Technical University of Denmark

Total Costs and Benefits of Biomass in Selected regions of the European Union

Almeida, A. de; Bauen, A.; Costa, F.B.; Ericson, S.O.; Giegrich, J.; Gosse, G.; Grabczewski, N. von; Groscurtha, H.-M.; Hall, D.O.; Marianoe, J. da Silva; Mariano, P.M.G.; Meyer, Niels I; Nielsen, Per Sieverts; C. Kern, B. Widmann; Nunes, C.; Patyk, A.; Poitrat, E.; Reinhardt, G.A.; Rosillo-Calle, F.; Scrase, I.; Vergé, C.; Widmann, B.

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– BioCosts –

The BioCosts Research Group:

A. de Almeida[e], A. Bauen[b], F.B. Costa[e], S.-O. Ericson[c], J. Giegrich[h], G. Gosse[i],
N. von Grabczewski[a], H.-M. Groscurth[a], D.O. Hall[b], O. Hohmeyer[a], K. Jörgensen[g],
C. Kern[f], I. Kühn[a], B. Leviel[i], R. Löfstedt[g], J. da Silva Mariano[e], P.M.G. Mariano[e],
N.I. Meyer[d], P.S. Nielsen[d], C. Nunes[e], A. Patyk[h], E. Poitrat[j], G.A. Reinhardt[h],
F. Rosillo-Calle[b], I. Scrase[b], C. Vergé[i], B. Widmann[f]

[a] Zentrum für Europäische Wirtschaftsforschung GmbH (ZEW); Project Co-ordinator
[b] King's College, University of London, Division of Life Sciences
[c] Vattenfall Utveckling AB, Bioenergy Programme
[d] Technical University of Denmark, Department of Buildings and Energy
[e] University of Coimbra, Instituto de Sistemas e Robotica
[f] Bayerische Landesanstalt für Landtechnik, TU München-Weihenstephan
[g] University of Surrey, Centre for Environmental Strategy
[h] Institut für Energie- und Umweltforschung GmbH (ifeu)
[i] Institut National de la Recherche Agronomique (INRA), Unite de Bioclimatologie
[j] Agence de L'Environnement et de la Maîtrise de l'Energie (ADEME)

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Project Co-ordinator:

Dr. Helmuth-Michael Groscurth
Zentrum für Europäische Wirtschaftsforschung GmbH (ZEW)
P.O. Box 10 34 43, D-68034 Mannheim, Germany
Phone: + 49 / 621 / 1235-219
Fax: + 49 / 621 / 1235-226
E-Mail: groscurth@zew.de

Executive Summary

Project Outline

In the BioCosts project, representative biomass-to-electricity and biomass-to-transport-service fuel cycles located at different sites within the European Union have been evaluated concerning their environmental and economic performance. Each case study was compared to a fossil-fuel fired reference case. The case studies examined comprise:

- utilisation of forestry residues in the Nässjö circulating fluidised bed combustion plant, Sweden, versus the use of Polish coal in the same plant;
- utilisation of forestry residues and short-rotation coppice for industrial combined heat and power production in Mangualde, Portugal, versus the use of fuel oil in an engine generating heat and power;
- production of biogas from animal slurry for municipal combined heat and power generation at Hashöj, Denmark, versus the use of Danish natural gas in the same engine;
- gasification of woody biomass for combined heat and power generation in Värnamo, Sweden, and Eggborough, UK, versus the use of coal in the Nässjö plant mentioned above and a UK power plant;
- production of cold-pressed rape-seed oil and its use in a cogeneration plant at Weissenburg, Germany, versus the use of diesel fuel in a similar engine;
- production of rape-seed oil methyl ester (RME) and its use for goods transport in Germany, versus the use of diesel fuel in the same fleet of trucks;
- production of ethyl tertiary butyl ether (ETBE) from sugar beets and sweet sorghum for transport applications in France, versus the use of methyl tertiary butyl ether (MTBE) from fossil sources for the same purpose.

Methodology

For the economic and environmental evaluation, the fuel cycles were divided into fuel production, conversion and clean-up stages. Assessing the economic performance involved production costs of energy or transport services as well as employment effects. Production costs are composed of investment, operation and maintenance, labour and fuel costs. Country specific effects such as taxes and subsidies were disregarded as far as possible. Data on direct employment of biomass fuel cycles were obtained from the operators. Indirect employment from the manufacture of equipment and employment for the production of fossil fuels were calculated with ZEW's enhanced input-output model EMI 2.0.

For each stage of the different biomass fuel cycles and their reference cases, a detailed inventory of direct emissions was compiled. Indirect emissions were again obtained by the EMI input-output model. For direct emissions of NO_x, SO_2 and particulates, external costs arising from impacts on human health were calculated with the EcoSense model developed within the ExternE project. The model implements an impact-pathway approach, consisting of air dispersion of pollutants, formation of secondary pollutants, calculation of physical impacts via exposure-response functions, and monetisation of impacts.

The applicability of neo-classical economic theory to global warming was discussed extensively. It was concluded that cost-benefit analysis is not an appropriate tool for this issue since neither the damage avoided nor the abatement costs can be determined with sufficient accuracy. Therefore, it is suggested to apply the concept of strong sustainability, a consequence of which would be to introduce safe minimum standards. As an indicator of the costs of implementing such standards and to facilitate comparing biomass fuel cycles to other CO_2 mitigation strategies, CO_2 abatement costs were calculated for each fuel cycle.

Impacts on the local biosphere, including impacts on soil, water, biodiversity and rural amenity were discussed qualitatively. Finally, the socio-economic framework in which the biomass fuel cycles are operated, were examined in order to derive institutional issues critical for their success or failure.

Results and Conclusions

The case studies revealed, that the energy use of biomass can have significant environmental advantages compared to the use of fossil fuels if it is organised appropriately.

First of all and beyond doubt, biofuels are an important option to reduce CO_2 emissions from fossil energy sources which contribute to global warming. In general, the advantages turn out to be larger and more cost efficient for solid and gaseous fuels than for liquid fuels.

The picture is more differentiated for conventional pollutants such as NO_x, SO_2, CO, VOC and particulate emissions. While there is always an advantage of biomass with respect to SO_2, there are cases where some of the other emissions are higher for the biomass fuel cycle than for the application of fossil fuels. However, in well managed cases, the difference is either small or emissions occur at low levels anyway. Concerning external costs from human health impacts of the pollutants listed, there is an advantage of biomass when compared to coal and oil, but a (small) disadvantage compared to natural gas. Remaining problems, regarding for instance NO_x or CO emissions, are mostly due to the technology applied and not due to the fact that biofuels are used as feedstock. Solutions to these problems are mostly available or seem feasible, but are not yet standard technology. Therefore, they should be tackled by carefully targeted R&D.

The emission inventories are dominated by the energy conversion stage of the fuel cycle while the clean-up stage has virtually no visible impact. The contribution of fuel production – though small in general – is the larger the more complicated the fuel preparation process is.

There are several other, mostly qualitative benefits and damage that accompany the energy use of biomass. First, the use of forestry residues may contribute to reducing acidification levels in the forest. Especially in Sweden, this is regarded as valuable and expresses itself in a high willingness-to-pay demonstrated by the wide acceptance of corresponding environmental taxes. Second, the use of biomass residues may contribute to solving waste problems which is illustrated by the production of biogas from animal slurry and the use of sewage sludge for fertilising short-rotation coppice.

Concerning impacts on biodiversity, water and soil quality, we have found negligible marginal effects in our case studies. This may change, however, if these fuel cycles are implemented at a larger scale. Adverse consequences may be avoided if the technologies are introduced carefully and if possible negative impacts are counteracted right from the beginning. For instance, energy crops should not be planted in areas which are or should be nature reserves, but in re-designated agricultural areas. Furthermore, the use of fertilisers has to be adapted to the actual uptake of the plants, and pesticides have to be applied sparsely. It may be worthwhile to examine in how far guidelines and a tax on fertilisers, pesticides etc. could promote such a behaviour.

Possible future competition for resources and land should be taken seriously at an early stage. Otherwise, developments such as the increasing share of organic farming in Denmark may erode the potential of biomass. Changing the diet towards less meat consumption, on the other hand, may contribute significantly to increasing the area available for energy crops.

It may also be concluded that it is important to involve local stakeholders at an early stage. This may help to ensure appropriate definition of and compliance with good practice guidelines and to preserve rural amenity, thus avoiding local resistance to the new technologies.

The combined production of heat and power has substantial advantages over separate production of these commodities if demand and supply can be brought into phase. With respect to the use of biomass, this is not only an issue of rational use of energy, but also of making optimal use of the scarce land resources available for energy purposes. Gas turbines and combinations of boilers and steam turbines are clearly preferable compared to internal-combustion engines which exhibit considerable problems with emissions of NO_x and methane. However, it should be noted that installing engines may be an economic necessity if one wants to realise cogeneration potentials in areas with low demand densities. Thus, there is a trade-off between energy efficiency and mitigation of global warming on the one hand and health impacts of conventional pollutants on the other hand.

Furthermore, there is an advantage of using residues compared to energy crops and of perennial woody crops over annual crops. This is due to the effort for growing annual crops and to the complex fuel preparation processes involved in converting biomass into a convenient biofuel. The advantages of liquid biofuels are less clear than for solid and gaseous fuels (and sometimes non-existent) as their production requires substantial amounts of fossil energy.

The different case studies revealed a broad range of energy production costs. Two case studies were found to be economic even under prevailing conditions, mainly because the feedstock is available at low cost. The other case studies are up to 50% more expensive than their reference cases, partly because the technologies are still at the stage of pilot projects. Thus, bringing down the internal costs of the promising biomass fuel cycles should be an important objective of R&D strategies at national and EU levels.

For a number of technologies, including biogas and gasification of forestry residues and short-rotation coppice, the CO_2-abatement costs are in the same range as the damage cost estimates of ExternE for global warming (60-170 US-$/t C). Combined with external costs from health impacts of conventional pollutants, we see a clear incentive to pursue the application of the biomass technologies. This is even more the case if one adopts the notion of strong sustainability as a policy guideline. In this case, the higher costs of biofuels and other renewable energies may be regarded as payments for an insurance against damage to the environment in general and the risk of global climate change in particular.

Nevertheless, market-based incentives should be used to support the market introduction of biomass-to-energy applications in order to select the most favourable application. Such incentives could be fuel or emission taxes which may be justified as an internalisation of external costs. However, reflecting the large uncertainties of external costs, the levels of such taxes should be determined by the objectives pursued rather than the external costs calculated. This principle is called standard-price approach in economics and is well in line with the concept of strong sustainability. An alternative instrument for implementing a standard-price approach are tradable permits as they are foreseen in the Kyoto protocol on global warming.

The energy use of biomass will most probably not lead to a decrease in employment. It may even contribute moderately to additional employment. However, improvements in efficiency necessary for economic reasons may also reduce the labour input into biomass fuel cycles. Thus, the energy use of biomass should not be regarded as a substantial contribution to solving the unemployment problem. Nevertheless, there may be a local benefits in rural areas.

With respect to socio-economic frameworks, the case studies examined indicate a number of issues which are essential for the success of biomass fuel cycles:

- It has to be demonstrated that the technology is mature and has environmental benefits.
- Economic conditions must be favourable. This can be influenced decisively by government policies.
- Within such constraints, entrepreneurs should be left as much freedom as possible to organise the fuel cycle efficiently.
- However, their efforts have to be closely monitored and made subject to tight environmental standards.
- The existence of determined groups of local people who want to promote innovative solutions is essential. Local benefits are crucial to guarantee local support of new technologies.
- The frameworks established have to be easy to understand, non-bureaucratic and reliable for substantial periods.

All in all, we emphasise that carefully chosen and well managed biomass fuel cycles can provide an important, if not indispensable, contribution to a sustainable future energy system for the European Union.

Part I: Objectives of the Project

The objective of the BioCosts project is to provide a comprehensive analysis of the economic and environmental impacts of the energy use of biomass. In so doing, the study supplements research on external costs of energy under the accounting framework ExternE developed for the European Commission (DG XII). However, this study takes a broader view by considering internal costs, employment effects, global warming and sustainability as well. Furthermore, it provides a comparison of each biomass technology under analysis with a carefully chosen reference case based on a fossil fuel.

Since possible impacts of biomass are highly dependent on fuel types and conversion technologies, the study covers a broad range of biomass applications by carrying out several case studies:

- utilisation of forestry residues in the Nässjö circulating fluidised bed combustion plant, Sweden;
- utilisation of forestry residues and short-rotation coppice for industrial combined heat and power production in Mangualde, Portugal;
- production of biogas from animal slurry for municipal combined heat and power generation at Hashöj, Denmark;
- gasification of woody biomass for combined heat and power generation in Värnamo, Sweden, and Eggborough, UK;
- production of cold-pressed rape-seed oil and its use in a CHP plant at Weissenburg, Germany;
- production of rape-seed oil methyl ester (RME) and its use for goods transport in Germany;
- production of ethyl tertiary butyl ether (ETBE) from sugar beets and sweet sorghum for transport applications in France.

For all case studies, detailed emission inventories for the different fuel-cycle stages are compiled. The impact-pathway approach as implemented in ExternE's EcoSense model, is used to calculate air dispersion of pollutants and the formation of secondary pollutants, to determine their impacts on selected receptors and to calculate the related damage in monetary terms. Other possible impacts, e.g. on biodiversity, soil, water or rural amenity, are discussed qualitatively.

Indirect emissions and employment effects are estimated by means of comparative-static input-output analysis with ZEW's I/O-model EMI 2.0 (formerly called "Emittentenstruktur").

Internal costs are calculated to examine the economic viability of the biomass applications. By comparing the biomass case with its reference application, CO_2-abatement costs are calculated and discussed with respect to current damage-cost estimates for the consequences of global climate change.

Finally, the socio-economic frameworks under which the different case studies operate are evaluated in order to reach conclusions on the issues critical for the success or failure of biomass-to-energy projects.

Part II: Scientific and Technical Description of the Project

1. Methodology

This report is organised in such a way, that first all methodological considerations are explained in Chapter 1. Their application to the case studies and the results are then described in Chapter 2. We have chosen this approach to avoid extensive redundancies in discussing methodological issues. Since much more material has been produced in the course of the project than can be cited here, readers are referred to the reports on the individual case studies and other project papers listed as references in the Appendix.

1.1. General Remarks

In the BioCosts project, representative biomass-to-electricity fuel cycles and biomass-to-transport-service fuel cycles located at different sites within the European Union are evaluated concerning their environmental and economic performance. To cover a broad range of biomass applications and their varying characteristics, the case studies deal with different combinations of conversion technologies and biofuels.

While earlier assessments, especially of fossil-fuel technologies, focussed on energy conversion as the main source of pollutants, it has meanwhile been acknowledged that it is necessary to evaluate all stages and activities of a given fuel cycle. Such a fuel cycle starts, for instance, with the extraction of the fuel in the case of fossil fuels, with the collection of residues or planting of energy crops when biomass is involved, or the production of the equipment as far as photovoltaics and wind energy are concerned. Fuels may then have to be prepared further before they can be converted into the final energy or the energy services delivered to the customer. Often, fuel cycles do not stop here, but clean-up activities may be necessary to take care of potentially hazardous or just voluminous waste.

When defining the different stages of the fuel cycle, it is essential to carefully select *system boundaries* and *allocation mechanisms*. System boundaries define which effects are regarded as part of the fuel cycle and which are left out of consideration. Allocation mechanisms are necessary to attribute the effects considered to the different commodities produced. This refers, for instance, to the combined production of heat and power or to the production of rapeseed oil and press cake, the latter of which still has an economic value as animal fodder.

The general rule for defining *system boundaries* in the BioCosts project is to compare the biomass-to-energy application with its fossil-fuel reference case and to attribute any difference, be it positive or negative, beneficial or potentially harmful, to the use of biomass. For agriculture, the farming of energy crops is compared to what would take place on that piece of land otherwise. This might be conventional farming of food crops or participation in the set-aside land scheme of the EU. For combustion, the efficiencies, costs and emissions of the use of biofuels are compared to those of fossil fuels. In addition to the direct effects, indirect effects of manufacturing the conversion equipment and during fuel preparation are taken into account. This is done via input-output analysis, described in Section 1.2.2. Finally, other indirect effects, which are not captured by the input-output model, are included if they account for a substantial share of the overall effect. This is the case for the application of fertilisers during farming of energy crops. The production of the fertilisers needs relatively large amounts of (fossil) energy, and consequently causes so many emissions, that it contributes substantially to the respective emission inventories.

In general, five stages of biomass fuel cycles may be distinguished. These would be growing of the plants (a stage which is not present in each of our case studies) – collection or harvesting – preparation of the fuel – conversion into electricity, heat or transport service – and clean-up (waste disposal). However, due to the dominance of the conversion stage and in order to increase clarity and comparability of our results, all biomass fuel cycles analysed in the BioCosts project are divided into only three main stages:

- production of the fuel,
- energy conversion,
- and clean-up/ waste disposal.

Transport activities are necessary at and between these stages. They are considered part of the production and the clean-up stage, respectively.

A general methodological problem is the *allocation of impacts and costs* between different commodities (e.g., electricity and heat) provided by most of the installations examined in the project. This problem has been discussed at length in the literature (cf. the survey in Jörgensen et al. 1998) and within the project. However, there is no unique solution to this problem. The most favourable, largely unbiased solution is the systems approach. It assesses two systems, which provide the same energy services, and calculates the respective costs and environmental impacts which may then be compared to decide which solution is to be preferred.

However, this approach is not applicable for the BioCosts project as we are obliged to produce results with respect to one unit of heat, electricity, or transport service. Thus, we are left with four options: allocation by *energy*, *exergy*, *mass* or *prices*. Allocation by energy means that emissions and internal costs are attributed to electricity and heat flows according to their energy content. In that case, one kilowatt-hour of electricity is regarded as equivalent to one kilowatt-hour of heat. From a physical point of view, this is not satisfactory since electricity is more valuable than (low-temperature) heat. The problem could be solved by exergy allocation, that is by attributing emissions with respect to the share of energy that can be converted into any other from of energy and which actually provides the energy service desired. For electricity, this share is 100%, while for heat at a temperature of 90^{o}C it is only about 25%.

Exergy allocation has two drawbacks. First, it is hard to communicate since the concept of exergy is not widely known among people who do not have a background in physics. Second, it may create the following artefact: Imagine that the overall efficiency of a cogeneration plant is improved in order to make electricity production more cost efficient. This effort may lead to a lower temperature of the heat produced and thus a lower exergy share of the heat and less external costs attributed to the heat. Consequently, from a business point of view, the allocation method would compensate lower internal costs of electricity by attributing more of the external effects to this commodity, which counters the original intention for the investment. From a more general point of view, however, this is not a problem.

Using the prices, at which electricity and heat are sold, as allocation index also creates problems since these prices depend on local market conditions not only in their level, but also in the way in which they are determined. Some installations produce electricity as the primary commodity, sell it at the usual market price and take whatever they get for the excess heat. In other cases, this is the other way round. Thus, a price driven allocation mechanism would compromise the comparability of the results.

Weighing these arguments, we have decided to use energy allocation as a compromise. It will ensure comparability of the results of different case studies, but it will have to be kept in mind when comparing our results with actual market prices of energy.

For non-energy by-products such as press cake or glycerine from the production of rapeseed oil methyl ester (RME), which occur during the production of biofuels, we use allocation by mass. First, it is necessary to attribute some of the external effects to the by-products if these are essential for the economic viability of the whole fuel cycle. Allocation by energy (and exergy), on the other hand, is obviously meaningless as these products are not used for energy purposes. Prices can also not be used for the reasons stated above. Thus, we are left with allocation by mass in these cases. Again, this is not fully satisfactory since the choice has an impact on the results, which has to be kept in mind.

The BioCosts study deviates from external costs studies carried out within the ExternE framework in that it defines *reference technologies* to which the use of biomass is compared. We regard this comparison as important. As it turns out, even the most thorough data collection in an international context will unavoidably involve a number of biases, which may be due to national peculiarities or specific features of the technology assessed. Thus, comparison with a reference technology, which is carefully chosen to represent the situation in the country if biomass was not applied at the respective site, may eliminate some of the biases described. In addition, since the reference technology is assumed to be in the same location as the biomass technology, the influence of the population density in the area hit by the exhaust plume cancels out in this comparison.

1.2. Assessment of the Economic Performance

1.2.1. Internal costs

The calculation of internal costs for the different case studies serves to assess and compare their economic viability. To achieve comparability of results, it does not suffice to simply state the production costs which owners and operators of the facilities claim. These costs are subject to various country specific conditions. Among these conditions are national laws and directives which determine general taxes, pollution standards, and subsidies for renewable energies as well as for their fossil counterparts. In our calculations, we try to omit these local influences as far as possible.

Therefore, calculations of energy production costs in the BioCosts project are done from the scratch by adding up all the contributions which can be identified. Starting with the conversion stage, there are the fixed costs of the conversion equipment. The largest part are the investment costs, which are determined by distributing the total investment over the life-time of the equipment using the annuity method with a general discount rate of 5%.[1] Other components of the fixed costs are operation and maintenance (commonly estimated as a fixed annual share of the investment) and labour. Variable costs are primarily fuel costs. For fossil fuels, we apply market prices excluding taxes and subsidies. For biofuels, we calculate fuel costs in detail, including again investment in equipment such as agricultural machinery, gasifiers etc. as well as operation and maintenance and labour costs. Finally, there are the costs of the

[1] We are aware of the fact that any choice of a discount rate is always debatable. Our decision was based on the objective to make the different case studies comparable and not so much by representing the business strategy of the respective company.

clean-up stage, which are included when applicable and available. However, as with most other effects considered in this study, the contribution of the clean-up stage turned out to be negligible. Finally, as discussed above, all costs are distributed to heat and electricity by energy content. Calculations are carried out with respect to the base year 1995.

It has to be stressed that the cost figures stated in the BioCosts project are an indicator for the economic viability of the biomass fuel cycles as compared to their fossil reference cases and, with some uncertainty due to local conditions, among each other. They should not be taken as a guideline for decisions in a business environment. One example may illustrate this point. While we assume equal production costs of heat and electricity, this will certainly not be reflected in the prices at which these commodities can be sold. In some countries, cogeneration facilities are governed by the conditions of the heat market. Thus, the operators have to offer a competitive price for heat to compete against other energy supply technologies. Whatever share of the costs and profits is left, has to be charged to the electricity price. In other environments, these conditions are reversed. Such specific circumstances are discussed in the case study reports, but are not the basis of the results presented in this report. Here, we apply the same methodology to all case studies to achieve the highest possible degree of comparability, even though we know that a number of compromises have to be made and that some of the figures we use are not completely independent of local information.

1.2.2. Employment effects

An important task of the BioCosts project is to determine, whether the energy use of biomass will lead to benefits with respect to employment. For this purpose, direct and indirect employment effects are calculated for the biomass technologies and their reference cases.

Direct employment involves all activities during fuel production (growing, harvesting, processing), operation and maintenance of the conversion equipment, and clean-up. For the biomass technologies, these activities were analysed in detail while for fossil fuel production they are determined by input-output analysis as described below.

Indirect effects are mostly due to the manufacture of energy technologies, which creates employment in the year in which the additional capacity is produced and installed, and to the provision of raw materials. Indirect effects are of special importance for technologies like photovoltaics, which have small impacts attributable to their direct use, but where larger impacts may be caused during the production of the intermediate goods needed for their manufacture. It may be possible to capture first order indirect effects through a life-cycle analysis for technologies such as wind turbines. The analysis of second order effects and first order effects for more complex technologies such as biomass cogeneration plants, however, is rather difficult if not impossible with that method. Thus, a comprehensive analysis of the total effects requires a separate instrument to incorporate intermediate employment effects and emissions. An appropriate tool for this task is an enhanced input-output analysis including sector specific employment (and emission) coefficients.

Input-output analysis is a standard tool of economics. The interdependencies of an economy, where the outputs of different industrial sectors constitute the inputs of other sectors (or the final demand), are mapped into a matrix structure (cf. Figure 1). The economy is divided into a production segment (I and III in Figure 1) consisting of different sectors or industries like steel production or telecommunication services, and a segment of final demand (II) comprising private demand, investments of industry, and public demand. The sectors of the production segment combine primary inputs (III) like labour and capital with intermediate inputs

Economic sub-model	Inter-industry transaction matrix Inputs of industry j = 1,2,...,58	Final demand
Outputs of industry i = 1,2,...,58	I. $\underline{\underline{A}}$ (a_{ij})	II. $\underline{\underline{Y}}$ (y_i)
Primary inputs	III. $\underline{\underline{P}}$ (p_j)	

Emission sub-model	Sector specific emission coefficients	Emission coefficients of final consumption
Gaseous Liquid Solid	$\underline{\underline{E}}_A$	$\underline{\underline{E}}_Y$

Figure 1 Schematic representation of an input-output table, together with a matrix of sector specific emission coefficients.

(I) like tires for cars which they receive from other industries for their production. Their products are delivered to final demand (II) or to other industries as intermediate inputs (I).

Input-output tables list all transactions inside the production segment as well as between the production sectors and final demand in monetary terms on an annual basis. Rows indicate goods delivered (outputs), while goods received by industries and final demand (II) are listed in columns (inputs). Sector-specific employment coefficients are given in an additional row in terms of person years per unit of gross production value. The sum of each column represents the total annual value of production of each industry (gross production), while the sum of each row indicates the total production delivered to final demand and other industries.

If all entries of a column are divided by its sum, we get the matrix of input-coefficients $\underline{\underline{A}}$ in segment I with each coefficient a_{ij} representing the share of the production of an industry which is bought as an intermediate product from another industry. Multiplying an industry's vector of direct input coefficients $\underline{a}_j$ by a given level of output of that industry yields the necessary direct inputs from other sectors. To get to second order effects, this calculation has to be repeated for each component of the vector of direct inputs, thus in case of the standard German input-output table up to 58 times. To get to third order effects, 58 times 58 such vector multiplications have to be carried out, and so on. Mathematically, this is equivalent to adding up a geometric series. Fortunately, in linear algebra this phenomenon can be represented by the inversion of the matrix of the direct input coefficients $\underline{\underline{A}}$. The resulting inverse matrix $(\underline{\underline{I}}-\underline{\underline{A}})^{-1}$ is called a 'Leontief-Matrix'. The inverse matrix provides us with coefficients which simply need to be multiplied by a given final demand $\underline{Y}$ to derive the total production $\underline{X}$ necessary to produce $\underline{Y}$ and all intermediate products (cf. Figure 2):

$$\underline{X} = (\underline{\underline{I}}-\underline{\underline{A}})^{-1} \cdot \underline{Y} \,. \tag{1}$$

To get indirect employment effects of a given final demand, one simply has to multiply Equation (1) by the specific employment coefficients of the different sectors:

Economic sub-model	Induced production of industry 1,2,...58	Sums	Final demand	Total production
Outputs of industry i = 1,2,...,58	$(\underline{I}-\underline{\underline{A}})^{-1}\,\underline{X}$	Σ ...	$\underline{Y}$	$\underline{X}$
Sums	Σ	Σ ...	$\Sigma\, y_i$	$\Sigma\, x_j$

Employment sub-model	Employment created directly / indirectly	
Employment created	$\underline{L}\ (\underline{I}-\underline{\underline{A}})^{-1}\,\underline{X}$	Σ ...

Emission sub-model	Direct and indirect emissions			Sum of all emissions
Gaseous Liquid Solid	$\underline{E}\ (\underline{I}-\underline{\underline{A}})^{-1}\,\underline{X}$	Σ ...	$\underline{E}_y$	Σ ...

Figure 2 Structure of the input-output model EMI to calculate direct and indirect employment and emission effects based on combined input-output and emission tables.

$$X_L = \underline{L} \cdot (\underline{I}-\underline{\underline{A}})^{-1} \cdot \underline{Y}. \qquad (2)$$

Furthermore, indirect production effects may be combined with sector specific emission coefficients stated with respect to one unit of output. Thus, indirect emissions of a given final demand can be calculated as

$$\underline{E}_y = (\underline{I}-\underline{\underline{A}})^{-1} \cdot \underline{Y} \cdot \underline{\underline{E}}_A\ . \qquad (3)$$

Figure 2 schematically represents this type of calculation based on combined input-output and emission tables. Software for an enhanced input-output and emissions model for Germany as described above was originally developed at the Fraunhofer Institute for Systems and Innovations Research – ISI (Hohmeyer and Walz 1992). Further development of this model, which is now called EMI 2.0, has then been carried out at ZEW. The schematic structure of the model is shown in Figure 1 and Figure 2. The input-output model is a functionally disaggregated open Leontief-Model with 58 sectors. Based on the official German input-output tables of the year 1988, employment coefficients, and a large database containing specific emission coefficients, the software facilitates the analysis of indirect employment effects as well as indirect emissions of a number of relevant air (CO_2, CO, NO_x, SO_2, VOCs, or particulates) and waste water pollutants plus many types of solid waste.

For the BioCosts project, OECD input-output tables were used with the EMI model for countries other than Germany. Furthermore, the shares of different energy sources were adapted accordingly. However, German coefficients for labour intensity and sector specific emissions had to be used due a lack of other data. Obtaining such data for a country and adapting them for the use with EMI is a costly task, which was clearly beyond the scope of the BioCosts project. For Portugal, no input-output table suitable for the use with EMI could be obtained. Since the economic structure of Germany and Portugal are very different, we decided not to use the German tables as a proxy for the Portuguese data, but to leave out these calculations. This will in most cases not compromise the results as indirect effects in general turned out to be small.

The EMI model was used in the BioCosts project to determine the indirect economic and environmental effects of manufacturing the conversion and fuel production equipment. For this purpose, a demand vector was determined by splitting investments to the different economic sectors. This vector was then fed into the EMI model. In addition, the employment effects of fossil fuel production were determined with EMI by feeding the fuel costs to the respective energy sector, because a detailed analysis of the labour used in fossil-fuel cycles was not within the scope of the BioCosts project. Indirect emissions during the production of fertilisers are not determined by input-output analysis since the structure of the input-output tables is not detailed enough for this task. Instead, results from life-cycle analysis carried out by Kaltschmitt and Reinhardt (1997) are used.

1.3. Assessment of Environmental Impacts

A wide variety of environmental burdens relating to our current energy systems have been identified over the past decades. In this context, the term burden summarises adverse consequences of a broad spectrum of human activities. This includes exploitation and exhaustion of non-renewable resources as well as emissions of poisonous or otherwise harmful substances into the biosphere. The respective environmental impacts are diverse in nature as well as in their spatial and temporal extension. Concerns about human induced global warming, regional air quality and resource depletion have resulted in increased interest in renewable energy sources that are potentially CO_2-neutral, less polluting or less resource demanding.

The advantages of biomass compared to fossil-fuel applications with respect to conventional airborne pollutants have often been questioned, since the biomass-to-energy conversion is based on similar combustion processes. Moreover, biomass differs from other renewable energies in that the range of biofuels and biomass applications is extensive, and therefore the respective environmental impacts are more diverse. Comprehensive life-cycle analyses (LCA) done for a broad range of biofuels by Kaltschmitt and Reinhardt (1997) for example show disadvantages of biofuels against fossil fuels with respect to some atmospheric pollutants, but also particular differences among the different biofuels considered. On the other hand, some environmental advantages of biofuels such as the conservation of fossil energy resources or the abatement of greenhouse gas emissions have been pointed out in numerous studies and are confirmed by Kaltschmitt and Reinhardt's analyses. The question arises if and how to weight the different burdens and impacts.

In the BioCosts project, we started with the mainstream economic approach from the variety of analytical techniques and methodologies developed by different academic disciplines for the appraisal of environmental and other effects of the use of energy technologies. This economic approach for 'taking the environment into account' is based on the concept of externalities[2] and aims at valuation of environmental impacts in monetary terms. Stirling (1997,

[2] The concept of externalities has been well established in neo-classical economic theory since an article of Arthur Pigou in 1912. A brief overview on the theoretical background is given in Box 1.

518) holds that this concept "now seems to be the dominant paradigm in the comparative environmental appraisal of contending energy options."

The objective to internalise external costs and benefits was also stated as a crucial pillar of environmental policy design in the Fifth Environmental Action Programme of the European Commission (CEC 1992). Therefore, research programmes on external costs of energy have played an important role at the European level. ExternE, for instance, is an extensive research project on external costs of fuel cycles, which has been funded by the European Commission since 1991 and recently went into its fourth phase (cf. CEC 1995a-f and CEC 1998).

The main advantage of this economic method is to provide a single and widespread criterion through which different objectives are made comparable, namely market prices.[3] External cost assessment of biomass fuel cycles offers the possibility to get a first idea whether biomass technologies can become economically competitive with fossil fuel technologies simply by accounting for environmental concerns in market prices.

Empirical studies on external costs of energy usually focus on the quantification of priority impacts instead of giving a detailed account of all direct and indirect energy and material flows associated with a system or process. We also clearly concentrate on monetising, if possible at all, those environmental impacts which – to our current knowledge – contribute significantly to the full external costs.

