	0.45 - 0.50
Global warming (Mid range)	0.26 - 0.55	1.45 - 3.68

*Yoll= mortality impacts based on 'years of life lost' approach
ng: negligible; n.q.: not quantified; iq: only impact quantified; - : not relevant

Results are also site dependent: the plant location influences results because of different meteorological parameters, different background emissions and concentrations of all the pollutants, and even more because of different receptors distribution: a plant causes different damages if placed in a rural site rather than in an urban area. Moreover, in the case of the italian oil fuel cycle case study, the plant is located at the border of the calculation grid, so that a part of the damage has probably been neglected. This appears clearly if we consider the damage specific to a unit emission of each pollutant (mECU/g of pollutant), as reported in Table 7.2. The value for NO_x for the gas power plant is about 60% higher than the one for the oil power plant. Since this parameter is almost independent from the technology, the difference between the two case studies is due to the different location only.

Table 7.2 Damages by pollutant

	ECU / t of pollutant	
Pollutant	**Gas fuel cycle**	**Oil fuel cycle**
SO_2 *- YOLL	-	9,700
NO_x *- YOLL	13,500	8,300
PM_{10} *- YOLL	-	12,300
NO_x (via ozone)	1,500	1,500
CO_2 (Mid range)	18 - 46	18 - 46

*YOLL= mortality impacts based on 'years of life lost' approach; VSL= impacts evaluated based on 'value of statistical life' approach.

In order to eliminate these differences and make a comparison which considers only the technical characteristics of the two power plants, a simulation has been carried out with the oil power plant situated in the same location of the gas power plant. The results are summarized in Table 7.3. As it can be seen, the differences between oil and gas are even more than the first results had shown: damages from the oil fuel cycle are about three times those from the gas fuel cycle.

Table 7.3 Comparison between the damages of the two fossil fuel cycles with the power plant in the same location

	mECU/kWh	
	Gas fuel cycle	**Oil fuel cycle**
POWER GENERATION		
Public health		
Mortality*- YOLL	5.5	18.4
of which TSP	*ng*	*1.6*
SO_2	*ng*	*10.9*
NO_x	*5.3*	*5.8*
NO_x (via ozone)	*0.18*	*0.23*
Morbidity	0.99	2.7
of which TSP, SO_2, NO_x	*0.67*	*2.3*
NO_x (via ozone)	*0.32*	*0.41*
Occupational health	0.012	9.3E-3
Crops	0.15	0.26
of which SO_2	*1.2E-3*	*0.059*
NO_x (via ozone)	*0.15*	*0.20*
Materials	0.047	0.24
Global warming (Mid range)	7.86 - 20.0	12.5 - 31.9
OTHER FUEL CYCLE STAGES		
Public health	0.058	1.6
Occupational health	0.087	0.45 - 0.50
Global warming (Mid range)	0.26 - 0.55	1.45 - 3.68

*Yoll= mortality impacts based on ‘years of life lost’ approach
ng: negligible; n.q.: not quantified; iq: only impact quantified; - : not relevant

7.2 Quantified description of the national energy sector

7.2.1 Energy balance 1995

In 1995, after the little decrease of 1993 and 1994, energy demand in Italy increased and reached 171.1 Mtoe (+4% with respect to 1994), while consumption for final uses was 125.8 Mtoe (120.9 Mtoe in 1994) (AEM, 1996).

National production from primary sources contributed to the coverage of internal needs by 19.1%, with a decrease of 3.2% with respect to 1994: the decrease was due to a lower production of natural gas (-1.8%), and to a strong decrease of primary electricity (-10.9%) due to a bad water availability that had negative effects of hydroelectric production.

The composition of gross internal consumption was very similar to the one of 1994: 56.6% of petroleum, 26% of natural gas, 10.3% of primary electricity (hydro and geothermal), 7.9% of coal.

The increase of the overall energy demand for final uses (+4%) was mainly due to the increment of industrial activities (+4.2%) and of transport sector (+3.45%): consumption for non energetic uses (chemical transformations) increased by 4%. Civil uses had an increment of 4.9% with respect to 1994.

The synthetic energy balance in Italy in 1995 is reported in Table 7.4

Table 7.4 Energy balance in Italy in 1995

Availability and uses			**1995**		
	solid fuels	natural gas	petroleum	Electric energy [a]	Total
1. Production	1.4	16.4	5.2	9.8	32.8
2. Import	13.0	28.6	107.7	7.8	157.1
3. Export	0.1	-	17.0	-	17.1
4. Stock variations	0.7	0.2	0.6	-	1.5
5. Gross internal consumption (1+2-3-4)	13.6	44.8	95.3	17.6	171.3
6. Consumption and losses energetic sector [b]	(1.0)	(0.5)	(6.1)	(37.9)	(45.5)
7. Transformation in electricity	(6.3)	(9.2)	(25.5)	41.0	-
Total final uses (5+6+7)	**6.3**	**35.1**	**63.7**	**20.7**	**125.8**
of which					
industry	5.0	15.3	6.7	10.4	37.4
transport [c]	-	0.2	38.4	0.5	39.1
other energetic uses [d]	1.1	18.7	9.3	9.8	38.9
non energetic uses	0.2	0.9	6.9	-	8.0
bunker	-	-	2.4	-	2.4

a) Primary electric energy (hydro, geothermal and thermoelectric) and import/export are evaluated at thermoelectric input of 2200 kcal/kWh (average effective consumption in thermoelectric plants)
b) For electric energy was used the conventional conversion coefficient of 860 kcal/kWh. The differences between the conventional coefficient of 2200 kcal/kWh and 860 kcal/kWh, are included in line "6 Consumption and losses in the energetic sector"
c) This include the consumption for the transports of Public Administration
d) This include consumption from domestic sector, commerce, services, public administration and agriculture

7.2.2 Production and consumption of electricity in 1995

The net national production in 1995 was 223.7 TWh (+3.6% with respect to 1994) of which 78% was produced by ENEL. Net production was determined by 17.3% by hydroelectric power - 41.9 TWh (-12.2%) - and by 82.7% by thermoelectric power with 199.7 TWh (+8.5%). Consumption for final uses were 243.4 TWh (+2.9% with respect to 1994).

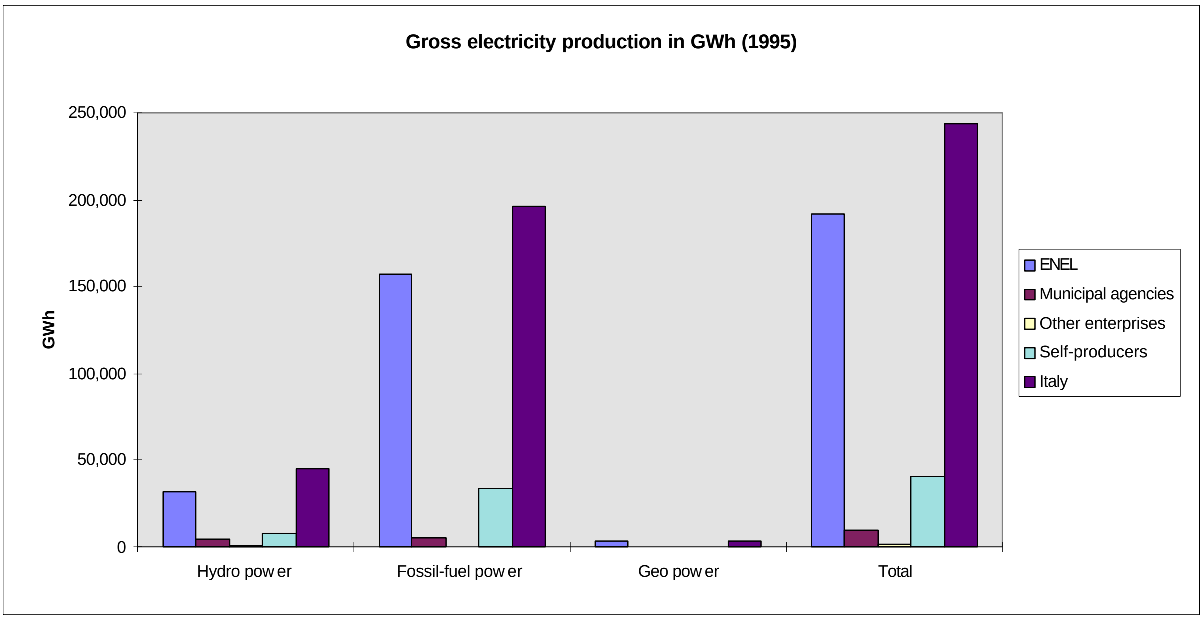

Figure 7-1 Gross electricity production in Italy in 1995

The total demand of electric energy in Italy in 1995 was 261.1 TWh, with an increment of 3% with respect to 1994. The electricity demand was driven by consumption for industrial uses, associated with a more limited increase of civil uses (Table 7.5 and Table 7.6). The demand of electric energy was covered by 92.5 % by national production, which increased of 4.2% with respect of 1994, and for the remaining part from the import/export balance, that had a decrease of 0.5%. The whole increment of electricity demand (7.5 TWh) was covered by an increase of national production (+7.7 TWh) and this allowed for a reduction of import.

Table 7.5 Balance of coverage of electric energy in Italy (TWh)

	1995 [(a)]	1994	95/94 (var. %)
Gross production			
Hydroelectric	41.9	47.7	-12.2
Thermoelectric	199.7	184.1	8.5
1. Total gross production	**241.6**	**231.8**	**4.2**
2. Electricity requirements for production services	12.3	11.6	6.0
3. Electricity requirements for pumping	5.6	4.2	33.3
4. Balance import-export	37.4	37.6	-0.5
5. Electric energy on the network (1-2-3+4)	**261.1**	**253.6**	**3.0**

(a) ENEL elaboration

Table 7.6 Consumption of electric energy in Italy (TWh)

	1995 [(a)]	1994	95/94 (var. %)
Consumption			
Agriculture	4.5	4.7	-4.2
Industry	129.8	124.2	4.5
Civil uses	57.3	57.0	0.5
Tertiary	51.8	50.6	2.4
1. Total consumption's	**243.4**	**236.5**	**2.9**
2. Losses	17.7	17.1	3.5
3. Electric energy demand (1+2)	**261.1**	**253.6**	**3.0**

(a) ENEL elaboration

7.2.3 The thermoelectric sector

As remarked above, 82.7% of electricity production in Italy in 1995 was produced by thermoelectric power. At the end of 1995 over 600 thermoelectric plants were installed

The efficient gross power installed in thermoelectric power plants by fuel type is summarized in Table 7.7.

Table 7.7 Efficient gross power installed in thermoelectric power plants by fuel type

Fuel type	**Efficient Gross Power (MW)**
Monofuel plants	
oil	19,418
gas	1,937
coal	20
others	154
Total	21,529
Bifuel plants	22,503
Multi-fuel plants	3,261

Table 7.8 shows the thermoelectric energy produced in Italy in 1995 by technology and type of fuel: more than 90% of electricity produced by the thermoelectric sector was produced in

conventional steam turbines plants (60% with oil, 12% with solid fuel, 17% with gas); natural gas was used in significant percentages also in gas turbines plants (2%) and in combined cycle plants (4%).

Table 7.8 Thermoelectric energy produced in Italy in 1995 by technology and type

	Internal combustion	Gas Turbine	Steam Turbine	Combined cycle
Gas	0.19%	2.06%	17.17%	4.30%
Solid fuels	0.00%	0.00%	12.32%	0.00%
Oil	0.24%	0.25%	60.36%	0.85%
Others	0.04%	0.01%	2.20%	0.01%

A final point concerns the dimension of the plants: Table 7.9 reports the efficient gross power installed in thermoelectric power plants by technology and facility size. More than 70% of facilities installed are over 100 MW and the percentage of small unit is extremely low.