In a first step, each case study produced comprehensive inventories of all environmental burdens via air, land and water pathways. This includes all upstream and downstream stages of the particular biomass fuel cycle under analysis regardless whether the impacts are considered quantifiable or not. Section 1.3.1 summarises the main findings of the different case studies in an integrated form. In a next step, a list of the impacts that might be most important has been identified for each fuel cycle. Joint priority impacts were then determined through a combination of expert judgement and literature review (see Section 1.3.2). Sections 1.3.3 to 1.3.6 describe the methodology used for further evaluation of the selected priority impacts: impacts of atmospheric pollution on human health, impacts of the fuel production stage on the local biosphere, impacts of greenhouse gas emissions on global warming, and impacts of biomass fuel cycles on rural amenity.

1.3.1. Identification of burdens and impacts of the biomass fuel cycles[4]

A synopsis of the burdens of biomass fuel cycles is given in Table 1. Not surprisingly the burden inventories indicate that the biomass conversion stage is the main source of emissions to air in all case studies. Transportation activities which occur at and between all stages of a biomass fuel cycle are not negligible, however, since most vehicles consume and burn fossil fuels. Among the 'classical' air pollutants attributable to biomass conversion and transportation are the primary emissions of nitrogen oxides (NO_x), sulphur dioxide (SO_2), total suspended particulates (TSP), carbon monoxide (CO), and hydrocarbons (HC) with the subcategory volatile organic compounds (VOCs).

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[3] On the other hand, it is often criticised that monetary values fail to address the multidimensional nature of environmental issues by reducing their complexity to one unit (e.g. Bernow et al. 1996, Endres 1995, Stirling 1997).

[4] For more details, please, refer to the case study reports.

Box 1: The Concept of External Effects – Theoretical Background

The concept of external effects has its theoretical basis in neo-classical welfare economics. Economic theory provides established arguments to identify, quantify, and monetise external environmental effects of energy supply and demand, and to incorporate them through various instruments, for instance taxes, into decision- and policy-making processes.

External costs are defined as the monetary values of impacts that are imposed on society or parts of it by activities of an individual or a group and that are not accounted for in the market price, and therefore, not in individual decision-making processes either. External effects are typically related to public goods and services, or goods and services for which no property rights are defined (for example clean air or biodiversity). Under these conditions, the market mechanism is not functioning correctly or is even non-existent. Economists refer to this phenomenon as market failure: the market fails to reflect costs to society in the market price. As a consequence, these goods and services are not used in an economically efficient or Pareto-optimal way, but they are misallocated in the economy. The good or service which does not have a price at all is usually overused. Preventing or correcting the misallocation ideally involves understanding the monetary value of external effects, and then finding a mechanism for integrating the environmental concerns into the private or public decisions (e.g., Baumol and Oates 1988). Thus, in neo-classical economic theory, environmental impacts and protection questions are formulated as optimal resource use problems through the extension of traditional cost-benefit analysis.

Due to a range of difficulties, which are partly the consequence of an information and data problem and partly of fundamental limits of the potential of scientific findings, the theoretical ideal of monetising externalities and determining the 'optimal' price is impossible to achieve in empirical studies. That leads to the necessity of a more pragmatic and implementation-oriented approach. Different conceptions of internalisation of environmental damage are possible. In a narrow sense internalisation refers to the goal of Pareto-efficiency in resource allocation, i.e. to the practice of optimisation. In a broader sense it refers to political processes and institutions for resolving conflicts over environmental concerns (O'Connor 1997, 455f.).

One should be aware of some underlying philosophical premises of the external cost approach. At the focal point of the welfare economic paradigm are the preferences of individual consumers; values of environmental goods or services are measured by the aggregation of consumer preferences. People's willingness to pay (WTP) for improved environmental quality or willingness to accept (WTA) compensation for environmental degradation is considered as the adequate valuation tool reflecting these preferences. However, the revealed WTP or WTA is for instance related to the individual's level of information and depends on the ability to pay, in addition to his or her preferences. Where regional income distribution is asymmetric as in the EU, an obstinate implementation of the concept could meet resistance from citizens (Endres 1995). Critical loads and levels are not necessarily reflected in the valuation measures.

Furthermore, in the context of environmental assessment, it is important to mention the differentiation between the category of use values and non-use values in economic theory. The idea of non-use values – economists use the terms option value, existence value, and intrinsic value to connote potential use and non-use values – is motivated by a concern that something important might be missed in use values. Flora and fauna have values beyond the money that they can fetch in the market. These values have to do with maintaining the integrity of ecosystems for society as a whole, including future generations; they have cultural, aesthetic, and ethical dimensions next to the material one. Yet, most of the techniques for the valuation of non-market goods are not designed to take account of non-use values.

The possibilities, limitations and biases of the externality concept as well as of the different techniques of monetary valuation have been extensively discussed in the literature. Refer e.g. to Pearce and Turner 1990, Hoevenagel 1991, or Markandya and Pearce 1989 for more details.

Many of these substances are also precursors of secondary pollutants formed by chemical reactions in the atmosphere with adverse impacts on many receptors – human, natural and build environment. Ground level ozone (O_3) or photochemical smog, for example, result from reactions between nitrogen oxides (NO_x) and hydrocarbons (HCs) in the presence of sunlight. Nitrate and sulphate aerosols are formed from SO_2, NO_x and ammonia (NH_3). The processes of wet (acid rain) and dry acidic deposition lead to acidification of water and soil. Typically, impacts on human health, agriculture, forests, terrestrial and aquatic ecosystems, and building materials are identified and linked with both, the primary and secondary atmospheric emissions. The latter may be transported up to thousands of kilometres away from the source of emissions.

Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) emissions are other important outputs of the combustion processes in plants and vehicles. Yet, with respect to biomass fuel cycles, direct CO_2 emissions from the conversion of biofuels into other energy forms may in general be seen as neutral with respect to global warming since corresponding amounts of CO_2 are fixed during the growing of the biomass on a similar time scale (Sinisalo and Savolainen 1996). In a total fuel cycle perspective, some greenhouse gas emissions do arise from fossil fuel use in machinery and in means of transportation and do have an impact on global warming. Balances of greenhouse gases for the entire fuel cycle of each case study will show the net contribution to global warming in terms of CO_2-equivalent emissions. These are calculated by adding CO_2 emissions from fossil sources and emissions of other infra-red active gases multiplied by their relative impact on global warming compared to CO_2. For CH_4 the Global Warming Potential (GWP) value with respect to its mass and a retention time of 100 years is 24.5, and for N_2O it is 320 (Reinhardt et al. 1997, IPCC 1995).

Besides atmospheric emissions, further burdens and impacts are typically attributed to transportation activities. They include health hazards due to traffic noise, the risk of road accidents and road damage. Since the energy density of biofuels is lower than that of fossil fuels, the biomass fuel cycle can be comparatively transport intensive.

At the energy conversion stage, condensate water discharges and solid waste outputs from the plant are mentioned in some case studies. After a qualitative assessment, the impacts are regarded as of minor importance, however. The ashes containing heavy metals can be disposed of by landfilling with no likely ecological impacts resulting from the leaching of noxious substances. If there is no heavy metal problem, another possibility is to recycle ash by returning it to soil. Research programmes on this topic are ongoing (cf., e.g. Jörgensen et al. 1998).

The upstream stages of the biomass fuel cycles are likely to have adverse impacts on biosphere, soil and water quality as well. The impacts are site-specific and dependent on management practice guidelines and the way in which they are implemented as well as on different cultivation processes and utilisation techniques.

In all case studies with energy crop plantations, use of fertilisers like nitrogen (N), phosphorous (P) and potassium (K) as well as pesticides, herbicides and fungicides is an issue and may cause significant local impacts. There is a risk of nitrate leaching into groundwater, and of polluting surface water with nitrogen, phosphates and pesticides. Due to the runoff of fertilisers and agricultural chemicals water can be contaminated and the quality of drinking water can deteriorate with direct effects on human health. The reduction of the oxygen concentration in water through nutrients as e.g. nitrogen may lead to excessive plant growth, i.e. eutrophication. The changes in water and soil quality might affect aquatic and terrestrial biodiversity. In addition, the production of fertilisers and pesticides is very energy intensive, thus, leading to additional emissions at the site of their production.

Table 1: Synopsis of burdens and adverse effects of biomass fuel cycles.

Stages of the Fuel Cycles	Emissions / Burdens	Receptors	Impact Categories
Growing and harvesting Fuel processing and production	Fertilisers (N, K, P) and pesticides use	Ecosystems Soil Aquatic systems: • Surface water • Groundwater	• Eutrophication • Aquatic biodiversity • Public health: drinking water contamination
	Soil erosion		• Soil quality • Eutrophication
	Resource and land use		• Biodiversity • Rural amenity
	Noise, visual intrusion	Public	Rural amenity
	Accidents, other hazards	Workers	Occupational health
Transportation activities (at and between all stages)	Atmospheric emissions: • Primary pollutants: NO_x, SO_2, TSP, CO, HCs • Secondary pollutants: Sulphate and nitrate aerosols, O_3 • CO_2, N_2O, CH_4	• Public • Crops • Forests • Materials • Ecosystems Numerous	Toxic effects on • Human health • Crop yield • Forestry yield • Building material • Ecosystems Global warming
	Road use		Road damage
	Noise	Public	Rural amenity
	Road accidents	Workers, public	Public and occupational health (minor and major injuries, death)
Energy conversion	Atmospheric emissions: • Primary pollutants: NO_x, SO_2, TSP, CO, HCs • Secondary pollutants: Sulphate and nitrate aerosols, O_3 • CO_2, N_2O, CH_4	• Public • Agriculture • Forests • Materials • Ecosystems Numerous	Toxic effects on • Human health • Crop yield • Forestry yield • Building material • Ecosystems Global warming
	Condensate water discharge: sulphates, sulphides, sulphites, total phosphorus, cadmium, total nitrogen		• Aquatic biodiversity • Public health: drinking water contamination
	Solid waste: fly ash and bottom ash		• Acidification • Public health
	Noise, smell, visual intrusion	Public	Rural amenity
	Accidents, other hazards	Workers	Occupational health
Clean-up (ash disposal)	Cf. burdens and impacts of transportation activities		

Soil erosion corresponds to a natural process in which soil material is weathered away and carried downstream by water or moved by wind. The soil erosion may be geological, and occur continually, or caused by human activities like agricultural production. Soil characteristics are an important factor for the estimation of soil erosion. Most of the sites under analysis in the BioCosts project are said not to be endangered by soil erosion. The only exception is the Portuguese site for poplar plantations.

Since agricultural production of biomass is relatively land intensive, large-scale implementation of biomass installations will significantly change the land use patterns and cause an increase in the demand for arable land on which to produce biomass. In the future, there might be competition for land with other human needs such as food and fibre production. Biomass cultivation also has the danger of reducing biodiversity in such a scenario. Here, however, we assess specific technologies at specific sites.

Some fuel cycle-specific effects require attention. In the Swedish forestry residue fuel cycle, the reduction in nitrogen load is regarded as the most significant net impact on soil. This effect is beneficial, since atmospheric deposition of nitrogen is currently above critical loads in most of Sweden and excess nitrogen causes eutrophication and acidification. Sewage sludge application at short-rotation coppice (SRC) sites are a special issue in the UK case study. Considering the fact that sewage sludge, which is applied to SRC in the case study, is regulated by law and would be applied to other agricultural land if SRC were not available, the impact might be small or even positive. A detailed discussion of the topic can be found in Bauen et al. (1998). In the Danish case study, the energy use of biogas produced from animal slurry contributes to solving a waste problem since farmers would have to store the slurry anyway.

Finally, positive and negative impacts on human senses are possible at all stages of the fuel cycles. For instance, noise pollution and odours can present a problem, especially in densely populated areas. Visual intrusion upon 'openness' of landscape, for example by storing harvested sticks on agricultural land, can cause strong feelings and thus disapproval of the energy use of biomass, in particular among visitors to the countryside. We incorporate these impacts under the category rural amenity.

1.3.2. Prioritisation of impact pathways

The notion of priority impact pathways serves two purposes. It reduces the number of impacts to be considered to a feasible amount and it enhances the comparability of the different case studies. Prioritisation does, however, not mean that the priority impacts are looked upon exclusively in the case studies. All case studies cover additional impact categories along with the priority impacts, both qualitatively (cf., the Swedish study by Jörgensen et al., 1998, and the UK study by Bauen et al., 1998) and quantitatively (cf. the Portuguese study by de Almeida et al. 1998) if regarded as essential. Vice versa, if any of the joint priority impacts does not apply to a case study, it is disregarded, and arguments are given why this is the case (cf. the Danish study by Meyer and Nielsen, 1998). The priority impacts identified are based on expert judgement and literature review and fall in the four categories:

- impacts of atmospheric emissions on human health,
- impacts of greenhouse gases on global warming,
- impacts of the fuel production stage on the local biosphere,
- impacts on rural amenity.

It should be evident why public exposure to air pollution is one focal point of our externality assessment. Primary and secondary atmospheric pollutants not merely affect the respiratory system. The physical impacts range from immediate and indirect fatalities to severe illnesses such as bronchitis and asthma as well as problems like hospital admissions or restricted activity days. Damage estimates for human health in general dominate the results of studies on external costs of energy (cf., e.g., CEC 1995a-f, CEC 1998, RCG/ Tellus 1993-1995).

Anthropogenic climate change is an environmental problem of so far unknown dimensions. Over the past years, it has been discussed extensively among experts and non-experts alike. The appraisal of potential increases or reductions of greenhouse gas emissions is essential for any environmental assessment of energy technologies.

Most of the research on external costs of energy focuses on atmospheric dispersion. In contrast to fossil fuel cycles, where the dispersion of emissions via soil and water does not lead to priority impacts, the feedstock production stage of the biomass fuel cycle can have significant impacts on local ecosystems and therefore needs further investigation with regard to these processes.

The selection of impacts on rural amenity as a priority impact has a somewhat different reasoning. The burdens may not lead to major physical damage, but have a high potential for creating public resistance and thus building an obstacle to the energy use of biomass. Hence, our case studies gave rural amenity special attention.

In the following two sections, we will first have a brief look at other studies on externalities of the energy use of biomass, their methodologies and impacts evaluated, on the one hand to inform the non-expert on the state-of-the-art, and on the other hand to support our chosen methodology. Then, we will discuss impacts which have been monetised in earlier studies, but are not considered priority impacts by the BioCosts project team.

1.3.2.1. Earlier studies on the external costs of biomass

In the past 15 years, there have been several empirical studies on environmental externalities of energy. Especially the more recent ones included biomass fuel cycles in their assessment.[5]

Methodology

ExternE, a research project on external costs of fuel cycles, which has been funded by the Commission of the European Communities under the JOULE programme since 1991, is so far the most extensive effort to advance the externality assessment (CEC 1995a-f, CEC 1998). By now, the project has established expert networks of more than 40 different European institutes from most countries of the European Union for the review, implementation, and dissemination of the evaluation methodology developed. In the second phase of ExternE (1993-1995), the accounting framework was applied to biomass fuel cycles in Portugal and Greece (CEEETA 1993 and 1995, NTUA 1995 and 1996). Biomass applications in 11 more countries were covered in the ExternE National Implementation project, which was part of ExternE phase III (1995-1997). Two other major studies were carried out in the United States: one for the US

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[5] Overviews are, for example, provided by Hohmeyer et al. 1996, Kühn 1998 or US Congress/ OTA 1994. In addition, two studies of the EU-APAS programme should be mentioned, which are based on the ExternE methodology (Faaij et al. 1998, Saez et al. 1998). Those studies include macro-economic effects on GDP, tax revenues and employment, which they view as external effects also.

Department of Energy by Oak Ridge National Laboratory and Resources for the Future (ORNL/ RFF 1994a-h), and one for different New York State organisations done by RCG/ Hagler, Bailly and Tellus Institute between 1992 and 1995 (RCG/ Tellus 1993-1995). Both American studies have evaluated one biomass fuel cycle. The only feedstock was wood residues in both cases and sensitivity analyses were conducted for different sites and technologies (ORNL/ RFF 1992, RCG/ Tellus 1993-1995, Vol. 4).

All three studies use a bottom-up methodology, the so-called damage function or impact-pathway approach which begins with a description of the site and technology and an engineering characterisation of emissions and burdens, and then ideally models the physical pathways from the transportation of emissions to changes in pollutant concentrations, to impacts on certain receptors, and, where possible, to monetary valuation of these (see Figure 3). This type of analysis offers a tool to determine marginal external costs and benefits. The impacts

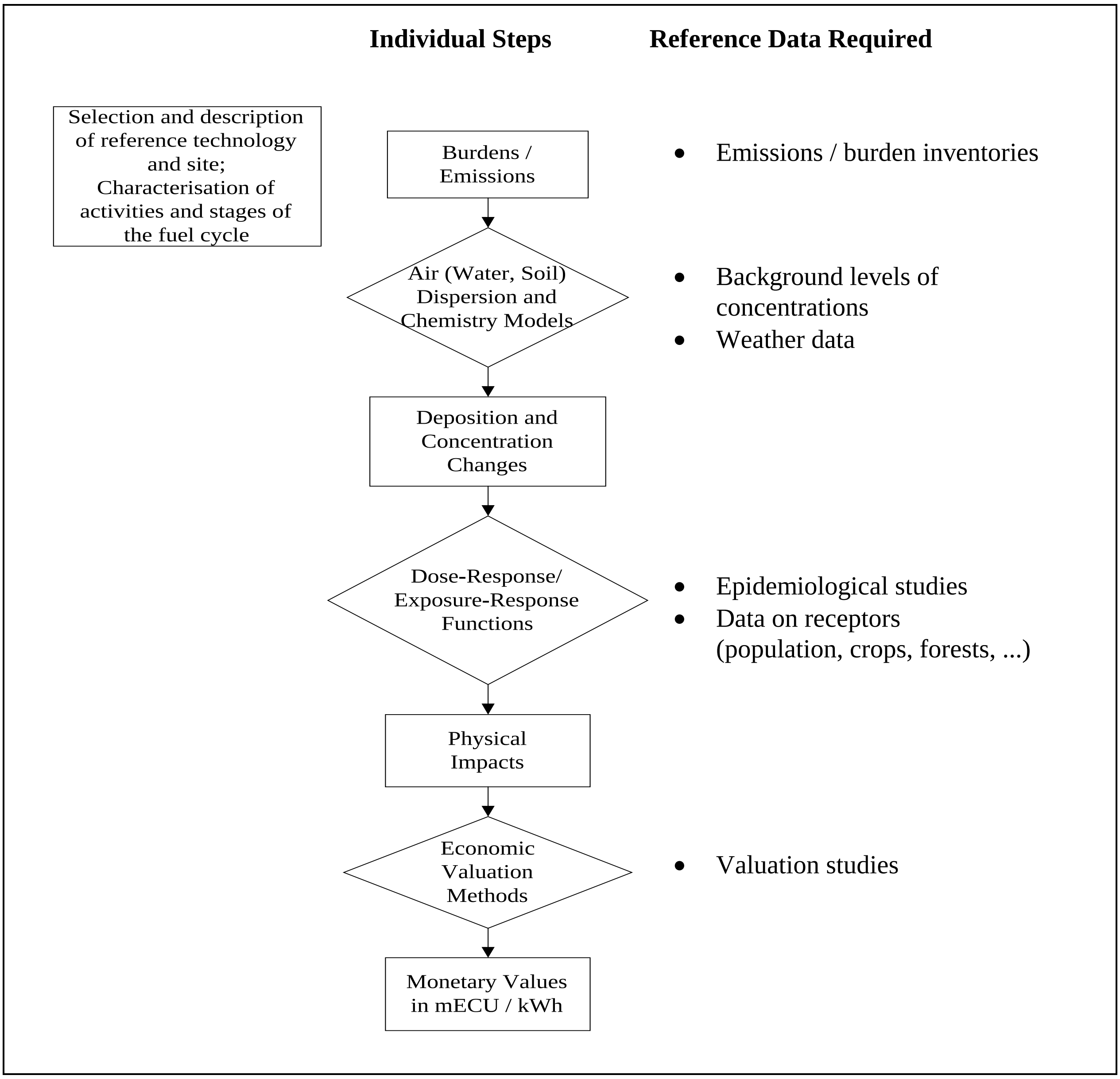

Figure 3: Impact-Pathway Methodology

assessed are incremental impacts due to an additional power plant at a specific site using a specified technology, not average impacts due to all existing burdens. Krupnick and Burtraw (1996) point to a relatively clear consensus on the general approaches for the air-human health pathways, the damage category given highest priority by all three project teams. The impacts of primary and secondary air emissions on human health are examined in most detail, physically and economically. The two orders of magnitude lower health damage calculated in the two American studies can partly be traced to the lower population density in the United States (Lee 1996), and partly to a lack of adequate regional air dispersion modelling (Kühn 1998).

On the other hand, earlier studies on externalities in the energy sector were mostly based on top-down approaches. They are primarily literature and statistics reviews, and calculate externalities, for example, from estimates of national damage and aggregated emissions of polluting activities. This type of analysis results in estimates of average damage costs. The earlier studies generally do not consider biomass, except for ECO Northwest (1986) and Ottinger et al. (1990). The facilities are located at mill sites or near lumber, wood products, or pulp and paper industries. The facilities are cogeneration plants, generating electricity and providing process steam for on- and off-site use. The feedstocks are mill waste, waste liquor, and forest residue. Ottinger et al. (1990) derived their estimates mainly from ECO Northwest (1986).

All studies note that their results contain substantial uncertainties and cannot incorporate all relevant categories of externalities. The studies differ in the methodology applied and in fundamental assumptions made. Thus, their resulting monetary values vary over a wide range, yielding a variety of rankings for the different generating options (cf., e.g., Stirling 1997).

Impacts assessed

The early studies by ECO Northwest (1986) and therewith Ottinger et al. (1990) focus their analysis on health effects from particulate and carbon monoxide emissions and on visibility improvement (due to replacement of open burning of slash with the fuelling of cogeneration). The energy conversion stage provides the basis of external costs, since no significant environmental effects are identified on the upstream stages of the fuel cycle. Significant effects are defined as those with economic values of more than 0.001 US-$/kWh.

Human exposures are estimated at low, high, and expected population densities in the areas exposed to the levels of concentration estimated for the different pollutants. No safe threshold is assumed to exist and dose-response functions are linear. CO accounts for about two thirds of the health effects. There is no further differentiation between health impacts, i.e. morbidity and mortality. Visibility loss is calculated by multiplying the lost visibility in kilometres by the number of residents around each source. The external benefits of visibility improvement and the external cost of health impacts roughly cancel one another in the final damage cost estimate for the biomass fuel cycle (only in the estimate at high population density do the health impacts exceed benefits of visibility improvement).

The ORNL/ RFF (1992) and the two ExternE phase II studies on biomass (CEEETA 1993 and 1995, NTUA 1995 and 1996), which start from a common accounting framework, identify and include more priority impacts as they take a total-fuel cycle perspective and the relevant methodologies were more advanced at that time. The impact pathways assessed comprise:

- human health impacts from primary air pollutants and ozone,
- groundwater contamination from nitrogen leaching,
- soil erosion,

- occupational health effects, i.e. accidents with subsequent minor injuries (inability to work lasting more than 3 days), with major injuries (inability to work lasting more than 50 days), or with deaths, and
- road damage.

Global warming is regarded as less relevant due to the recycling of carbon in the growth phase and, thus, CO_2-balances for the total fuel cycle are not drawn up.

The US study applied the damage function approach to a representative biomass-to-electricity fuel cycle. The assumed benchmark technologies were a conventional steam turbine (spreader-stoker) and biomass gasification combined with a gas turbine. The analysis was carried out for reference sites in two regions (ORNL/ RFF 1992). The Portuguese case study looked into the power generation from biomass of eucalyptus plantations and from eucalyptus bark on the one hand (Case 1a and 1b), and the use of wood chip fuel obtained from wood waste and from timber industry waste for heat purposes on the other hand (Case 2, cf. CEEETA 1993). Electricity generation at two Greek sites from agricultural energy crops, i.e. from fibre sorghum and Cynara cardunculus, was examined in the study by NTUA (1995).

In all three studies, the water-to-human health pathway plays a negligible role. Damage from groundwater contamination through nitrogen leaching are found to be several orders of magnitude smaller than other external cost estimates, they are in the range of 10^{-2} to 10^{-6} mECU/kWh. The low significance of discharges to water might partly be due to modelling difficulties and to a lack of detailed information on the adverse consequences for other pollutants and receptors, but it is in line with the qualitative assessment of the BioCosts case studies and with Kaltschmitt and Reinhardt (1997). The method by which soil erosion is valued in the European studies results in cost figures which are orders of magnitude below other damage estimates. Only in the US study, a positive effect of about 1 mECU/ kWh has been calculated.

When the studies by ORNL/ RFF, CEEETA and NTUA were carried out, accurate regional air dispersion models for secondary pollutants as well as models to estimate ozone concentrations for both local and regional (viz. short- and long-range) analyses were not yet available. Therefore, the human health damage are much smaller than in the most recent ExternE studies (CEC 1998), but they are still a dominant impact category in all studies. In the Greek case studies they account for about 97 and 99% of the total damage values. For the US study, the major source of damage from the biomass fuel cycle were the health effects from particulates and ozone, the latter of which, however, involved some very rough modelling. Only the Portuguese study estimates occupational health as the largest damage category in both case studies (between 1.4 and 2.4 mECU/kWh). The comparatively high costs for occupational health are interpreted to reflect the high level of mortality and injuries from road transportation in Portugal. Yet, it is also admitted that "the assumption that considers the level of impacts identical during the life time of the plant may be too strong. ... A scenario with a progressive reduction of the level of accidents and of their consequences seems more realistic." Moreover, the calculated level of road damage is of the same order of magnitude as health damage from air pollutants in the Portuguese study; estimates for impacts of particulates and ozone on human health are below 0.1 mECU/kWh of energy produced for Case 1a, 1b and 2. Damage to public roads from the feedstock-hauling trucks was negligible in the study by NTUA in contrast to the ORNL/ RFF study. In the latter, it accounts for about 1.5 mECU/kWh.

Based on the results of the studies, the relevance and ranking of impact pathway categories is not definite but some trends are evident. In comparison to parallel case studies on other renewable energies, the total damage cost estimates were somewhat higher for biomass, although they did not exceed 5 mECU/kWh.

In the National Implementation studies of ExternE phase III, the technologies assessed range from conventional technologies such as grate boilers, to fluidised bed systems, and gasification technologies, the majority being combustion technologies. Cogeneration plants have also been a frequent choice. The biofuel chosen for assessment by most teams is wood or forestry residues. However, different energy crops have been appraised as well (CEC 1998).

The ExternE studies typically analyse impacts of atmospheric pollution on human health, on building materials, on commercial crops, and forests, as well as the impacts (of mainly accidents) on occupational health. Global warming is taken into account as well. At the conversion stage, the impacts of air emissions (in particular TSP and NO_x) on human health, and especially on mortality, clearly contribute the most to the total quantified damage costs. For global warming only low damage costs are quantified, since it was assumed that there is no net atmospheric CO_2 build-up from the burning of biomass grown sustainably. In sum, all non-human health impacts assessed at the conversion stage account for a few percent on average.

Air pollutant emissions also cause the major impacts at the upstream stages of the biomass fuel cycles. The overall damage estimates for these stages are significant in most case studies, mainly due to the transport of the feedstock and fuel, although they are usually smaller than those attributed to the conversion stage.

The ExternE team summarises "that it is difficult to define a typical biomass fuel cycle, and the cause for the different results obtained." The external cost estimates range from about 1 to about 30 mECU/kWh. The Spanish case study looking at a plant co-firing forestry residues and lignite even produces results of 17 to 130 mECU/kWh. The modelling of regional atmospheric chemistry and deposition and the monetisation of related impacts is an important progress in ExternE phase III as compared to earlier studies. It has increased the total cost estimates, however. Ozone modelling and evaluation are still regarded as very difficult and therefore only implemented very roughly. Research projects are on-going on these issues.

1.3.2.2. Pathways not selected as priority impacts

The stated objective of the BioCosts study was to take the ExternE methodology as the starting point for the externality assessment. At the beginning of ExternE phase III, a first version of the computer model EcoSense which calculates external costs of energy use through the impact-pathway methodology was made available by the Institute of Energy Economics and the Rational Use of Energy (IER) of the University of Stuttgart, Germany. The model implements the ExternE accounting framework for all impacts for which a formal air dispersion and chemistry model is needed and which can be quantified and monetised. It determines concentration changes of air pollutants due to emissions from the stack of a specific plant up to thousands of kilometres away from the site. After extensive testing of the EcoSense model, we concluded that it is the best tool available for the externality assessment of our priority pathway "impacts of atmospheric emissions on human health".[6] Since the ExternE methodology has meanwhile been implemented and disseminated widely, this decision will improve the comparability of our results with other studies.

Of the priority impacts decided upon for the BioCosts project, EcoSense is only suitable to cover impacts on human health. How we proceeded with other priority impacts is described in

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6 Please refer also to Section 1.3.3 or, for more details, to the discussion paper by Groscurth and Kühn (1997).

Sections 1.3.4 to 1.3.6. Other impacts covered by EcoSense or in ExternE, but not further evaluated here, are briefly surveyed in the following paragraphs.

Impacts of air emissions on agriculture, forests, and materials

Impacts of atmospheric pollution on crop and forestry yields, and on damage to building materials can be monetised with the help of EcoSense. In all biomass case studies done so far, the aggregated damage estimates of these impacts do not exceed 1 mECU/kWh. Test runs of the EcoSense model for the case studies of the BioCosts project yielded no figure higher than 0.1 mECU/kWh. Thus, the cost estimates for the categories listed are one to three orders of magnitude smaller than for impacts on human health by air pollutants and, in any event, the external costs are insignificant compared to the internal costs.

The comparatively low values for these atmospheric impacts may reflect the limitations of scientific knowledge. Dose-response functions for various air pollutants on agriculture or on forests have proved to be particularly complex for a number of reasons. Generally applicable dose-response functions for effects of acidification on forests are hardly available (cf. CEC 1995b for detailed discussion). Moreover, valuation of material damage is highly dependent on the building material and the cultural significance of the objects in question.

After weighing these arguments carefully, we decided not to state EcoSense results on crop and forestry yields as well as on damage to buildings in this report. Using the methodology available would only lead to non-recognisable contributions to our results. However, we would like to stress that some of these impacts might become more important in the future as scientific knowledge improves or valuation by society changes.

Road damage and road accidents

There is a discussion in studies on external costs of transport whether road damage is an external effect at all. Most studies argue that road damage is internalised, indeed, in taxes and fees. Anyhow, they have usually turned out to be of minor importance in comparison to other impacts of traffic. A sample calculation in the Portuguese case study, for instance, arrived at 0.03 mECU/kWh (de Almeida et al. 1998).

Examination of the costs of potential road accidents with subsequent deaths due to additional traffic in the biomass fuel cycles indicates that we have not left out a significant impact in external cost terms.[7] Data on road deaths per km travelled by heavy goods vehicles (HGV), provided in the case study reports, were used to roughly estimate the external cost of biomass transport. Based on a value of statistical life (VOSL) of 3.1 million ECU, the external costs estimated range from 0.03 to 0.4 mECU/kWh.

1.3.3. Human health

For human health impacts, only the inhalation pathway is considered, but not transport through the food-chain or through effluent releases to the aquatic pathway nor the effects related to solid waste. No preliminary assessment of ozone impacts has been carried out due to the lack of an adequate model for ozone formation processes. Therefore, the results have to be

[7] Estimates are documented in the BioCosts discussion paper "External costs of road deaths by biomass transport" by Scrase (1998).

treated as a partial assessment of public health impacts, yielding a lower limit of the actual external costs.

Especially for ozone, it may be concluded that high emissions of its precursors such as NO_x and VOC would also lead to substantial additional health impact by ozone. However, since ozone formation is site specific it seems not appropriate to simply add average damage costs to the otherwise marginal external costs. As the results for our case studies show, NO_x emissions alone provide a rather clear view on which case studies are favourable and which are not with respect to human health impacts. Evaluating ozone will most likely not change the ranking.

The assessment of the air-human health impact pathways is based on the ExternE methodology, i.e. all impacts are calculated with EcoSense version 2.0. The individual modules of the impact-pathway approach are outlined here. For more details, the reader is referred to the methodology reports of ExternE Phase II and III (CEC 1995b, CEC 1998).

1.3.3.1. Air dispersion modelling

The EcoSense model has two modules for air-dispersion modelling, one for local dispersion up to about 50 km from the source and one for regional dispersion over several thousand kilometres. The latter model also includes chemical reactions during the time of transport. The main primary pollutants considered are NO_x, SO_2, and TSP. In addition, the local model covers a number of so-called micro-pollutants such as CO or heavy metals.

Local dispersion model

The local range (< 50 km) atmospheric transport model – the US-EPA Industrial Source Complex Short Term model (ISCST2) – calculates hourly concentrations of the three primary pollutants SO_2, NO_x and particulates at the centre of each $10 \cdot 10\ km^2$ EUROGRID cell for one year. Annual and seasonal mean values are obtained by temporal averaging of the model results. However, the high temporal resolution is only used for weather data, but not for emissions. For the latter, only annual averages are taken into account. Since the weather data needed for the local model are very specific, they are not available routinely for all locations. As a standard procedure within ExternE, they are in that case roughly estimated from primary data such as wind speeds and stability classes.