Table 7.9 Efficient gross power installed in thermoelectric power plants by technology and facility size

	Internal combustion	Gas Turbine	Steam Turbine	Combined cycle
up to 25	0.7%	0.0%	0.0%	0.0%
25-50	0.0%	2.1%	7.9%	0.6%
50-100	0.0%	3.7%	7.5%	0.9%
over 100	0.0%	3.4%	72.7%	0.5%

7.2.4 Hydroelectric sector

Hydroelectric production in Italy represents the main resource for power regulation in the national electric network. Hydroelectric production in Italy was born in the first decades of this century thanks to the incentives to the investments in internal energetic resources, to a favorable hydrographical and hydrological situation of the territory and to socio-economical conditions of industrial liberism that are in favor of the birth of private companies for hydroelectric production.

In a first development phase, the construction of hydroelectric power plants, both storage projects and run-of-the-river projects, was aimed at satisfying the increasing consumption, with demand largely lower than the available power. In a second phase, after the second world war, the hydraulic resource was deployed to a level close to its economic convenience, while the availability of low price fossil fuels moved the investments toward thermoelectric production for base load coverage, while hydroelectric plants were used for peak-shavings purposes.

In the seventies and eighties, after the establishment of the national electricity board (ENEL) in 1962, there were incentives to thermoelectric production by using funds coming from taxes imposed on energy distributed over the national territory (“cassa conguaglio”): this lead to a distortion of energetic market, unique in the European context, that is in favor of thermoelectric production.

Towards the end of the eighties, a partial correction of this distortion occurred, thanks to the development of a culture based on the quality of the service provided, with a correct coverage of load and the guaranty of the continuity of the service: this lead to an increased attention towards hydroelectric plants because of their capacity of regulation.

The characteristics of the italian scenario of hydroelectric production can be summarized as follows:

- the available resources have already been almost completely exploited before the sixties, with the construction of all the plants economically convenient. The only plant under construction today is the one of Pont Ventoux-Susa in Alta Val di Dusa (municipality of Torino, Piemonte);
- the existing plants are in general beyond the half of their technical life, and require now maintenance and refurbishment interventions;
- the development scenario was conditioned by specific legislative measures;
- hydroelectric production is now used mainly for power regulation and emergency, while thermoelectric production is aimed at covering the base load;
- the sensitivity toward hydroelectric plants has evolved together with an increased attention toward ecological aspects and issues related to the improvement of life-quality. From a sensibility toward the aspects related to economic development of the territory and of

transport systems induced by investment for hydroelectric plants construction, we witnessed an increased attention toward the multi-uses of water resources, the environmental and hygienic issues of rivers, the issues related to the safety of the territory, the principles of sustainable development and optimal use of water. This increased attention lead to a reform of legislation on the subject and to an increased burden of authorization procedures, both for the construction of new plants and for the modifications and refurbishment of already existing structures;

- in the medium term, with the completion of the privatization process of the energy market and with the entrance of new capitals, an upturn in the hydroelectric sector is likely to occur, with new initiatives such as the refurbishment of existing plants, the construction of small plants in particularly favorable conditions, the construction of pumping plants.

Power installed and electricity production

In 1995 the overall efficient gross power installed in hydroelectric plants was 20.072 MW (+0.5% with respect to 1994) of which 82.5% in ENEL plants, 6.0% in municipalities plants, 9% in self-producers plants. At the end of 1995 1883 hydroelectric plants were in operation in Italy, 1085 of which with an efficient gross power lower than 1 MW (see Table 7.10).

The overall gross electricity production in 1995 was 41.906 GWh, corresponding to 17.3% of the national electricity production. Hydroelectric plants in Italy can be classified into three categories: plants with a reservoir with a retention time higher than 400 hours, plants with modulation basins with a retention time lower than 400 hours and higher than 2 hours, run-of-river plants without reservoir or with a reservoir with a retention time lower than 2 hours.

Table 7.11 reports the gross electricity production from hydroelectric plants by geographical areas (north, center, south) and category of plants in 1995. As one can see the production is equally distributed among the three different categories.

Table 7.10 Gross efficient power (MW) of hydroelectric plants in Italy in 1995

Class	Plants	Efficient gross power
over 200	16	7,661
from 100 to 200	22	3,017
“ 50 “ 100	29	1,914
“ 30 “ 50	61	2,432
“ 20 “ 30	56	1,411
“ 10 “ 20	104	1,488
“ 5 “ 10	130	938
“ 1 “ 5	380	851
less than 1	1,085	360
total	1,883	20,072

Table 7.11 Gross electricity production from hydroelectric plants in Italy in 1995 (GWh) by geographical areas and category of plant.

Gross production in GWh			
Geographical areas			
Type of plant	natural	pumping	total
Northern Italy			
reservoir	8,292	2,943	11,235
basin	11,261	14	11,275
run-of-river	12,012	1	12,013
total	31,565	2,958	34,523
Central Italy			
reservoir	344	3	347
basin	1,942	6	1,948
run-of-river	997	-	997
total	3,283	9	3,292
Southern Italy			
reservoir	1,068	1,158	2,226
basin	1,006		1,006
run-of-river	859		859
total	3,283	1,158	4,091

7.3 Aggregation methods

The purpose of the Aggregation Task is to propose a methodology for the aggregation of marginal damages derived from individual power plants to the level of the whole system. Since the preferred approach entails the use of a version of Ecosense that is not available at the moment, the present note suggests a possible way of calculating the externalities for the whole Italian country, using the marginal values obtained with Ecosense. Since Ecosense allows one to estimate the marginal damages associated with the power production phase only, even the aggregation phase will focus on this stage of the fuel cycle, which is, in terms of emissions, the most significant for almost every pollutant.

7.3.1 Global damages

In order to compute the damages derived from the emission of greenhouse gases, the values derived from the IPCC (1996) have been used. These values are the following: 3.8-139 ECU/t of CO_2, 520 ECU/t of methane and 17,000 ECU/t of nitrous oxide. A mid range of 18 to 46 ECU/t of pollutant (with a discount rate of 3% and 1% respectively) has been considered for CO_2. Damages are site independent and therefore these values are valid for all emissions.

To convert damage values in ECU/t to the total electricity sector damage, it is necessary to multiply by the specific emissions from the power sector in tons. Emissions have been taken from national statistics for the whole power sector (upstream fuel cycles emissions should ideally be added, but these are a second order correction at least for carbon dioxide).

As far as the electricity production stage is concerned, the base year for the calculations is 1990, for which CORINAIR data are available for Italy (Table 7.12)

Table 7.12 Emissions in Italy from LPS

Pollutant	Total emission (t)
CO2	1.05E+08
methane	3,591
nitrous oxide	16,356

As for the other stages, the only significant emissions are those of methane coming from the natural gas transport sector. Considering that in 1994, 6,531 kt of natural gas were used for electricity production, the total quantity of gas methane emissions from gas transport activities were roughly 6,500 t (the ratio methane emissions/methane transported is 0.001, i.e. 1‰).

7.3.2 Regional damages

The regional scale damages, that is those due to SO_2, NO_x and TSP emissions, have been derived by aggregating from the fossil fuel power plant analyzed. These damages include only those damage categories that were valued during the single plant analysis: for this reason the total quantified damage exclude impacts to forests, fisheries, natural ecosystems and buildings of cultural value, for which no reliable dose-response functions or valuation techniques were found.

To assess total damages due to national emissions from the electricity sector, the specific damages for each pollutant (ECU/t) were multiplied by the national electricity sector emissions. National emissions were taken from national statistics for these emissions (Corinair, 1990). This approach assumes that the reference power plant values are transferable within the country. For low stacks there may actually be significant site sensitivity, especially for particulates emitted in an urban environment. However, for high stacks the sensitivity might be small, as the range of these pollutants exceeds the size of all European countries. The approximation should be therefore reasonable for the electricity sector where high stacks predominate.

This is not true in the case of Italy, because the country is stretched along the north-south direction and it is surrounded by the sea. This was also confirmed by the analysis reported in paragraph 7.1. For this reason the proposed approach is based on a sensitivity analysis performed on different sites throughout the country. In order to limit the number of simulations in different locations, the Italian territory has been divided into seven sectors considered as homogeneous, according to geography, morphology and industrialization; for each of them a location has been selected and a power plant has been placed. The selected locations are industrial areas with a high concentration of power plants. The locations of the sites and their area of influence are shown in Figure 7-2.

A simulation with Ecosense was carried out with a reference plant (e.g. oil fueled vapor turbine power plant, which is the most representative in Italy) in each of the seven locations, and the damage (in mECU/g) was calculated for each pollutant and for each site (Table 7.13).

Figure 7-3 reports the reduction of damage with respect to the site with the highest value (considered as the reference location).

Emissions from the electricity sector were taken from CORINAIR (1990) as far as SO_2 and NO_x are concerned. As for TSP, emissions data are not included in the CORINAIR database: TSP emissions were then estimated from fuel consumption for thermoelectric power generation, taking 1994 as reference year.

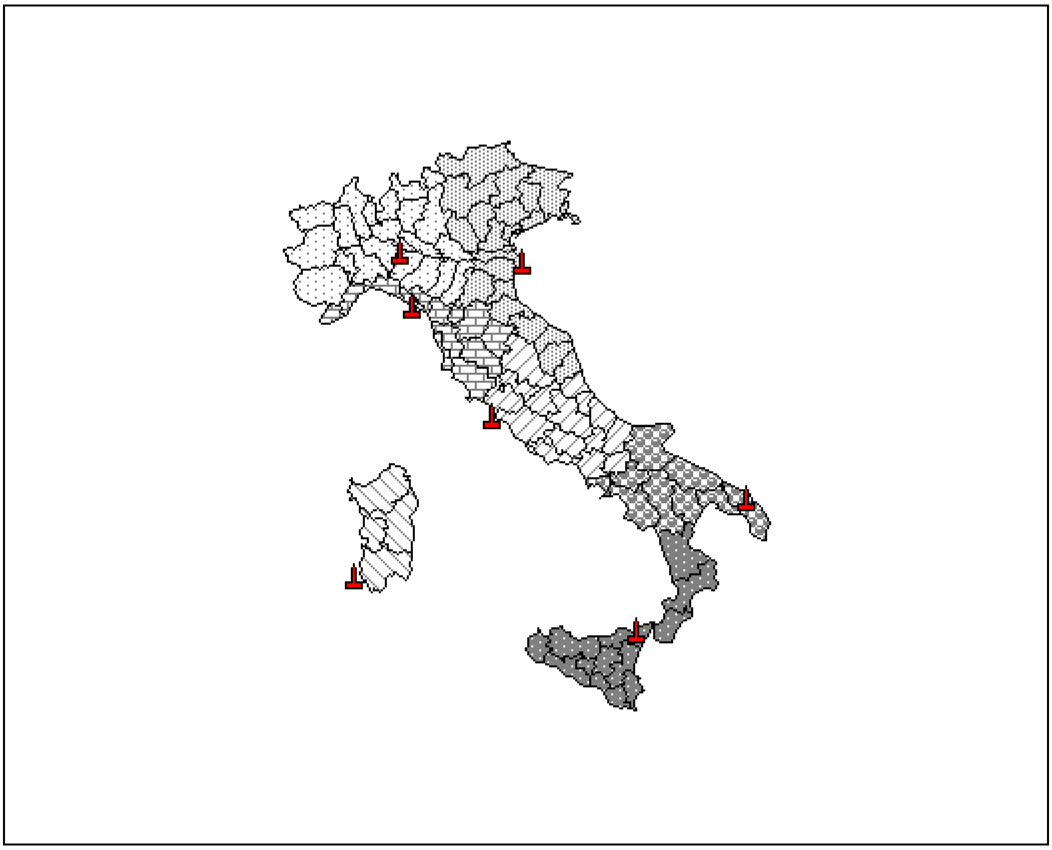

Figure 7-2 - Sites chosen for testing the hypotheses of spatial transferability of results

Table 7.13 - Damage (mECU/g) for each pollutant and for each site.

Pollutant	Piacenza	Brindisi	Cagliari	Civitavecchia	La Spezia	Messina	Porto Tolle
NOx	11.4	5.8	6.2	8.1	10.2	4.6	8.4
TSP	20.7	8.2	5.7	9.2	11.4	6.1	11.0
SO2	12.0	6.9	7.2	8.7	9.8	5.7	9.5

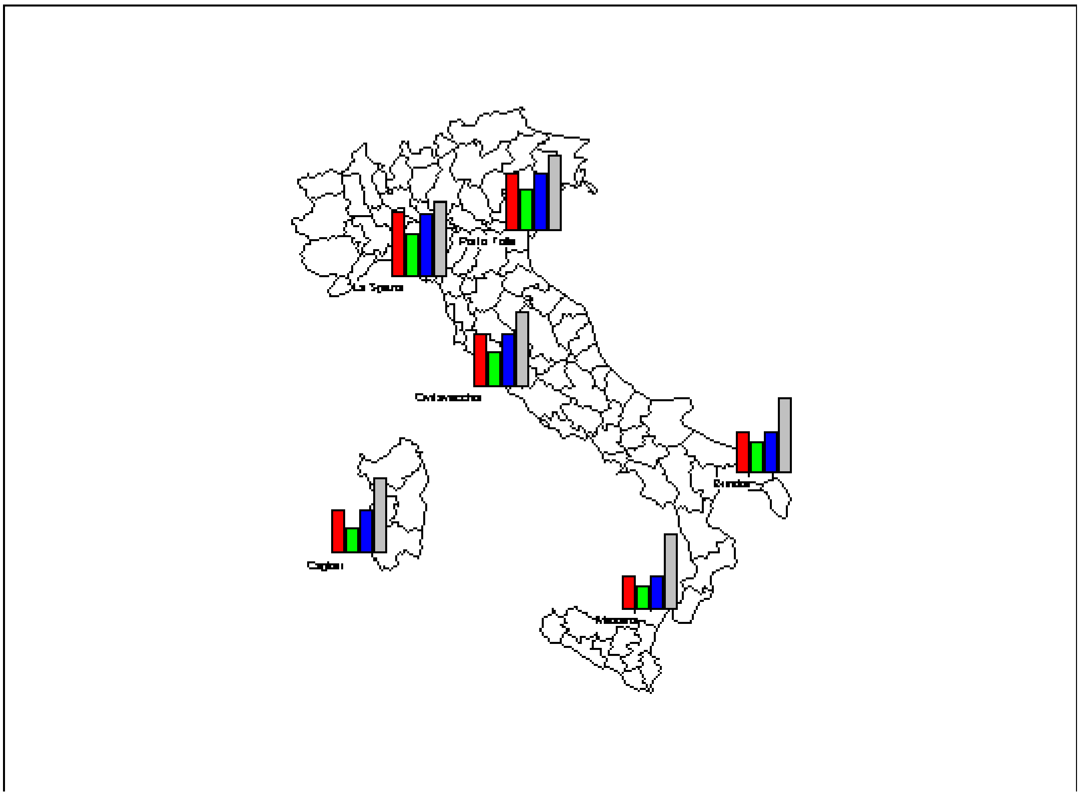

Figure 7-3 - Reduction of damage with respect to the site with the highest value (Piacenza)

7.4 Results

7.4.1 Global damages

The minimum and maximum values of the global damages resulting from the electricity sector in Italy are reported in Table 7.14.

Table 7.14 Global damages (MECU) for the whole Italian electricity sector (electricity production stage only).

Pollutant	Min.	Max.
CO_2 - low - high	399	14,595
CO_2 - mid 3% - mid 1%	1,890	4,830
Methane	1.87	
Nitrous oxide	278	

As for damages associated with yearly emissions of methane from the natural gas transport stage, limited to natural gas used for thermoelectric power production only) the value of the global damage is about 3.38 MECU.

As one can see the global damage due to methane emissions during the natural gas transport phase is comparable with the global damage due to methane emissions at the power production stage (see Table 7.14).

7.4.2 Regional damages

The regional damage associated with national emissions was obtained summing up the damages computed for the seven sectors (Table 7.15).

Table 7.15 Regional damage due to the electric sector in Italy

Pollutant	Piacenza	Brindisi	Cagliari	Civitavecchia	La Spezia	Messina	Porto Tolle	Total
NOx	676	253	134	521	796	271	582	3,233
TSP	43	55	26	13	330	8	205	680
SO2	1,463	391	479	1,404	1,323	427	1,394	6,881
	2,182	699	639	1,938	2,449	707	2,180	**10,794**

The total value of the damage, obtained by adding global damage to the regional one, ranges from about 13,000 to about 16,000 MECU/y (Mid range), which corresponds to about 1.4% to 1.7 of the Italian GDP of 1995.

8. POLICY CASE STUDY: DEFINING THE ROLE OF SOLID WASTE INCINERATION AS A MEANS OF ENERGY PRODUCTION AND WASTE DISPOSAL IN A LARGE URBAN AREA

8.1 The solid waste problem in Milan

The municipality of Milan, the second Italian city with 1.3 million inhabitants, has been generating increasing amounts of solid wastes. Between 1980 and 1995 municipal solid wastes (MSW) collected by AMSA, the local waste and sanitation utility, have increased from 531,700 to 731,800 tonnes/year, an average rate of 2.1%, despite a slightly diminishing population. Consumption habits and an ever increasing flow of commuters working in the city (up to 800,000 during the day) are the main explanation for this fact. The share of combustible materials has also been steadily increasing (the actual composition of solid wastes in Milan is given in Appendix XI).

In latest years, solid waste generation seems to be stabilising. However, disposal problems have dramatically worsened, notably in the Nineties, and have led to several "waste emergency" situations where no disposal options appeared to be available shortly afterwards. These conditions have often hit the headlines and triggered emergency policies, including the National Government intervention and the appointment of special commissioner with large powers.

The waste disposal system in Italy has always been based mainly on landfilling. The role of other options like sorting/recycling and incineration increased slowly until the end of the 1970's, but public concern about dioxin emission after the 1976 Seveso accident led to the closure of most plants. The new 1982 waste act (Presidential Decree n. 915/82) set tougher environmental standards and outlawed most of existing incinerators and sorting plants, which had to be renovated. This process was however very slow, as regards incinerators, due to both financial difficulties and the increasing public opposition; on the other hand, sorting and recycling did not appear economical at the time. As a consequence of these difficulties, the share of landfilling within municipal solid waste (MSW) disposal increased to above 90% nationally and has not fallen below this threshold since.

However, the landfill option has never been available to such extent in Milan. The city is situated in a densely populated area where it is not easy to find suitable areas. Therefore, incineration has locally played a larger role than it did at the national level: it already amounted to 33% of the waste in 1980, but later suffered from the same problems described above and had to undergo a burdensome restructuring. Its share dropped to 17% in 1985 and later recovered to 21% in 1995.

Recycling, now mainly based on citizens' sorting and separate collection, slowly rose from 2% in 1985 to 10% in 1995, driven by national policies aimed at selected fractions. It started from glass, exhausted batteries and expired drugs and later spread to paper and cardboard, aluminium and plastic bottles, tyres, wood.

Remarkable opposition in the interested suburbs hampered further expansion of both incineration and sorting plants, so that incremental MSW flows headed for the few landfill sites available in the province, despite increasing landfilling costs. The average disposal cost skyrocketed from 8 liras/Kg before the 1982 Act to 43 in 1985, 101 in 1990 and 126 in 1995. In fact, a 1989 regional law allowed more room for private undertakings in the development of landfills and this led to the opening of several sites, including a large one at Cerro Maggiore, 25 Km MW of Milan, in the last area of the province where some dismissed quarries could be used for waste landfilling. Note that waste disposal outside the province is hardly acceptable to local populations, involves higher trucking costs and is now banned as a normal practice by EU directives as well as by the new (1997) Waste Act (Decree 22/97).

The Cerro site has been receiving up to 2800 tons/day for about five years, not only from the city of Milan but from the rest of the province as well. The province of Milan has over 3.7 million inhabitants over a surface area of nearly 2000 Km^2, and includes most of the largest Italian conurbation, estimated at 5.2 million people. It is therefore among the most densely populated areas in Europe.

Increasing annoyance of people living in the neighbourhood of the site has exploded during 1995, as Lombardy's new regional administration was about to grant authorisation for a further extension of the plant activities. A long blockade of the landfill triggered a new waste emergency in Milan and AMSA, the solid waste authority, had to delay street collection for a few days.

The results of several months of sharp debates and the intervention of municipal, regional and even national government can be summarised as follows:

1. an extensive recycling system was to be set up in order to bring recycling to over 30% of Milan generated MSW;

2. the Cerro landfill site was to be closed down by the end of 1996;

3. the existing 460 tonnes/day incinerator "Silla" in the suburb of Figino was to be rebuilt and its capacity almost doubled to nearly 900 tonnes/day, while the smaller and recently refurbished "Zama" plant (390 t/d), located in the south-east of the city would continue operations;

4. in the short run, a treatment called "waste trituration" would allow their disposal in other landfills outside the province, although at higher costs.

The recycling system is based on generalised sorting by citizens, who are requested to dispose of their wastes by four to five different channels; sorting criteria differ in the central areas of the city and in the outskirts. Sorted materials are partly transferred to recycling industries and partly treated in a further selection plant, while another is under construction.

8.2 The case study

It is beyond the scope of this case study any analysis of the desirability of recycling in general or of the ways it is pursued in Milan. It probably involves significant external costs as citizens' burden, space occupation, disamenities and water pollution of the selection plants. However, there is general (although not unanimous) agreement that combined private and external costs of recycling up to a certain extent should be lower than those of both landfilling and incineration. Thus, we take for granted the increase in recycling and do not further deal with this option.

Likewise, we do not question or analyse any emergency policy adopted for the immediate solution of the MSW disposal problem in Milan.

The goal of the present paper is instead an assessment of the decision summarised by points (2) and (3) in paragraph 8.1, namely the closure of the landfill site and the substantial replacement of its role by a new, larger incinerator equipped with energy recovery.

The policy plan, as outlined above, does not involve exact replacement of the lost landfill capacity by incineration. Note however that the existing Silla plant would have to be reconstructed or dismissed anyway within a few years. For both simplicity and generality we decided to consider an entirely new plant, and to analyse by comparison with the hypothesis that the Cerro landfill site would be authorised to take the same amount of wastes. Intermediate solutions could be largely analysed by interpolation as most results are linearly related to emissions. The consequences of some non-linear relationships will be discussed in section 8.3.

8.2.1 Analysis of externalities: locations, technologies, impact pathways.

The construction of the new incinerator has been lately auctioned off by AMSA. It will be a Grate type furnace with secondary combustion chamber and energy recovery. The emission control system will include selective non catalytic reduction (SNCR) with ammonia injection in secondary combustion chamber and dry type tail-end system with final baghouse filter for removal of acid gases, particulate matters and toxic micropollutants through addiction of hydrated lime and activated carbon.

Energy production may consist of both heat and electricity but an all-electric assumption has been considered as heat recovery is far from certain. The plant will be located in the same site of the old incinerator, in the suburb of Figino, a partially rural area about 8 Km NW of the city centre.

For comparison with the landfill option, it ought to be recalled that incineration achieves a 70% reduction of MSW by weight and a 90% reduction by volume, but bottom ashes and exhausted air pollution containment devices must still be disposed of in landfill site. While a final decision on this point has not yet been taken we assume for comparability that such site is still the same (Cerro) which is assessed in the next section. Note however that only transport externalities are actually evaluated for this stage of the cycle, therefore any landfill site in the area and at similar distance would yield similar results. More remote sites would yield higher transport external costs but at decreasing rate, as transport would probably occur through less populated areas.