The concentration of pollutants is calculated with a Gaussian distribution function:

$$C = \frac{Q}{2\pi u \sigma_z \sigma_y} e^{-\frac{y^2}{2\sigma_y^2} - \frac{h^2}{2\sigma_z^2}} , \qquad (4)$$

where Q is the emission rate, u the wind speed, y the distance from the plume, h the stack height, σ_y the cross-wind standard deviation, and σ_z the vertical standard deviation. Thus, the exponential factor goes to 1 for $h \to 0$ and to 0 for $h \to \infty$ which is in line with a policy of high stacks. The model is appropriate for long time periods where statistical deviations of wind directions cancel out. The plume rise due to momentum and thermal effects must be estimated separately and added to h, yielding h_{eff} .

Concentration changes resulting from the local dispersion model are strictly linear with respect to emissions. Furthermore, dispersion model results for different types of emissions are identical. Both observations are due to the fact that the local model does not take into account air chemistry or deposition.

Dispersion model results depend on stack height, temperature and flue gas volume. The stack height enters calculations directly as a variable and indirectly via parameters which have different values for stack heights below 60 m, between 60 and 120 m, and above 120 m.

Model runs for stack heights associated with small stationary energy conversion units such as cogeneration plants are possible. Calculations for very small sources at very small heights (e.g. cars) do not make sense as results depend critically on local topography and meteorological conditions. Thus, the local model can be used for the biomass energy conversion units, but should not be used for transport applications (personal communication with IER).

Runs with the local module of EcoSense have been carried out for all biomass-to-electricity (and heat) case studies. However, it turned out that these results do not contribute significantly to the total value of external costs. On average, the local model contributes 0.2% to the total figure for health damage, with a maximum of 1.5%. Only in the hypothetical case in which the installations are moved to Lauffen in Germany, average figures increase to 0.8% with a maximum of 3%. In addition, local runs face large uncertainties due to the fact that weather data sets had to be estimated roughly for most BioCosts' sites. Finally, considering the site-dependency of all these model calculations, for us it does not seem appropriate to have a very high level of temporal resolution for weather data while using only a single figure for average emissions. Thus, in order to restrict the information provided to the part that is relevant for policy making, results of the local model are not stated in this report.

Regional dispersion model

The regional range (> 50 km) model – the Windrose Trajectory Lagrangian plume model – includes both primary emissions and the annual average concentration plus dry and wet deposition of secondary acid species such as sulphates and nitrates caused by SO_2 and NO_x emissions across Europe. Ozone modelling is not available.

The modelling is not done as dispersion from a source, but by summing up all particles emitted which reach a 100·100 km^2 receptor cell at a given time. For this purpose, for each cell 24 trajectories are considered whose contributions are weighted by frequencies of wind directions. It is assumed that all pollutants travel for 96 hours at 7.5 m/s, that is about 2600 km.

Sometimes one gets negative concentration changes for sulphates and nitrates. This happens if SO_2 and NO_x emissions occur at very different levels. In that case, chemical reactions with background emissions may lead to a lower formation of sulphates or nitrates than in the reference case which regards those background emissions exclusively. Background concentrations of pollutants are derived by running a zero-emission power plant with background emissions.

The regional model does not involve flue gas volume or temperature. It only distinguishes between emissions above and below 100 m stack height.

The regional model was originally developed for point sources with stacks. However, it may provide an acceptable approximation for the effects of transport emissions. The first prerequisite is that the area in which the transport takes place is of restricted size. This is the case for the transport of forestry residues, short-rotation coppice and cold-pressed rape-seed oil. It is not the case for the transport of RME and ETBE as well as the use of ETBE in cars in France. The second condition is that transport should not be the main effect evaluated.

Based on these two conditions, we decided to add transport emissions during the production of biofuels to the emissions during conversion as a sensitivity analysis. We do not add indirect emissions, as they cannot be located. And we do not apply EcoSense for the two case studies on RME and ETBE which involve transport as the service derived.

1.3.3.2. Exposure-response functions

Studying different pollutants and health endpoints, ExternE identified and implemented specific linear exposure-response functions (ERFs) via comprehensive literature reviews and expert judgements. In ExternE phase I and II, most ERFs were based on epidemiological studies carried out in the United States due to a lack of studies for Europe. The ERFs link ambient particulate matter, nitrate and sulphate pollution with specific health endpoints such as acute mortality, hospital admissions and emergency room visits (ERVs) for various respiratory causes, restricted activity days (RADs), provocation or exacerbation of asthma, and lower respiratory symptoms like wheeze, dyspnoea or chest tightness.

For ExternE phase III, the EU-sponsored APHEA study on acute mortality and hospital admissions in 12 urban areas has given new evidence for European countries (e.g., Touloumi et al. 1996). Several exposure-response functions had to be changed or added in the EcoSense model in version 2.0. The ERFs for acute mortality and morbidity impacts are now based on European studies. Moreover, there is an attempt to take into account and quantify both chronic mortality and chronic morbidity effects, since they may cause serious health impacts. Yet, it is pointed out that the strength of evidence is substantially less for chronic than for acute effects. The ERFs for chronic mortality and morbidity are still derived from American studies. The function for chronic mortality caused by particulates is obtained from a single US study by Pope et al. (1995). Earlier death, not extra death is analysed. This ERF is of major importance for the overall external cost estimates (see below). Further details on the reasoning why certain endpoints or ERFs have been chosen can be found in CEC 1995b and CEC 1998.

1.3.3.3. Economic valuation

The ExternE research project has also compiled, analysed and evaluated a long list of empirical literature on health valuation. A selection of the endpoint categories and their monetary values is summarised in Table 2. Again it must be recorded that the American literature in the area of valuation of health effects is comprehensive, the European one is relatively scarce. (For more details, please, refer to CEC 1995b and CEC 1998).

The external cost results obtained in the BioCosts project with EcoSense 2.0 show that 99% of the total health damage stem from only 6 health endpoints, namely

- chronic years-of-life lost (YOLL),
- asthma,
- chronic bronchitis,
- restricted activity days,
- acute YOLL, and
- bronchodilator usage.

Consequently, and also since the ERFs are linear, we will only present detailed results for these impact categories in Chapter 2 and indicate the share of the remaining health impacts as an aggregated figure.

There is a distinction between chronic mortality, that is death within a latency period linked to long term exposure to pollutants, and acute mortality, which is immediate or short term death due to air pollution. Within the ExternE accounting framework, the valuation of acute and chronic mortality is crucial for the final results since these impacts constitute more than

Table 2: Monetary valuation of impacts on human health in the BioCosts project based on ExternE Phase III (CEC 1998).

Mortality	
Value of a statistical life (VOSL)	3 100 000 ECU
Value of a life year lost (VLYL, chronic mortality)	
for 0% discount rate	98 000 ECU
for 3% discount rate	84 330 ECU
for 10% discount rate	60 340 ECU
Value of a life year lost (VLYL, acute mortality)	
for 0% discount rate	73 500 ECU
for 3% discount rate	116 250 ECU
for 10% discount rate	234 000 ECU
Morbidity (per person and day or damage)	
Chronic bronchitis in adults	105 000 ECU
Restricted activity day (RAD)	75 ECU
Emergency room visit (ERV)	223 ECU
Bronchodilator usage, acute asthma attack	37 ECU

two thirds of the damage cost estimate in most case studies. The concept for valuing mortality has been changed fundamentally in the course of the ExternE project. In phase III, "values of life years lost" (VLYL) were defined in addition to the "value of a statistical life" (VOSL).

As a central estimate, a VOSL of 2.6 million ECU in 1990 prices was used in the first two phases of ExternE. This value was later corrected to 1995 prices, so that it amounts to 3.1 million ECU in ExternE phase III and in the EcoSense version which the BioCosts project applies for its estimates of human health impacts. The VOSL was derived by taking an average value of European and US studies which estimate the willingness to pay (WTP) for a reduction in the risk of death or the willingness to accept (WTA) compensation for an increase in the risk based on three different valuation techniques (cf. CEC 1995b).

First, the wage-risk approach looks at the increased compensation people receive, other things being equal, to work in more hazardous occupations. The WTA estimates in the EXMOD model, which was used in the RCG/ Tellus (1993-1995) study, are primarily based on wage-risk studies. Of the 75 studies considered, 54 are wage-risk studies of salary differentials of employees who enter voluntarily into compensatory arrangements where their on-the-job risk is taken into account in negotiating a fair wage. However, the average values for involuntary exposure to an increased risk of death might vary from the values for voluntary exposure.

Second, in Contingent Valuation Method (CVM) studies, persons are asked for their WTP for measures that reduce the risk of death or their WTA for measures that increase it. Using this type of WTP estimates to value the risk of death is subject to many biases and very controversial. It has been shown that WTA and WTP measures for the same issue can differ widely, especially in the case of non-market goods with no close substitutes. Consumer Market Studies, finally, are based on actual voluntary expenditures on items that reduce the risk of death from certain activities. They provide WTP estimates. The two extensive American studies on externalities of energy also chose the VOSL approach for valuing mortality and derived numbers of the same order of magnitude, that is of about 3 million ECU (ORNL/ RFF 1994a-h, RCG/ Tellus 1993-1995).

The VOSL approach has been questioned for several reasons. In the VOSL concept the number of premature deaths are valued independently of age, that is the actual life span reduction or expected quality of life, that intuitively would be important determinants for the individual willingness to pay. Moreover, the VOSL estimates are mostly based on studies of individuals with normal life expectancies. The issue of life years lost was in particular raised as epidemiological evidence showed that acute mortality impacts by air pollution affect parts of the population with very short life expectancies. Epidemiologists assume that the life span reduction might be of the order of weeks to perhaps a year for acute mortality. The "years of life lost" (YOLL) concept therefore considers changes in life expectancy and values the years of life lost instead of the numbers of premature deaths. Due to a lack of empirical studies for the valuation of a life year lost, the VLYL used in ExternE are derived from the central VOSL estimate. Including discount rates and probabilities to survive, the total VOSL value was split onto one life year. A fixed average rate of 9 months of life span reduction (factor 0.75) for sulphate and nitrate health impacts was agreed upon.

This calculation can only be a temporary measure, since it assumes that the person asked for his or her WTP for a reduced risk of premature death takes account of his or her average life expectancy, and that the individual does not see and value the risk of premature death, but the risk of the loss of discounted life years. Therefore, some experts of the ExternE team state that the evidence for the VLYL concept is limited (Friedrich and Krewitt 1997, 59) and that the way the value is calculated from the VOSL is not satisfying. At an ExternE Meeting on October 31, 1997, it was suggested that systematic interviews (CVM studies) should be done, which are designed for the issue of willingness to pay (WTP) for an additional life year with different life expectancies.

Furthermore, the WTP estimates in the economic literature refer to sudden deaths, and not deaths within a latency period. In the previous EcoSense versions, the calculation of chronic mortality was therefore considered unreliable, and the results were not included in the summary tables. The new VLYL approach takes account of the time lag between exposure and mortality. Again, in lack of data, a weighted VLYL was calculated, assuming a constant distribution of the impact over 30 years, i.e. from year 1 after exposure to year 30 the risk is increased by 1/30th of the value given by the exposure–response function. Although this assumption is not satisfying, damage estimates on chronic mortality are now included in the ExternE phase III results (CEC 1998). Table 2 shows the values for YOLL calculated in ExternE.

Passing from a valuation based on number of premature deaths at full value of a statistical life to one based on YOLL (years of life lost) the cost of acute mortality due to air pollution is reduced by 1-2 orders of magnitude. In addition, chronic mortality estimates are included. Thus, ExternE phase III results are based on a very different concept of monetisation. This makes it more difficult to compare ExternE results with results of other major externality studies since the YOLL approach has not been used so far. In general, the ExternE experts agree that the YOLL concept is the appropriate approach epidemiologically and economically, i.e. valuation-wise. We adopt the YOLL concept here in order to ensure comparability with the latest ExternE national implementation studies.

1.3.4. Global warming and sustainability

It is an empirically well-founded fact that the composition of the atmosphere is changed by human activities (IPCC 1996a-c). Especially the concentrations of CO_2, CH_4, N_2O, CFCs and other infra-red active gases have been increasing dramatically. Today, the vast majority of climatologists agree that it is likely that, consequently, global average temperatures will rise. They see a considerable risk of adverse impacts on the living conditions on earth. Even though critics of this view receive a lot of public attention, most of their arguments can easily be rejected on the grounds of basic errors or misconceptions.

In this section, we will argue that the solutions which standard economic theory provides for such a problem are not sufficient. We will therefore suggest an alternative which is based on concepts developed within the emerging field of ecological economics and the idea of sustainable development. More details are given in a BioCosts discussion paper on global warming (Kühn and Groscurth 1997).

1.3.4.1. Solutions of standard economics

The standard economic approach to analysing global warming relies on cost-benefit analysis, the traditional economic technique for evaluation of projects and public policy issues. Pearce (1993, 56) describes it as "an appraisal procedure that evolved from concerns with mainly localised and certainly marginal changes to the state of the economy." Cost-benefit analysis attempts to equate the marginal damage of greenhouse gas emissions to the marginal cost of reducing them, thus to weigh the costs and benefits of climate change or alternative control strategies in terms of a common monetary unit. The ultimate goal is to determine the optimal level of greenhouse gas reduction, i.e. efficient strategies to reduce the cost of climate change.

Damage costs

Research on global warming impacts has focused on a scenario which assumes a doubling of pre-industrial concentrations of CO_2-equivalents (weighted sum of CO_2, CH_4 and N_2O). The IPCC (1996a) indicates that the increase of the global mean surface temperature could range from 1 to 3.5°C between 1990 and 2100. Table 3 to Table 5 summarise impact categories, valuation methods and external cost estimates of CO_2 emissions derived in the most prominent damage cost studies reviewed by the IPCC (1996c). It has to be concluded that the estimates vary widely. As will be shown, the differences arise primarily from ethical judgements and scenario assumptions.

There is little agreement across the studies listed about the magnitude or even the ranking of the different damage categories (cf. Table 3). Due to the lack of knowledge and the complexity of the processes involved, studies usually deal with only a subset of damage and are often restricted to a qualitative description of physical impacts (cf. Table 4).

A few examples may demonstrate that the selection of impacts covered often seems rather arbitrary or governed by the data available. Nordhaus (1991), for instance, assesses only agricultural impacts and costs of sea level rise in some detail, while concluding that an overall figure of 1% of the US GDP is a good assumption for unmeasured and non-quantifiable factors. His values for agricultural losses are low due to the assumption that carbon fertilisation effects of higher CO_2 levels may compensate agricultural damage. Thus, he concentrates very much on economic losses of US farmers. Cline (1992) sees the "electricity demand" as an important damage category due to a potentially increased use of air conditioning in the US. Impacts like migration of people or tropical diseases, famines or wars, on the other hand, have mainly been ignored, since they are difficult to quantify. The potential relevance of these impacts, which will hit developing countries in the first place, is pointed out by Hohmeyer and Gärtner (1992), who estimate that an extra 900 million death from hunger could be caused between 2010 and 2030 due to global warming damage to agriculture. This figure for famine-

Table 3 Monetised damage of a doubling of the CO_2 concentration in the atmosphere to the present US economy (base year 1990; billion $ of annual damage).

Damage Category	Cline (2.5°C)	Frankhauser (2.5°C)	Nordhaus (3°C)[a]	Titus (4°C)	Tol (2.5°C)[b]
Agriculture	17.5	8.4	1.1	1.2	10.0
Forest loss	3.3	0.7	small	43.6	–
Species loss	4.0 + a[c]	8.4	[c]	–	5.0
Sea level rise	7.0	9.0	12.2	5.7	8.5
Electricity	11.2	7.9	1.1	5.6	–
Non-elec. heating	-1.3	–		–	–
Human amenity	+ b[c]	–		–	12.0
Human morbidity	+ c[c]	–		–	–
Human life	5.8	11.4		9.4	37.4
Migration	0.5	0.6		–	1.0
Hurricanes	0.8	0.2		–	0.3
Construction	± d[c]	–		–	–
Leisure activities	1.7	–	[d]	–	–
Water supply					
Availability	7.0	15.6		11.4	–
Pollution	–	–		32.6	–
Urban infrastructure	0.1	–		–	–
Air pollution					
Trop. O_3	3.5	7.3		27.2	–
Other	+ e[c]	–		–	–
Mobile air condition	–	–		2.5	–
Total	61.1	69.5	55.5	139.2	74.2
	+ a + b + c ± d + e[c]				
(% of GDP)	(1.1)	(1.3)	(1.0)	(2.5)	(1.5)b

[a] Transformed to 1990 base. [b] US and Canada, base year 1988. [c] Costs that have been identified but not estimated. [d] Not assessed categories, estimated at 0.75% of GDP.
Note: Figures represent *best guesses* of the respective authors. Although none of the studies reports explicit confidence intervals, figures should be seen as reflecting orders of magnitude only.
Sources: IPCC 1996c, 203, Cline 1992, Frankhauser 1995, Nordhaus 1991, Titus 1992, Tol 1995.

related deaths alone is two orders of magnitude higher than Fankhauser's figures for all climate change induced mortality.

Hohmeyer (1996) expands on this by showing that, depending on three normative assumptions, the present monetary value of potential future damage can vary by several orders of magnitude. The value judgements involved concern the question of countries covered (e.g., US, OECD countries, countries in transition, developing countries, or the world as a whole), the decision which value of a statistical life to take, and the choice of a discount rate – 0, 1, 3 or 10%. Accordingly, Hohmeyer sees the danger that economists might "produce arbitrarily high or low monetary damage estimates" which can then be applied to back up whatever political goals and action.

This issue is further illustrated by Azar and Sterner (1996) who show that, using Nordhaus' (1991) DICE model, values up to 590 US-$ per ton of carbon can be derived by assuming longer retention of CO_2 in the atmosphere, using a pure rate of time preference of zero, and weighting damage by the inverse of income. Varying assumptions for these three parameters, Azar and Sterner (1996) attain marginal costs between 13 and 590 US-$ per ton of carbon. Sensitivity analyses in other damage cost studies for one or two of these parameters arrive at similar results (cf. estimate ranges given for some studies in Table 5).

Table 4 Overview of the valuation methods used for climate change impacts.

	Market Impacts				Non-market Impacts		
Valuation method	Primary economic sector damage	Other economic sector damage	Property loss	Damage from extreme events	Ecosystem damage	Human impacts	Damage from extreme events
Fully estimated by willingness to pay	Agriculture		Dry-land loss Coastal protection		Wetland loss		
Fully estimated using approximations	Forestry	Water supply		Hurricane damage	Forest loss		Hurricane damage
Partially estimated	Fisheries [a]	Energy demand Leisure activity	Urban infrastructure	Damage from droughts [b]	Species loss	Human life Air pollution Water pollution Migration	Damage from droughts [b]
Not estimated		Insurance Construction Transport Energy supply		Non-tropical storms River floods Hot/cold spells Other catastrophes	Other ecosystem loss	Morbidity Physical comfort Political stability Human hardship	Non-tropical storms River floods Hot/cold spells Other catastrophes

[a] Often included in wetland loss. [b] Primarily agricultural damage. *Source:* IPCC (1996c, 189)

Thus, the two single most important and most controversial issues are *discounting* and the valuation of *non-market damage*, or in other words, questions of intergenerational and intragenerational equity. *Discounting* is the basic analytical tool economists use to compare economic effects that occur at different points in time. It addresses the trade-off between consumption today and consumption in the future. The relationship between discount rate and present value of future damage is such that the higher the discount rate, the lower the present value and the lower consideration is given to impacts on future generations. The further away in the future, the less counts the damage in today's decisions. Therefore, the choice of discount rate is crucial for analyses of climate change policy, because the time horizon is extremely long. Moreover, mitigation costs tend to arise earlier than the benefits of avoided damage.

The economic literature distinguishes two concepts. The concept of social rate of time preference, which is the sum of the rate of individual or pure time preference and the rate of increase of welfare derived from higher per capita incomes in the future, leads to discount rates between 0.5% and 3% depending on the values chosen for the different parameters. The concept of market returns to investment leads to discount rates between 3% and 6% for long-term investments. An attempt to partly take account of the high sensitivity of results to the choice of the social rate of time preference is the concept of time-variant discount rates (Rabl 1996). Rennings and Hohmeyer (1997) argue for:

- 0% as a rate for long-term effects which are expected to rise with GDP,
- 1% as rate for social time preference ignoring individual time preference,
- 3% as a rate for social time preference including individual time preference, and
- higher discount rates representing market discount rates.

Nevertheless, it may be concluded, that no satisfying solution has been suggested to the problem of discounting so far. IPCC (1996c, 8) predicts that how best to choose a discount rate for global, long-term issues is and will likely remain an unresolved question in econom-

Table 5 The external costs of CO_2 emissions in different decades (in 1990 $/tC).

Study	Type	1991-2000	2001-2010	2011-200	2021-2030
Nordhaus (1991)	MC		7.3		
			(0.3 - 65.9)		
Ayres and Walter (1991)	MC		30 - 35		
Nordhaus (1994)	CBA				
Best guess		5.3	6.8	8.6	10.0
Expected value		12.0	18.0	26.5	n.a.
Cline (1992)	CBA	5.8 - 124	7.6 - 154	9.8 - 186	11.8 - 221
Peck and Teisberg (1992)	CBA	10 - 12	12 - 14	14 - 18	18 - 22
Fankhauser (1994)	MC	20.3	22.8	25.3	27.8
		(6.2 - 45.2)	(7.4 - 52.9)	(8.3 - 58.4)	(9.2 - 64.2)
Maddison (1994)	CBA/MC	5.9 - 6.1	8.1 - 8.4	11.1 - 11.5	14.7 - 15.2
Azar and Sterner (1996)	MC	short retention time of CO_2, discount rate 3%, no income weighting: 13			
		long retention time, discount rate 0%, income weighting: 590			
ExternE (Eyre et al. 1997)	MC	1% discount rate: 170			
		3% discount rate: 60			

MC = marginal social cost study. CBA = shadow value in a cost-benefit study. Figures in parenthesis denote 90% confidence intervals. *Sources:* As shown and IPCC (1996c, 215).

ics. One should add that this is not astonishing as ethical judgements are needed which might better be left to society and not science. The choice of discount rate is a matter of basic policy goals.

The estimates of *non-market damage*, such as human health, risk of human mortality and damage to ecosystems, form another important component of available estimates of the social costs of climate change. They are regarded as speculative and not comprehensive, and thus as a source of major uncertainty in assessing the implications of global climate change for human welfare. The literature on monetary valuation of such non-market effects reflects a number of divergent views and approaches (IPCC 1996c).

There is no consensus about how to value statistical lives or how to aggregate statistical lives across countries. In virtually all the literature listed above "the developing country statistical lives have not been equally valued at the developed country value, nor are other damages in developing countries equally valued at the developed country value" (IPCC 1996c, 10).

Cline (1992) values extra deaths per million of population at 595 000 US-$ each, on the basis of their lifetime earnings. Fankhauser chooses a figure of 1.5 million US-$ for deaths in developed countries. He reports the range of such values from the literature as 200 000 to 10 million US-$, with an average of 3 million US-$, and so regards his figure of 1.5 million US-$ as "fairly conservative". For middle- and low-income countries Fankhauser chooses figures of 300 000 and 150 000 US-$ respectively. He claims that this difference "merely reflects the fact that the willingness to pay for increased safety (a lower mortality risk) is higher in developed countries" (Fankhauser 1995, 14).

Others argue that intragenerational equity requires to value lives equally across countries, but not to use the VOSL for a high-income country. The ratio of US GDP to world GDP is suggested for deriving a uniform valuation of statistical life in both OECD and developing countries. Another way of so-called equity weighting is that chosen by Azar and Sterner (1996). It is based on the general assumption that marginal utility of income declines logarithmically. Then, the appropriate weighting is the inverse of income (see above). This, however, means that developed country life is worth less in situations where people in developing countries are to be killed as well. Again, it must be stated that no satisfactory solutions is available to this issue.

Abatement costs

The costs of CO_2 abatement have been estimated in three principal ways: through global models, single country models, and detailed calculations of the cost and environmental performance of different carbon-saving technologies. The models may be either general equilibrium (GE) models that concentrate on long-term equilibrium resource allocations and relative prices, macroeconomic models which focus more on short-term adjustment and non-equilibrium effects, or technology-based models (cf. IPCC 1996c, 297-366 for more details).

Modelling of the whole economy is sometimes referred to as a 'top-down' approach, while modelling based on detailed technological analysis is called 'bottom-up'.[8] IPCC (1996c, 13) describes top-down models as "aggregate models of the entire macro-economy; they typically incorporate relatively little detail on energy consumption and technological change." They continue that "bottom-up models incorporate detailed studies of engineering costs of a wide range of available and forecast technologies, and describe energy consumption in great detail; they typically incorporate relatively little detail on non-energy consumer behaviour and interactions with other sectors of the economy." Bottom-up studies are more optimistic about the potential for low or negative cost emission reductions, and the capacity to implement that potential. Many top-down studies, on the other hand, suggest that the annual costs of stabilising CO_2 emissions may ultimately exceed 1-2% of GDP.

Thus, results also yield a very wide range of estimates due to significant differences in choice of methodologies, assumptions about the efficiency of energy and other markets, no-regret potentials and technological progress as well as about the ability of government institutions to address perceived market failures or imperfections (IPCC 1996c, 12). Secondary environmental benefits may be substantial but are usually not included in the assessment.

Ekins (1995) points out that all the models based on a production function approach have an explicit negative linkage between higher energy prices and GDP. None of them introduces any countervailing considerations which might offset this effect, as there is revenue recycling, unemployed resources, a non-distortionary equilibrium, and changes in investment options and rate and direction of technical change, rate of productivity growth. Furthermore, as Kümmel, Lindenberger and Eichhorn (1997) show, the neo-classical assumption that the production factors contribute to the gross production value proportionately to their average cost share, may be grossly wrong. Using a dynamic approach which analyses time series as a whole instead of building averages of static, one-year calculations, they conclude that energy may contribute up to 50% to the gross production. If this result is only partly correct, then it is no wonder that GE models do only show small effects when energy prices are increased moderately or, vice versa, yield exorbitant costs if forced to change the energy system substantially. Thus, they may not map reality correctly in this point. Furthermore, at least one of the most prominent models of this type, the EU's GEM-E3, does not even map renewable energy technologies, which are an important means to mitigate global warming, in a way that would allow for a massive introduction of these technologies.

8 Relevant top-down studies are, among others, Edmonds and Reilly (1986), Burniaux et al. (1992), Manne and Richels (1990), Jorgenson and Wilcoxen (1991), Rutherford (1992). Prominent bottom-up studies are, e.g., CEC (1991), IPSEP (1993), SEI/ Greenpeace (1993), UNEP (1994).

The engineering based models study the technical and economic parameters of available and forecast technologies and describe energy consumption in great detail. Even though called "bottom-up", many of the respective models are highly aggregated, namely with respect to space and time. They assume that all energy conversion processes take place in one point (even though accounting for average transport losses) and are restricted to average annual demand and supply data. These assumptions are hard to justify if one has to deal with cogeneration technologies which have to deliver electricity and heat at the same time and in the same location or with intermittent energy sources which have to be used instantly when available. To map the respective technologies, a high temporal and spatial resolution is necessary (Groscurth and Schweiker 1994).

While it is problematic to determine marginal abatement costs for a whole economy, it is, however, possible to calculate CO_2 abatement cost for individual technologies as compared to fossil-fuel reference technologies. Even though such an approach is site-specific, it is possible to carry it out repeatedly for different conditions and derive an average figure. Using high resolution models of local energy systems, it is also possible to calculate CO_2 abatement costs of combinations of such technologies. This task is not trivial since combining technologies may lead to substantial competition or to synergy effects (Bruckner et al. 1997).

Conclusion

In the context of global warming, economists themselves have been questioning the applicability of the marginal cost approach. IPCC Working Group III states that "both costs and benefits may be hard, sometimes impossible, to assess. This may be due to large uncertainties [inherent in the complexity of the problem], possible catastrophes with very small probabilities, or simply lack of consistent methodology for monetising the effects" (IPCC 1996c, 9). The global scope of the problem, the potential for irreversible damage, the long time horizons, long time lags between emissions and effects, and wide regional variation in causes and effects are some further key characteristics of global warming which complicate the decision making process. Cost-benefit analysis is not the appropriate tool for this task.

Acknowledging the complexity of interactions, insufficient knowledge, uncertainties and the long-term nature of the problem, we think that a global strategy to prevent major climate changes should be put on a different basis. Since the calculation of both marginal damage costs and marginal abatement costs is infeasible in the context of global warming, the determination of the 'optimal level of emissions' in the sense of neo-classical economics is just not possible. Thus, we propose to base the global policy on the basic principles of strong sustainability: "Only a safe minimum standard for greenhouse gas emissions ... seems to be a reasonable approach to man made global warming" (Hohmeyer 1996).

1.3.4.2. Ecological economics and the concept of sustainability

According to Daly (1996), the basis of ecological economics is a new pre-analytic vision of the economy. Rather than regarding the economy as an isolated system exclusively described in monetary terms, it should be viewed as a subsystem of a larger, finite and non-growing ecosystem. Consequently, there is an optimal scale for the economic subsystem. One necessary, though not sufficient requirement for approaching the optimum is that the throughput – that is the input of raw materials, their conversion into useful commodities and, finally, into waste outputs – remains within the regenerative and absorptive capacities of the ecosystem. Second, the economic subsystem must not grow beyond the scale at which it can be permanently sustained or supported by the containing ecosystem. The essence of these two conditions is physical and not economic. They are governed by natural laws and are thus – at least as far as we know today – not subject to change.

A further issue which is crucial for the stability of a socio-economic system is the fair distribution of resources and wealth. The current situation, in which parts of the world or parts of many societies are becoming richer and richer while an increasing number of people is fighting for their very existence, is inherently unstable. This is even more so as industrialised countries do not shrink back from selling more and more weapons to the poor. As in physics, small potential differences are a necessary condition for any development, but large potential differences tend to release themselves in catastrophic events. Based on these thoughts, it is a fundamental decision to be made by today's societies whether they want to continue on the road currently taken or whether they want to ensure a more equitable distribution of resources and wealth, not at last in their own interest. In addition to intragenerational equity, the interests of future generations have to be considered as well. One rule suggested is that future generations should be left with as many options as possible to decide upon the way in which they want to live. In addition, we should take care that they will not be worse off than we are.

Only then, after the physical and social constraints have been defined, the question arises how the economy should be organised and how the resources available should be allocated efficiently. For this task, free markets have proven to be an appropriate tool.

To sum up, the developing field of ecological economics defines three orthogonal objectives for an economy (Daly 1996):

- *Scale* – that is the relative size of the economic subsystem within the surrounding ecological system the size of which is finite and constant;
- *Distribution* – that is the question of equity and justice within the current generation and between current and future generations;
- *Allocation* – that is the efficient use of production factors to produce goods and services.

According to Daly, these objectives cannot be traded against each other by means of cost-benefit analysis. Trade-offs rather have to be determined by public discussion and suitable social decision processes. The approach just outlined is often denoted as concept of "strong sustainability", while the neo-classical approach of balancing costs and benefits is called "weak sustainability". [hmg1]One important guideline of a policy of strong sustainability is the *precautionary principle.* It involves the prevention of impacts which may cause very large damage to humanity even if they occur with very small probabilities or if their existence has not been proven beyond doubt.

In addition, in ecological economics management rules for the use of renewable and non-renewable resources are defined:

- Renewable resources may only be used at or below the rate of regeneration.
- Non-renewable resources may only be used at a rate at which alternatives can be developed and provided.
- Emissions from human activities have to be restricted to a level which will not exceed the natural assimilative capacity of the ecosystems.

With respect to global warming, we can now draw the following conclusions: Scientific evidence for an increase of the average global temperature and subsequent climate change is overwhelming. The potential impacts of this development on the living conditions on earth are dramatic. Thus, the precautionary principle tells us to mitigate the risk of climate change, no matter whether this is an optimal strategy (in an economic sense) under prevailing economic conditions and evaluation procedures.

The resulting physical objective has been determined quite clearly in numerous scientific councils (e.g. IPCC 1996a-c, Enquete 1991 and 1995): carbon dioxide emissions have to be reduced by 50 to 60% globally in order to confine the CO_2 concentration in the atmosphere to twice the pre-industrial level of 280 ppm and to mitigate even though not completely avoid climate change.

The social objective is also straight forward: Since developing countries will need more energy in the future to ensure acceptable living conditions for their people, most of the reductions necessary will have to take place in industrialised countries. Thus, the Enquete Commission of the German Parliament concluded that these countries will have to decrease their absolute CO_2 emissions by 80% compared to the 1990 level until the year 2050 (Enquete 1991).

After such objectives have been agreed upon by society, it is of course important to choose a cost effective strategy for pursuing them. The EU research project "Long-Term Integration of Renewable Energy Sources into the European Energy System ..." has demonstrated that such a strategy is technically feasible and economically affordable (LTI-Research Group 1998). The use of biomass is thereby considered as one of the most important future energy sources. Thus, it is essential to assess the economic standing of biomass technologies and to compare them among each other and with competing energy technologies. In addition, it is important to determine (and ultimately mitigate) possible adverse environmental impacts other than global warming which may result from using biomass energetically. How the latter tasks are tackled within in the BioCosts project is described elsewhere in this section (1.3). It remains to determine, in how far the different energy uses of biomass may contribute to mitigating global warming. We do so by compiling CO_2 balances for the fuel cycles and by calculating abatements costs for the technologies, but not for energy systems as a whole.