Table 8.1 Technical and emissions data of the new Milan MSW incinerator

Waste incineration capacity (average)	t/d	900
Solid residues	t/d	270
No. of lines		2
Stack diameter	m	3
Full load hours	hrs/y	7440
Stack height	m	100
Flue gas temperature	°K	393
O_2 in flue gas (min.)	%	11
Actual flue gas stream	Nm^3/h	250,000
Net calorific value of waste	KJ/Kg	15,000
Net electricity output	MW	33.3
Maximum hourly emissions:		
PCDD/DF (TEQ)	ng/Nm^3	0.05
Cd + Tl	mg/Nm^3	0.05
Hg	mg/Nm^3	0.05
HCl	mg/Nm^3	10
SO_x (as SO_2)	mg/Nm^3	50
NO_x (as NO_2)	mg/Nm^3	200
CO	mg/Nm^3	50
TSP	mg/Nm^3	3
Pb+Cr+Cu+Mn+Ni+As+Cd+Hg	mg/Nm^3	2
Sb+As+Pb+Cr+Co+Cu+Mn+Ni+V+Sn	mg/Nm^3	0.5
HCN	mg/Nm^3	0.5
P_2O_5	mg/Nm^3	5

Technical and environmental characteristics of the winner bid are given in Table 8.1. The calorific value of the waste of over 15,000 KJ/Kg may appear relatively high, but it is justified by the fact that MSW burnt are already stripped of large part of their water content as well as other inert matter (glass, metals) by previous sorting activities.

The main impact pathways are found in **Table 8.2**, as developed by IEFE within Core and Maintenance ExternE research projects, to which the reader is referred for discussion. All impacts of air pollution are dealt with by Ecosense 2.0. All ExternE values are accepted.

Table 8.2 Burdens and impact pathways for the new Silla incinerator

BURDEN/ POLLUTANT	MEDIUM	RECEPTOR	IMPACT
TSP	air	Public health	Mortality, Morbidity
Acidic aerosols	air	Public health	Mortality, Morbidity
TCDDeq, Cd	air	Public health	Mortality
HCl	air	Public health	Morbidity
Ozone	air	Public health	Mortality, Morbidity
Construction	work	Workers	Accidents
CO_2	air	World	Global warming
SO_2	air	Agriculture	Crop damage
Ozone	air	Agriculture	Crop damage
SO_2, acid. dep.	air	Buildings	Materials corrosion
Acid. Deposition	air	Forests	Acidification
Visual impact	amenity	Residents	Property value loss
Ashes transport	Air	Public health	Mortality, Morbidity
Ashes transport	Accidents	Public health	Mortality, Morbidity

It would be desirable a more complete assessment of disamenities suffered in the neighbourhoods of the plant, mainly from traffic of collection trucks and odours from temporary storage of waste. A suitable study could not be performed within the scope of this case study, but analysis of disamenities of another incineration plants near Busto Arsizio (about 20 Km NW of Milan) by hedonic pricing did not reveal any value loss of property as related to distance from the plant.

As regards other, potentially relevant impact pathways of ashes disposal (in a landfill) and other solid incineration residuals, the main one is related to risks of leakages through bottom liners polluting the soil and water table. However, these impacts are not assessed for several reasons. First, impacts should be negligible as the risk of such leakages is small for modern landfill technologies. Second, their assessment is hardly pursued by impact pathway methodology due to the large data requirement required to track pollutants' pathways. Third, such impacts should be similar for an ashes and a MSW landfill site, since the most feared soil and water pollutants (heavy metals) are found in both sites: amid heavy metals, only a small proportion of cadmium and a slightly larger share of mercury contained in MSW are dispersed through the atmosphere. Fourth, some impacts, like those of leachate collected at the site are not only similar but also mostly internalised by landfill regulations.

It is remarkable that modern isolation practices of sanitary landfills have triggered higher landfill gas generation rates than previously experienced. Part of the groundwater and soil impact has therefore been turned to the atmosphere and is therefore included in our estimates.

Turning to the alternative option, represented by the Cerro landfill site for direct disposal of solid wastes, less actual data are available as its further use has hardly been considered. We assume it to be equipped with a biogas collection system and Otto cycle, diesel engines for energy recovery. Technical and emission data are given in **Table 8.3.**

Table 8.3 Technical and emissions data of the Cerro Maggiore landfill site

Dimensions	m	~280x280
MSW intake	t/day	900
Landfill gas generation	Nm^3/t	160
Landfill gas collection capacity	Nm^3/h	3600
CH_4	%	45
CO_2	%	55
benzene	mg/m^3	17 - 28
H_2S	mg/m^3	12 - 55
Methylchloride	mg/m^3	1.0 - 1.8
Trichloroethylene	mg/m^3	4.5 - 29.6
Tetrachloroethylene	mg/m^3	27 - 92
1,2 dichloropropane	mg/m^3	1.0 - 9.7
toluene	mg/m^3	19 - 123
xylene	mg/m^3	26 - 31
freon 113	mg/m^3	1.0 - 2.6
Energy recovery process		
Gross power	MW	1.92
Engines	No.	4
Stack diameter	m	0.6
Full load hours	hrs/y	7500
Stack height	m	20
Flue gas temperature	°K	773
Actual flue gas stream	Nm^3/h	2,000
Net average electricity production	MW	1.8
Conversion efficiency	%	12.3
SO_x emissions (as SO_2)	mg/Nm^3	55.3
NO_x emissions (as NO_2)	mg/Nm^3	247.9
TSP emissions	mg/Nm^3	0

Impact pathways to be analysed are described by **Table 8.4**. Their evaluation has been performed consistently with the ExternE methodology, using where possible the same set of exposure-response funtions and monetary values. A relevant exception is given by the evaluation of disamenities, which were analysed by a specific hedonic pricing study (Ascari et al., 1996).

In this study, it is found that approximation of the environmental burden of the site by simple distance measures is a very poor index of its actual annoyance for neighbouring population, whose exposition to odours depends on local meteorological conditions. Therefore, a Gaussian plume (Industrial Source Complex Short Term) dispersion models is utilised to estimate increased tracer (H_2S) concentration in the neighbouring area as related to plant characteristics, emission rates and local meteorology. This allows to estimate mean concentration as well as the probability of overcoming odour perceptive thresholds, which is higher under high stability conditions, and is evaluated for a grid of cells located around the site.

In the econometric part of the study, these estimates of odour annoyance and toxic impacts are utilised as well as customary property and neighbourhood variables for an hedonic pricing study of the housing market. The estimated relationship between property value losses and H_2S concentration is taken as a measure of willingness to pay to avoid disamenities from the plant and aggregated over the affected area where odours fall above the perceptive threshold.

Table 8.4 Burdens and impact pathways for the Cerro Maggiore landfill site

BURDEN/ POLLUTANT	MEDIUM	RECEPTOR	IMPACT
Windblown bottom ashes	air	Public health	Mortality/morbidity
Leachate	water table	Public health	Mortality/morbidity
CO_2, CH_4	air	World	Global warming
H_2S, S-organics	air	Forests, crops	Acidification
H_2S, S-organics	air	Residents	Odours/Amenity
Benzene	air	Public health	Chronic mortality
Acidic aerosols	air	Public health	Mortality/morbidity
Ozone	air	Public health	Mortality/morbidity
MSW transport	Accidents	Public health	Mortality/morbidity
MSW transport	Air	Public health	Mortality/morbidity
MSW transport	Air	Public health	Mortality/morbidity
Construction	work	Workers	Accidents

Other impacts of the landfill site are straightforward applications of the ExternE methodology as atmospheric pollution and its effects are assessed by Ecosense 2.0 or by the accepted methodology for the valuation of contributions to global warming. As regards the latter, note however that MSW landfilling involves not only less emissions with respect to incineration, but these are also delayed as each ton of MSW leads to emissions of biogas over about 15 years, with a relatively fast build-up (up to a maximum of 20 m^3/tonne/year after five years) followed by a slower decline and total emissions set at 160 m^3/tonne of MSW. This delay is taken into account by discounting at 1%, which is consistent with methodological assumptions of the valuation.

Greater care is required for transportation of MSW, where other important differences between the incineration and landfill options will arise.

It should be noted that the larger distance of the landfill site (with respect to the incinerator) from the centre of the waste generation area involves the estimation of transport externalities, which has been pursued by currently available techniques as developed within the ExternE Transport Project: local impacts are modelled by ROADPOL and regional impacts by

Ecosense. Emission data are taken from the Corinair 1991 inventory for trucks. The valuation of imputed road accidents is also added.

It is assumed that transport of MSW to the incinerator involves similar impacts as transport to the city suburbs heading for the landfill site; the excess transport distance entailed by landfilling is estimated as 40 Km. In the case of incineration, similar (though smaller) externalities are estimated for the transport to the same landfill site of fly and bottom ashes as well as exhausted abatement devices, which amount to about 30% of the mass of the original waste (10% in volume).

8.3 Results and discussion

Results are given in **Table 8.5** and summarised in Figure 8.1. External costs are given as related to one tonne of MSW disposed of at the new proposed Silla plant. The same external costs were also computed in terms of costs per kWh for each of the two technologies analysed. These results are given and discussed in the Maintenance report, as the data in terms of cost per ton are more interesting for the policy case study.

These results may be surprising, as landfilling is characterised by smaller external costs than incineration. A crucial point lies in the assessment of disamenities, which in our study turned out to be related to odours. In fact, it is also possible that households fear the landfill for other reasons as well, i.e. drinking water pollution, disease spread by animals breeding on the plant, increased traffic, or even the social stigma associated with this land use. This may involve larger externalities than those estimated by the hedonic pricing study, but if this was the case externalities should be related to distance rather than the odour dispersion pattern. It is more likely that, for whatever reasons people dislike such plant, their perception of the site is related to the most apparent impact. Therefore, we tend to think that the estimation of the hedonic pricing study is a relatively accurate measure of its perceived impact.

On the other hand, it is also possible that a proper study reveals perceptive effects also in the neighbourhood of an incinerator. Local opposition about the latter is just as common as it regards landfills and has been actually even more "successful" in blocking such initiatives in Italy, although this is not the case for other countries and may be rather related to poor management or other difficulties of public decision making.

Further, we recall that some impacts of the landfill site on soil and groundwater, however unlikely, would not be avoided by incineration as ashes and other solid exhausts must be landfilled anyway. A reservation on this point derives however by the fact that an exhaust landfill, being an order of magnitude smaller, is more easily controlled against improper use, for instance the unlawful disposal of toxic and dangerous wastes.

From a normative perspective, MSW landfilling seems therefore to be affected by fewer external costs than incineration even in the case of a densely populated area like the province of Milan. In particular, the area affected by landfill disamenities (7.5 km around the Cerro maggiore plant) has a density of 1650 inhabs./km^2.

This point does not consider how difficult the search for a suitable site may result. In other word, a scarcity premium may be added to capital and operational costs of the plant, but this is likely to be internalised and conceptually different from externalities.

In fact, landfill externalities are more site specific than those of incinerators, as a larger share of external costs occur locally. A similar study for a less populated area would certainly show an even more striking preference for landfilling. The proximity criterion itself, requiring MSW to be disposed of as close as possible to their generation areas, may be questionable. On this point, note that transport externalities are not negligible so that beyond a certain distance they should dominate other impacts, and disamenities in particular. On the other hand, even transport externalities are mainly local (over 98% in our case, excluding global warming) and therefore strongly related to population density; incineration externalities in turn may be relatively less dependent on the distance from the origin of wastes (at least up to few hundreds kilometers) as they are mainly spread by wind dispersion at greater distance[i]. To sum up, the break even point where incineration externalities fall below those of landfilling may well fall farther away than expected. This point may be the subject of further research.

Table 8.5 Damages of the new Silla waste incinerator and the Cerro Maggiore landfill site

	MSW Incinerator ECU/tonne	Landfill ECU/tonne
Power Generation		
Public health (mortality and morbidity)		
TSP	*1.01*	*0*
SO_2	*3.39*	*0.05*
NO_x	*17.65*	*0.19*
NO_x (via ozone)	*1.62*	*0.02*
Cd-PCDD/F	0.02	-
Benzene	-	7.3E-05
Crops	0.49	0.005
Ecosystems	nq	nq
Materials	0.22	0.012
Monuments	*nq*	*nq*
Low	7.48	
mid	50.60	18.86
Upper	95.70	
Other fuel cycle stages		
Transport/Public health	1.46	4.60
TSP	*1.44*	*4.55*
DME	*0.013*	*0.041*
SOx	0.003	0.011
Road accidents	0.14	0.68
Occupational health	0.41	0.14
Ecological effects	ng	ng
Road damages	nq	nq
Noise	nq	nq
Disamenities	nq	13.2
Global warming		
Global warming		
Lower	0.011	0.04
Upper	0.029	0.09

*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

Inclusion of global warming externalities strongly reinforces the preference for landfills. Intuitively, the latter are a "carbon sink" where part of the organic compounds of MSW are assimilated by the ground. On the contrary, the incinerator releases all organic substances (including stable ones) into the atmosphere.

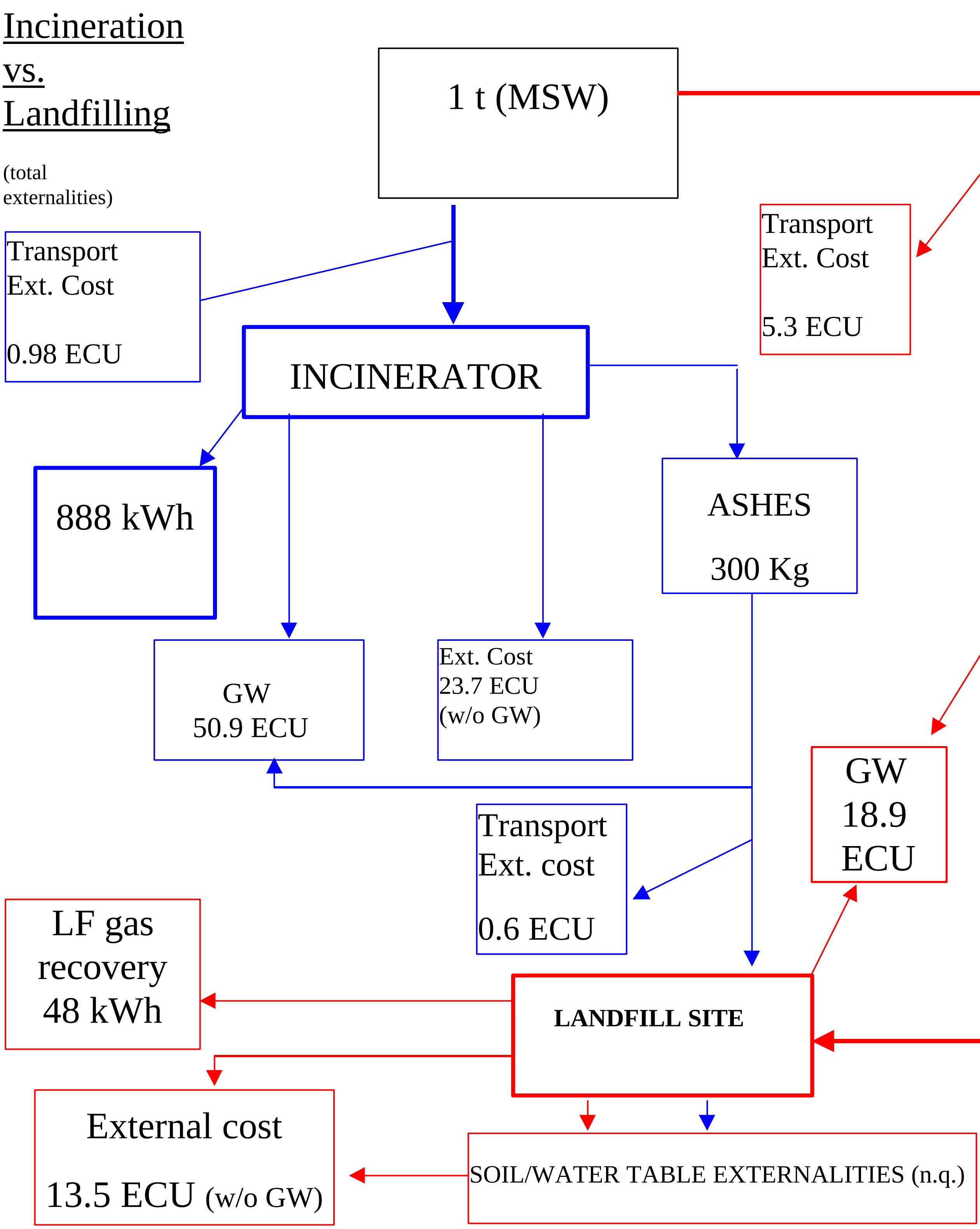
Incineration
vs.
Landfilling
(total externalities)
1 t (MSW)
Transport Ext. Cost 0.98 ECU
INCINERATOR
Transport Ext. Cost 5.3 ECU
888 kWh
ASHES 300 Kg
GW 50.9 ECU
Ext. Cost 23.7 ECU (w/o GW)
GW 18.9 ECU
Transport Ext. cost 0.6 ECU
LF gas recovery 48 kWh
LANDFILL SITE
External cost 13.5 ECU (w/o GW)
SOIL/WATER TABLE EXTERNALITIES (n.q.)

Figure 8-1

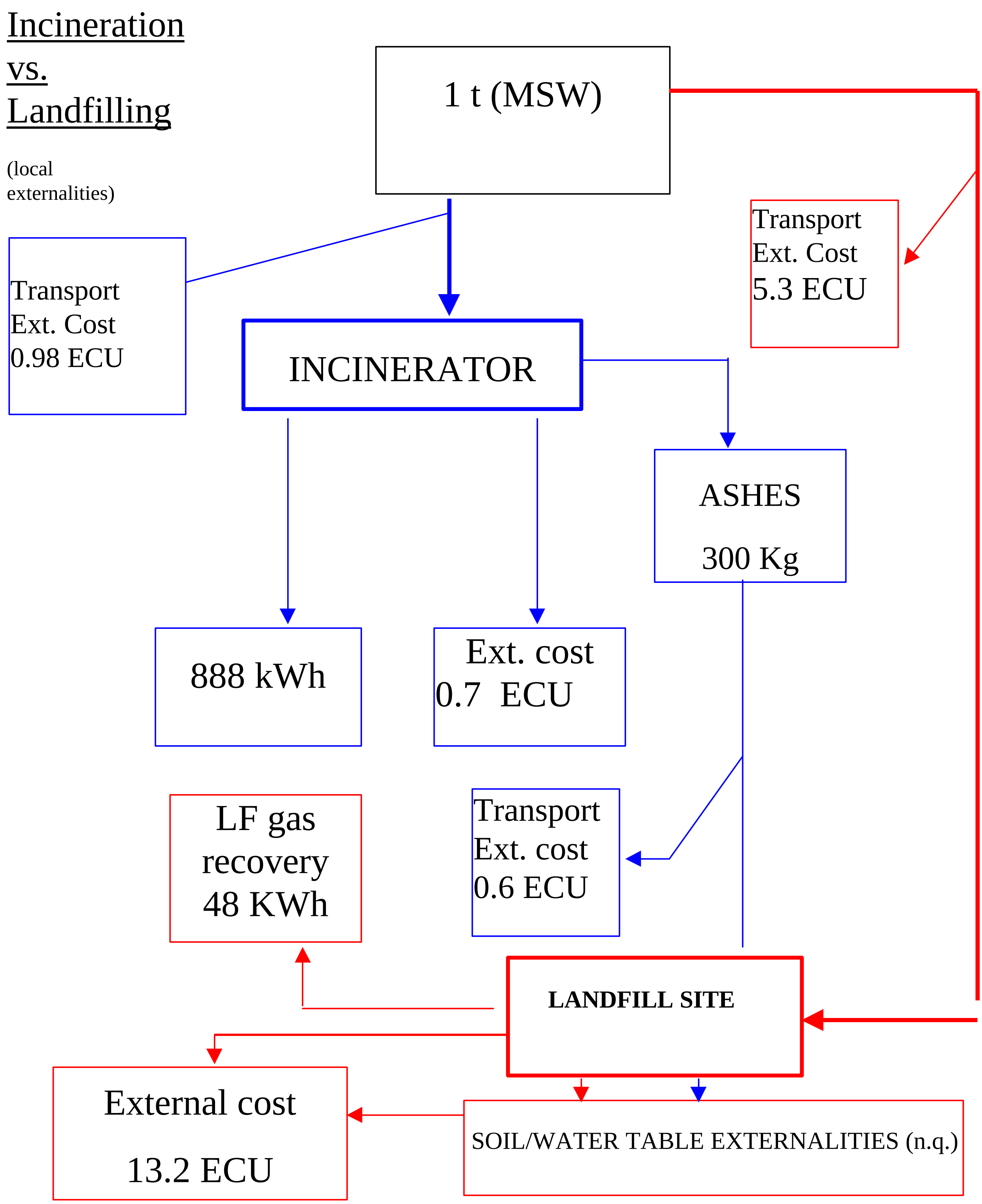
Incineration
vs.
Landfilling
(local
externalities)
1 t (MSW)
Transport
Ext. Cost
0.98 ECU
INCINERATOR
Transport
Ext. Cost
5.3 ECU
ASHES
300 Kg
888 kWh
Ext. cost
0.7 ECU
LF gas
recovery
48 KWh
Transport
Ext. cost
0.6 ECU
LANDFILL SITE
External cost
13.2 ECU
SOIL/WATER TABLE EXTERNALITIES (n.q.)

Figure 8-2

Figure 8.2 summarises "local" external costs of both options, as defined by the ExternE accounting framework, i.e. those occurring within a square of 100x100 Km centered around the plant. It may be noted that within such realm landfill externalities far exceed those of the incinerator. In fact, 98.4% of landfill external costs occur locally if global warming estimation are excluded (49.3% if the latter are included): this is the case of 10.3% only of incineration externalities (3.5% including global warming). Since the MSW disposal technology is usually chosen locally, this may be a reason of the common political preference for incineration over landfilling.

All this considered, in the Milan case it is therefore reasonable that municipal, provincial and regional authorities favour the option characterised by a smaller impact on the relevant community. However, the same preferences should not be expected to be held by the national or EU administration.

As regards the Italian point of view, it is remarkable that national policy have consistently favoured incineration. Capital subsidies for this option have long been made available to local authorities. Since 1992, a price of 280 lire/kWh (147 mECU) for eight years is paid by ENEL, the National electric utility, for energy produced out of renewable source , including MSW. This involves a subsidy of at least 100 mECU over ENEL’s avoided cost of electricity generation. However this subsidy (now temporarily dropped, and likely to be reduced in the future) is also justified as a premium for national versus foreign energy sources. Landfilling is in turn discouraged, since the 1996 budget law by a levy of 20 lire (10.5 mECU) per Kg of disposed waste.

8.4 Conclusions

The main apparent conclusions of this case are as follows:

? Incineration entails larger external costs on per tonne basis, despite the fact that the landfill site of this study is located in a rather densely populated area. Inclusion of global warming impacts reinforces this preference.

? The largest external costs of incineration are linked to macropollutant emission, notably to nitrogen oxides; these exceed Cadmium impacts by two order of magnitudes, and Dioxins by three. It is interesting to note that that NO_x is the pollutant where fewer improvements about emission rates have been achieved lately.

? On the other hand, landfilling involves much larger external costs if only local impacts (defines as those occurring within a 100x100 Km square around the plant) are considered. This may explain and possibly justify the actual choices of local authorities.