Direct CO_2 emissions from the conversion of biofuels into other energy forms may, in general, be seen as neutral with respect to global warming since corresponding amounts of CO_2 are fixed during the growing of the biomass on similar time scales (Sinisalo and Savolainen 1996). In addition to direct CO_2 emissions, several indirect effects require attention. Especially in the short run, there are the emissions from the production of the equipment and of the biofuels themselves. In the long run, after a major restructuring of the energy system, the energy necessary for these tasks would also come from renewable energies. Since we calculate today's impacts and costs and want to stay on the safe side, we consider the current energy mix and its emissions. The emissions of fuel preparation will be calculated within the BioCosts project since all steps of the fuel cycle are examined. The emissions from the production of equipment will be derived from economic data via ZEW's input-output model.

We calculate the cost of avoiding one unit of CO_2 by comparing costs and CO_2 emissions of biomass use and the reference case and then dividing both figures. This may be done with and without adding the external costs of other impacts examined. The results may be applied to compare biomass technologies to other options of mitigating global warming as there are energy efficiency measures and competing environmentally benign energy technologies.

In order to satisfy the demand for standard economic reasoning, we will compare the abatement costs calculated with the range of damage costs stated above. This may lead to helpful arguments supporting the claim to change market conditions in a way that gives biomass technologies a fair chance or to at least launch sizeable market introduction programs which will lead to a decrease of the costs and which will keep biomass technologies alive as an important option for future use.

1.3.5. Impacts on the local biosphere

Although qualitative assessment in the case study reports and earlier external cost studies give some evidence that burdens of the upstream stages of the biomass fuel cycles might have physical impacts on biosphere of comparatively small importance, they were selected as priority impacts in the BioCosts project. There is a risk that biomass growing, collection and processing, if not carried out properly, implies more significant negative impacts on the biosphere, such as increased erosion, soil and water eutrophication, or loss of biodiversity. Agricultural management practices do have a decisive influence on the results (e.g., Verwijst and Makeschin 1996). The impacts furthermore depend on the location, which determines the major abiotic site characteristics such as soil type, annual precipitation and temperature. Finally, there is an ongoing discussion about potentially large negative effects of large scale biomass cultivation on the biosphere (e.g. Cook 1991, Cook and Beyea 1996).

Yet, we face several problems in assessing local impacts of biomass feedstock systems on biosphere. There is an obvious lack of detailed information on the relatively new energy cropping systems (Kaltschmitt and Reinhardt 1997, Verwijst and Makeschin 1996). Most studies make only general comparisons with conventional agriculture. According to the state of the art and the conditions given, we do not consider it possible to conduct a thorough quantification. It is obvious that it is extremely difficult, if not impossible, to conduct a quantitative balance at the inventory level. Qualitative statements are possible and may be explained in some detail.

Usually, it is not questioned that ecosystem functions are important to many human activities. Yet, often they are undervalued or neglected in the actual decision-making process. With their recent article in Nature, Costanza et al. (1997) want to emphasise this point by giving a 'crude' estimate for the current economic value of ecosystem services of the entire biosphere to society. Based on published valuation studies and a few original calculations, the authors derive as lower limit a value range which is 1 to 3 times the current global GNP. The article and reactions to it (cf. Ecological Economics, Vol. 25, No. 1) show that there are many unresolved ethical, scientific, and methodological issues in the field of valuing ecological functions (also cf. Linddal and Naskali 1993).

An extensive literature review confirmed our initial assessment that the current scientific knowledge of the system relations as well as the information base of reliable empirical data are too small to come up with an accounting framework for ecological impacts which is similar to that for impacts on human health. The complexity and diversity of ecosystems prevent the description of impacts in terms of dose-response functions. Uncertainties arise both because of the unknown character of ecosystem impacts, and because of the difficulty of assessing these impacts from a socio-economic point of view (cf. Barbier et al. 1994, Heywood and Watson 1995, Kosz 1997, Pearce and Moran 1994).

1.3.5.1. Biodiversity

Concerning the issue of biodiversity, the scientific community even has difficulties in formulating a consensus on the definition and measurement of biodiversity. They basically agree that biological diversity refers to the range of variations or differences in living organisms and their environments, and that it can be distinguished by the three main levels of biological hierarchy: genes, species and ecosystems (cf., e.g., Barbier et al. 1994, Heywood and Watson 1995). Current and projected trends in loss of threatened and extinct species as a share of total species known are considered a useful indicator, and data are available. For estimating rates of loss for habitat and ecosystems simplistic measures of land use change can be used as a proxy. Yet, both indicators do not convey adequately the implications of the problem of biodiversity loss for ecosystems and human welfare.

The majority of land in Europe is currently dedicated to intensive agriculture. Among the major threats to biodiversity agriculture plays a leading role. According to Foster et al. (1996) very little work has been carried out in Europe on assessing the precise impact that energy crops have on the biodiversity of wildlife and the landscape character. In the future, the development of a bioenergy industry may cause changes in the arable landscape with the introduction of energy crops. Perennial energy crops can provide an alternative to traditional agricultural crops and set-aside land schemes. If the plantations are not managed intensively, they may introduce diversity and structure to the landscape. Yet, it is essential to ensure that plantations are designed and sited in ways that minimise ecological disruption and provide maximum environmental benefits.

Different European studies do not agree on the biodiversity of short rotation willow and poplar coppice. In Germany and the UK it is considered to be very good, whereas in Holland it is considered to be poor.

There has been quite a number of contingent valuation studies, but mostly on specific topics. In most cases, values have been derived for the protection of single endangered species or habitats in certain areas (cf. overview in Pearce 1993, Perrings 1995).

In a working paper for the BioCosts project, Hohmeyer (1997) developed a strategy on how to approximately take account of the issue in economic terms for large-scale cultivation of biomass: There is a study by Hampicke (1991) on willingness to pay for biodiversity in Germany. It estimates that to preserve the full current biodiversity, protected areas have to be increased significantly, that is from about 1 to 3.2 million hectare (ha) which corresponds to 14% of the total land area of Germany. The related cost would be about 0.5-1 billion ECU per year. On the other hand, the WTP which has been estimated by asking 3 000 households amounts to 1.5 to 3.7 billion ECU/a or 500 to 1 000 ECU/(ha·a). It may be possible to deduce a ranking of areas of different importance to biomass which could then be assigned different willingness to pay amounts. The Swedish land mapping scheme explained during the visit of the forest operations could be an example of such a ranking. Then, it would have to be determined which types of areas would be affected by a large scale use of biomass technologies.

Impacts on biodiversity are clearly non-linear. Nature will be able to cope with impacts of agricultural activities up to a certain point, but beyond that irreversible effects will occur. The immediate marginal impact of our case studies on biodiversity, if any, is small and often reversible. None of our case studies will lead to the extinction of species. On the other hand, if these case studies were extended to large areas without taking precautions, negative impacts of the case studies involving intensive agriculture may be severe, while other case studies may exhibit benefits. Using Hohmeyer's proposal for estimating these effects proved non-feasible due to a lack of data for the countries involved.

Thus, we are left with a qualitative discussion of the impacts on biodiversity, which are stated along with the other case study results in Chapter 2 and, in more detail, in the case study reports. There is a tendency in all case studies to regard the issue of biodiversity as of minor importance for the respective feedstock and site.

1.3.5.2. Soil and water

In general, soil erosion problems rather exist on hilly, sloping fields and more so in the semi-arid regions of southern Europe (Dalianis and Panoutsou 1996, 8). Compared to many other conventional agricultural crops grown in the same areas energy crops like eucalyptus, willows or miscanthus even have a positive effect on soil erosion due to their huge canopy according to Dalianis and Panoutsou. Only sweet and fibre sorghum fields are considered vulnerable to erosion. These statements mainly agree with the observations in our case studies. With the exception of the Portuguese plantation site, soil erosion is not identified as a problem.

In former external cost studies, two approaches have been taken to quantification of the change in soil erosion rates. The approach used in the ExternE phase II studies on biomass (CEEETA 1993, NTUA 1995) is to use the Universal Soil Loss Equation. This is a data intensive approach, requiring accurate information on rainfall intensity, soil composition and structure, topography and vegetation cover. Simplifying assumptions are necessary. In both studies only soil loss due to water erosion was considered. Use of the Universal Soil Loss Equation seems to be rather inaccurate. It is only suitable for medium textured soils, on slopes less than 122 metres long and with mean slope angles of 3 to 18%. It was developed for conditions in the Eastern USA and has not proven correct in tests in Europe. An alternative approach is taken in the US study (ORNL/ RFF 1992). This appears more straightforward, more inclusive (i.e. all types of erosion) and less prone to errors introduced by large data sets. Their approach is to find empirical data for local soil erosion rates under existing crop regimes, and infer rates for energy crops from these.

The ExternE studies calculate yield losses and physical impacts in terms of surface water turbidity. Neither is valued since the former is not considered an external cost and for the latter European cost figures were not available. The only valuation made is that of sediment removal from water bodies. A more adequate valuation should consider wind as well as water erosion, and extend the set of damage valued to include TSP removal from drinking water, recreational and biological impacts of turbidity, and global warming impacts of energy inputs to replace lost nutrients. Yet, literature review has shown that there is no progress with respect to the valuation of possible impacts of soil erosion at a specific site. To get a feeling for the order of magnitude of soil erosion damage corresponding to the poplar plantations, the Portuguese case study (de Almeida 1998) estimated the costs based on the ExternE methodology mentioned.

There are models covering the dispersion of emissions from agriculture on soil and water. However, they are usually site-specific and require calibration with measured data. To carry out such an effort for the case studies would have gone beyond the scope of the BioCosts project. Satisfactory (site-specific) dispersion modelling and quantification of impacts on ecosystems and humans does not seem possible with our current knowledge. Rough calculations and methods are possible and available for selected water and soil pathways. Yet, they lead to small or negligible cost figures as some former studies and individual calculations in the BioCosts case studies have shown.

In general, it is claimed that there is no measurable negative impact if pesticides and fertilisers are used properly (e.g., Reinhardt et al. 1997). For every unit of agricultural chemical applied some portion will leach into groundwater, some will leave the site as runoff and be lost to erosion, and some will be volatilised. However, a more significant fraction of the applied chemical will be taken up by the plant. Specific rates were synthesised from numerous literature sources. The same estimates have been used for all locations and species even though site and species specific differences would be expected. Yet, insufficient information was available to estimate site- and species-specific emission rates.

Again, we are at a point, were we have to state that current knowledge does not allow for a more quantitative analysis. Qualitative assessment, however, indicates that the impacts known today are small compared to those regarding human health and global climate.

1.3.6. Rural amenity

Rural amenity issues have particularly been emphasised in the UK case study (cf. Bauen et al. 1998). Impacts are local and site-specific. Visual amenity for example is a local scale impact. Because of the heterogeneous nature of landscape, the visual effects of the same technology in different places can be expected to be very different. Visual amenity impacts of all large industrial installations are a major concern in land use planning in much of Europe. It has also been of particular concern for renewable energy sources, especially wind turbines, which frequently need to be sited in rural areas.

In an external cost study the value of landscape is confined to its economic definition – willingness to pay (WTP) for landscape preservation. Studies indicate that public responses to the visual impacts depend on the social context, in particular public control and understanding of the project.

What is required to specify the source of the external costs is: the magnitude of the noise emissions, any variation of noise as a function of time of day, an analysis of any tonal content and an analysis of fluctuations. Because of differences in public attitude to noise in urban and rural areas, the damage estimates are quite uncertain. However, even the highest values which seem plausible are in the range 0-1 mECU/kWh for wind (CEC 1995).

We have added rural amenity to the priority impacts, because experience with other new technologies shows that changes to the accustomed environment in which people live may lead to fierce resistance. This is hard to monetise as willingness to pay may come out low in a theoretical situation, but reach very high values after the fact. Therefore, we discuss potential impacts of our case studies on rural amenity. The much more important conclusion, however, is that all renewable energy projects need the understanding and support of the local community. This can be ensured by early information and by keeping at least some of the (monetary) benefits within the local community.

1.4. Summary of the Methodology Applied

After having discussed pros and cons of different methodological approaches at some length, it seems helpful to briefly summarise what has actually been done in the BioCosts project and how it is presented in the following chapter.

The section on each case study starts with a description of the biomass technology and its reference case. Next, a summary of technical and economic data is provided. Due to the restricted space available for this report, especially the technical information has been limited to those figures which can be compared among the case studies. For more detailed information, the reader is referred to the individual case study reports which are available from the coordinator of the BioCosts project or to the book that will be published on this project. Economic information comprises the internal costs (investment, O&M, labour and fuel costs) as well as direct and indirect inputs of the production factors labour and energy. Indirect labour figures are determined with the EMI input-output model.

In the consecutive subsection, emission inventories are provided with respect to the different stages of the fuel cycle. Direct emissions have been obtained from owners and operators of the facilities and, where this was not possible, from literature. Indirect emissions from manufacturing of equipment were determined with the EMI model. Indirect emissions from the production of fertilisers were determined by life-cycle analysis (Patyk and Reinhardt 1997). Then, input data and results of EcoSense calculations are stated. Here, we distinguish 8 different scenarios: First, we run EcoSense just for the conversion stage of the biomass fuel cycle at the original site of the application. Then, direct emissions of the fuel production are added, which are mostly due to transport activities. Finally, these two calculations are repeated for the reference technology and for a hypothetical case, in which biomass and reference technology are moved to Lauffen in Germany. The latter EcoSense run is made to compare the technologies without the influence of their specific locations. Lauffen was selected as common site because it has been used in the ExternE project extensively.

Finally, there are subsections discussing environmental impacts not covered by the quantitative analysis and the socio-economic framework in which the biomass installation operates.

While biomass and reference technologies are compared in the respective sections, the different biomass technologies are compared to each other with respect to internal and external costs as well as emission levels of different pollutants in the summary section 2.9 following the individual descriptions. Global warming is discussed by stating the CO_2-abatement costs, which can easily be calculated by dividing the emissions of CO_2-equivalents avoided by the use of biomass as compared to its reference case by the cost difference of the two cases. These abatement costs are then compared to damage cost estimates obtained from the literature.

At this point, we would like to comment on the general significance of the results obtained, not only in this project, but in any study on external costs of energy use. There remain substantial uncertainties, which are due to limited scientific knowledge as well as severe methodological problems, which are partly not resolvable. On the other hand, we observe that the relative results comparing two case studies largely depend on emission rates. Thus, emissions themselves can be taken as a good indicator of environmental impacts in multi-criteria analysis without the need to monetise their impacts. Many people in the field hold it anyway that the traditional goal of neo-classical economic theory – that is reaching a pareto-optimal state of the economy – is far too ambitious or non-relevant with respect to environmental problems.

However, decision makers need advice when tackling the severe environmental problems which industrial societies face today. Therefore, we agree with Miser and Quade (1985, 15) who state that, "systems analysis is the multidisciplinary problem-solving activity that has evolved to deal with the complex problems that arise in public and private enterprises and organisations." While expectations for obtaining precise scientific facts in relation to environmental problems are limited, systems analysis has a strong orientation towards practical applications. "The goal is clearly to suggest actions or decisions within a limited range of time even if the knowledge of the system is incomplete" (Groscurth and Schweiker 1995). Consequently, the BioCosts project has tried to provide a number of indicators on the economic and ecological performance of biomass fuel cycles which may help decision makers to reach conclusions. By stating methodological problems openly, we want to put decision makers in a position where they can make their personal choice between methodologies and corresponding assumptions and where they will be able to determine the consequence of these choices. For example, if a decision maker chooses to rely on external costs calculated by means of the

EcoSense model he or she should first be aware of the methodological limitations of the model itself and second keep in mind that the model implicitly accepts the fundamental assumptions of neo-classical economics. He or she will still have to decide how long-term impacts should be valued, i.e. which discount rate should be used. Rather than adding damage estimates of global climate change, which we regard as very uncertain, to our external costs figures, we provide the means to compare CO_2-abatement costs with the damage figures. Consequently, decision makers should first determine their own view of the severity of global warming and may then conclude from our results, which biomass applications should be given priority in mitigating climate change.

2. Case Studies

2.1. Utilisation of Forestry Residues in a Circulating Fluidised Bed Combustion Plant in Sweden

2.1.1. Description of the technology and its location

This case study analyses the use of forestry residues as fuel in a circulating fluidised bed (CFB) combustion plant producing 35 GWh/a of electricity and 125 GWh/a of heat, which is supplied to a district heating grid.[9] The fuel cycle starts with the collection and stacking of branches which are left in the forest after cutting and removal of the economically more valuable parts of the trees. The cutting of trees itself is not considered part of the fuel cycle as it is done for non-energy purposes and would occur in the reference case as well. The stacks serve for drying from 50% to 35-40% humidity and temporal storage of the residues. Afterwards, branches are chipped by a mobile chipper and chips are brought to a road-side location by a shuttle vehicle capable of moving in difficult terrain. From there, they are transported over up to 100 km to the power plant by large diesel trucks. All in all, about 25% of the residues are left in the forests in order to maintain soil quality and biodiversity. During a visit to these forest operations, the BioCosts team got an impression of the very efficient organisation of the fuel production process. The participating forest owners are members of a co-operative which organises the wood production. The chipping and transport is done by self-employed workers or small businesses. Wood chips obtained in the described way contribute 50% to the plant's fuel supply, while the other half is made up of saw mill waste from a nearby wood factory.

Upon arrival at the plant, the wood chips are further prepared by removing larger pieces of wood and pieces of metal. The chips are then stored in a facility which has a capacity for three days' worth of fuel. The fuel is combusted in a circulating fluidised bed furnace. For this purpose, it is injected into a bed of inerts consisting of a mixture of sand and ash. This mix of materials is then fluidised in an upward flow of air, which is strong enough to convey some material out of the furnace with the flue gas where it enters a cyclone separator. The solids are singled out and returned to the furnace. The process technology applied offers good control of the combustion reaction. Therefore, it allows for a low degree of unburned fuel and for very low emission levels. The plant is equipped with a flue-gas condensation unit which recovers the latent heat of the water vapour in the exhaust gases. It further comprises two steam turbines which drive the electricity generator.

The ashes remaining after combustion are assumed to be spread in the forests as a fertiliser, even though this procedure is only in a state of development at the moment. The current standard is landfilling of the ashes, but it seems likely that the recycling of ashes will become dominant in the near future. The advantage of this recycling would be a natural fertilising effect and the prevention of a decrease in the concentration of important minerals in the soil.

The electricity produced at the plant is fed into the general distribution grid, while the heat is sent to the municipal district heating system. The operation of the plant is heat driven, which means that the heat load determines the level of operation of the plant. In particular,

[9] Data on this case study have mainly been supplied by Vattenfall Utveckling AB and the plant operators. For an account of other sources, please, refer to the case study report (Jörgensen et al. 1998).

this leads to a complete shut-down of the plant during summer months, when only very little heat is used for hot-water supply.

As the fossil-fuel fired reference technology for this case study it is considered that Polish coal is fired in the same plant. This is a realistic scenario, since this fuel was actually used in the plant during earlier years. The technical data are therefore almost identical. Nowadays, the plant is operated on biofuels exclusively.

2.1.2. Technical and economic data

The technical data of the plant are summarised in Table 6. The relatively low number of full-load hours is due to heat-load oriented scheduling of plant operation. The thermal capacity of the plant is lower in the reference case since the vapour content of the flue gases is too small to facilitate flue-gas condensation.

Table 6 Technical data of the combined heat and power (CHP) plant at Nässjö, Sweden.

		Use of forestry residues and saw-mill waste	Reference Case: Use of Polish coal
Capacity			
Electrical	MW_{el}	9	9
Thermal	MW_{th}	27 *	21
Internal use	MW_{el}	1	1
Full-load hours	h / a	4400	4400
Fuel input	MWh / a	145000	145000
Net electricity production	MWh / a	35200	35000
Net heat production	MWh / a	119000	92400
Total energy output	*MWh / a*	*154000*	*128000*

All values rounded to three significant digits; *: Including flue gas condensation

The specific energy production costs of the plant are shown in Table 7. They are dominated by investment costs, which are higher for the reference case due to the lower heat output. The use of saw-mill waste as a fuel, which is obtained at very low cost, results in an additional advantage for the biomass case. Consequently, one kilowatt-hour of electricity or heat is produced from biomass at 19 mECU/kWh at this plant, while the use of Polish coal leads to costs of 23 mECU/kWh. Thus, in this case, the use of biofuels is economically efficient. This pic-

Table 7 Specific energy production costs of the CHP-plant at Nässjö, Sweden, in mECU/kWh.

	Use of forestry residues and saw-mill waste	Reference case: Use of Polish coal
Conversion		
– Investment	9.1	11
– Operation & maintenance	1.7	2.2
– Labour	2.3	2.7
Fuel	5.9	7.2
Clean-up	0.18	0.27
Total	*19*	*23*

Values rounded to two significant digits.

ture would change if 100% forestry residues were used. Then, the average cost of the biofuel would rise to 12 mECU/kWh, yielding overall production costs of 25 mECU/kWh. The Nässjö plant was chosen, because it has been closely monitored and the data situation was thus very good. However, meanwhile a second, more advanced plant of this type was built at Växjö, Sweden. Among other advantages, it was demonstrated that the investment costs can be reduced by some 30%.

The specific input of the production factors energy and labour into the plant is summarised in Table 8. Less than one unit of energy input per unit of output is necessary in the biomass case since inputs are based on the lower heating value, thus disregarding flue-gas condensation. Labour figures will be discussed jointly for all case studies in Section 2.8.2.

Table 8 Specific input of production factors at the CHP-plant at Nässjö, Sweden.

		Use of forestry residues and saw-mill waste			Reference case: Use of Polish coal		
Production factor	Unit	Fuel production	Conversion	Clean-Up	Fuel production	Conversion	Clean-Up
Energy input							
Total energy	MWh/MWh	0.014	0.94	0.00011	0.064	1.1	0.00027
Fossil energy	MWh/MWh	0.014	0	0.00011	0.064	1.1	0.00027
Labour input							
Direct	h/MWh	0.082	0.11	§	§	0.13	§
	h/ECU	4300	5500	§	§	5500	§
Indirect	h/MWh	0.015	0.21	§	0.23	0.25	§
	h/ECU	780	11000	§	10000	11000	§

All values rounded to two significant digits; §: Value not applicable or insignificant.
Energy figures stated with respect to electricity and heat produced.

2.1.3. Emissions of air pollutants and the related external costs

Direct and indirect emissions of air pollutants are stated in Table 9 and Figure 4. Indirect emissions were obtained using the EMI input-output model described in Section 1.2.2. Direct emissions during fuel production are exclusively due to the operation of vehicle engines for collecting, chipping, and transporting the biofuel. The same holds for the clean-up stage, where only the transport and spreading of ashes is relevant. Direct emissions during the conversion stage stem from the combustion process in the CHP-plant.

First, it may be observed that indirect emissions and emissions during the clean-up stage are insignificant. The contribution of fuel production to the overall emissions of some pollutants such as CO, NO_x , and, for the reference case, SO_2, are non-negligible, but nevertheless emission levels are dominated by the conversion stage. It has been estimated that just about 3% of the energy in chips is needed for harvesting, chipping and transportation over 100 km (Vattenfall 1995). The only exception are emissions of CO_2-equivalents in the case of biofuel, where the fuel production and combustion stages contribute roughly equal amounts. Considering total emission levels, there is a large advantage for biomass with respect to SO_2 which is due to the fact that the biofuels contain only very low amounts of sulphur. For the other pollutants with the exception of particulates, we find small advantages of the biofuel at low overall emission levels. For particulates, the quantified emissions of the biofuel exceed those of coal, but this is most probably an artefact due to the fact that data on the particulate emissions during the production of coal in Poland could not be obtained.

Table 9 Specific emissions from the CHP-plant at Nässjö, Sweden, in g/kWh.

Pollutant	Use of forestry residues and saw-mill waste: Fuel production	Use of forestry residues and saw-mill waste: Conversion	Use of forestry residues and saw-mill waste: Clean-Up	Reference case: Use of Polish coal: Fuel production	Reference case: Use of Polish coal: Conversion	Reference case: Use of Polish coal: Clean-Up
Direct emissions						
VOC	0.0055	0	0	&	0	0
CO	0.019	0.17	0.00015	&	0.2	0.00028
NO_x	0.063	0.2	0.00046	0.071	0.24	0.00072
Particulates	0.0048	0.0068	0	&	0.0082	0
SO_2	0.0025	0.034	0	0.28	0.68	0
CO_2 *	3.6	340	0.03	59	390	0.059
CO_2-Equivalents **	3.6	5.4	0.03	59	410	0.059
Indirect emissions						
VOC	0.00039	0.00039	§	0.018	0.0017	§
CO	0.00073	0.02	§	0.0017	0.02	§
NO_x	0.0016	0.0042	§	0.0042	0.0042	§
Particulates	0.00013	0.0028	§	0.00058	0.0028	§
SO_2	0.00025	0.003	§	0.042	0.003	§
CO_2	0.14	1.3	§	2.1	1.3	§
CO_2-Equivalents	0.14	1.4	§	2.3	1.4	§

All values rounded to two significant digits; &: Value not available; §: Value not applicable or insignificant. * All CO_2 emissions from fossil and renewable fuels. ** CO_2-Equivalents: CO_2 emissions from fossil energy sources plus weighted emissions of CH_4 and N_2O.

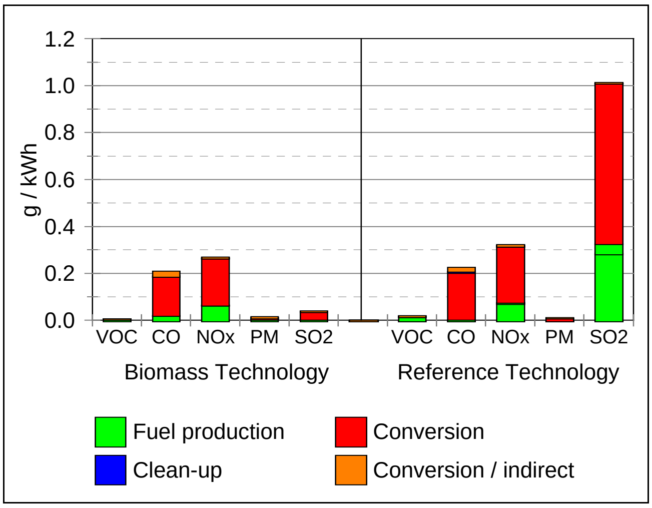


Figure 4 Specific emissions of air pollutants from the CHP-Plant at Nässjö, Sweden.

Input data for and results of EcoSense calculations are stated in Table 10 and Figure 5. For the Nässjö location, the external costs resulting from human health impacts are in the range of 1 mECU/kWh for the biofuel and of 4 mECU/kWh for the use of coal (at 0% discounting).

This advantage for the biomass fuel cycle would be even larger, if the plant was located at Lauffen in Germany. In that case, external effects for both biomass and coal are about five times bigger than in Sweden, which is due to the higher population density in the path of the plume. The impacts from fuel production prove to be low. Figure 5 clearly shows that the external costs are dominated by chronic fatalities (expressed as chronic years-of-life-lost – YOLL) and asthma caused by nitrates and sulphates, which are secondary pollutants occurring mostly at large distances from the source of pollution. Since the biomass plant at Nässjö already shows very favourable results with respect to environmental impacts, there is no immediate need for a sensitivity analysis into a further reduction of emission levels even though this would still be possible technically.

Table 10 EcoSense input data and external costs of the CHP-plant at Nässjö, Sweden, with respect to human health impacts and air pollutants.

Fuel		Bio-mass	Bio-mass	Fossil	Fossil	Bio-mass	Bio-mass	Fossil	Fossil
Location		Nässjö	Nässjö	Nässjö	Nässjö	Lauffen	Lauffen	Lauffen	Lauffen
Fuel-cycle stages		Con-version	All stages	Con-version	All stages	Con-version	All stages	Con-version	All stages
EcoSense Data									
Gross electricity production	MW	9	9	9	9	9	9	9	9
Electricity sent out	MW	8	8	7.94	7.94	8	8	7.94	7.94
Full-load hours	h / a	4400	4400	4400	4400	4400	4400	4400	4400
SO_2 emissions	mg / Nm^3	6.7	7.21	140	198	6.7	7.21	140	198
NO_x emissions	mg / Nm^3	40	52	49	64	40	52	49	64
Particulate emissions	mg / Nm^3	1.34	2.3	1.68	1.69	1.34	2.3	1.68	1.69
Flue gas volume	Nm^3 / h	40500	40500	38900	38900	40500	40500	38900	38900
Flue gas temperature *	K	321	321	321	321	321	321	321	321
Stack height	m	63	63	63	63	63	63	63	63
Stack diameter	m	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Anemometer height	m	10	10	10	10	10	10	10	10
Geographical latitude	degree	57	57	57	57	49	49	49	49
Geographical longitude	degree	14	14	14	14	9.18	9.18	9.18	9.18
Elevation at site	m	292	292	292	292	165	165	165	165
Priority Impacts (99%)									
Chronic YOLL	mECU/kWh	0.72	0.93	2.6	3.4	3.4	4.5	11	15
Asthma	mECU/kWh	0.05	0.052	0.61	0.81	0.088	0.087	2.4	3.2
Chronic bronchitis	mECU/kWh	0.052	0.067	0.18	0.24	0.25	0.33	0.79	1
Restricted activity days	mECU/kWh	0.019	0.025	0.068	0.089	0.091	0.12	0.3	0.39
Acute YOLL	mECU/kWh	0.012	0.016	0.056	0.074	0.074	0.095	0.3	0.4
Bronchodilator usage	mECU/kWh	0.0026	0.0033	0.0092	0.012	0.012	0.016	0.04	0.052
Sum (0% discounting)	*mECU/kWh*	*0.85*	*1.1*	*3.5*	*4.6*	*3.9*	*5.1*	*15*	*20*
Sum (10% discounting)	*mECU/kWh*	*0.6*	*0.77*	*2.6*	*3.5*	*2.8*	*3.6*	*11*	*15*
Pollutants									
Nitrates	mECU/kWh	0.59	0.8	0.51	0.64	3.3	4.4	3.3	4.1
Sulphates	mECU/kWh	0.24	0.25	2.9	3.9	0.42	0.42	11	15
NO_x	mECU/kWh	0.0068	0.0087	0.008	0.0097	0.042	0.056	0.051	0.064
SO_2	mECU/kWh	0.00041	0.00052	0.031	0.041	0.0085	0.0093	0.17	0.24
Particulates	mECU/kWh	0.027	0.046	0.032	0.032	0.15	0.26	0.18	0.19
Sum (0% discounting)	*mECU/kWh*	*0.86*	*1.1*	*3.5*	*4.6*	*4*	*5.2*	*15*	*20*
Ignored impacts		*0.8%*	*0.8%*	*0.7%*	*0.7%*	*0.8%*	*0.8%*	*0.7%*	*0.7%*

EcoSense input data are rounded to three, external cost figures to two significant digits. Results refer to mid-range damage estimates of long-range dispersion. Local dispersion and impacts on crops and forestry yields as well as building damage have been assessed and found insignificant. * As a non-critical simplification, flue gas temperatures are set equal for the use of biomass and fossil fuels

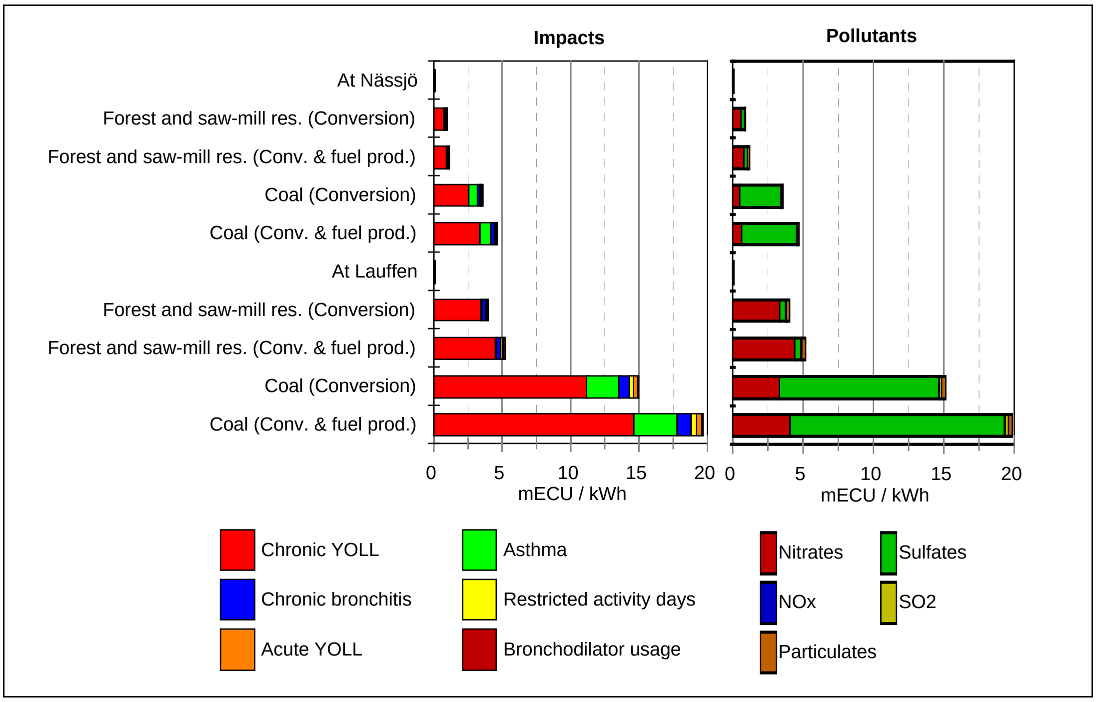


Figure 5 External costs of the CHP-plant at Nässjö, Sweden, with respect to human health impacts and air pollutants in mECU/kWh.