? Contrary to what this study seems to suggest, EU and Italian national policy favours incineration over landfilling as a waste disposal option. In Italy, the former is awarded a subsidy of about 190 liras (100 mECU/KWh) over the avoided cost of electricity of the National Electricity Board (ENEL), whereas the latter is subject to a levy of about 20 liras per tonne of MSW.

? However, it has to be emphasized that the results of the present study have to be taken with caution for several reasons. Firstly, they are site-specific, and not easily applicable to different locations in Europe. Secondly, as all the ExternE evaluations, they are subject to a not negligible degree of uncertainty. Last not least, they are the outcome of a specific, precise point of view. Other studies that evaluate the waste treatment technologies have taken a different perspective, taking into accout (as a benefit for the incineration) also the displaced external costs of energy production by different fuel cycles. This may well change the results presented in our study.

[ii] It is sometimes suggested that siting MSW incinerators or other large combustion plants to less populated area would reduce their damages; however, the ExternE project has shown that this is not true in general. For example, if we compare externalities for the main pollutant emissions estimated (with Ecosense) for the new Milan plant and for a smaller (320 tonnes/day) incinerator near Cremona, a town of 80,000 located 70 Km SE of Milan in a pretty rural area, we obtain the following results (ECU/tonne):

Pollutant	Milan	Cremona
SO_x	10173	10677
Nox	13244	12726
TSP	50506	58339

9. CONCLUSIONS

The methodology developed within the ExternE project was successfully applied to four case studies of energy production in Italy: two fossil fuel cycles, a hydroelectric power plant and an energy production process from waste incineration. The obtained results allow to make partial comparisons between the different fuel cycles: in particular, direct comparison can be made only between the two fossil fuel cycles, for which the same methodology has been used. As for the hydroelectric cycle, the different methodology used, does not allow for comparison with the fossil fuels cycles also because of the different role these forms of energy play within the national energy mix. Electricity production from waste deserves particular considerations because of the peculiarity of the cycle itself: the results suggest in fact that when choosing among alternative for waste treatment, it becomes determinant for the local policy maker to state what his policy priority is - waste treatment in itself, or energy supply - since the choice suggested by the analysis changes radically. The study showed that externalities of fossil fuel cycles are significant as they are the same order of magnitude of the electricity production costs (in the case of oil fuel cycle they are even higher than production costs, if actual emissions factors are used) and could significantly affect energy policy decisions.

Nevertheless, the obtained figures cannot be used straight to make economic evaluation of energy policies, because of the high uncertainties that affect results. This is especially true for global warming damages, for which results span three orders of magnitude: further research is needed in this field in order to obtain more reliable figures. Also in the field of human health some research is necessary, in order to refine the existing dose-response functions (mainly derived from U.S. studies) and to investigate their transferability to the European context. As for mortality, it has been shown that the VSL approach gives rise to results much higher than those obtained with the YOLL approach, and it is still questionable whether it's better to use one or the other.

As a consequence of these considerations, it follows that the monetary approach should be used together with other instruments, such as multi-criteria analysis, cost-effective analysis, as a support to the decision making process. Nevertheless this study represents the most comprehensive and up to date application of the calculation of externalities of the electricity production, and could represent a well structured and scientifically based tool for supporting the current dialogue on how to include environmental issues into the decision making process in the energy sector.

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Appendices I to VIII apply for all national implementations and are therefor not included here. They can be found in a separate volume called APPENCICES.

APPENDIX IX: DETAILS OF THE OIL FUEL CYCLE

Table IX.1: Fuel cycle characteristics

Stage	Parameter	Quantity	Source of data and comments
1. Crude oil extraction			EC, 1995
	Location	North Sea, Baltic Sea	
	Calorific value of oil (MJ/kg)	41.8	
	Oil field production (bpd)	8,000	
	Energy requirement (% of crude oil produced)	0.17-0.19	
2. Crude oil transportation			EC, 1995
	Mode of transport	tanker/pipeline	
	Tanker		
	Distance travelled (km)	1,700	
	Consumption (MJ/t*km)	0.1	
	Fuel used	diesel	
3. Crude oil refining			EC, 1995
	Total annual output (kJ)	$3.37*10^{15}$	
	Annual feedstock input (t)	$84.45*10^{6}$	
	Annual production (t)	$79.89*10^{6}$	
	Refinery thermal efficiency (%)	96	
	Electricity requirements (kWh/t input)	65.1	
4. Fuel oil transport to power plant			FEEM
	Type of transport	tanker/pipeline	
	Tanker		
	Distance travelled (km)	10,800	
	Fuel consumption ($TJ/10^{6}t$*mile)	0.33	
	Fuel used	fuel oil, diesel	
	Pipeline		
	Length (km)	40	
	Diameter (inches)	10	
	Capacity (10^{6} t/yr)	2.5	
5. Power generation			ENEL

Stage	Parameter	Quantity	Source of data and comments
	Fuel	Oil	
	Technology	Steam turbines	
	Location	Monfalcone (GO)	
	Installed power (MW)	640	
	Efficiency (%)	40	
	Oil consumption (t/h)	134	
	Full load hours	5,000	
	Lifetime (years)	25	
	Pollution control system	low NO_x burners, ESP,FGD	
	FGD effective (%)	80	
	ESPs effective (%)	> 90	
	Size of the plant		
	land area required (ha)	20	
	cooling system	water cooling	
	stack height (m)	150	
	stack diameter (m)	6.2	
	Labour (workers)	70	
	Flue gas data		
	flue gas volume (Nm^3/h)	1,700,000	
	flue gas temperature (K)	418	
	Pollutants concentration in flue gas (mg/Nm^3)		
	CO	30	
	NO_x	200	
	TSP	50	
	SO_2	400	
	Water needs		
	cooling system (m^3/h)	100,000	
	industrial use (m^3/h)	n.a.	
	civil uses (m^3/day)	n.a.	
	Other materials demand		
	limestone (t/yr)	67,000	
	Liquid effluents		
	water treatment system (m^3/yr)	n.a.	
	cooling system (m^3/h)	100,000	
	FGDs sludge	n.a.	

Stage	Parameter	Quantity	Source of data and comments
	Solid wastes		
	solid residues from water treatment plant (t/yr)	n.a.	
	ashes (t/yr)	1,500	
	gypsum (t/yr)	120,000	
6. Limestone extraction			
	Location	n.a.	
	Annual production	n.a.	

Table IX.2: Quantification of burdens - Oil Fuel Cycle

Stage	**Burden**	**Quantity**	**Source of data**	**Impact assessed?**
1. Crude oil extraction				
	Occupational health		EC, 1995/INAIL	
	Normal operation			
	fatal accidents / TWh	0.0008-0.0082		✓
	major injuries / TWh	0.0097-0.15		✓
	minor injuries / TWh	0.086-1.37		✓
	Major accidents			
	fatal accidents / TWh	0.0011		✓
	Air emission factors (g/kWh)		EC, 1995	
	CO_2	5.93		✓
	CH_4	0.021		✓
	SO_2	0.0045		
	NO_x	0.0034		✓
	VOC	0.013		✓
	CO	n.q.		
	TSP	ng		
	Liquid effluents		EC, 1995	
	water based drilling fluids (m^3/y)	16,300		
	hether based drilling fluids (m^3/y)	27		
	produced water (m^3/y)	126,481		
	discharged drain water (m^3/y)	3,956		
	Physical presence of structures	n.q.		
2. Crude oil transportation				
	Occupational health		EC, 1995	
	Normal operation			
	fatal accidents / TWh	0.035		✓
	major injuries / TWh	0.21		✓
	minor injuries / TWh	2.74		✓
	Major accidents			
	fatal accidents / TWh	0.0064		✓
	Air emission factors (g/kWh)		EC, 1995	

Stage	Burden	Quantity	Source of data	Impact assessed?
	CO_2	3.0		✓
	CH_4	ng		✓
	SO_2	0.04		
	NO_x	0.04		✓
	VOC	n.q.		
	CO	n.q.		
	TSP	ng		
3. Crude oil refining				
	Occupational health		EC, 1995	
	fatal accidents / TWh	0.0022		✓
	major injuries / TWh	0.062		✓
	minor injuries / TWh	2.23		✓
	Air emission factors (g/kWh)		EC, 1995	
	CO_2	35.7		✓
	CH_4	0.0022		✓
	SO_2	0.17		
	NO_x	0.067		✓
	VOC	0.046		✓
	CO	0.0060		
	TSP	0.0088		
4. Fuel oil transportation				
	Occupational health		EC, 1995	
	fatal accidents / TWh	0.035		✓
	major injuries / TWh	0.21		✓
	minor injuries / TWh	2.74		✓
	Air emission factors (g/kWh)			
	CO_2	35.1		✓
	CH_4	ng		✓
	SO_2	0.83		
	NO_x	0.32		✓
	VOC	1.39		✓
	CO	ng		
	TSP	0.025		
	Oil spills		EC, 1995	
	average operational discharges (g/kWh)	0.14		
	accidental	n.q.		

Stage	Burden	Quantity	Source of data	Impact assessed?
	Accident risk	n.q.		
5. Power generation				
	Occupational health		ENEL/INAIL	
	fatal accidents / TWh	0.0015		✓
	major injuries / TWh	0.020		✓
	minor injuries / TWh	0.38		✓
	Air emission factors (g/kWh)		ENEL/Min. Env.	
	CO_2	693.2		✓
	CH_4	0.018		✓
	SO_2	1.12		✓
	NO_x	0.56		✓
	VOC	0.028		✓
	CO	0.084		
	TSP	0.14		✓
	N_2O	0.002		✓
	Noise emissions	n.q.		
	Solid waste production (t/yr)	100	ENEL	
	Emissions to water (m^3/h)			
	cooling waters	100,000		
5a. Power plant construction				
	Occupational health		ENEL/INAIL	
	fatal accidents / TWh	0.0048		✓
	major injuries / TWh	0.10		✓
	minor injuries / TWh	1.91		✓
	Air emissions	n.q.		
	Noise	n.q.		
	Road use	n.q.		
6. Limestone extraction				
	Occupational health		ENEL/INAIL; EC, 1995	
	fatal accidents / TWh	0.0071		✓
	major injuries / TWh	0.13		✓
	minor injuries / TWh	4.25		✓

Table IX.3: Impacts and damages from the oil fuel cycle

Impact	Impact units/TWh	Impacts number	Damages mECU/kWh	ECU/t_{poll}	σ_g range
Air pollution					
5. Power generation					
Primary PM_{10}					
Mortality	YOLL	16.0	1.35	9,600	B
	deaths	-	4.95	35,400	B
Morbidity		-	0.18	1,300	A
Materials - cleaning costs		-	nq	-	
NO_x - all from nitrate aerosol					
Mortality	YOLL	48.4	4.10	7,300	B
	deaths	-	15.0	26,800	B
Morbidity		-	0.53	900	A
Materials damage - cultural					
Critical loads exceedance					
Effects on crop yield (N deposition)			ng	ng	B
SO_2 - as sulphate, unless marked SO_2					
Mortality	YOLL	110.2	9.35	8,300	B
	deaths	-	34.2	30,500	B
Mortality (SO_2)	YOLL	2.14	0.33	300	B
	deaths	-	8.85	7,900	B
Morbidity	cases	-	1.17	1,000	A
Materials damage - cultural					
Critical loads exceedance					
Effects on crop yield (SO_2)			0.062	60	B
O_3 (NO_x only)					
Mortality	YOLL	2.18	0.24	410	?
	deaths	-	7.56	13,000	?
Morbidity		-	0.42	730	?
Materials damage - utilitarian					
Critical loads exceedance					
Effects on crop yield			0.20	350	B
Acid deposition					
Materials damage (with SO_2)			0.25		B
Effects on crop yield			0.010		B