2.1.4. Other environmental impacts

Other potential environmental impacts of concern mainly arise at the fuel collection and processing stage. For the Swedish people, soil acidification and "Waldsterben" is an environmental issue of high priority. Therefore, the reduction in nitrogen load by residue removal and ash recycling is considered the most significant net impact on soil in the fuel cycle. This effect is at present beneficial, since atmospheric deposition of nitrogen is currently far above critical loads in southern Sweden. Excess nitrogen causes eutrophication and acidification. The net removal of nitrogen through the Nässjö fuel cycle has been found to lie in the range of 84 to 92 % in pine forest and 87 to 94 % in spruce forests. The numbers have been calculated by taking all nitrogen emissions in the cycle into account. They are equivalent to 1.4 to 1.7 g N/kWh of electricity produced for the Nässjö case (cf. Jörgensen et al. 1998).

This benefit of nitrogen removal from the forest could be valued monetarily by taking the NO_x-emissions tax of 14 ECU/kg N levied in Sweden as a proxy for the willingness to pay for the reduction of the damage caused by nitrogen. In the case of Nässjö, using this value to monetise the nitrogen removal potential would give a positive externality of 20-25 mECU/kWh. Suggestions to create an additional incentive to use biofuels from this figure have been made by Burström and Johansson (1995) as well as Lundborg (1996). The authors conclude that in Sweden, forestry residue-associated nitrogen removal has the potential to become a major driving force in the switch to biofuels, if the political will to internalise the externality exists.

Soil erosion is not regarded a problem in the forest fuel cycle. Tree stumps are normally left in the ground after the tree has been felled. The root system of the old tree is therefore left in place, preventing loss of soil until new trees are established.

In the past, many forest managers have paid little attention to nature conservation, leading to a decrease in the number of plant and animal species present. However, the management practice guidelines established nowadays want to ensure that the biodiversity of managed forests increases. Management practices are distinguished according to land characteristics and individual management plans are now available to forest owners. Biodiversity is fostered by practices such as leaving some healthy and rotting trees as well as some residues on the clear-cut and by preserving wet areas. One approach contributing to biodiversity is to preserve old-growth forests and to manage re-growth forests. Residue removal can be used to counteract nitrogen deposition in areas where it exceeds critical loads, and also to prevent a resulting shift in forest flora and fauna.

Careful evaluation of the removal of felling residues and of the return of ashes is essential in order to avoid nutrient depletion in certain areas. It must be noted that ashes return minerals but not nitrogen. Also, proper management of felling residues and ashes is essential for counteracting nutrient imbalance and acidification.

Noise pollution could present a problem in some stages of the wood chip fuel cycle. Yet, traffic occurs on roads that do not pass through densely populated areas. The plant meets the noise generation restrictions placed on it by the authorities. Chipping and sawmills are the two noisiest activities in the fuel cycle, yet, they are or should not be carried out in residential areas. Most of the impacts on recreation is due to the actual logging and felling management practice, which is not included in the system boundaries for this study, since logging is mainly carried out for timber production.

The accident risk for forestry workers is above the average for occupational health impacts. Separate statistics for residue collection and chipping are not available. However, it is reasonable to assume that the highest risk occurs during the actual felling of the tree, which is not attributable to the energy use, but to timber production.

The solid waste generated by the plant could be disposed of by landfilling with no likely environmental impacts resulting from the leaching of noxious substances. An extensive research programme on ash recycling is ongoing to assess the potential of returning the ash to the soil. The results so far lead to believe that ash recycling is desirable and it does not present adverse environmental effects (Nilsson 1996).

2.1.5. Socio-economic framework

The CFB plant considered is located about 2 km north-west of the centre of Nässjö, a city of about 30 000 inhabitants in the Swedish county of Jönköping. It is owned by Vattenfall Östsverige, a regional division of Vattenfall AB, one of the two largest utilities in Sweden. The plant is operated by Nässjö Affärswerk, a municipal utility which also purchases the heat produced for its district heating grid. The electricity is sold to Vattenfall's grid.

The level of air pollution in Nässjö is well below the guidelines. 90% of the sulphur deposition in the county of Jönköping stems from sources outside Sweden. The measured sulphur deposition has decreased steadily during the 1990ies. Before the construction of the district heating system, oil-fired furnaces constituted the biggest contributor to SO_2 emissions with total emission level at 30 µg/m^3. Nowadays, the SO_2 concentration is about 10 µg/m^3, to which the CHP plant contributes about 10%.

Nitrogen deposition has been around 5 kg per hectare and year lately, which is the target level of the Swedish Environmental Protection Agency (SEPA) for the region. Local NO_x levels are about 15 µg/m^3 and are dominated by traffic emissions.

Today, the re-emergence of interest in renewable energy sources is a major issue in Sweden. Thus, several energy and environmental taxes have been set up. Currently these are, among others, taxes on CO_2 and sulphur for heating fuels, an NO_x tax, a production tax on electricity from nuclear plants, and a tax on fertilisers and other agricultural chemicals. A public energy tax was set up in Sweden as early as 1957. It was first introduced to promote oil substitution, but has then been converted to improve the environmental performance of energy supply.

Taxes are now the strongest instrument for reducing CO_2 emissions in the district heating sector. This favours the use of biofuels, which remain untaxed except for NO_x emissions. Environmental taxes were a major incentive for Vattenfall to invest in power plants like the ones in Nässjö and Växjö. The Swedish NO_x tax scheme is very interesting for our study due to the way in which it was derived. First, it was determined that the marginal cost of reducing NO_x emissions in electricity production and district heating is between 0.3 and 9 ECU/kg NO_x. Plants are now liable to pay 4.3 ECU/kg of NO_x emissions into a central fund, the money of which is recycled to the same plants with respect to the amount of useful energy recovered. The net effect is that plants with emissions above average pay money to those with emissions below average. Thus, an economic incentive to reduce NO_x emissions is created. Since there is a broad consensus about this tax scheme in Sweden, the height of the tax might be taken as a willingness to pay for the reduction of acidification levels in Swedish forest. Acidification is regarded as the most urgent environmental problem due to energy consumption in Sweden, even though our study shows higher damage costs for health impacts.

The construction of the Nässjö plant was also subsidised in 1988 with some 1.6 million ECU under a scheme supporting small CHP plants, but not specifically biofuels.

Last not least, there is support by local stakeholders for the use of biofuels. It provides an additional source of income for forest owners and (self-)employment for a network of small businesses. In addition, the local community regards the use of biofuels as a way to reduce local environmental impacts.

More details on the sophisticated and very efficient network for using forestry residues in Sweden may be found in the case study report (Jörgensen et al. 1998) and in the BioCosts summary paper on socio-economic frameworks (Grabczewski 1998).

The use of biofuels in Sweden amounted to 84 TWh or 18% of the total energy demand in 1995. It is thought possible to double this figure to 170 TWh, 97% of which would be supplied by forest fuels. It is believed that market factors will govern the actual biofuel production limits in the next 10 years.

2.2. Utilisation of Forestry Residues and Short-Rotation Coppice for Industrial Combined Heat and Power Production in Portugal

2.2.1. Description of the technology and its location

This case study deals with the use of woody biomass in an industrial cogeneration facility located within a medium fibre density board factory at Mangualde in Portugal's Central Region.[10] Two situations are considered: First, the existing situation where wood residues in the form of bark and wood powder are used as a fuel, and second, a hypothetical situation, in

[10] The information on the plant has mostly been gathered from the company SIAF itself.

which short-rotation coppice is produced from poplar plantations as an additional fuel. Short-rotation coppice refers to trees growing faster than average trees such as, for example, eucalyptus, poplar, or maple. The main advantages of such crops are that they provide a steady and reliable source of fuel compared to natural forests and wood waste, and that they can be harvested at a faster rate than conventional forests.

Currently, the wood board factory utilises the bark resulting from the debarking process of pine round-wood to generate heat and electricity. In addition, residues from the factory such as wood powder resulting from the polishing process are co-fired. This situation is considered as Case 1. In 1994, the boiler consumed 54.9 kt of fuel consisting of 33.5 kt of bark, 18.4 kt of wood powder and 3.0 kt of wood fibres in 8140 hours of operation.

After drying, the bark is stored in a silo and is later transferred to the boiler by a drag chain conveyor. The wood powder is transported in hollow tubes by an air flow. The boiler used is stoker-fired with a slow moving grate, which provides a thinner and better distributed bed of burning fuel and continuous ash removal from the grate. The boiler has a thermal capacity of 23 MW and typically produces 17 t/h of steam at 59 bar and 110 t/h of hot gases. The steam is fed into a turbine while the gases are used to heat water and the condensed steam as well as for drying purposes in the factory. Using the bark residues for energetic purposes involves no up-stream stages of the fuel cycle since all the necessary operations would still occur without burning the bark.

The study also comprises a hypothetical situation where biomass from hybrid poplar crops specifically grown for energy purposes are utilised in an additional facility that would replace equipment which currently operates on fossil fuels and which serves as the reference case described below. For this Case 2, the whole growing phase, consisting of soil preparation, plantation of trees, fertilisation, harvesting, transportation, storage, and fuel preparation has to be taken into account. For this purpose, a piece of soil located some 75 km away from the factory site is analysed. However, since there is no short-rotation forestry at the moment, this is a hypothetical study. We assume an 18 year operation cycle for the plantation, starting with tree planting in year 1, requiring maintenance each year and harvesting in the years 6, 12, and 18. Preparation of 1 ha of soil will require 15 hours of operation of a 100 kW tractor. Planting is done by a group of 8 workers who cover a hectare in 7 hours. During planting, each tree must receive 80 g of a binary type fertiliser. Once per rotation, the ground must be fertilised and undergrowth has to be removed. Harvesting involves cutting and cleaning of the poplar and transportation to the combustion site.

The reference case is defined by an existing fuel-oil engine which supplies heat and electricity to the factory. Emissions during fuel-oil transport in Portugal are taken into account, but not emissions during oil extraction.

2.2.2. Technical and economic data

The technical data for Cases 1 and 2 as well as the reference case are summarised in Table 11. The capacities of Case 1 and the reference case are determined by the existing equipment, while Case 2 is designed to replace the reference case considering the fact that roughly half the electricity produced by the latter is exported to the grid which is not necessary.

The specific energy production costs of the different facilities are shown in Table 12. The investment costs of Case 1 are somewhat difficult to define since the equipment is integrated into other factory equipment and therefore some costs are hard to allocate to energy production. Second, the fuel cost of Case 1 is very low since bark and wood-powder are residues

Table 11 Technical data of the industrial CHP installation at Mangualde, Portugal.

		Case 1: Use of bark and wood-powder	Case 2: Use of short-rotation coppice	Reference case: Use of fuel oil
Capacity				
Electrical	MW_{el}	3	3.3	6.3
Thermal	MW_{th}	23	12	7.61
Internal use	MW_{el}	0.4	0.3	0.378
Full-load hours	h / a	8140	8300	8140
Fuel input	MWh / a	229000	251000	125000
Net electricity production	MWh / a	21200	24900	48200
Net heat production	MWh / a	200000	99200	62000
Total energy output	*MWh / a*	*221000*	*124000*	*110000*

All values rounded to three significant digits.

Table 12 Specific energy production costs at the industrial CHP installation at Mangualde, Portugal, in mECU/kWh.

	Case 1: Use of bark and wood-powder	Case 2: Use of short-rotation coppice	Reference case: Use of fuel oil
Conversion			
– Investment	1.2	6	3.1
– Operation & maintenance	0.4	1.1	3
– Labor	0.19	1.9	0.36
Fuel	1.2	17	12
Clean-up	0.056	0.015	0
Total	*3.0*	*26*	*19*

Values rounded to two significant digits.

which can be obtained at very low cost, mostly from the factory itself. Thus, Case 1 is economically very attractive, while Case 2 is more expensive than the reference case due to the higher equipment cost and due to efforts made for fuel production.

The specific inputs of the production factors energy and labour into the facilities are sum-

Table 13 Specific input of production factors for the use of bark and wood-powder (Case 1) at the industrial CHP installation at Mangualde, Portugal.

		Case 1: Use of bark and wood-powder			Reference case: Use of fuel oil		
Production factor	Unit	Fuel production	Conversion	Clean-Up	Fuel production	Conversion	Clean-Up
Energy input							
Total energy	MWh/MWh	0.0033	1.04	0.0003	0.0026	1.1	0
Fossil energy	MWh/MWh	0.0033	0	0.0003	0.0026	1.1	0
Labour input							
Direct	h/MWh	0.03	0.074	0.0015	0.012	0.074	0
	h/MECU	10000	25000	§	630	3900	§
Indirect		*– Not available – **					

All values rounded to two significant digits; §: Value not applicable or insignificant.
* For Portugal, no I/O-table sufficient for the use within the EMI model could be obtained.
Energy figures stated with respect to electricity and heat produced.

Table 14 Specific input of production factors for the use of short-rotation coppice (Case 2) at the industrial CHP installation at Mangualde, Portugal.

		Case 2: Use of short-rotation coppice			Reference case: Use of fuel oil		
Production factor	Unit	Fuel production	Conversion	Clean-Up	Fuel production	Conversion	Clean-Up
Energy input							
Total energy	MWh/MWh	0.029	2.0	0.00014	0.0026 *	1.1	0
Fossil energy	MWh/MWh	0.029	0	0.00014	0.0026 *	1.1	0
Labour input							
Direct	h/MWh	0.4	0.27	§	0.012	0.074	§
	h/MECU	15000	10000	§	630	3900	§
Indirect		*– Not available –* **					

All values rounded to two significant digits; §: Value not applicable or insignificant. * This figures seems rather low. It does only include transport, not refining. ** For Portugal, no I/O-table sufficient for the use within the EMI model could be obtained. Energy figures stated with respect to electricity and heat produced.

marised in Table 13 and Table 14. It should be noted that the energetic efficiency of Case 2 is rather low. This is due to the fact that more heat is produced with the electricity needed than can be used in the factory. Also, the energy input during fuel production is higher in Case 2 than for the two other cases which is due to the operation of agricultural equipment, the transport of the coppice, and last, but not least, the energy necessary to produce the fertilisers applied. Labour figures will be discussed below in Section 2.8.2.

2.2.3. Emissions of air pollutants and the related external costs

Direct and indirect emissions of air pollutants are stated in Table 15, Table 16, and Figure 6. Since it was not possible to adapt the Portuguese input-output table available to the EMI model, there are no input-output results for this case study. However, this is not a major drawback as all the other case studies show that indirect effects are of minor importance. The only effect that might contribute significantly, namely the production of fertilisers, would not be

Table 15 Specific emissions from the industrial CHP installation (Case 1) at Mangualde, Portugal in g/kWh.

	Case 1: Use of bark and wood-powder			Reference case: Use of fuel oil		
Pollutant	Fuel production	Conversion	Clean-Up	Fuel production	Conversion	Clean-Up
Direct emissions						
VOC	0.002	0.38	0.00018	0.0015	0.15	§
CO	0.0056	2.3	0.00052	0.0044	0.26	§
NO_x	0.017	0.62	0.0016	0.013	6.6	§
Particulates	0.0012	0.2	0.00011	0.00092	0.11	§
SO_2	0.0016	0.036	0.00015	0.0013	3.6	§
CO_2	0.87	340	0.079	0.67	430	§
CO_2-Equivalents	0.87	0	0.079	0.67	430	§
Indirect emissions	*– Not available –* *					

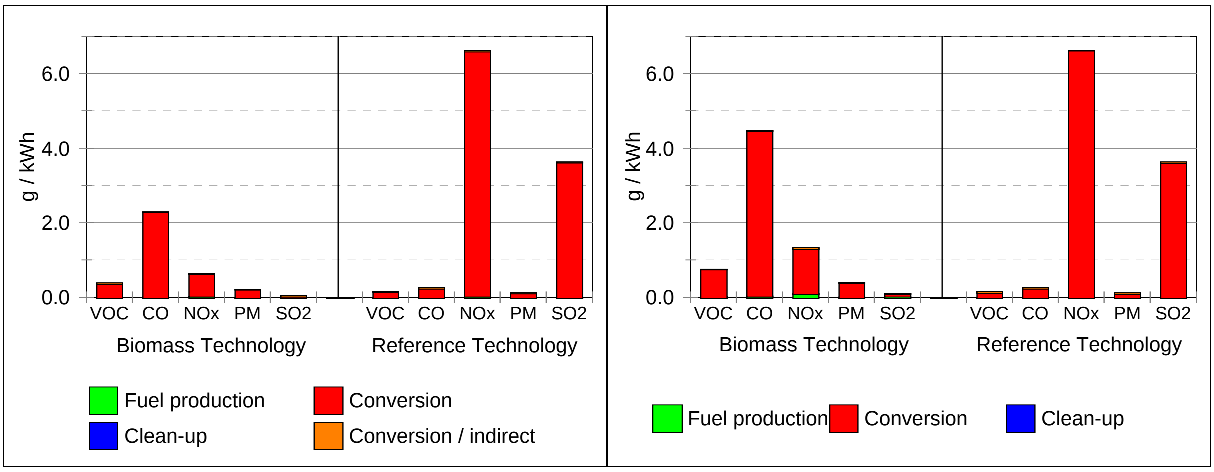
All values rounded to two significant digits; &: Value not available; §: Value not applicable or insignificant.
CO_2-Equivalents: CO_2 emissions from fossil energy sources plus weighted CH_4 and N_2O emissions.
* For Portugal, no I/O-table sufficient for the EMI model could be obtained.

covered accurately by the I/O-model anyway and is therefore included by using the emission factors given by Patyk and Reinhardt (1997). The direct emissions are again dominated by the combustion process with some contributions from fossil-fuel fired combustion engines in tractors and trucks.

Table 16 Specific emissions from the industrial CHP installation (Case 2) at Mangualde, Portugal in g/kWh.

	Case 2: Use of short-rotation coppice			Reference case: Use of fuel oil		
Pollutant	Fuel production	Conversion	Clean-Up	Fuel production	Conversion	Clean-Up
Direct emissions						
VOC	0.011	0.74	0	0.0015	0.15	§
CO	0.031	4.4	0.00024	0.0044	0.26	§
NO_x	0.094	1.2	0.00073	0.013	6.6	§
Particulates	0.0064	0.39	0	0.00092	0.11	§
SO_2	0.0088	0.07	0	0.0013	3.6	§
CO_2 *	4.7	660	0.037	0.67	430	§
CO_2-Equivalents **	4.7	0	0.037	0.67	430	§
Indirect emissions ***						
VOC	0.00053	&	§	&	&	§
CO	0.0025	&	§	&	&	§
NO_x	0.016	&	§	&	&	§
Particulates	0.0017	&	§	&	&	§
SO_2	0.021	&	§	&	&	§
CO_2	2.6	&	§	&	&	§
CO_2-Equivalents	3.9	&	§	&	&	§

All values rounded to two significant digits; &: Value not available; §: Value not applicable or insignificant. * All CO_2 emissions from fossil and renewable fuels. ** CO_2-Equivalents: CO_2 emissions from fossil energy sources plus weighted emissions of CH_4 and N_2O. *** Data refer to fertiliser production only (Patyk and Reinhardt 1997). For Portugal, no I/O-table sufficient for the use within the EMI model could be obtained.



Case 1 Case 2

Figure 6 Specific emissions of air pollutants from the industrial CHP installation at Mangualde, Portugal.

It is somewhat surprising that the specific emissions of Case 2 are significantly higher than those of Case 1 even though similar technology is considered and fuel production has almost no impact. This result is due to the low overall energetic efficiency of Case 2, which in turn is caused by the fact that not all of the heat produced with the electricity needed can be utilised.

Case 1 has two major advantages over the reference case, namely NO_x and SO_2 emissions. The latter it caused by the fact that the biofuel does hardly contain any sulphur and the first is attributable to the application of a boiler/ steam-turbine combination rather than an engine technology, which is notorious for its high NO_x emissions. For VOC, particulates and CO there are slight disadvantages of the biofuel technology.

Input data and results of EcoSense calculations are stated in Table 17, Table 18, Figure 7, and Figure 8.

Table 17 EcoSense input data and external costs of the industrial CHP installation (Case 1) at Mangualde, Portugal.

Fuel		Bio-mass	Bio-mass	Fossil	Fossil	Bio-mass	Bio-mass	Fossil	Fossil
Location		Mangu-alde	Mangu-alde	Mangu-alde	Mangu-alde	Lauffen	Lauffen	Lauffen	Lauffen
Fuel-cycle stages		Con-version	All stages	Con-version	All stages	Con-version	All stages	Con-version	All stages
EcoSense Data									
Gross electricity production	MW	3	3	6.3	6.3	3	3	6.3	6.3
Electricity sent out	MW	2.6	2.6	5.92	5.92	2.6	2.6	5.92	5.92
Full-load hours	h / a	8140	8140	8140	8140	8140	8140	8140	8140
SO_2 emissions	mg / Nm^3	0.894	0.938	383	383	0.894	0.938	383	383
NO_x emissions	mg / Nm^3	16	16	697	698	16	16	697	698
Particulate emissions	mg / Nm^3	5.07	5.1	12	12	5.07	5.1	12	12
Flue gas volume	Nm^3 / h	104000	104000	56200	56200	104000	104000	56200	56200
Flue gas temperature	K	393	393	393	393	393	393	393	393
Stack height	m	10	10	10	10	10	10	10	10
Stack diameter	m	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Anemometer height	m	10	10	10	10	10	10	10	10
Geographical latitude	degree	41	41	41	41	49	49	49	49
Geographical longitude	degree	7.76	7.76	7.76	7.76	9.18	9.18	9.18	9.18
Elevation at site	m	550	550	550	550	165	165	165	165
Priority Impacts (99%)									
Chronic YOLL	mECU/kWh	7.7	7.9	89	89	14	14	150	150
Asthma	mECU/kWh	0.12	0.13	8.5	8.5	0.032	0.037	12	12
Chronic bronchitis	mECU/kWh	0.56	0.58	6.4	6.4	0.99	1	11	11
Restricted activity days	mECU/kWh	0.2	0.21	2.4	2.4	0.36	0.37	3.9	3.9
Acute YOLL	mECU/kWh	0.074	0.076	1.1	1.1	0.23	0.24	3.5	3.5
Bronchodilator usage	mECU/kWh	0.028	0.028	0.32	0.32	0.049	0.05	0.53	0.53
Sum (0% discounting)	*mECU/kWh*	*8.7*	*8.9*	*110*	*110*	*15*	*16*	*180*	*180*
Sum (10% discounting)	*mECU/kWh*	*5.9*	*6.1*	*76*	*76*	*11*	*11*	*130*	*130*
Pollutants									
Nitrates	mECU/kWh	6.2	6.4	66	66	10	11	110	110
Sulphates	mECU/kWh	0.58	0.6	41	41	0.15	0.18	60	60
NO_x	mECU/kWh	0.018	0.019	0.17	0.17	0.13	0.14	1.5	1.5
SO_2	mECU/kWh	0.0006	0.00074	0.3	0.3	0.0089	0.0094	0.99	0.99
Particulates	mECU/kWh	1.9	1.9	1.1	1.1	4.6	4.6	2.7	2.8
Sum (0% discounting)	*mECU/kWh*	*8.8*	*9*	*110*	*110*	*15*	*16*	*180*	*180*
Ignored impacts		*0.8%*	*0.8%*	*0.7%*	*0.7%*	*0.8%*	*0.8%*	*0.8%*	*0.8%*

EcoSense input data rounded to three, external costs to two significant digits.
Results refer to mid-range damage estimates of long-range dispersion. Local dispersion and impacts on crops and forestry yields as well as building damage have been assessed and found insignificant.

Table 18 EcoSense input data and external costs of the industrial CHP installation (Case 2) at Mangualde, Portugal.

Fuel		Bio-mass	Bio-mass	Fossil	Fossil	Bio-mass	Bio-mass	Fossil	Fossil
Location		Mangu-alde	Mangu-alde	Mangu-alde	Mangu-alde	Lauffen	Lauffen	Lauffen	Lauffen
Fuel-cycle stages		Con-version	All stages	Con-version	All stages	Con-version	All stages	Con-version	All stages
EcoSense Data									
Gross electricity production	MW	3.3	3.3	6.3	6.3	3.3	3.3	6.3	6.3
Electricity sent out	MW	3	3	5.92	5.92	3	3	5.92	5.92
Full-load hours	h / a	8300	8300	8140	8140	8300	8300	8140	8140
SO_2 emissions	mg / Nm^3	1.16	1.31	383	383	1.16	1.31	383	383
NO_x emissions	mg / Nm^3	20	22	697	698	20	22	697	698
Particulate emissions	mg / Nm^3	6.58	6.69	12	12	6.58	6.69	12	12
Flue gas volume	Nm^3 / h	180000	180000	56200	56200	180000	180000	56200	56200
Flue gas temperature	K	393	393	393	393	393	393	393	393
Stack height	m	10	10	10	10	10	10	10	10
Stack diameter	m	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
Anemometer height	m	10	10	10	10	10	10	10	10
Geographical latitude	degree	41	41	41	41	49	49	49	49
Geographical longitude	degree	7.76	7.76	7.76	7.76	9.18	9.18	9.18	9.18
Elevation at site	m	550	550	550	550	165	165	165	165
Priority Impacts (99%)									
Chronic YOLL	mECU/kWh	15	16	89	89	27	28	150	150
Asthma	mECU/kWh	0.17	0.19	8.5	8.5	0.062	0.08	12	12
Chronic bronchitis	mECU/kWh	1.1	1.2	6.4	6.4	1.9	2.1	11	11
Restricted activity days	mECU/kWh	0.4	0.43	2.4	2.4	0.7	0.75	3.9	3.9
Acute YOLL	mECU/kWh	0.15	0.16	1.1	1.1	0.46	0.49	3.5	3.5
Bronchodilator usage	mECU/kWh	0.054	0.058	0.32	0.32	0.095	0.1	0.53	0.53
Sum (0% discounting)	*mECU/kWh*	*17*	*18*	*110*	*110*	*30*	*32*	*180*	*180*
Sum (10% discounting)	*mECU/kWh*	*12*	*12*	*76*	*76*	*21*	*22*	*130*	*130*
Pollutants									
Nitrates	mECU/kWh	12	13	66	66	21	22	110	110
Sulphates	mECU/kWh	0.83	0.91	41	41	0.3	0.39	60	60
NO_x	mECU/kWh	0.034	0.036	0.17	0.17	0.26	0.28	1.5	1.5
SO_2	mECU/kWh	0.004	0.0046	0.3	0.3	0.018	0.02	0.99	0.99
Particulates	mECU/kWh	3.8	3.8	1.1	1.1	8.9	9.1	2.7	2.8
Sum (0% discounting)	*mECU/kWh*	*17*	*18*	*110*	*110*	*30*	*32*	*180*	*180*
Ignored impacts		*0.8%*	*0.8%*	*0.7%*	*0.7%*	*0.8%*	*0.8%*	*0.8%*	*0.8%*

EcoSense input data rounded to three, external costs to two significant digits.
Results refer to mid-range damage estimates of long-range dispersion. Local dispersion and impacts on crops and forestry yields as well as building damage have been assessed and found insignificant.

External costs from human health impacts for Case 1 are in the range of 9 mECU/kWh, for Case 2 they amount to 18 mECU/kWh. In both cases, moving the equipment to Lauffen, Germany, will almost double the external costs. Even though these figures are high compared to the other case studies examined in the BioCosts project, they have to be compared to external costs of the reference case which are as high as 110 mECU/kWh. The latter figure is mostly due to the sulphur content of the fuel oil and the high NO_x emissions of the engine.

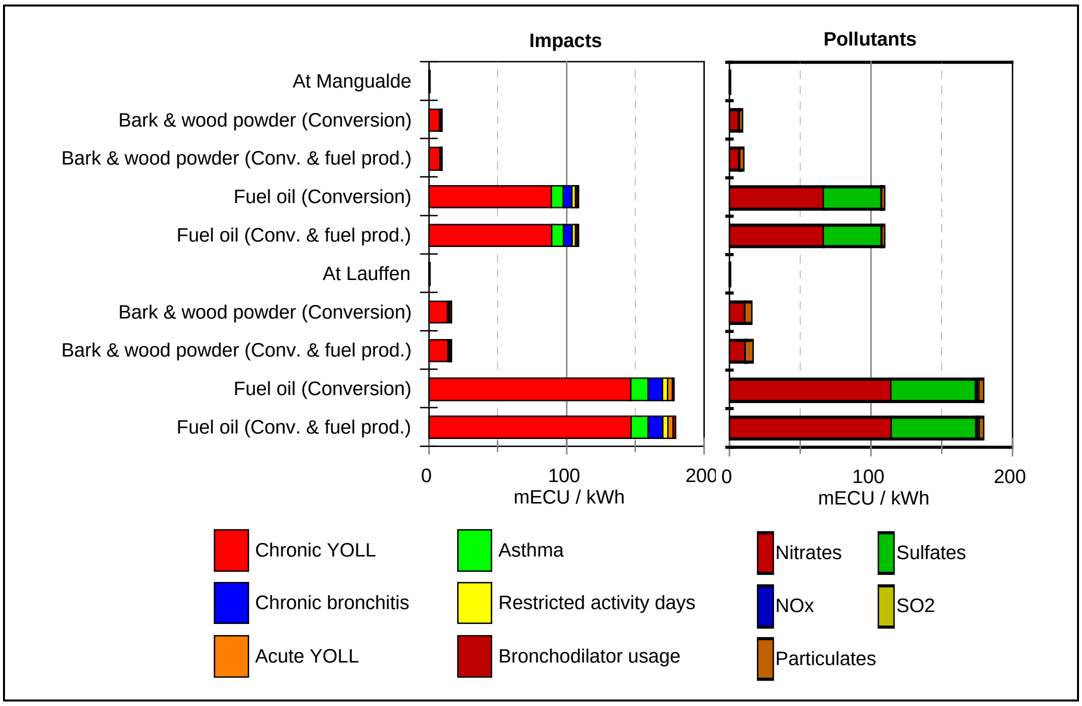


Figure 7 External costs of the industrial CHP installation (Case 1) at Mangualde, Portugal, with respect to human health impacts and air pollutants in mECU/kWh.

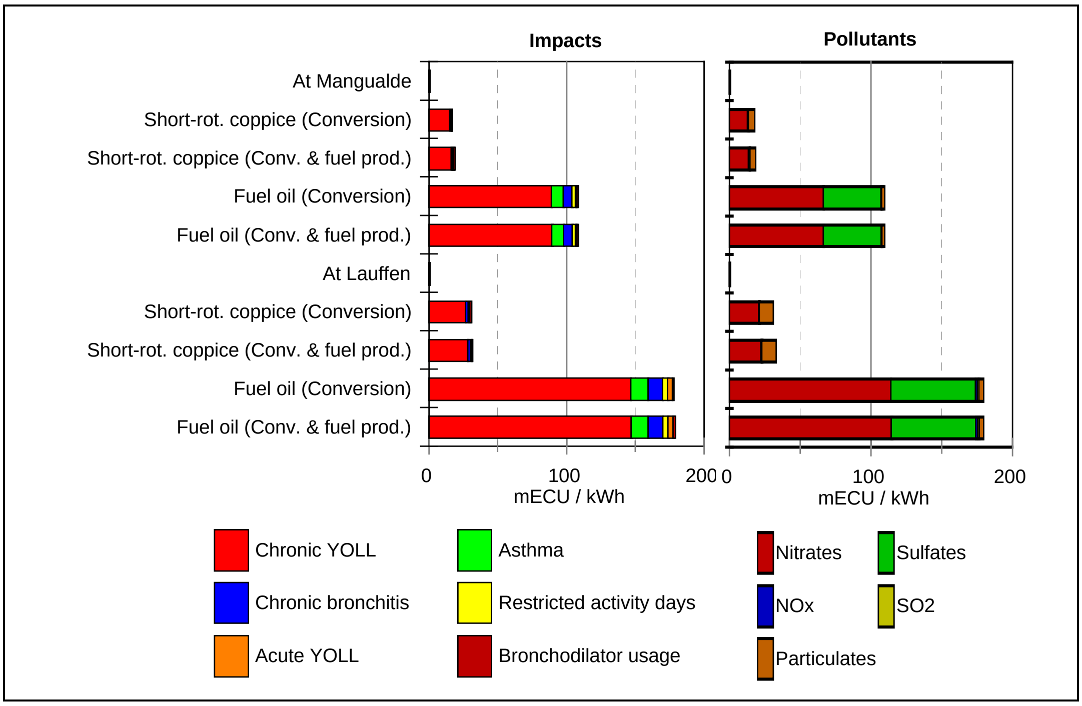


Figure 8 External costs of the industrial CHP installation (Case 2) at Mangualde, Portugal, with respect to human health impacts and air pollutants in mECU/kWh.

2.2.4. Other environmental impacts

As it was mentioned above, soil erosion is a problem at the Portuguese cultivation sites. Yet, short-rotation coppice (SRC) may stabilise otherwise erosive sites by reducing runoff on steep slopes. SRC is said to have an advantage over reference crops with respect to erosion. A gross estimate of the soil erosion damage corresponding to six hybrid poplar plantations arrives at costs of 0.12 to 0.47 mECU/kWh which is still 1-2 orders of magnitude smaller than the costs calculated for health damage. Almeida et al. (1998, 61-65) based their estimate on the universal soil loss equation and the methodology used in earlier ExternE studies (cf. Section 1.3.2.1 above).

Negative environmental impacts can definitely be expected from the use of fertilisers and pesticides, if too large quantities are given or if they are not implemented correctly. Yet, as with all other case studies examining energy crops, first, the difference to the agricultural reference case is rather small, and second, scientific modelling of the site-specific impacts on human health, biodiversity, and ecosystems is still limited. There is a method available to roughly calculate the impacts of nitrate leaching on groundwater or, to be precise, on drinking water (cf. Section 1.3.2.1). The calculation of these impacts for the area of about 1 200 hectares under analysis amounts to damage values smaller than 10^{-3} mECU (Almeida 1998, 51-54).

All forestry activities affect biodiversity preservation to some degree. The tree plantations in monoculture associated with the short-rotation crops reduce the diversity of plant and animal species, and have impacts on natural habitats. However, it is generally understood that poplar crops have significantly less impacts than other SRC such as pine-tree and eucalyptus. They permit a major level of plant and animal diversity because of their physiological characteristics. Anyhow, without ecologically sound practices which would for example only allow farming of crops suited for the local climatic and soil characteristics, the impacts of large-scale cultivation of SRC on biodiversity can be significant.

2.2.5. Socio-economic framework

The wood board factory selected for this case study lies in Portugal's Central Region, which is divided into two distinct geomorphologic areas, namely the coastal border and the early massif. The coastal border, consisting of sand, clay, sandstone and limestone, has a regular topography, and is characterised by a flood plain and areas of sea erosion. In the early massif, where schist and granite predominate, there is a landscape of plateaus, abrupt escarpments and sunken basins. The Central Region has the most important hydrographic basins in Portugal. It has a temperate climate in the transition between the Atlantic and the Mediterranean climate with distinct characteristics in different areas due to altitude, relief and proximity to the sea. Rainfall patterns are highly irregular over the year.

With respect to agriculture and forestry, the Central Region is divided in two major areas, one next to the ocean (Beira Litoral) and the other one inland (Beira interior). 26% of the total land is used for agricultural purposes, 44% is covered by forests. The most common species in these forests are pine and eucalyptus. The forests are severely endangered by forest fires, which destroyed between 3 and 7% of the total forests in each year between 1990 and 1994. 43% of the total agricultural land is occupied by temporary crops (cereals, potatoes, etc.), 23% by permanent crops (vine, olives, etc.). The remaining area consists of permanent pasture, vegetable gardens, or fallow grounds.

The population of the Central Region amounts to 1.7 million inhabitants on 24 000 km^2. The region is marked by small and medium urban centres.

The national policy on biofuels in Portugal is determined by two major objectives, namely to reduce the dependency on energy imports and to protect the scarce area suitable for agriculture. Thus, there are several laws in effect which promote electricity production from indigenous sources by industry and independent producers. Second, silviculture is seeking to use crops with shorter rotation cycles and larger yields than the traditional ones. However, due to potential problems with mono-cultures and soil erosion, projects which involves areas larger than 50 ha are subject to monitoring and permission by government authorities. Setting up larger schemes of cultivation is difficult in Portugal since the ownership of forests is mostly private, but very fragmented due to the traditional inheritance schemes. 71% of the property has a size of less than 4 ha, only 1% has more than 100 ha. Up to now, it has not been possible to set up efficiently organised co-operatives as it is the case in Sweden.

2.3. Production of Biogas from Animal Slurry for Municipal Combined Heat and Power Generation in Denmark

2.3.1. Description of the technology and its location

This case study analyses the production of biogas from animal slurry supplemented by industrial organic waste at Hashöj, Denmark. The biogas is utilised in a nearby municipal combined heat and power plant, which provides electricity and district heating for the town of Dalmose.[11]

Animal slurry is supplied to the biogas plant from 19 farms around Dalmose. It is in most cases produced in stables without animal bedding. The slurry is transported from the farms to the biogas plant in unpressurised tanks. After digestion, it is transported back to the farms or stored in 8 large intermediate storage tanks situated some 6 km from the plant. A major incentive for the farmers to participate in such a biogas production scheme is provided by a Danish law that forces them to store the slurry anyway, because they are only allowed to apply it to their fields during 3 months of the year.

After arriving at the biogas plant, the slurry is mixed at a ratio of 2:1 with industrial organic waste containing easily digestible organic matter from different food processing industries.[12] This waste improves the efficiency of the gas production significantly. Its supply is a crucial factor for a future extension of the biogas production in Denmark as most of the waste available is already utilised in the existing biogas facilities.

Biogas is produced by anaerobic digestion where organic matter is converted into methane (CH_4). In a first step, fermentative bacteria hydrolyse and ferment the organic matter into fatty acids, alcohol, carbon dioxide, amonia and sulphides. These products are then consumed by acetogenic bacteria producing hydrogen, carbon dioxide, and acetic acids. Finally, two kinds of methanogenic bacteria take over, one reducing carbon dioxide to methane and the other converting decarboxylate acetic acid into CH_4 and CO_2. Temperatures between 35 (mesophilic) and 55^{o}C (thermophilic) are regarded optimal for biogas production. In the mesophilic case, which is used at Hashöj, the organic matter has to be heated to 70^{o}C for one hour for hygienic reasons. The material is kept in the reactor for 12-20 days.

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[11] The data on biogas production and its use in a CHP plant have mainly been obtained from the operators of the two installations.

[12] The typical mixing ratio of joint biogas plants in Denmark is 4:1.

The biogas produced is transported via a 2 km pipeline to the CHP-plant at Dalmose, where it is combusted in a gas engine. The facility provides 400 households with 5 GWh of heat and 3 GWh of electricity per year. There is no clean-up stage after combustion as no ash is produced. The transport of the digested slurry back to the farms is included in the production stage, since the trucks collecting the fresh slurry bring back the digested slurry on the return trip. Spreading the digested slurry on the fields need not be considered in the analysis as it would occur in the reference case too.

The biogas case has to consider the transport of slurry and biogas as well as the energy that is necessary to produce the biogas. For the latter, gas from the plant itself is used while the electricity used is assumed to be produced in the CHP-plant. Therefore, the corresponding amounts of gas and electricity are subtracted from the respective output of the biogas and the CHP plant as internal consumption being supplied by renewable sources.

The reference case is defined as using natural gas from a Danish North Sea field in the same gas engine. It is assumed that the farmers would store the slurry locally, where it would emit methane to the environment. This methane is produced by natural processes in the storage tank, even though at a much slower rate than at the biogas plant. These emissions are relevant for global warming analysis as methane has a 25 times higher global warming potential than CO_2. Thus, the biogas production creates an additional benefit by avoiding these methane emissions. This is taken into account in the emission balance.

2.3.2. Technical and economic data

The biogas plant has a production capacity of 5 300 m^3 of biogas per day with an input of 134 tonnes of organic material per day. It has two 600 m^3 input tanks, two 30 m^3 sterilising tanks, a 1 200 m^3 storage tank for degassed slurry, and a 2 200 m^3 storage tank for the biogas. A summary of technical data can be found in Table 19. The difference in total energy output indicated there does not influence the main results since they are normalised to energy units.

The specific energy production costs of this biogas/CHP-installation are shown in Table 20. They amount to 64 mECU/kWh in the biogas case and 41 mECU/kWh if natural gas is used. The costs are dominated by fuel costs, which are higher in the case of biogas than for natural gas. This is due to the fact that the collection and processing of the slurry is rather costly. However, no monetary compensation is included here for the additional benefits which the biogas production provides, neither for the avoided methane emissions at the farms nor for the individual storage of the slurry which would have to be provided otherwise. Furthermore,

Table 19 Technical data of the biogas / CHP installation at Hashöj, Denmark.

		Use of biogas	Reference case: Use of natural gas
Capacity			
Electrical	MW_{el}	0.76	0.76
Thermal	MW_{th}	1.36	1.36
Internal use	MW_{el}	0.0681	0.00789
Full-load hours	h / a	4230	4560
Fuel input	MWh / a	10300	11200
Net electricity production	MWh / a	3220	3470
Net heat production	MWh / a	4940	5380
Total energy output	*MWh / a*	*8150*	*8850*

All values rounded to three significant digits.

Table 20 Specific energy production costs of the biogas / CHP installation at Hashöj, Denmark, in mECU/kWh.

	Use of biogas	Use of natural gas
Conversion		
– Investment	7	6.4
– Operation & maintenance	1.2	1.1
– Labour	0.61	0.57
Fuel	55	33
Clean-up	0	0
Total	*64*	*41*

Values rounded to two significant digits.

it has to be noted that there is a risk of rising prices of natural gas in the years to come as the use of natural gas increases throughout Europe.

The specific input of the production factors energy and labour into the plants is summarised in Table 21. It should be noted that the production of biogas is five times more energy intensive than the production of natural gas. However, less fossil fuel is used for biogas as most of the energy used for its production is considered to be internal use at the biogas plant itself, originating from the slurry. Labour figures will be discussed in Section 2.8.2.

Table 21 Specific input of production factors at the biogas / CHP installation at Hashöj, Denmark.

		Use of biogas			Use of natural gas		
Production factor	Unit	Fuel production	Conversion	Clean-Up	Fuel production	Conversion	Clean-Up
Energy input							
Total energy	MWh/MWh	0.55	1.2	§	0.1	1.2	§
Fossil energy	MWh/MWh	0.047	0	§	0.1	1.2	§
Labour input							
Direct	h/MWh	0.41	0.068	§	§	0.063	§
	h/MECU	6400	1100	§	§	1500	§
Indirect	h/MWh	0.57	0.17	§	0.33	0.16	§
	h/MECU	8800	2700	§	8000	3800	§

All values rounded to two significant digits; §: Value not applicable or insignificant. Energy figures stated with respect to electricity and heat produced.

2.3.3. Emissions of air pollutants and the related external costs

Direct and indirect emissions into the atmosphere are indicated in Table 22 and Figure 9. Indirect emissions from the production of equipment were obtained using the EMI input-output model. For the production of natural gas, data from Kaltschmitt and Reinhardt (1997) were used. Direct emissions during fuel production comprise transport activities during slurry collection only since fuel and electricity used during the production of the biogas are handled as internal consumptions and are included in the conversion stage. The rather high emissions of CO_2-equivalents during the conversion stage are the equivalents of methane emissions that occur with all gas-driven engines (Nielsen 1996). There is a trade-off between methane and NO_x emissions. Since there is no regulation on NO_x emissions from small CHP engines in Denmark so far, no efforts have been made to lower these emissions at the Dalmose plant.

Table 22 Specific emissions from the biogas / CHP installation at Hashöj, Denmark in g/kWh.

Pollutant	Use of biogas: Fuel production	Use of biogas: Conversion	Use of biogas: Clean-Up	Reference case: Use of natural gas: Fuel production ***	Reference case: Use of natural gas: Conversion	Reference case: Use of natural gas: Clean-Up
Direct emissions						
VOC	0.034	0.011	0	0.00029	0.011	0
CO	0.17	0.091	0	0.0028	0.091	0
NO_x	0.17	1.1	0	0.0098	1.1	0
Particulates	0.0082	0	0	0	0	0
SO_2	0.016	0.0092	0	0	0.0014	0
CO_2 *	13	300	0	8.3	260	0
CO_2-Equivalents **	13	84	0	14	650	0
Indirect emissions						
VOC	0.013	0.0027	§	&	0.0027	§
CO	0.11	0.037	§	&	0.037	§
NO_x	0.028	0.007	§	&	0.007	§
Particulates	0.022	0.0066	§	&	0.0066	§
SO_2	0.022	0.0058	§	&	0.0058	§
CO_2	5.6	1.7	§	&	1.7	§
CO_2-Equivalents	7.3	2.1	§	&	2.1	§

All values rounded to two significant digits; &: Value not available; §: Value not applicable or insignificant. * All CO_2 emissions from fossil and renewable fuels. ** CO_2-Equivalents: CO_2 emissions from fossil energy sources plus weighted emissions of CH_4 and N_2O. *** Total emission values for Norway from Kaltschmitt and Reinhardt (1997). No indirect emissions considered separately.

These NO_x emissions cause external costs, which are about 8 times higher than for the Nässjö CHP-plant described above. Appropriate catalytic converters would be capable of lowering these NO_x emissions, though at additional cost. It has to be noted that the high NO_x emissions are not a problem of the biogas in the first place, but of the engine technology. NO_x emissions in the reference case using natural gas are at a similar level.

Input data and results for EcoSense calculations are stated in Table 23 and Figure 10. For the Danish location, external costs resulting from human health impacts are around 8

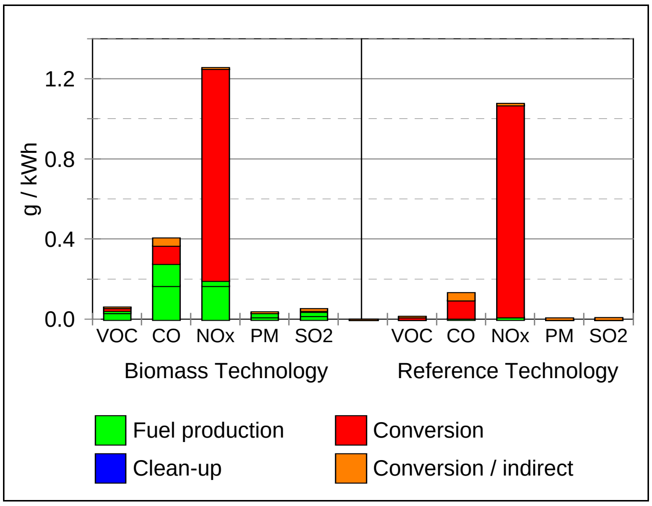


Figure 9 Specific emissions of air pollutants from the biogas / CHP installation at Hashöj, Denmark.

mECU/kWh in the case of biogas and 6 mECU/kWh for the use of natural gas. The higher values for biogas are due to higher NO_x emissions during the fuel production and higher SO_2 emissions during fuel production and combustion. Transferring the whole biogas installation to Lauffen in Germany would increase external costs to about 23 mECU/kWh, that is by a factor of three.

Table 23 EcoSense input data and external costs of the biogas / CHP installation at Hashöj, Denmark.

Fuel		Bio-mass	Bio-mass	Fossil	Fossil	Bio-mass	Bio-mass	Fossil	Fossil
Location		Hashöj	Hashöj	Hashöj	Hashöj	Lauffen	Lauffen	Lauffen	Lauffen
Fuel-cycle stages		Con-version	All stages	Con-version	All stages	Con-version	All stages	Con-version	All stages
EcoSense Data									
Gross electricity production	MW	0.76	0.76	0.76	0.76	0.76	0.76	0.76	0.76
Electricity sent out	MW	0.692	0.692	0.752	0.752	0.692	0.692	0.752	0.752
Full-load hours	h / a	4230	4230	4560	4560	4230	4230	4560	4560
SO_2 emissions	mg / Nm^3	1.4	3.81	0.208	0.208	1.4	3.81	0.208	0.208
NO_x emissions	mg / Nm^3	160	186	161	161	160	186	161	161
Particulate emissions	mg / Nm^3	0	1.25	0	0	0	1.25	0	0
Flue gas volume	Nm^3 / h	5000	5000	5000	5000	5000	5000	5000	5000
Flue gas temperature	K	392	392	392	392	392	392	392	392
Stack height	m	35	35	35	35	35	35	35	35
Stack diameter	m	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Anemometer height	m	10	10	10	10	10	10	10	10
Geographical latitude	degree	55	55	55	55	49	49	49	49
Geographical longitude	degree	11	11	11	11	9.18	9.18	9.18	9.18
Elevation at site	m	22	22	22	22	165	165	165	165
Priority Impacts (99%)									
Chronic YOLL	mECU/kWh	5.9	7	5.4	5.4	17	20	16	16
Asthma	mECU/kWh	0.3	0.32	0.24	0.24	0	0	0	0
Chronic bronchitis	mECU/kWh	0.43	0.5	0.39	0.39	1.3	1.5	1.1	1.1
Restricted activity days	mECU/kWh	0.16	0.18	0.14	0.14	0.45	0.53	0.42	0.42
Acute YOLL	mECU/kWh	0.097	0.12	0.089	0.089	0.36	0.42	0.33	0.33
Bronchodilator usage	mECU/kWh	0.021	0.025	0.019	0.019	0.062	0.072	0.056	0.056
Sum (0% discounting)	*mECU/kWh*	6.9	8.1	6.3	6.3	19	23	18	18
Sum (10% discounting)	*mECU/kWh*	4.8	5.7	4.4	4.4	13	16	12	12
Pollutants									
Nitrates	mECU/kWh	5.5	6.5	5.1	5.1	20	23	18	18
Sulphates	mECU/kWh	1.4	1.5	1.1	1.1	0	0	0	0
NO_x	mECU/kWh	0.074	0.085	0.068	0.068	0.25	0.28	0.23	0.23
SO_2	mECU/kWh	0	0	0	0	0.0023	0.0055	0.00024	0.00024
Particulates	mECU/kWh	0	0.062	0	0	0	0.2	0	0
Sum (0% discounting)	*mECU/kWh*	7	8.2	6.3	6.3	19	23	18	18
Ignored impacts		0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%	0.8%

EcoSense input data rounded to three, external costs to two significant digits.
Results refer to mid-range damage estimates of long-range dispersion. Local dispersion and impacts on crops and forestry yields as well as building damage have been assessed and found insignificant.

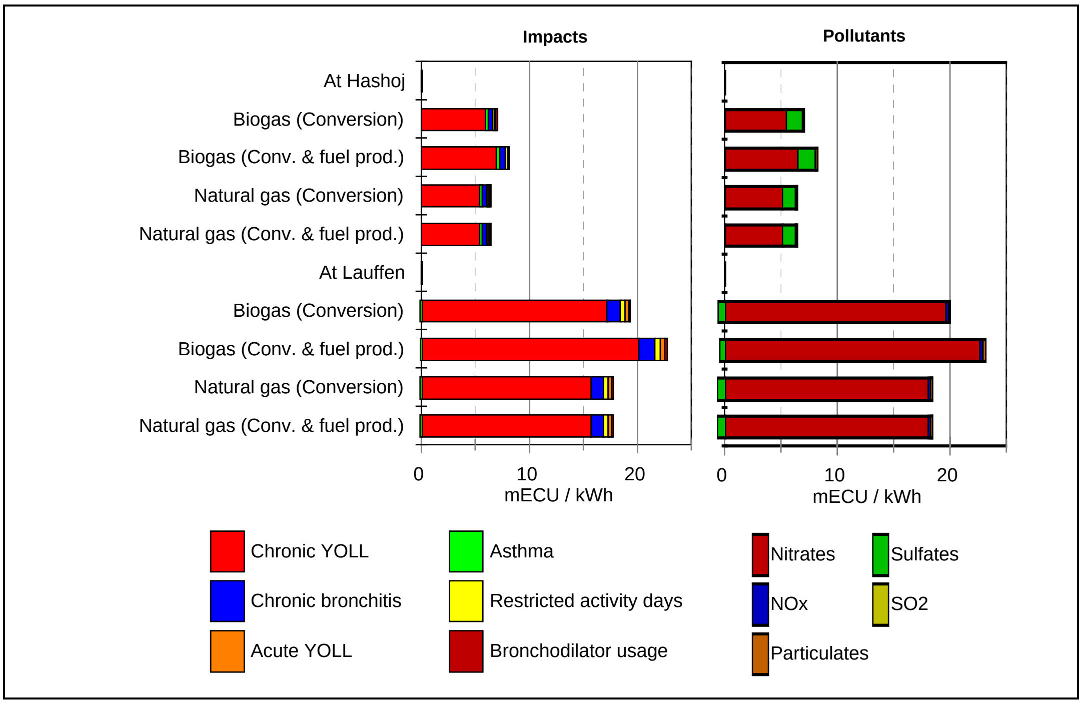


Figure 10 External costs of the biogas / CHP installation at Hashöj, Denmark, with respect to human health impacts and air pollutants in mECU/kWh. The negative contribution of sulphates for Lauffen is due to reactions with background pollutants.

2.3.4. Other environmental impacts

In the Danish case study, the energy use of biogas produced from slurry also contributes to solving a waste problem. Farmers would have to store the slurry anyway, since they are only allowed to spread it on their fields from March to May. Collecting and storing it jointly improves the efficiency, while producing biogas helps to even make some profit out of the waste treatment and to avoid uncontrolled methane emissions to the atmosphere. The degassed slurry may later be spread to the fields as a fertiliser. However, this whole scheme is under criticism by supporters of organic farming. First, they do not want slurry from unknown sources on their fields. Second, they want the slurry in its original chemical composition. And finally, they are critical of intensive animal farming in the first place. Thus, if organic farming further increases its market share, which is rather likely, this may have a severe impact on the potential for biogas production in Denmark and elsewhere.

Impacts on rural amenity can be considered negligible, especially when comparing them to the agricultural reference case. To our current knowledge, biodiversity is not affected either.

However, the consequences of transportation activities for road damage and accidents might be of concern in the biogas fuel cycle, since the wear and tear on roads from one truck is similar to that of more than 10 000 cars. There is a necessity for 5 loads of biomass and 2 loads of organic waste per day to keep the biogas plant running. Yet, rough calculations of total damage costs arrive at external costs well below 1/100 of a mECU/kWh. For the impacts of road accidents on human health, the monetary estimate is even lower.

2.3.5. Socio-economic framework

The Hashöj biogas plant is situated in the western part of the island of Zealand, near the town of Slagelse, which has about 30 000 inhabitants. The agriculture on Zealand is mostly production of grain. Therefore, only a small number of biogas plants have been established on Zealand so far, which leads to larger transport distances than in the more slurry intensive areas of Denmark such as Jutland. The industrial organic waste for the plants stems mainly from slaughterhouses in Ringsted located at a distance of about 20 km.

Since 1990, environmental problems have been given priority in the official Danish energy policy. The reduction of greenhouse gas emissions is a central issue targeting at a 20% reduction from 1990 to 2005. To achieve this goal, the contribution of renewable energies should be doubled during this period, while energy consumption is to be reduced by 15%. A central decision in this process was to change district heating systems to cogeneration. The Danish government is actively supporting the introduction of renewable energies with elaborated taxation and subsidy schemes as well as a decisive research and development strategy.

The Danish energy policy is currently based on a broad consensus, even including the large utilities, which are non-profit organisations. This may be subject to change by the liberalisation of electricity markets. However, the Danish government is determined to protect its possibilities to pursue environmental objectives.

At present, the use of biomass amounts to 61 PJ/a or 6% of the Danish primary energy supply. The largest contributions come from (organic) waste, wood and forestry residues, and straw. Biogas contributes 2 PJ/a. The estimated potential of biomass resources in Denmark is about 150 PJ/a. While no increase seems possible in the use of waste and wood residues, the largest additions are expected to come from energy forests, biogas and straw. The overall potential for biogas is estimated to about 30 PJ/a. However, the realisation of this figure depends heavily on the outcome of the controversy on organic farming discussed above.

2.4. Gasification of Woody Biomass for Combined Heat and Power Generation in Sweden and the UK

2.4.1. Description of the technology and its location

Gasification, as considered in this case study, is a thermochemical process, in contrast to the biochemical production of biogas described in the Danish case study in Section 2.3. Today, the coupling of biomass gasification with gas and steam turbines can provide a clean and efficient use of biomass, suitable for industrial and utility scale applications. Biomass integrated gasification, gas and steam turbine combined cycle systems (BIG/CC) are currently at the demonstration stage and their widespread implementation will depend on a number of factors: success of the technical demonstration, economic competitiveness and environmental performance. In this case study, an already operating scheme using high-pressure gasification of forestry residues at Värnamo in Sweden and a low-pressure gasification scheme to be operated with short-rotation coppice and currently under construction at Eggborough in the UK will be analysed.[13]

[13] Data on the two installations have mostly been obtained from Bioflow Ltd. and ARBRE Energy Ltd., who are the owners/ operators of the facilities.

It should be stressed right at the beginning that the high-pressure BIG/CC plant at Värnamo is a demonstration facility where the emphasis is on successful operation of the integrated gasifier rather than on optimisation of the energetic and economic efficiency. The facility is owned and operated by Bioflow Ltd., which is a joint venture of the Finnish boiler and gasifier manufacturer Ahlström and Sydkraft, the second largest Swedish energy utility. The operation of the plant started in September 1996 and it has gathered some 5 000 hours experience of gasification and 1 300 hours of integrated gasification-gas turbine operation since then.

The fuel cycle starts with the collection of forestry residues, as was the case for the Nässjö plant described in Section 2.1. After interim storage at the plant's site, the wood chips are crushed, screened and dried before being fed into the gasifier. The drying takes place in a separate installation and uses a biomass fuelled rotary kiln dryer. Future plants will have an integrated drying facility, which will improve the energy balance of the system and reduce drying costs.

After drying the fuel is fed to the gasifier through a lock hopper system, which uses nitrogen as the inert gas. In the future, a piston feeder should be added to the lock hopper and flue gas from the generating system could replace the nitrogen. These modifications would considerably reduce feeding costs. The air for gasification is provided by the compressor of the gas turbine and further pressurised in a booster compressor. The gasification yields a low-calorific value gas consisting of up to 12% hydrogen and 7.5% methane as well as some 50% nitrogen, 14% CO_2 and 16% CO (Stahl 1997).

The gasification process generates solid waste products in the form of bottom and fly ash. In the case of woody biomass gasification in circulating fluidised bed gasifiers, the solid residue will consist of pure wood ash mixed with bed material and is not likely to contain significant amounts of hazardous substances such as heavy metals or polyaromatic hydrocarbons. The ash may be landfilled or recycled to the forests.

The fuel gas is cooled to about 350^{o}C and the heat recovered is used to generate steam for the steam turbine. The product gas is cleaned in a hot gas filter and then used to fire the gas turbine. The exhaust gas from the gas turbine is cooled using a conventional heat recovery steam generator producing additional steam for the steam turbine. The exhaust steam from this turbine provides district heating. Thus, the total efficiency of the combined cycle is about 82% with further improvements possible.

The second part of this case study is the low-pressure BIG/CC plant to be built in Eggborough, UK, by ARBRE Energy Ltd., which is a joint venture of Yorkshire Environmental, TPS Termiska Processor, Swalec Power and AEP Associated Energy Projects. The plant will be fuelled by wood chips, 80% of which will be provided by short-rotation coppice (SRC) willow and poplar plantations and the remaining 20% by forestry residues. The project has obtained planning permission and construction of the plant is to be completed in late 1999. Much effort has been dedicated by the developers to the establishment of SRC plantations in the area surrounding the plant. To date, a few hundred hectares of SRC have been established.

The UK presents a very different biomass resource picture compared to Sweden. In the UK, forest cover is only about 2 million ha compared to Sweden's 23 million hectare. Thus, development schemes like the plant in Eggborough will have to rely on energy crops or possibly organic waste from other sources. The plant will require some 60 kt of wood chips at 30% moisture content per year. SRC will be planted mainly on set-aside land or on land degraded by previous agricultural, forestry or industrial uses. Sewage sludge is envisaged to be applied to the plantations as a slurry at establishment and then every 3 or 4 years subsequently, at a rate of 7 dry tonnes per hectare. Inputs of sludge are based on the nutrient requirements of the crop and will not exceed 250 kg N per hectare and year. Application will conform to EC guidelines on the application of treated sewage sludge to agricultural land (Pitcher and Lundberg 1995). Fields are harvested every 3 to 4 years. The lifetime of the plantation is expected to be 15-16 years. Transport to the plant site will make use of large commercial vehicles, bulk containers or articulated trailers with a likely capacity of 60 m^3.

The fuel must be dried to less than 20% moisture in order to meet the gasification process requirements. This is done using flue gas from the heat recovery systems described below. The gasifier is of the atmospheric air blown circulating fluidised bed type using sand as bed material. The fuel gas exits the gasifier at a temperature of about 900°C and passes through a primary and secondary cyclone to remove ash, wood char and sand which are returned to the bottom of the gasifier. The fuel gas then enters the tar cracker, a second circulating fluidised bed reactor similar to the gasifier reactor except that dolomite is used as a bed material instead of sand. Further partial combustion of the fuel gas will maintain the temperature of the tar cracker unit. The fuel gas then passes through another set of primary and secondary cyclones for removal of the dolomite which is returned to the bottom of the tar cracker. The fuel gas then passes through a set of gas coolers and baghouse filters. The coolers function as feedwater heaters and the steam raised is used in the heat-recovery, steam-generation (HRSG) system. The baghouse filter captures residual dust from the fuel gas. The gas then goes to a wet gas scrubber in order to condense the water vapour and the majority of small hydrocarbons which would otherwise condense in the gas compressor. An acidic solution is used to scrub the gas in order to remove ammonia and other traces of alkali compounds. The fuel gas is then split into two streams, the majority of the gas going to the compressor and the remainder to the HRSG supplementary burner. The compressed fuel gas is then fired in a 4 MW_{el} gas turbine manufactured by European Gas Turbines Ltd suitable for operation on low calorific value gases. The flue gas from the turbine goes to the HRSG system to raise steam for a 6 MW_{el} steam turbine and is finally sent to the dryer, following condensation of the water vapour, for the drying of the wood chips. A series of ancillary equipment, known as the Balance of Plant (BoP), is required for the functioning of the plant. The BoP includes the water treatment plant, the effluent treatment plant, a chemical storage, an auxiliary fuel storage and a fire water reservoir. The gasification system is developed by TPS Termiska Processer AB, Studsvik, Sweden.

The coal-fired version of the Nässjö plant described in Section 2.1 serves as reference case for the Värnamo plant as well. Its data have been scaled in order to better meet the size of the Värnamo facility. Thus, the specific data stated in the following are in the same order of magnitude as for the Nässjö case, but may deviate somewhat from those data. For the Eggborough plant, a standard, modern UK coal-fired power plant is taken as reference. This is appropriate since the biomass plant is sited in the vicinity of some 8 GW of coal-fired power plants.

2.4.2. Technical and economic data

The technical data for the Värnamo and the Eggborough plant are summarised in Table 24 and Table 25, respectively. The Värnamo plant is a CHP installation with a gross electric capacity of 6 MW (4.2 MW gas and 1.8 MW steam turbine) and a thermal capacity of 9 MW. It should be noted that the steam turbine has a very low efficiency of 15-20% which is due to the fact that it is a second-hand model which has been selected to reduce investment costs while at the same time being able to demonstrate integrated operation of gasification and a combined-cycle power plant. The Eggborough plant, on the other hand, is a pure power plant with a capacity of 10 MW_{el}.

Table 24 Technical data of the high-pressure BIG/CC plant at Värnamo, Sweden.

		Use of producer gas	Reference case:* Use of Polish coal
Capacity			
Electrical	MW_{el}	6.0	3.86
Thermal	MW_{th}	9.0	9.0
Internal use	MW_{el}	0.20	1.0
Full-load hours	h / a	4400	4400
Fuel input	MWh / a	79800	62200
Net electricity production	MWh / a	25500	12600
Net heat production	MWh / a	39600	39600
Total energy output	*MWh / a*	*65100*	*52200*

All values rounded to three significant digits; *: This reference case is identical to the one in the Swedish case study. It was, however, scaled to match the Eggborough plant.

Table 25 Technical data of the low-pressure BIG/CC plant at Eggborough, UK.

		Use of producer gas	Reference case: Use of UK coal
Capacity			
Electrical	MW_{el}	10	8
Thermal	MW_{th}	0	0
Internal use	MW_{el}	2	0
Full-load hours	h / a	7450	7450
Fuel input	MWh / a	186000	175000
Net electricity production	MWh / a	59600	59600
Net heat production	MWh / a	0	0
Total energy output	*MWh / a*	*59600*	*59600*

All values rounded to three significant digits.

The specific energy production costs of the two plants are shown in Table 26. It has to be stressed that all specific figures stated for the Eggborough case are higher than for the other case studies of the project since this facility is the only one which produces electricity exclusively. The cost figures of both gasification plants are dominated by the investment costs. This is not surprising since the technology is at a demonstration stage and much specific develop-

Table 26 Specific energy production costs of the BIG/CC plants at Värnamo, Sweden, and Eggborough, UK, in mECU/kWh.

	Värnamo		Eggborough	
	Use of producer gas	Use of Polish coal	Use of producer gas	Use of UK coal
Conversion				
– Investment	35	11	42	10
– Operation & maintenance	4.5	2.2	7	4.3
– Labour	2.2	3	2.4	0
Fuel	13	6.8	38	19
Clean-up	0.26	0.76	0.76	2.7
Total	*54*	*24*	*90*	*36*

Values rounded to two significant digits.

ment work has to be carried out. However, it is very likely that after successful demonstration, costs may be reduced sharply. Fuel production costs are higher for the Eggborough plant, because it involves active plantation and harvesting of short-rotation coppice. In summary, both biomass cases are significantly more expensive than their fossil-fuel fired counterparts.

The specific input of the production factors energy and labour is stated in Table 27 and Table 28. The high specific energy input for the Eggborough case is due to the fact that only electricity is produced. The labour data will be discussed in Section 2.8.2.