Impact	Impact units/TWh	Impacts number	Damages mECU/kWh	ECU/t_{poll}	σ_g range
Greenhouse gas emissions					C
CO_2 - low - high		-	2.63 - 96.4	3.8 - 139	
CO_2 - mid 3% - mid 1%		-	12.5 - 31.9	18 - 46	
N_2O		-	0.034	17,000	
CH_4		-	0.0094	520	
Other stages - within Europe					
O_3 (VOC)					
Mortality	YOLL	3.73	0.41	250	?
	deaths	-	12.9	7,700	?
Morbidity		-	0.73	440	?
Materials damage - utilitarian					
Critical levels exceedance					
Effects on crop yield			0.31	190	B
O_3 (NO_x)					
Mortality	YOLL	1.64	0.18	410	?
	deaths	-	5.67	13,000	?
Morbidity		-	0.32	730	?
Materials damage - utilitarian					
Critical levels exceedance					
Effects on crop yield			0.15	350	B
Greenhouse gas emissions					C
CO_2 - low - high		-	0.30 - 11.1	3.8 - 139	
CO_2 - mid 3% - mid 1%		-	1.44 - 3.67	18 - 46	
N_2O		-	n.q.	-	
CH_4		-	0.012	520	
Occupational health effects					A
1. Crude oil extraction					
Fatalities - Normal operation	deaths	0.0008-0.008	0.0025-0.025		
Major injuries	cases	0.0097-0.15	0.0009-0.014		
Minor injuries	cases	0.086-1.37	0.0006-0.010		
Fatalities - Major accidents	deaths	0.0011	0.0034		
2. Crude oil transportation					
Fatalities - Normal operation	deaths	0.035	0.11		
Major injuries	cases	0.21	0.020		

Impact	Impact units/TWh	Impacts number	Damages mECU/kWh	ECU/t_{poll}	σ_g range
Minor injuries	cases	2.74	0.019		
Fatalities - Major accidents	deaths	0.0064	0.020		
3. Crude oil refining					
Fatalities	deaths	0.0022	0.0068		
Major injuries	cases	0.062	0.0059		
Minor injuries	cases	2.23	0.016		
4. Fuel oil transportation					
Fatalities - Normal operation	deaths	0.035	0.11		
Major injuries	cases	0.21	0.020		
Minor injuries	cases	2.74	0.019		
Fatalities - Major accidents	deaths	0.0064	0.020		
5. Power plant operation					
Fatalities	deaths	0.0015	0.0047		
Major injuries	cases	0.020	0.0019		
Minor injuries	cases	0.38	0.0027		
5a. Power plant construction					
Fatalities	deaths	0.0048	0.015		
Major injuries	cases	0.10	0.0097		
Minor injuries	cases	1.91	0.013		
6. Limestone extraction					
Fatalities	deaths	0.0071	0.022		
Major injuries	cases	0.13	0.013		
Minor injuries	cases	4.25	0.030		

APPENDIX X: DETAILS OF THE GAS FUEL CYCLE.

Table X.1: Fuel cycle characteristics

Stage	Parameter	Value	Source of data and comments
1. Exploration			AGIP
	Location	Adriatic Sea, Italy	
	Technology	Air gun seismic surveys	
2. Wells drilling			AGIP
	Technology	Jack Up Units	
	Drilling fluids	Oil and water based	
	Duration	25 days/well (1,300 meters deep)	
3. Gas production and treatment			AGIP
	Location (extraction)	Adriatic Sea	
	Gas field production (Sm^3/day)	$1.2*10^7$	
	Number of wells	102	
	Number of platforms	8	
	Reservoir depth (meters)	1,000 - 1,300	
	Composition of gas (%mol)		
	Methane	99.62	
	Ethane	0.06	
	Propane	0.02	
	Heavy hydrocarbons	0.02	
	Carbon dioxide	0.02	
	Nitrogen	0.26	
	Helium	-	
	Net calorific value (MJ/Sm^3)	33.96	
	Energy consumption (Toe/10^6Toe produced)	6.8	
	Electric energy needed (MWh/10^9 m^3 of gas)	4.45	
	Location (treatment)	Falconara plant	
	Distance from extraction field (km)	60	
	Treatment plant nominal capacity (Sm^3/day)	13,800	

Appendix X: Details of the gas fuel cycle

Stage	Parameter	Value	Source of data and comments
	Gas consumption (10^6 Sm^3/yr)	37.76	
4. Gas transport			SNAM
	Mode of transport	Pipeline	
	Pipeline length (km)	447	
	Pipeline diameter (inches)	26-48	
	Gas volume transported (Nm^3/h)	$48.9*10^9$	Whole transmission system (year 1994)
	Gas leakages (% of transported volume)	0.08	"
	Compressor station		"
	number	22	
	installed power (MW)	806	
	energy consumption (TJ)	6185	
	Labour	2756 workers	"
4a. Pipeline construction			SNAM
	Material demands		
	steel (t)	$154*10^3$	length:447 km, pressure: 75 bar
	Labour	n.a.	
	Construction period	n.a.	
5. Power generation			ENEL
	Fuel	Natural gas	
	Technology	Combined cycle	
	Location	Trino Vercellese (VC)	
	Installed power (MW)	694	
	Efficiency (%)	46.7	
	Gas consumption (Nm^3/h)	154,000	
	Full load hours	6,000	
	Lifetime (years)	25	
	Pollution control system	low NO_x burners	
	Size of the plant		
	land area required	23 ha	
	cooling system	2 air cooling towers	
	cooling tower height (m)	100	
	cooling tower diameter (m)	65	
	Labour (workers)	120	
	Flue gas data		ENEL/Min. of Env.
	flue gas volume (Nm^3/h)	5,000,000	

Stage	Parameter	Value	Source of data and comments
	flue gas temperature (K)	393	
	Pollutants concentration (mg/Nm^3)		
	CO	30	
	NOx	60	
	TSP	ng	
	SO_2	ng	
	Water needs		ENEL
	industrial uses (m^3/h)	80	
	civil uses (m^3/day)	48	
	Liquid effluents		
	water treatment system (m^3/yr)	150,000	
	Solid wastes		
	solid residues from water treatment plant (t/yr)	100	
5a. Power plant construction			
	Material demands (t)		ENEL
	concrete	400,000	
	steel	12,000	
	Labour (workers/year)	725	
	Construction period (years)	3	

Table X.2: Quantification of burdens- Gas Fuel Cycle

Stage	**Burden**	**Quantity**	**Source of data**	**Impact assessed?**
1. Exploration				
	Noise		AGIP	
	air gun seismic survey			
2. Wells drilling				
	Occupational health			
	fatal accidents / TWh	n.q.		
	major injuries / TWh	n.q.		
	minor injuries / TWh	n.q.		
	Air emission factors (g/kWh)		AGIP	
	CO_2	0.20		✓
	CH_4	ng		✓
	SO_2	ng		
	NO_x	0.0031		✓
	VOC	n.q.		
	CO	ng		
	TSP	ng		
	Wastes		AGIP	
	Drilling muds (t)	1530		ng
	Cuttings (m^3)	91,800		ng
	Urban wastes (t)	51,000 t		ng
	Liquid effluents		AGIP	
	Treated waste water (m^3)	32,640		ng
	Physical presence of structures		AGIP	
3. Gas production and treatment				
	Occupational health		AGIP/INAIL	
	Normal operation			
	fatal accidents / TWh	0.0009		✓
	major injuries / TWh	0.010		✓
	minor injuries / TWh	0.39		✓
	Major accidents			
	fatal accidents / TWh	0.017		✓
	Air emission factors (g/kWh)		AGIP	
	CO_2	8.42		✓
	CH_4(flared gas)	ng		✓

Stage	Burden	Quantity	Source of data	Impact assessed?
	SO_2	ng		
	NO_x	0.010		
	VOC	n.q.		
	CO	0.0049		
	TSP	ng		
	Water discharge (m^3/ 10^6 m^3 of gas)		AGIP	
	produced water	11		
	Wastes (kg/10^9 m^3 gas)			
	Special	122		
	Toxic	0.008		
	Used oils	4		
	Batteries	0.3		
4. Gas transport				
	Occupational health		SNAM/INAIL	
	fatal accidents / TWh	0.0001		✓
	major injuries / TWh	0.0008		✓
	minor injuries / TWh	0.031		✓
	Air emission factors (g/kWh)			
	CO_2	1.73		✓
	CH_4	0.15		✓
	SO_2	ng		
	NO_x	0.011		✓
	VOC	ng		
	CO	0.0043		
	TSP	ng		
	Accident risk	n.q.		
	Noise (80 m from source, by compressor stations)	50-55 dBA		
	Environment alteration	n.q.		
4a. Pipeline construction				
	Occupational health			
	fatal accidents / TWh	n.q.		
	major injuries / TWh	n.q.		
	minor injuries / TWh	n.q.		
	Air emissions	n.q.		
	Other burdens			
	noise	n.q.		

Stage	Burden	Quantity	Source of data	Impact assessed?
	land occupation	n.q.		
5. Power generation				
	Occupational health		ENEL/INAIL	
	fatal accidents / TWh	0.0019		✓
	major injuries / TWh	0.026		✓
	minor injuries / TWh	0.49		✓
	Air emission factors (g/kWh)		ENEL/Min Amb	
	CO_2	432.9		✓
	CH_4	0.029		✓
	SO_2	ng		✓
	NO_x	0.44		✓
	VOC	0.038		✓
	CO	0.22		
	TSP	ng		✓
	Noise emissions(dBA 120 m)	51	ENEL	ng
	Solid waste production (t/yr)	100		ng
	Emissions to water (m^3/yr)	150,000		ng
5a. Power plant construction				
	Occupational health		ENEL/INAIL	
	fatal accidents / TWh	0.0035		✓
	major injuries / TWh	0.076		✓
	minor injuries / TWh	1.42		✓
	Air emissions	n.q.		
	Noise	n.q.		
	Road use	n.q.		ng

Table X.3: Impacts and damages from the gas fuel cycle

Impact	**Impact units/TWh**	**Impacts number**	**Damages mECU/kWh**	**ECU/t_{poll}**	**σ_g range**
Air pollution					
5. Power generation					
NO_x - all from nitrate aerosol					
Mortality	YOLL	62.0	5.3	11,877	B
	deaths	-	21.1	43,661	B
Morbidity		-	0.67	1,532	A
Materials damage - cultural					
Critical loads exceedance					
Effects on crop yield (N deposition)			ng	ng	B
O_3 (NO_x only)					
Mortality	YOLL	1.73	0.18	410	?
	deaths	-	5.99	13,000	?
Morbidity		-	0.32	730	?
Materials damage - utilitarian					
Critical loads exceedance					
Effects on crop yield			0.15	350	?
Acid deposition					
Materials damage (with SO_2)			0.047		B
Effects on crop yield			0.0017		B
Greenhouse gas emissions					C
CO_2 - low - high		-	1.71 - 60.2	3.8 - 139	
CO_2 - mid 3% - mid 1%		-	7.86 - 20.0	18 - 46	
N_2O		-	0.051	17,000	
CH_4		-	0.015	520	
Other stages - within Europe					
O_3 (NO_x only)					
Mortality	YOLL	0.15	0.016	410	?
	deaths	-	0.50	13,000	?
Morbidity		-	0.029	730	?
Materials damage - utilitarian					
Critical levels exceedance					
Effects on crop yield			0.012	350	?
Greenhouse gas emissions					C