Table 27 Specific input of production factors at the high-pressure BIG/CC plant at Värnamo, Sweden.

		Use of producer gas			Use of Polish coal		
Production factor	Unit	Fuel production	Conversion	Clean-Up	Fuel production	Conversion	Clean-Up
Energy input							
Total energy	MWh/MWh	0.029	1.2	0.00094	0.11	1.2	0.00044
Fossil energy	MWh/MWh	0.029	0.0029	0.00094	0.11	1.2	0.00044
Labour input							
Direct	h/MWh	0.21	0.67	0.00055	§	0.13	0.0016
	h/MECU	3800	12000	§	§	5500	§
Indirect	h/MWh	0.25	0.84	§	0.22	0.25	§
	h/MECU	4600	16000	§	9200	10000	§

All values rounded to two significant digits; §: Value not applicable or insignificant.
Energy figures stated with respect to electricity and heat produced.

Table 28 Specific input of production factors at the low-pressure BIG/CC plant at Eggborough, UK.

		Use of producer gas			Use of UK coal		
Production factor	Unit	Fuel production	Conversion	Clean-up	Fuel production	Conversion	Clean-up
Energy input							
Total energy	MWh/MWh	0.095	3.1	0.0027	0.26	2.9	0.0019
Fossil energy	MWh/MWh	0.095	0.0042	0.0027	0.26	2.9	0.0019
Labour input							
Direct	h/MWh	1	0.99	0.0015	1.2	0.27	0.0043
	h/MECU	11000	11000	§	33000	7500	§
Indirect	h/MWh	1.4	1.5	§	0.38	0.52	§
	h/MECU	16000	17000	§	11000	14000	§

All values rounded to two significant digits; §: Value not applicable or insignificant.
Energy figures stated with respect to electricity and heat produced.

2.4.3. Emissions of air pollutants and the related external costs

Direct and indirect emissions of air pollutants are shown in Table 29 and Table 30 as well as Figure 11. In general, emissions from the Värnamo plant are lower than those from the Eggborough facility since the former has the more advanced technology. In both cases, fuel production contributes to the emissions perceptibly. In the case of CO, there is also a noticeable share from the production of the conversion equipment. Otherwise, it may again be concluded that indirect emissions are insignificant and that overall emissions are dominated by the conversion stage.

Table 29 Specific emissions from the high-pressure BIG/CC plant at Värnamo, Sweden, in g/kWh.

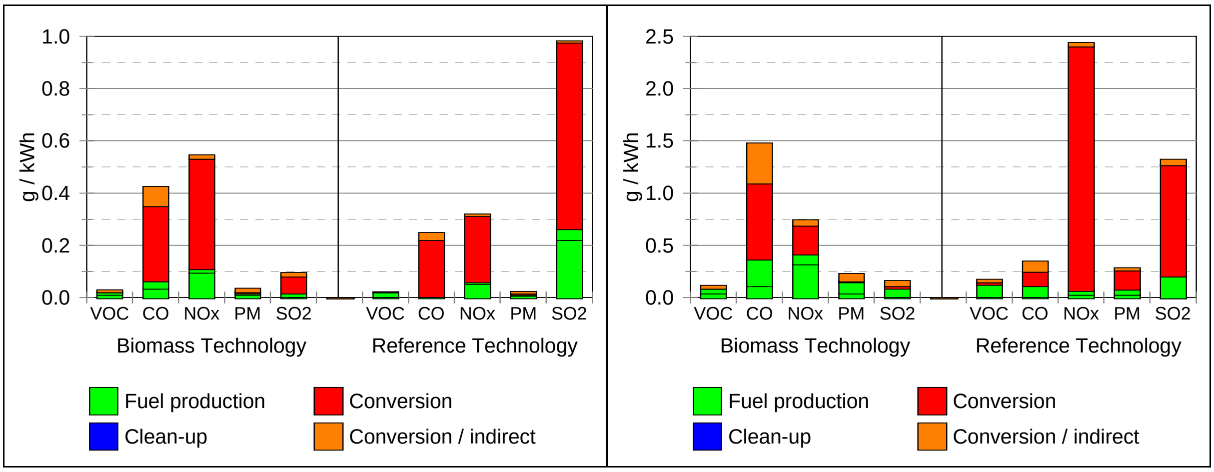
	Use of producer gas			Reference case: Use of Polish coal		
Pollutant	Fuel production	Conversion	Clean-Up	Fuel production	Conversion	Clean-Up
Direct emissions						
VOC	0.015	0	0	0.0022	0	0
CO	0.037	0.29	0	0.0035	0.21	0.00027
NO_x	0.095	0.42	0.00031	0.055	0.25	0.0009
Particulates	0.013	0.0062	0	0.0098	0.0086	0
SO_2	0.002	0.065	0	0.22	0.72	0
CO_2 *	12	350	0.02	46	410	0.016
CO_2-Equivalents **	12	0.28	0.02	72	430	0.016
Indirect emissions						
VOC	0.0086	0.0053	§	0.018	0.0022	§
CO	0.027	0.076	§	0.0017	0.029	§
NO_x	0.014	0.016	§	0.0043	0.0065	§
Particulates	0.0042	0.012	§	0.00058	0.0051	§
SO_2	0.016	0.012	§	0.042	0.005	§
CO_2	2.7	5	§	2.1	2	§
CO_2-Equivalents	2.7	5.1	§	2.3	2.1	§

All values rounded to two significant digits; §: Value not applicable or insignificant.
* All CO_2 emissions from fossil and renewable fuels. ** CO_2-Equivalents: CO_2 emissions from fossil energy sources plus weighted emissions of CH_4 and N_2O.

Table 30 Specific emissions from the low-pressure BIG/CC plant at Eggborough, UK, in g/kWh.

	Use of producer gas			Reference case: Use of UK coal		
Pollutant	Fuel production	Conversion	Clean-Up	Fuel production	Conversion	Clean-Up
Direct emissions						
VOC	0.046	0	0	0.0074	0.018	0
CO	0.11	0.73	0.00026	0.012	0.13	0.00076
NO_x	0.32	0.28	0.00089	0.027	2.3	0.0025
Particulates	0.041	0.016	0	0.033	0.18	0.00022
SO_2	0.0064	0.025	0	0.00035	1.1	0
CO_2 *	60	890	0.21	9	940	0.045
CO_2-Equivalents **	60	0.72	0.21	95	960	0.045
Indirect emissions						
VOC	0.048	0.023	§	0.12	0.028	§
CO	0.25	0.39	§	0.11	0.1	§
NO_x	0.094	0.053	§	0.043	0.029	§
Particulates	0.1	0.069	§	0.048	0.023	§
SO_2	0.08	0.051	§	0.21	0.049	§
CO_2	17	15	§	18	7.2	§
CO_2-Equivalents	32	20	§	37	12	§

All values rounded to two significant digits; §: Value not applicable or insignificant.
* All CO_2 emissions from fossil and renewable fuels. ** CO_2-Equivalents: CO_2 emissions from fossil energy sources plus weighted emissions of CH_4 and N_2O.



Värnamo Eggborough

Figure 11 Specific emissions of air pollutants from the BIG/CC plants at Värnamo, Sweden, and Eggborough, UK and their respective reference technologies. Please, note the different scales.

Not surprisingly, both biomass gasification schemes have strong advantages over their references cases with respect to SO_2. For VOC and particulates, differences are small in both cases, with slight advantage for the biomass in the Eggborough case and for the fossil-fuel in the Värnamo case. This is due to the very high environmental standards for coal-fired power plants in Sweden. This argument also explains why NO_x emissions are higher for the Värnamo plant than for the coal-fired version of the Nässjö plant. This is different in the UK, where the NO_x emissions from the coal-fired power plant are 3 times higher than those from the biomass fuel cycle. For CO, both gasification facilities perform significantly worse than their counterparts.

Input data and results of EcoSense calculations are stated in Table 31, Table 32, Figure 12, and Figure 13. The differentiated picture drawn during the discussion of emission levels is not reflected in the calculations of external costs, where the situation seems very clear. This may be due to the advantages of the biomass applications in the most important and thus most valued areas, namely NO_x and SO_2 emissions. It may, on the other hand, also be due to shortcomings in the methodology since the EcoSense model does not account for all pollutants in the same detailed way.

Next to the Nässjö plant, the Värnamo plant has the lowest external costs of all case studies, ranging at about 2 mECU/kWh. For the (rather advanced) reference case they lie at 4-5 mECU/kWh. Due to the low NO_x levels of the fossil-fuel plant, its external effects are dominated by SO_2 emissions. As for the Nässjö CFB plant, external costs increase by a factor of five, if the installation is moved to Lauffen, Germany.

The Eggborough plant exhibits external costs of 4-5 mECU/kWh, its reference case of 25 mECU/kWh. Here, the costs for the reference case are driven by the NO_x emissions. Also, in this case we see the largest influence of particulates of all case studies, however it is restricted to just above 10% of the total effects. Since the area hit by the plume is much more populated than in the Swedish case, these costs increase by only a factor of 2.5 when moving the facility to Lauffen.

Table 31 EcoSense input data and external costs of the high-pressure BIG/CC plant at Värnamo, Sweden, with respect to human health impacts and air pollutants.

Fuel		Bio-mass	Bio-mass	Fossil	Fossil	Bio-mass	Bio-mass	Fossil	Fossil
Location		Vär-namo	Vär-namo	Vär-namo	Vär-namo	Lauffen	Lauffen	Lauffen	Lauffen
Fuel-cycle stages		Con-version	All stages	Con-version	All stages	Con-version	All stages	Con-version	All stages
EcoSense Data									
Gross electricity production	MW	6	6	3.86	3.86	6	6	3.86	3.86
Electricity sent out	MW	5.8	5.8	2.86	2.86	5.8	5.8	2.86	2.86
Full-load hours	h / a	4400	4400	4400	4400	4400	4400	4400	4400
SO_2 emissions	mg / Nm^3	8.13	8.38	58	76	8.13	8.38	58	76
NO_x emissions	mg / Nm^3	52	64	21	25	52	64	21	21
Particulate emissions	mg / Nm^3	0.769	2.43	0.699	1.5	0.769	2.43	0.699	0.699
Flue gas volume	Nm^3 / h	46600	46600	35100	35100	46600	46600	35100	35100
Flue gas temperature	K	403	403	403	403	403	403	403	403
Stack height	m	50	50	63	63	50	50	63	63
Stack diameter	m	1.4	1.4	1.1	1.1	1.4	1.4	1.1	1.1
Anemometer height	m	10	10	10	10	10	10	10	10
Geographical latitude	degree	57	57	57	57	49	49	49	49
Geographical longitude	degree	14	14	14	14	9.18	9.18	9.18	9.18
Elevation at site	m	300	300	300	300	165	165	165	165
Priority Impacts (99%)									
Chronic YOLL	mECU/kWh	1.5	1.8	2.7	3.5	7	8.7	12	15
Asthma	mECU/kWh	0.085	0.085	0.69	0.88	0.17	0.16	2.5	3.2
Chronic bronchitis	mECU/kWh	0.11	0.13	0.19	0.25	0.51	0.63	0.83	1.1
Restricted activity days	mECU/kWh	0.039	0.048	0.072	0.093	0.19	0.23	0.31	0.4
Acute YOLL	mECU/kWh	0.025	0.03	0.058	0.075	0.15	0.18	0.32	0.41
Bronchodilator usage	mECU/kWh	0.0052	0.0065	0.0098	0.013	0.025	0.031	0.042	0.054
Sum (0% discounting)	*mECU/kWh*	*1.7*	*2.1*	*3.7*	*4.8*	*8*	*9.9*	*16*	*20*
Sum (10% discounting)	*mECU/kWh*	*1.2*	*1.5*	*2.8*	*3.6*	*5.7*	*7*	*12*	*15*
Pollutants									
Nitrates	mECU/kWh	1.3	1.6	0.38	0.51	7	8.6	3.5	4.2
Sulphates	mECU/kWh	0.41	0.41	3.3	4.2	0.8	0.76	12	16
NO_x	mECU/kWh	0.014	0.016	0.0096	0.011	0.089	0.11	0.053	0.065
SO_2	mECU/kWh	0.0015	0.0015	0.03	0.04	0.017	0.017	0.18	0.24
Particulates	mECU/kWh	0.024	0.077	0.034	0.072	0.14	0.44	0.19	0.41
Sum (0% discounting)	*mECU/kWh*	*1.7*	*2.1*	*3.8*	*4.9*	*8.1*	*10*	*16*	*20*
Ignored impacts		*0.8%*	*0.8%*	*0.7%*	*0.7%*	*0.8%*	*0.8%*	*0.7%*	*0.7%*

EcoSense input data rounded to three, external costs to two significant digits.
Results refer to mid-range damage estimates of long-range dispersion. Local dispersion and impacts on crops and forestry yields as well as building damage have been assessed and found insignificant.

Table 32 EcoSense input data and external costs of the low-pressure BIG/CC plant at Eggborough, UK, with respect to human health impacts and air pollutants.

Fuel		Bio-mass	Bio-mass	Fossil	Fossil	Bio-mass	Bio-mass	Fossil	Fossil
Location		Eggbo-rough	Eggbo-rough	Eggbo-rough	Eggbo-rough	Lauffen	Lauffen	Lauffen	Lauffen
Fuel-cycle stages		Con-version	All stages	Con-version	All stages	Con-version	All stages	Con-version	All stages
EcoSense Data									
Gross electricity production	MW	10	10	8	8	10	10	8	8
Electricity sent out	MW	8	8	8	8	8	8	8	8
Full-load hours	h / a	7450	7450	7450	7450	7450	7450	7450	7450
SO_2 emissions	mg / Nm^3	3.19	4.01	146	146	3.19	4.01	146	146
NO_x emissions	mg / Nm^3	36	77	320	324	36	77	320	320
Particulate emissions	mg / Nm^3	2.03	7.35	25	29	2.03	7.35	25	25
Flue gas volume	Nm^3 / h	62100	62100	58400	58400	62100	62100	58400	58400
Flue gas temperature	K	345	345	345	345	345	345	345	345
Stack height	m	41	41	240	240	41	41	240	240
Stack diameter	m	1.35	1.35	10	10	1.35	1.35	10	10
Anemometer height	m	10	10	10	10	10	10	10	10
Geographical latitude	degree	54	54	54	54	49	49	49	49
Geographical longitude	degree	0	0	0	0	9.18	9.18	9.18	9.18
Elevation at site	m	15	15	15	15	165	165	165	165
Priority Impacts (99%)									
Chronic YOLL	mECU/kWh	1.9	4.1	20	21	4.6	10	50	51
Asthma	mECU/kWh	0.033	0.014	1.6	1.6	0.045	0.018	3.6	3.6
Chronic bronchitis	mECU/kWh	0.14	0.3	1.5	1.5	0.34	0.74	3.6	3.7
Restricted activity days	mECU/kWh	0.05	0.11	0.54	0.55	0.12	0.27	1.3	1.4
Acute YOLL	mECU/kWh	0.046	0.096	0.54	0.55	0.097	0.2	1.1	1.1
Bronchodilator usage	mECU/kWh	0.0068	0.015	0.073	0.075	0.017	0.036	0.18	0.18
Sum (0% discounting)	*mECU/kWh*	*2.2*	*4.7*	*25*	*25*	*5.3*	*11*	*60*	*61*
Sum (10% discounting)	*mECU/kWh*	*1.5*	*3.3*	*18*	*18*	*3.7*	*8*	*43*	*44*
Pollutants									
Nitrates	mECU/kWh	1.8	3.9	14	15	4.7	10	38	39
Sulphates	mECU/kWh	0.16	0.069	7.5	7.5	0.22	0.087	17	17
NO_x	mECU/kWh	0.031	0.065	0.26	0.26	0.059	0.13	0.5	0.5
SO_2	mECU/kWh	0.0027	0.0036	0.15	0.15	0.0064	0.008	0.29	0.29
Particulates	mECU/kWh	0.2	0.72	2.3	2.7	0.35	1.3	4.1	4.8
Sum (0% discounting)	*mECU/kWh*	*2.2*	*4.7*	*25*	*25*	*5.3*	*12*	*60*	*61*
Ignored impacts		*0.8%*	*0.8%*	*0.8%*	*0.8%*	*0.8%*	*0.8%*	*0.8%*	*0.8%*

EcoSense input data rounded to three, external costs to two significant digits.
Results refer to mid-range damage estimates of long-range dispersion. Local dispersion and impacts on crops and forestry yields as well as building damage have been assessed and found insignificant.

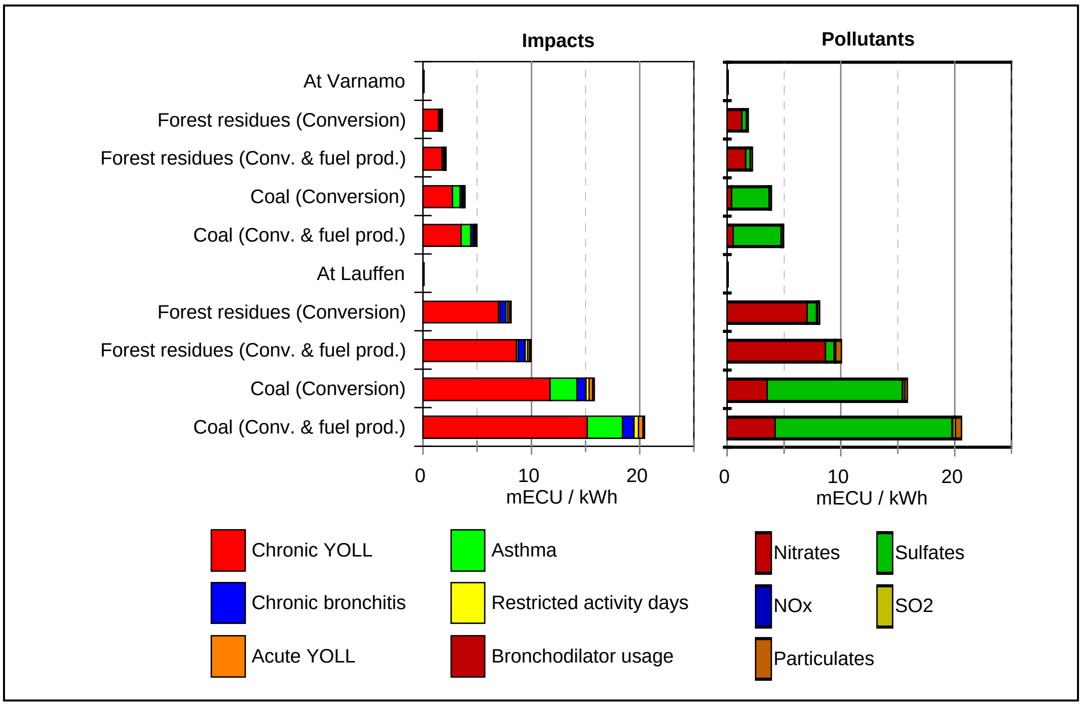


Figure 12 External costs of the high-pressure BIG/CC plant at Värnamo, Sweden, with respect to human health impacts and air pollutants in mECU/kWh.

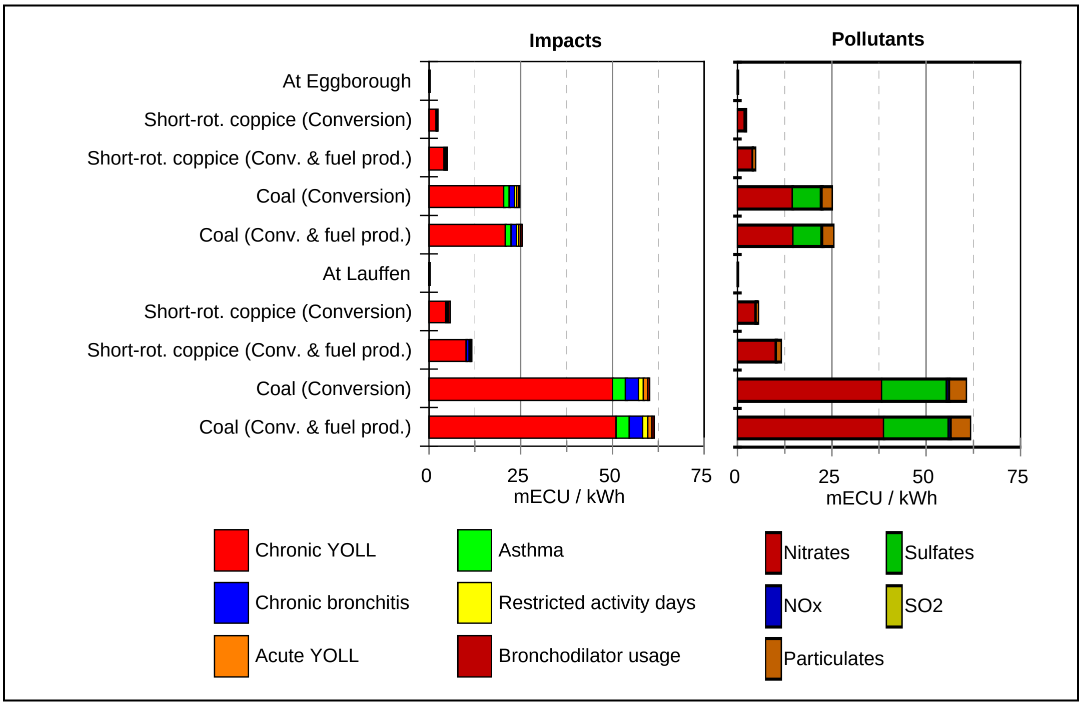


Figure 13 External costs of the low-pressure BIG/CC plant at Eggborough, UK, with respect to human health impacts and air pollutants in mECU/kWh.

2.4.4. Other environmental impacts

Environmental impacts of the use of forestry residues in Sweden have been discussed in Sec. 2.1.4, thus we restrict the discussion here to the UK part of the case study.

Impacts associated with short-rotation coppice (SRC) plantations are mostly expected to be beneficial compared to the cultivation of conventional crops. Generally, it is thought that soil erosion rates under SRC are lower than under annual crops. Since the available soil erosion maps for the UK indicate that the soil erosion problem in the case study area is negligible anyhow, any benefit is unlikely to be significant. However, a benefit might occur in other land areas where SRC is grown.

The application of sewage sludge can be a problem. Heavy metals can reduce soil micro-fauna, restrict crop growth and be toxic to humans and animals. Zinc, cadmium and copper are the metals of greatest concern, because they are most likely to be present in sludge amended to soils in quantities that approach those which might affect animal health or food safety. The case study report (Bauen et al. 1998, 40-44) discusses this issue and a possible way of arriving at monetary values in detail. In the SRC plantations under study only treated sewage sludge from smaller rural treatment plants will be used. This should mean that the concentration of toxic elements such as heavy metals is relatively low. The sewage sludge would be applied to other agricultural land if SRC were not available. There is some evidence that willow SRC selectively takes up heavy metals, which will then be concentrated in ash at the gasification facility (Riddell-Black et al. 1996). Thus, the net impact of this disposal route could be an environmental benefit, compared to the reference case of disposal to agricultural land. Alternatively it may be possible to dispose of some ash to land, if heavy metals can be concentrated in a small fly ash fraction which is landfilled, or treated to remove the metals (Obernberger et al. 1996).

The location of the planned facility at Eggborough in North Yorkshire is in many respects not typical of rural areas where similar bioenergy projects may be developed in future. Air and water pollution levels are particularly high, due to the concentration of large coal-fired power stations in the area. The area is not valued highly for its landscape nor biodiversity, and there is a network of large roads. In this context any negative impacts the Eggborough facility might have on rural amenity are not likely to be perceived as significant. In a less polluted and industrialised setting resistance to change would be more likely (for more details see Bauen et al. 1998, 47-51).

In some other respects the location could be expected to give rise to higher damage and lower benefits than in a 'typical' setting. The effective precipitation (rainfall) in this area is low, and SRC plantations could adversely affect surface fresh water availability and the quality of groundwater recharge (cf. Bauen et al. 1998, 44ff.).

2.4.5. Socio-economic framework

The framework of the use of forestry residues in Sweden has been discussed in Sec. 2.1.5, thus we again restrict the discussion here to the UK part of the case study.

The UK government's intention is to work towards 1 500 MW of new renewable energy capacity by the year 2000. The Non Fossil Fuel Obligation (NFFO) is the policy tool used to stimulate the development of this generating capacity. Under present arrangements almost all renewable energy projects in the UK are dependent on guaranteed premium rates for the electricity they sell. These are financed by a surcharge on consumers' electricity bills (the Fossil Fuel Levy), which is used to reimburse the Regional Electricity Companies (RECs), which are required to buy the electricity under the NFFO. Generators are guaranteed a premium price for the duration of their contract. Contracts are awarded on the basis of a competitive bidding process. The aim is that in successive rounds of the NFFO the premium price is gradually reduced, so that it converges with the market price of electricity. In the third round of NFFO bidding, three gasification projects, including the Eggborough plant, were approved and contracted at 0.12 ECU/kWh.

The NFFO has been a notable success in stimulating renewable energy in Britain, particularly in the case of wind power. However, NFFO has been heavily criticised in general (Mitchell 1995) and in its implications for biomass energy (ETSU 1996; Taylor 1996). The NFFO is concerned exclusively with electricity, and thus heat, liquid fuels (and to date biomass combustion electricity) have been excluded. The potential for price convergence is the stated reason for concentration on wood gasification due to its higher efficiency compared to combustion. The bidding process is always over-subscribed, and only the lowest bids are accepted. This forces projects to minimise costs and seek as much assistance from other sources as possible. Preparation of a bid is a lengthy and costly process and the prospect of failure prevents the inception of many projects.

Part of the high capital cost reflects the real risks involved in financing technologies which are unproven or uncertain in their performance. However, this risk may be perceived greater than it actually is, due to the poor awareness of biomass power systems amongst financiers. Renewable energy developers also suffer from an image of poor commercial and financial credibility. A further consideration, which affects all enterprises in the UK, is the short-term outlook of the British financial institutions. Leasing of capital equipment from finance houses (who benefit from favourable capital allowances on taxes) is becoming increasingly common for renewable energy projects. However, finance houses are not interested in leasing equipment where technologies are unproven, as is often the case with biomass conversion technologies. This relatively cheap source of finance may become available for biomass technologies in the future. Most renewable energy projects are carried out by corporations, and thus are liable to corporation tax on their profits.

As part of the local framework, the National Farmers' Union (NFU) and most of its members are keen to diversify into new crops, and are particularly keen to make productive use of set-aside land. The rapid take up for oil seed rape is evidence of this enthusiasm. However the policy climate is unfavourable for farmers to make the long-term commitment necessary for the success of perennial crops such as SRC. Support to farmers for SRC is dependent on changes in supply and demand for food crops in the EU. The percentage of arable farmers' land that must be set-aside has recently fallen from 15% to 5% and many farmers suspect this will fall to zero in the near future. The price for wood that project managers can afford to offer would presently make it unprofitable for farmers to contract supply from land that is not receiving set-aside payments. Under these circumstances it is understandable that farmers are reluctant to make the long-term commitment that SRC implies. In the face of uncertain policies and markets, farmers want to retain flexibility afforded by annual crops. In the Eggborough case study most of these obstacles for farmers are removed. A fixed contract is offered, which guarantees an annual income, plus the additional revenue at harvest every 3 years. All management of the crop is to be undertaken by the fuel supply contractors, Border Biofuels.

North Yorkshire, the case study region, is politically and socially conservative. Typically farms are large arable concerns, operated as successful modern businesses. The reluctance to move into SRC production, which ARBRE's Eggborough project has encountered, may reflect this conservatism. Set-aside land is not popular, because farmers want to make productive use of their land. However, it seems that the additional income that could be made from producing

SRC on set-aside land is too uncertain and insufficient to overcome these barriers. In some European countries there is a tradition of farmers acting co-operatively to initiate new schemes, such as biomass powered CHP in Denmark and Sweden. In the UK, however, farmers tend to act in a more individualistic manner and co-operatives of any kind are uncommon.

Yorkshire Environmental, which is a fully-owned subsidiary of Yorkshire Water, are the project developers for the UK case study. They possess two of the ingredients that appear to be essential for successful renewable energy projects to take off: Far-sighted, experienced and aggressive management, and access to affordable and timely financing. They became interested in biomass energy, which provides a secure outlet for treated sewage sludge from the company's treatment plants. This was an important consideration since dumping waste at the sea has to cease by the end of 1998, under the Urban Waste Water directive. About 50% of sewage sludge in the UK is already applied to agricultural land, and the remaining alternatives are incineration or tipping, which are costly.

The electricity utility companies in the UK are unlikely to initiate bioenergy schemes as their vested interests are closely tied up with those of the fossil fuel industries alongside which they have developed. However, there is some evidence that utilities are increasingly interested in direct ownership of renewable generating capacity rather than buying electricity from privately owned projects.

Small private companies are active in generating electricity from renewable energies, but two major obstacles limit the involvement of small independent generators in the biomass field. Firstly, there is a lack of awareness in the business community of the very concept of biomass energy. The second major obstacle is the access to appropriate financing. This problem is exacerbated by the fact that an NFFO contract is no guarantee that a project will go ahead, as it could fail the secure planning permission (another lengthy and costly process). Furthermore, the competitive nature of the NFFO selection procedure means that many projects do not go ahead because they cannot, in fact, supply electricity at the contracted price.

The major players in the renewable energy business in the UK are new companies which are owned or closely affiliated to ex-nationalised industries. Water companies and Regional Electricity Companies (RECs), primarily concerned with transmission from the national grid to consumers, have been particularly successful in securing NFFO contracts. Experience with large engineering projects and experience in the electricity supply industry are clearly advantages. Another key reason for subsidiaries of large companies taking the initiative in biomass power projects is the availability of funds from the parent company's operating profits.

The RECs are obliged to buy electricity from suppliers who have been awarded a NFFO contract. Smaller generation facilities are connected directly to the REC's distribution network. Due to the pricing structure buying from an embedded generator can actually be cheaper for a REC than buying from the pool. Preliminary analysis has found that the value of embedded generation to a REC above the pool purchasing price is 12-17 mECU/kWh (Taylor 1996). Under present arrangement it is understandable that RECs are enthusiastically meeting their obligation under NFFO and even investing in biomass-fired facilities themselves.

After liberalisation of the electricity market in 1998 consumers will be able to buy directly from generators or from independent suppliers of 'green electricity'. Furthermore, under a liberalised energy market the time horizons and financial muscle of generators will be diminished compared to the situation under the old state owned monopoly. This would discourage investment in large coal or nuclear facilities and encourage more diverse, decentralised and dispersed generation (Patterson and Grubb 1996). To counteract this optimism, increased liberalisation inevitably means less state support for renewable energies, and the ability of biomass to compete with natural gas on price terms is constrained by the necessarily higher capital costs incurred by the gasification stage. The eventual outcome in terms of the market penetration of biomass and other renewable energies cannot be accurately predicted, but one can safely say that a new set of key actors with different opportunities and constraints will constitute the framework in future.

Assuming that the project manager has organised adequate financing for the project and identified a market to return the investment, a major hurdle remains in gaining planning permission for the facility. The UK has a highly developed planning bureaucracy with considerable powers. Negotiating the planning process is a costly and time consuming process.

Though the NIMBY ('Not In My Back Yard': Electricity provision is seen as a national concern which should be taken care of anywhere but where they live.) attitude is a problem, local opposition is fuelled by other considerations: the global environmental benefits are remote and intangible, whilst the local benefits are poorly understood. People are very defensive of the landscape they are accustomed to. If landscape changes associated with SRC make any noticeable impact one should expect that a vocal opposition will develop.

In the UK, renewable energies contribute approximately 1% of primary energy and 2% of electricity (6 TWh in 1992). The main component is the 1.2 GW hydropower capacity in Scotland, which accounts for two thirds of these figures. The 'accessible resource' for electricity generation from short-rotation coppice in 2025 is estimated at almost 200 TWh/a. This estimate was made under the assumptions that electricity must be produced at less than 120 mECU/kWh at 8% discount rate and that all surplus land (ca. 5.5 million ha by 2010) is used for energy crops at a yield of 21 odt/(ha·a). The UK is one of the most sparsely wooded countries in Europe with only about 10% of its land area covered by trees, predominantly in Scotland and Wales. Therefore, the potential of forestry residues is estimated at only about 1.4-1.8 TWh/a.

2.5. Production of Cold-Pressed Rape-Seed Oil and its Utilisation in a CHP plant in Germany

The BioCosts project focuses on two distinct energy applications of rape seeds: first, the use of cold-pressed rape-seed oil in a stationary adapted Elsbeth engine serving as a CHP plant;[14] second, the use of rape-seed oil methyl ester (RME), produced in a complex chemical process, for a transport application. The latter is described in Section 2.6.

2.5.1. Description of the technology and its location

The municipal energy utility of the town of Weissenburg in Bavaria, Germany, operates a cogeneration facility at its public outdoor pool which consists of two rape-seed oil-fired engines and a peak-load boiler. The decision for the use of rape-seed oil was triggered by the fact that the pool had to be renovated and that state subsidies could only be obtained for this purpose if 50% of the energy supply came from renewable energy sources. In addition, the municipal utility has an interest in an own electricity generation capacity in order to avoid expensive load peaks during supply by the regional utility. Considering costs of 12 ECU per

[14] The data on the production of rape, supplied by ifeu, are also documented in Kaltschmitt and Reinhardt (1997). The data on the remaining parts of the fuel cycle have mostly been supplied by the operators of the facilities.

kilowatt (kW) of power to be paid for availability of capacity, savings of 2 500 ECU per year are possible. This situation is responsible for the unusual operation schedule of the unit. It runs mainly during the summer and is used for only 1-2 hours per day during winter peak-load times. The utility claims an interest in environmentally friendly technology and responsibility as a public enterprise as additional motivation for installing the biomass technology.