Impact	Impact units/TWh	Impacts number	Damages mECU/kWh	ECU/t_{poll}	σ_g range
CO_2 - low - high		-	0.039 - 1.44	3.8 - 139	
CO_2 - mid 3% - mid 1%		-	0.19 - 0.48	18 - 46	
N_2O		-	n.q.	-	
CH_4		-	0.078	520	
Occupational health effects					A
3. Gas production and treatment					
Fatalities - Normal operation	deaths	0.0009	0.0027		
Major injuries	cases	0.010	0.0010		
Minor injuries	cases	0.39	0.0027		
Fatalities - Major accidents	deaths	0.017	0.052		
4. Gas transportation					
Fatalities	deaths	0.0001	0.0003		
Major injuries	cases	0.0008	0.0001		
Minor injuries	cases	0.031	0.0002		
5. Power plant operation					
Fatalities	deaths	0.0019	0.0060		
Major injuries	cases	0.026	0.0024		
Minor injuries	cases	0.49	0.0034		
5a. Power plant construction					
Fatalities	deaths	0.0035	0.011		
Major injuries	cases	0.076	0.0072		
Minor injuries	cases	1.42	0.0099		

APPENDIX XI: DETAILS OF WASTE INCINERATION

Table XI.1: Fuel cycle characteristics

Stage	Parameter	Quantity	Source of data, comments
1.Waste transport	Origin	Provisional store in Milano, v. Olgettina	
	Destination	Incinerator of Milano-Silla	
	Distance	10 km	
	Alternative destination for MSW disposal	Landfill of Cerro M.	
	Distance	50 km	
	Mode of transport	Road (100%)	
	Vehicle	Heavy duty diesel vehicle	
	Capacity	15 t.	
	MSW weight	279000 t/yr	
	trips per year	18600	
	Air emissions		
	TSP	0.15 t/yr	
	NO_x	1.38 t/yr	
	SO_x	0.03 t/yr	
	CO	1.36 t/yr	
	VOC	0.14 t/yr	
	CO_2	110.2 t/yr	
2. Power generation	Waste composition (in weight)		
	Paper and cardboard	31%	
	Organic matter	29%	

	Plastic	17%
	glass and inert matter	2%
	wood	1.4%
	metals	0.4%
	clothes	5.2%
	napkins	3.5%
	other	10.5%
	calorific power	15000 kJ/kg
	combustion techology	Grate-type furnace
	efficiency (all electric)	21%
	net power	33.3 MW
	load hours	7440
	lifetime	10 yr
	pollution abatement technology	Selective non-catalytic reduction
	stack height	100 m.
	stack diametre	3 m.
	Flue gas volume	250000 Nm^3/h
	air emissions	
	TSP	5.58 t/yr
	NO_x	372 t/yr
	SO_x	93 t/yr
	CO_2	306900 t/yr
	Cd	18.6 kg/yr
	PCDD/PCDF	9.3E-05 kg/yr
	Solid residuals (ashes)	83700 t/yr
3. Ashes transport	Destination	Landfill of Cerro M.
	Distance	20 km
	Mode of transport	Road (100%)

	Vehicle	Heavy duty diesel vehicle
	Capacity	15 t.
	MSW weight	83700 t/yr
	trips per year	5580
	Air emissions	
	TSP	0.09 t/yr
	NO_x	0.83 t/yr
	SO_x	0.02 t/yr
	CO	0.81 t/yr
	VOC	0.08 t/yr
	CO_2	66.15 t/yr
4. Ashes disposal	Location	Cerro Maggiore
	Type of facility	Landfill with biogas recovery and energy production
	biogas generation	160 m^3/t
	biogas recovery	60%
	biogas calorific power	3700 kcal/m^3
	combustion techology	Otto cycle engine
	net efficiency	11.7%
	net power	1.8 MW
	load hours	7500
	stack height	20 m.
	stack diametre	0.6 m.
	air emissions	
	TSP	0
	NO_x	3,71 t/yr
	SO_x	0.82 t/yr
	CO_2 */average emission*	4161 t/yr

over 15 yr)

CH4 /average emission over 15 yr)	351 t/yr

Table XI.2: quantification of burdens

Stage	Burden	Quantity	Source of data	Impact assessed?
1. Waste transport				
	Occupational health			
	accidents - fatal	nq		x - no data
	accidents - major injury	nq		x - no data
	accidents - minor injury	nq		x - no data
	noise levels	nq		x - no data
	Public health		-	
	accidents - fatal	0.012 cases/yr	ISTAT (1995)	✓
	accidents - major injury	nq		
	accidents - minor injury	nq		
	Air emissions (transport)		Corinair (1991)	
	CO_2	110.2 t/yr		✓
	CH_4	nq		x - no data
	CO	1.36 t/yr		✓
	SO_2	0.03 t/yr		✓
	NO_x	1.38 t/yr		✓
	$PM_{2.5}$	0.15 t/yr		✓
	VOC	0.14 t/yr		✓
	Traffic congestion	nq		x - no data
	Noise	nq		x - no data
	Odours	nq		x - no data
2. Power generation	Occupational health			
	accidents - fatal	nq		x - no data
	accidents - major injury	nq		x - no data
	accidents - minor injury	nq		x - no data

Stage	Burden	Quantity	Source of data	Impact assessed?
	Air emissions			✓
	CO_2	306900 t/yr		✓
	SO_2	93 t/yr		✓
	NO_x	372 t/yr		✓
	PM_{10}	5.58 t/yr		✓
	HCl, HF	nq		x - no data
	Heavy Metals	nq		x - no data
	of which Cd	18.6 kg/yr		✓
	PCDD/PCDF	9.3E-05 kg/yr		✓
	Odours	nq		x - no data
	Noise	nq		x - no data
3. Transmission	No additional burdens			
4. Transport of solid residuals (ashes and slug)				
	Occupational health			
	accidents - fatal	nq		x - no data
	accidents - major injury	nq		x - no data
	accidents - minor injury	nq		x - no data
	Public health			
	accidents - fatal	0.007 cases/yr	ISTAT (1995)	✓
	accidents - major injury	nq		x - no data
	accidents - minor injury	nq		x - no data
	Air emissions (vehicle)		Corinair (1991)	
	CO_2	66.15 t/yr		✓
	CH_4	nq		x - no data
	CO	0.81 t/yr		✓
	SO_2	0.02 t/yr		✓

Stage	Burden	Quantity	Source of data	Impact assessed?
	NO_x	0.83 t/yr		✓
	$PM_{2.5}$	0.09 t/yr		✓
	VOC	0.08 t/yr		✓
	Air emissions (fugitive dust)			✓
	PM_{10}	nq		x - no data
	of which heavy metals	nq		x - no data
	Traffic congestion	nq		x - no data
	Noise	nq		x - no data
5. Ashes disposal	Occupational health			
	accidents - fatal	nq		x - no data
	accidents - major injury	nq		x - no data
	accidents - minor injury	nq		x - no data
	Air emissions from activities on site			
	CO_2	nq		x - no data
	CH_4	nq		x - no data
	CO	nq		x - no data
	SO_2	nq		x - no data
	NO_x	nq		x - no data
	PM_{10} - combustion	nq		x - no data
	PM_{10} - fugitive dust	nq		x - no data
	VOC	nq		x - no data
	Leachate	nq		x - no data
	Visual impact (landfill)		Ascari et al. (1996)	✓
	Noise	nq		x - no data

Stage	Burden	Quantity	Source of data	Impact assessed?
6. Construction	Occupational health			
	accidents - fatal	0.152 cases/TWh	IEFE (1995)	✓
	accidents - major injury	3.9 cases		✓
	accidents - minor injury	60.8 cases		✓
	Air emissions from materials production			
	CO_2	nq		x - no data
	SO_2	nq		x - no data
	NO_x	nq		x - no data
	PM_{10} - combustion	nq		x - no data
	Air emissions from materials transport			
	CO_2	nq		x - no data
	SO_2	nq		x - no data
	NO_x	nq		x - no data
	PM_{10} - combustion	nq		x - no data
	Air emissions from activities on site			
	CO_2	nq		x - no data
	SO_2	nq		x - no data
	NO_x	nq		x - no data
	PM_{10} - combustion	nq		x - no data
	PM_{10} - fugitive dust	nq		x - no data
	Noise	nq		x - no data
	Road use	nq		x - no data
11. Demolition	Occupational health			

Stage	Burden	Quantity	Source of data	Impact assessed?
	accidents - fatal	nq		x - no data
	accidents - major injury	nq		x - no data
	accidents - minor injury	nq		x - no data
	Air emissions from materials production			
	CO_2	nq		x - no data
	SO_2	nq		x - no data
	NO_x	nq		x - no data
	PM_{10} - combustion	nq		x - no data
	PM_{10} - fugitive dust	nq		x - no data
	Noise	nq		x - no data
	Road use	nq		x - no data

Table XI.3: Impacts and damages from waste incineration fuel cycle (Milano – Silla)

Impact	***Impact - units/TWh***	**Impacts - number**	**Damages mECU/kWh**	***ECU/t_{poll}***	**σ_g, range**
Air pollution					
6. Power generation					
Primary PM_{10}			1.1	50506	A
Acute mortality	YOLL	0.08	0.01		
	deaths	0.11	0.33		
Chronic mortality	YOLL	11.8	0.93		
	deaths	1.18			
Acute and chronic morbidity	cases		0.16		
Materials - cleaning costs					
NO_x - all from nitrate aerosol			19.9	13244	A
Acute mortality	YOLL	1.51	0.23		
	deaths	2.01	6.25		
Chronic mortality	YOLL	208.8	17.6		
	deaths	20.8			
Acute and chronic morbidity	cases		2.28		
Materials damage - utilitarian					
Materials damage - cultural					
Critical loads exceedance					
Effects on crop yield					
SO_2 - as sulphate			3.8	10173	A
Acute mortality	YOLL	0.30	0.05		
	deaths	0.39	1.22		
Chronic mortality	YOLL	40.23	3.39		
	deaths	4.23			
Acute and chronic morbidity	cases		0.43		

Materials damage – utilitarian (SO2)			0.25		
Materials damage – cultural (SO2)			n.q.		
Critical loads exceedance			n.q.		
Effects on crop yield (SO2)			0.002		
O_3				1494	B
Acute mortality			0.66	412	
Acute morbidity			1.17	732	
Effects on crop yield			0.56	350	
Greenhouse gas emissions					C
CO_2	-	-			
low			8.4	6.8	
mid			57.0	46	
high			107.8	87	
N_2O	-	-	nq		
CH_4	-	-	nq		

1.1.1 Waste transport

Primary PM_{10}			1.03	3974280	A
Chronic mortality	YOLL	10.59	0.89		
Cancers (DME)	cases	6.9e-03	0.01		
Acute and chronic morbidity	cases	701.1	0.12		
NOx (as nitrates)		nq	nq	nq	
Sox (as sulfates)		nq	nq	nq	
O_3			9.1E-03		B
Acute mortality			2.6E-03		
Acute morbidity			4.6E-03		
Effects on crop yield			1.9E-03		
Greenhouse gas emissions					C

CO_2					
low	-	-	3.1E-03	6.8	
mid			2.0E-02	46	
high			3.8E-02	87	
N_2O	-	-	nq	nq	
CH_4	-	-	nq	nq	
Road accidents					
deaths	VSL	0.05	0.15	-	A

1.1.1.1 Ashes and slug transport

Primary PM_{10}			0.62	3974280	
Chronic mortality	YOLL	6.35	0.54		
Cancers (DME)	cases	4.1e-03	0.01		
Acute and chronic morbidity	cases	420	0.07		
NOx (as nitrates)		nq	nq	nq	
Sox (as sulfates)		nq	nq	nq	
O_3					B
Acute mortality			1.5E-03		
Acute morbidity			2.7E-03		
Effects on crop yield			1.1E-03		
Greenhouse gas emissions					C
CO_2					
low	-	-	1.8E-03	6.8	
mid			1.2E-02	46	
high			2.3E-02	87	
N_2O	-	-	nq	nq	
CH_4	-	-	nq	nq	
Road accidents					

deaths	cases	0.03	0.09	-	A
Construction					
Occupational health effects					B
1. Construction					
Fatalities	VSC	0.15	0.47	-	
Major injuries	cases	3.22	nq	-	
Minor injuries	cases	49.6	nq	-	