Only one acceptable offer was made for the cogeneration technology. It consists of two engines with an electrical capacity of 110 kW each, which have been adapted for the direct use of unprocessed rape-seed oil. The investment for the biomass plant was some 75 000 ECU higher than for a comparable gas-driven unit. The installation runs well. The only severe problem was created when the oil delivered had been polluted during transport. As a consequence, the unit had to be shut down for three weeks.

The "Genossenschaft zur Verarbeitung nachwachsender Rohstoffe e.G." (co-operative for the processing of renewable resources) has emerged from the "Trocknungsgenossenschaft Gunzenhausen" (drying co-operative), which has some 1 300 member farmers. The latter co-operative organises the joint drying of green fodder and cereals. Since most of the infrastructure necessary for processing rape seeds had already been available, the economic risk for opening the additional branch was small. Since the old co-operative was only allowed to provide services, but not to buy or sell goods, a second co-operative was formed which currently has 137 members. Its only responsibility is to buy rape seeds, have it pressed by the first co-operative and sell the oil produced. Both co-operatives are managed by the same people.

There were only very few examples for such an oil processing unit. The press and filters were bought separately, while the rest of the installation, especially the electric and controls, was self-planned and self-made. The functioning of the filters is controlled visually before switching between different modes of operation. In addition, samples of the oil are taken and examined daily. The local tank holds 200 000 litres of oil. For technical purposes, oil is taken from the tank (after a resting period of one week) at 1 meter height in order to avoid pollution by sediments from the ground. Oil, which is then added to animal fodder, is drawn from the ground to get rid of sediments. However, this whole regime is a precautionary measure, since no pollution has been detected in the tank so far.

The extraction residues, which are called press cake, may be sold as a animal fodder at a price of 144 ECU/t. Since they are a valuable economic good, all emissions from the oil production stage and before have are divided between oil and press cake according to their mass. Thus, only 35% of the fuel cycle emissions up to this point are attributed to the rape-seed oil.

The reference technology considered is the use of diesel fuel in a similar engine. This is the fossil-fuel application which comes closest to the use of the biofuel with respect to emissions, but it may not be the most realist case as gas-fired engines are usually preferred for small CHP units in Germany.

2.5.2. Technical and economic data

The technical data of the facility and its reference case are summarised in Table 33 (for more details, please, refer to the case study report, Widmann and Kern 1997). The data for the reference plant have been obtained from GEMIS (1995). The very low number of full-load hours, which has severe consequences for the specific cost figures stated below, is due to the unusual operation schedule explained above.

Energy production costs are stated in Table 34. The investment costs are higher for the rape-seed oil engine since this is not a standard version produced at large numbers. The pro-

Table 33 Technical data of the CHP plant at Weissenburg, Germany.

		Use of rape-seed oil	Use of Diesel fuel
Capacity			
Electrical	MW_{el}	0.22	0.1
Thermal	MW_{th}	0.22	0.154
Internal use	MW_{el}	0	0
Full-load hours	h / a	1260	1260
Fuel input	MWh / a	705	370
Net electricity production	MWh / a	277	126
Net heat production	MWh / a	277	194
Total energy output	*MWh / a*	*554*	*320*

All values rounded to three significant digits.

duction of the rape-seed oil is also rather cost intensive. Together, these two factors lead to energy costs for the rape-seed oil case of 110 mECU/kWh, which are two times higher than for the diesel case. For the investment cost, it may well be expected that cost could be reduced to the level of the reference case. The potential for cost reductions in the fuel production is low since it is dominated by the agricultural part, which is a standard operation, rather than by the oil pressing part, which has potential for optimisation.

Running the equipment for 5 000 rather than 1 260 hours would reduce the energy production costs to 67 mECU/kWh for rape-seed oil and to 26 mECU/kWh for diesel. The first figure is still high when compared to the other case studies.

The specific inputs of the production factors energy and labour are shown in Table 35. Labour figures will be discussed in Section 2.8.2.

2.5.3. Emissions of air pollutants and the related external costs

Direct and indirect emissions of air pollutants are stated in Table 36 and Figure 14. Again we have a significant advantage of the biofuel for SO_2. For the other pollutants, we find only very small differences, which are not really significant to favour one or the other technology. However, NO_x emissions are excessive in both the biofuel and the reference case. We have observed this problem for the other engine-driven CHP units in the BioCosts study as well. Nevertheless, the figures for this facility are by far the highest ones observed. It is unlikely that they are faulty, since the emissions at the existing unit have been measured and the data for the reference case have been obtained from an independent source. It should be stressed,

Table 34 Specific energy production costs at the CHP-unit at Weissenburg, Germany, in mECU/kWh.

	Use of rape-seed oil	Use of Diesel fuel
Conversion		
– Investment	52	31
– Operation & maintenance	11	6.4
– Labour	0	0
Fuel	52	24
Clean-up	0	0
Total	*110*	*61*

Values rounded to two significant digits.

Table 35 Specific input of production factors at the CHP-unit at Weissenburg, Germany.

Production factor	Unit	Use of rape-seed oil: Fuel production *	Use of rape-seed oil: Conversion	Use of rape-seed oil: Clean-Up	Use of Diesel fuel: Fuel production	Use of Diesel fuel: Conversion	Use of Diesel fuel: Clean-Up
Energy input							
Total energy	MWh/MWh	0.21	1.2	§	0.13	1.2	§
Fossil energy	MWh/MWh	0.15	0	§	0.13	1.2	§
Labor input							
Direct	h/MWh	0.06	0.09	§	§	0.16	§
	h/MECU	550	820	§	0	2600	§
Indirect	h/MWh	1.5	1.1	§	0.46	0.64	§
	h/MECU	14000	9800	§	7500	11000	§

All values rounded to two significant digits; §: Value not applicable or insignificant.
* Only 35% of the effects are allocated to the oil, the rest being attributed to the press cake residue.
Energy figures stated with respect to electricity and heat produced.

that this is a problem of the technology, that could well be solved by appropriate flue-gas treatment, and not a problem of the biofuel.

Input data and results from EcoSense calculations are stated in Table 37 and Figure 15. The excessive NO_x emissions dominate the external costs of 140 mECU/kWh almost completely. The small difference between the biofuel and the reference case, which comes out at 160 mECU/kWh, is due to SO_2 emissions. In this case, moving the installation to Lauffen makes only a small difference, since Weissenburg is located only about 150 km east of Lauffen.

Table 36 Specific emissions from the CHP-unit at Weissenburg, Germany, in g/kWh.

Pollutant	Use of rape-seed oil: Fuel production ***	Use of rape-seed oil: Conversion	Use of rape-seed oil: Clean-Up	Reference case: Use of Diesel fuel: Fuel production ****	Reference case: Use of Diesel fuel: Conversion	Reference case: Use of Diesel fuel: Clean-Up
Direct emissions						
VOC	0.008	0.12	§	0.063	0.044	§
CO	0.015	1.6	§	0.021	3	§
NO_x	0.066	8.9	§	0.081	9.2	§
Particulates	0.0046	0.29	§	0.0039	0.6	§
SO_2	0.0024	0	§	0.13	1.1	§
CO_2 *	8.4	460	§	36	310	§
CO_2-Equivalents **	8.5	0	§	37	310	§
Indirect emissions						
VOC	0.0067	0.014	§	§	0.005	§
CO	0.028	0.15	§	§	0.053	§
NO_x	0.13	0.061	§	§	0.021	§
Particulates	0.022	0.022	§	§	0.0075	§
SO_2	0.059	0.03	§	§	0.01	§
CO_2	29	18	§	§	6.3	§
CO_2-Equivalents	63	20	§	§	6.9	§

All values rounded to two significant digits; &: Value not available; §: Value not applicable or insignificant.
* All CO_2 emissions from fossil and renewable fuels. ** CO_2-Equivalents: CO_2 emissions from fossil energy sources plus weighted emissions of CH_4 and N_2O. *** Only 35% of the effects are allocated to the oil, the rest being attributed to the press cake residue. **** Indirect emissions included in the account of direct emissions.

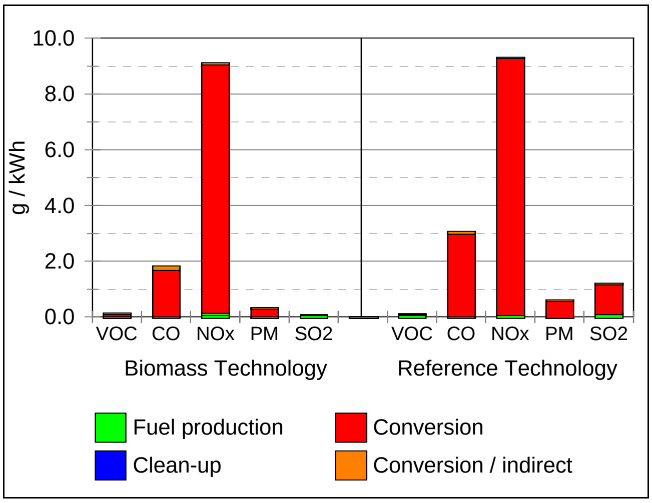


Figure 14 Specific emissions of air pollutants from the CHP-unit at Weissenburg, Germany.

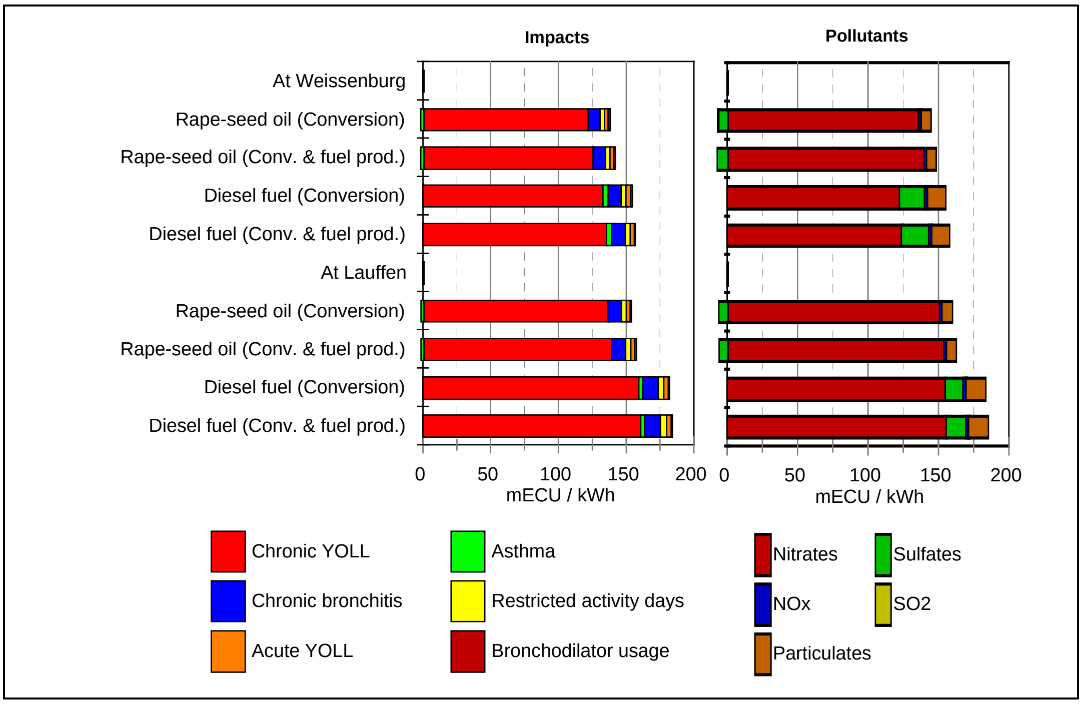


Figure 15 External costs of the CHP-unit at Weissenburg, Germany, with respect to human health impacts and air pollutants in mECU/kWh.

2.5.4. Other environmental impacts

Table 37 EcoSense input data and external costs of the CHP-unit at Weissenburg, Germany, with respect to human health impacts and air pollutants.

Fuel		Bio-mass	Bio-mass	Fossil	Fossil	Bio-mass	Bio-mass	Fossil	Fossil
Location		Weiss-enburg	Weiss-enburg	Weiss-enburg	Weiss-enburg	Lauffen	Lauffen	Lauffen	Lauffen
Fuel-cycle stages		Con-version	All stages	Con-version	All stages	Con-version	All stages	Con-version	All stages
EcoSense Data									
Gross electricity production	MW	0.22	0.22	0.1	0.1	0.22	0.22	0.1	0.1
Electricity sent out	MW	0.22	0.22	0.1	0.1	0.22	0.22	0.1	0.1
Full-load hours	h / a	1260	1260	1260	1260	1260	1260	1260	1260
SO_2 emissions	mg / Nm^3	0	0.349	91	103	0	0.349	91	103
NO_x emissions	mg / Nm^3	1300	1310	787	794	1300	1310	787	787
Particulate emissions	mg / Nm^3	43	44	51	52	43	44	51	51
Flue gas volume	Nm^3 / h	1500	1500	1170	1170	1500	1500	1170	1170
Flue gas temperature	K	408	408	408	408	408	408	408	408
Stack height	m	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
Stack diameter	m	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13
Anemometer height	m	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.7
Geographical latitude	degree	49	49	49	49	49	49	49	49
Geographical longitude	degree	11	11	11	11	9.18	9.18	9.18	9.18
Elevation at site	m	422	422	422	422	165	165	165	165
Priority Impacts (99%)									
Chronic YOLL	mECU/kWh	120	130	130	140	140	140	160	160
Asthma	mECU/kWh	0	0	3.7	4	0	0	2.6	2.9
Chronic bronchitis	mECU/kWh	8.9	9.2	9.7	9.8	10	10	12	12
Restricted activity days	mECU/kWh	3.2	3.3	3.5	3.6	3.6	3.7	4.2	4.3
Acute YOLL	mECU/kWh	2.7	2.8	3.2	3.2	2.8	2.9	3.3	3.3
Bronchodilator usage	mECU/kWh	0.44	0.45	0.48	0.49	0.49	0.5	0.57	0.58
Sum (0% discounting)	*mECU/kWh*	*140*	*140*	*150*	*160*	*150*	*160*	*180*	*180*
Sum (10% discounting)	*mECU/kWh*	*95*	*98*	*110*	*110*	*110*	*110*	*130*	*130*
Pollutants									
Nitrates	mECU/kWh	140	140	120	120	150	150	150	160
Sulphates	mECU/kWh	0	0	18	19	0	0	13	14
NO_x	mECU/kWh	1.9	1.9	2	2	1.9	1.9	1.9	1.9
SO_2	mECU/kWh	0	0.00027	0.3	0.32	0	0.00045	0.29	0.31
Particulates	mECU/kWh	6.1	6.4	12	13	6.6	6.9	13	14
Sum (0% discounting)	*mECU/kWh*	*140*	*140*	*150*	*160*	*150*	*160*	*180*	*190*
Ignored impacts		*0.8%*	*0.8%*	*0.8%*	*0.8%*	*0.8%*	*0.8%*	*0.8%*	*0.8%*

EcoSense input data rounded to three, external costs to two significant digits.
Results refer to mid-range damage estimates of long-range dispersion. Local dispersion and impacts on crops and forestry yields as well as building damage have been assessed and found insignificant.

Caused by the application of nitrogen (N) fertiliser, N_2O and NH_3 emissions are released. Input data for the calculation of these emissions are the applied amount of N fertiliser and specific emission factors, which are however quite uncertain. Details can be found in Patyk and Reinhardt (1997). The results of N_2O depend strongly on the production and use of nitrogen fertiliser. Whereas the data for the production are quite reliable, for the usage there is a range from almost no emission up to four times as much as. Therefore, the respective results for the whole life cycles may be in the range of -50% up to +125% depending on the actual soil and weather conditions.

Rape-seed farming is a well-known agricultural activity. There is little difference to be expected compared to other crops. There are, however, differences compared to set-aside land since no fertilisers will be applied to the latter and tractor use is about 50% lower. As with other energy crops, keeping to "good practice guidelines" is essential to ensure minimal adverse impacts on the environment.

So far, there were no complaints about bad smells around the CHP plant, neither from the inhabitants of the nearest dwelling which is only 60 m away, nor from the visitors of the pool.

2.5.5. Socio-economic framework

The German electricity feed law (Stromeinspeisungsgesetz), which guarantees fair buy-back rates for electricity from renewable energy sources, is not applicable in this case since the unit is operated by a utility and not by an independent power producer.

The municipal utility expects severe changes of the framework in which they operate when electricity markets are deregulated. They fear that they will not be able to successfully compete with large suppliers. Consequently, it would no longer be possible to subsidise municipal services like pools or public traffic, which mostly produce deficits, by profits from electricity, gas, and water supply. In addition, the unbundling of these services would create disadvantages in taxation, because deficits in some sectors could no longer be balanced with profits in others. Up to now, the legally necessary connection between the different sectors has been provided by using the water in pools as heat storage for the cogeneration units.

For the manufacturer of the cogeneration engines, the East German company AMS, rape-seed oil engines are the market niche in which they hope to survive. They aim at producing 1 000 engines per year, 50% of which will be fuelled by rape-seed oil. Smaller engines, for which there is a higher demand, cannot be offered presently, since development and production costs would be too high and banks deny the necessary credits.

Operating of drying installations requires an official approval by the county authorities. Thus, the county of Weissenburg ruled that, due to its potential emissions of pollutants and endangering of water reservoirs, the additional oil processing had to obtain a formal permit, too. Since the quantities in question are small, the permit was granted without problems. Additionally, standard building regulations had to be met.

The largest incentive for rape-seed farming for energetic purposes was the possibility to use areas which were part of the EU set-aside land program and could, thus, not be used otherwise. When this scheme started in 1993, each farm business which cultivated more than 15.6 ha of land, for which the EU paid premiums, had to set aside 15% of that area. During a period of 6 years, each part of the land had to be set aside at least once. Due to rising world market prices of cereals, the set-aside share was first reduced to 12%, then 10% in 1996 and has now reached 5%. A rotation between different parts of the land is no longer necessary. Farmers fear that the whole scheme might be abandoned soon.

To use set-aside land for farming energy rape seeds, it is required to stick to the following procedure: Even before sowing, the farmer has to make a contract with the future buyer of the rape seeds, that is in this case, with the oil mill. This contract specifies the related areas, the expected harvest etc. in many details. At the same time, the farmer has to apply for a premium. All measures undertaken have to be documented in writing. All deviations from the procedure fixed in the contract with respect to areas, amounts, degree of humidity etc. will lead to labour intensive inquiries. In addition, the buyer has to provide a security payment which amounts to 120% of the premium of the farmer. This security is 450 ECU/ha at the moment and added up to 0.75 million ECU for the co-operative during the last 3 years. All the steps described have to be concluded at different dates, which causes further complications. Finally, different authorities are responsible for the different steps – yet another source of misunderstandings. Up to now, the co-operative conducts all contract administration free of charge. They will probably have to charge for this in the future, a measure which would probably further discourage farmers from producing energy rape seeds, even though fair prices were paid in the past.

In the region examined, consumer rape seeds are grown on 4% of the total agricultural land of 33 000 ha. Of the 2 000 ha set-aside land, 300 to 1 000 ha have been used for energy rape seeds between 1993 and 1996. The soil is well suited for rape seeds if it is not grown more often than every sixth year. The potential for the production of rape-seed oil is rather limited. It is estimated at 54 PJ/a by Kaltschmitt and Wiese (1993) or 3.5% of the total German demand for motor fuels of 2 700 PJ/a in 1995. It may be of advantage to reserve this fuel for applications which have especially high damage potentials if fossil fuels are used, such as ships on drinking water reserves or lubrication for forestry equipment. Another option could be to have farmers use 10-15% of their land to become energetically self-sufficient.

2.6. Production of Rape-Seed Oil Methyl Ester and its Use for Goods Transport in Germany

2.6.1. Description of the technology and its location

As explained in Section 1.3.3.1 on air dispersion modelling, the transport applications examined are very different from the electricity and heat producing ones. Consequently, the EcoSense model is not appropriate in these cases. Thus, we restrict ourselves to providing a detailed inventory of emissions, a qualitative discussion of environmental impacts, and to computing CO_2 abatement costs in Section 2.9.

The start of the rape-seed oil methyl ester (RME) fuel cycle is identical to the rape-seed oil fuel cycle described in the previous section since it involves the growing of rape seeds. For determining transport distances, it is assumed that the rape seeds are grown in the Wetterau region, but all specific environmental and economic data are assumed to be identical to the Bavarian case study described above.

From there on, things become different. The rape seeds are transported to a central facility at which they are refined in a chemical process to meet standardised physical parameters. This is assumed to take place in a refinery located at Neuss in the state of North-Rhine Westphalia. Then, the refined oil is transported by ship to the only German industrial-scale esterification plant at Leer. There, the oil is transformed into RME.[15] Finally, it is transported back to the Wetterau region by trucks where it is used in a truck fleet dedicated to transporting sugar beets during harvesting operations. The "Wetterauer Agrarservice GmbH" bought 916 t of RME in 1995 to operate these trucks. This application was chosen, since this truck fleet was operated on diesel fuel in 1993 and on RME in 1995 and thus the data situation is good.

Oil refining starts with the cleaning and drying of the seeds, which is necessary to secure the functioning of the facility and to ensure a high quality of the product. After that, the seeds are crushed and conditioned, which means that they are exposed to steam at temperatures of 80-90^{o}C for 15-30 minutes. This procedure improves oil separation, deactivates some enzymes and destroys mould and germs. Also it adjusts the moisture content to a proper level.

[15] Data on transesterification have mostly been taken from literature documented in the case study report (Widmann and Kern 1997) as the companies involved regarded this information as confidential.

Next, the seeds are pressed with a screw press, which extracts about 50% of the oil content. The residues are then treated with hexane to dissolve the remaining oil. The hexane is later distilled off from the oil as well as from the extraction residues called meal and recycled.

The actual refining comprises degumming, neutralisation, bleaching and deodorisation. After these steps, the oil is called fully refined and has the quality of edible oil. Since the extraction meal is an economic good which is sold for non-energetic purposes, emissions from the refining stage are divided between oil and meal with respect to their mass. This leads to only 40% of all emissions from the refining stage and before being attributed to the fuel cycle.

Since running vegetable oil in standard diesel engines may severely damage such machines, the oil has to be chemically adapted in such a way that it meets the requirements of standard diesel engines. This is done by esterification. For this purpose, the refined oil is transported to the transesterification plant at Leer in Northern Germany by an 800-t inland ship. The transport distance is about 500 km. The plant at Leer was chosen, because it is the only industrial scale facility of its kind in Germany.

During transesterification, the triglycerid contained in the refined oil is split during a reaction with methanol into three molecules of fatty acid methyl ester and glycerol. The glycerol is again a marketable by-product, to which 12% of the emissions are allocated according to its mass. The 0.11 t of methanol needed per ton of RME have to be produced from fossil fuels which is rather energy intensive.

2.6.2. Technical, economic and environmental data

Emission data are summarised in Table 38 and Figure 16. They are stated with respect of the transport service provided, which is measured in ton-kilometres (t·km) to account for the amount of goods transported and the distance covered. The indirect emissions stated for the production of rape seeds are due to the use of fertilisers. It should be noted that for conven-

Table 38 Emission data on the production and use of RME for a transport application (in grams per ton-kilometre).

Emissions in g/(t·km) Fuel-cycle steps	VOC	CO	NO_x	PM	SO_2	CO_2-Equiv. [3]
RME						
Production of seeds, direct [1]	0.0015	0.0028	0.012	0.00087	0.00045	1.6
Production of seeds, indirect [1]	0.0013	0.0054	0.025	0.0042	0.012	12
Oil production and refining [1]	0.00014	0.0011	0.002	0	0	1.7
Transport to esterification [1]	0.00065	0.0017	0.0083	0.00028	0.00014	0.45
Esterification [2]	0.0001	0.00047	0.00081	0	0.00059	1.7
Transport to end use	0.0013	0.0027	0.011	0.00061	0.00027	0.89
End use [5]	0.053	0.26	1.1	0.033	0 [4]	1.1
SUM	*0.058*	*0.27*	*1.1*	*0.039*	*0.013*	*20*
Diesel						
Production	0.014	0.0048	0.018	0.00088	0.03	8.1
End use	0.12	0.25	1.0	0.056	0.025	81
SUM	*0.13*	*0.25*	*1.0*	*0.056*	*0.054*	*89*

All values rounded to two significant digits. [1] 40% of emissions allocated to the oil, 60% to extraction meal. [2] 88% of emissions allocated to RME, 12% to glycerol. [3] CO_2-Equivalents: CO_2 emissions from fossil energy sources plus weighted emissions of CH_4 and N_2O. [4] Not really zero, but very small. [5] Values obtained from Schäfer et al. (1998).

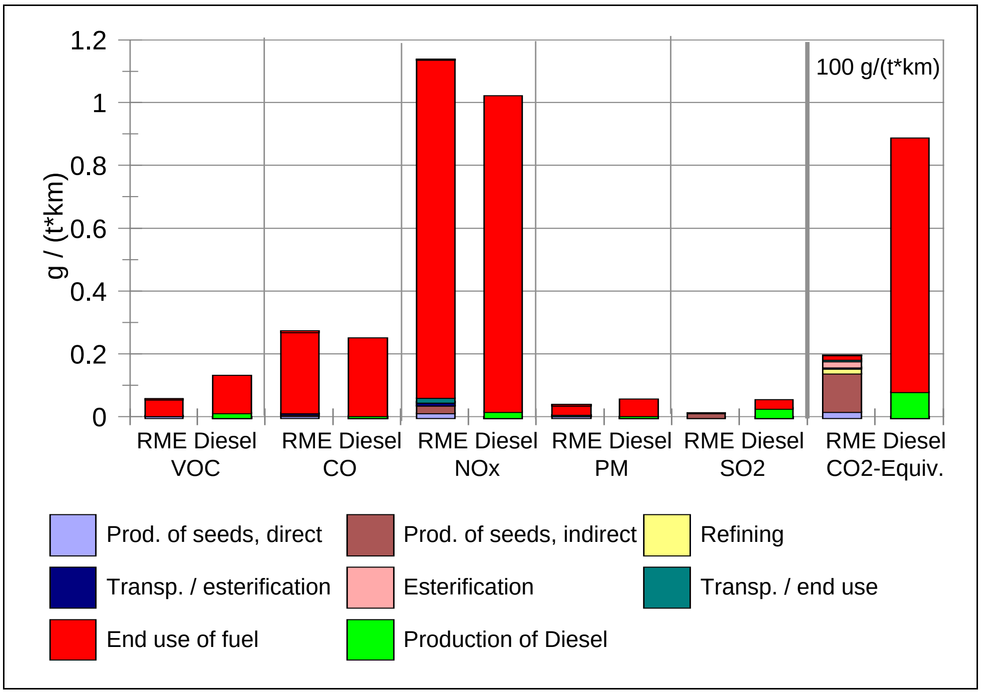


Figure 16 Emissions during production and use of RME and diesel fuel for a transport application in g/(t·km) for conventional pollutants and 100 g/(t·km) for CO_2-equivalents.

tional pollutants the differences between RME and diesel fuel are in general rather small (cf. Figure 16). For SO_2, PM and VOC, we find a small advantage and for NO_x and CO a small disadvantage of RME compared to diesel fuel. However, considering uncertainties and the fact that all this information is site-specific, we do not regard these differences as significant. Nevertheless, as Figure 16 shows, there are substantial benefits with respect to CO_2-equivalent emissions, even though they are not as large as in most of the other case studies discussed above. As for the use of cold-pressed rape-seed oil, this is due to the large amount of energy needed to produce the fertilisers applied during rape-seed farming.

Primary energy input and costs of the RME fuel cycle are shown in Table 39 and Figure 17. Due to the high effort of producing rape-seeds and during esterification, the cost of a service unit in the RME cycle is 13 mECU/(t·km). Thus, it is more than two times higher than the cost of the diesel fuel cycle which amounts to 5.7 mECU/(t·km). Again due to the use of fertilisers and the esterification process, the primary energy input for RME production is slightly higher, but as CO_2-equivalent emissions showed, most of the energy is from renewable sources. Therefore, the latter contribution is shown in white colour in Figure 17. Labour figures and indirect emissions from manufacturing the equipment could not be derived since no reliable data on investment costs could be obtained.

Table 39 Data on primary energy and costs of RME use for a transport application.

Fuel-cycle steps	Primary energy MJ / (t·km)	Costs mECU/(t·km)
RME		
Production of seeds, direct	0.027	5.6
Production of seeds, indirect	0.079	§
Refining	0.031	0.83
Transport to esterification	0.0059	0
Esterification	0.13	6.1
Transport to end use	0.012	0.24
Product	0.96 *	§
SUM	*1.3*	*13*
DIESEL		
Production	0.11	5.7
Product	1.1	§
SUM	*1.2*	*5.7*

* This figure includes solar energy taken up during plant growth.

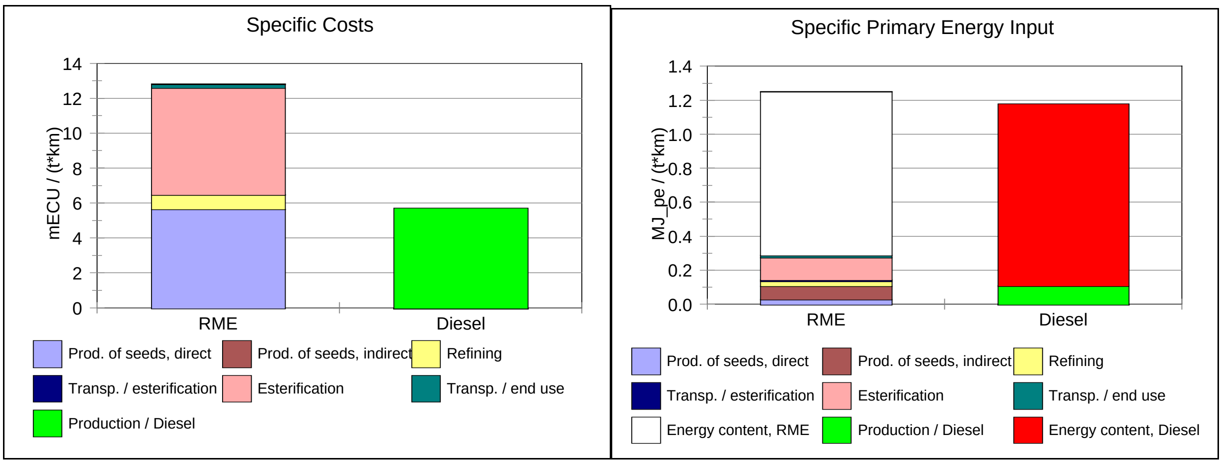


Figure 17 Specific costs and primary energy input of RME and diesel fuel for a transport application in mECU/(t·km) and MJ_{pe}/(t·km), respectively.

2.6.3. Other environmental impacts

The possible impacts of rape farming have been discussed above. The refined oil does not present a danger to the environment since it is fully biodegradable and therefore put into the lowest water-endangering class 0 in Germany. RME is only slightly more problematic and thus put in class 1 on a scale ranging from 0 to 3.

2.7. Production of Ethyl Tertiary Butyl Ether from Sugar Beets and Sweet Sorghum for Transport Applications in France

2.7.1. Description of the technology and its location

The tightening of regulations on transport emissions in Europe and the subsequent switch to unleaded gasoline has lead to an increased use of oxygenate compounds like MTBE (methyl tertiary butyl ether) and ETBE (ethyl tertiary butyl ether) in France. Their addition to gasoline increases the octane index, improves combustion and reduces the quantities of unburned compounds like aromatic hydrocarbons, especially benzene, in the exhaust gases.[16] Nowadays, ethers may have a volume share in gasoline of 15% in the EU. In this case study, the production of ETBE from sugar beets and sweet sorghum is considered as an alternative to the use of MTBE, which is produced from fossil fuels.[17]

ETBE is obtained from ethanol and isobutylene with the following reaction:

$$C_2H_5OH + H_2C{=}C(CH_3)_2 \rightarrow CH_3CH_2OC(CH_3)_3 \ .$$

The ethanol is produced from sugar beets or sweet sorghum. The plants are first converted into fermentable sugar products, namely green juice and green syrup. Then, ethanol is produced via fermentation of the sugar products, distillation and dehydration. Isobutylene is a by-product of the catalytic cracking of naphta in the petroleum industry. For MTBE production, methanol, made from natural gas, is used instead of ethanol.

Usually, sugar beets are cultivated within different crop rotation schemes including various cereals, peas or potatoes. In our case, the cultivation starts with a mustard as an intermediate crop. Then, starting in October, the soil is ploughed and fertilisers are applied. In March, sugar beets are seeded, and later weed-killers, insecticides and fungicides are applied. Finally, harvesting takes place in October. The data on fertilisers used in the emission balances below are the ones derived by Patyk and Reinhardt (1997). The sugar beet cultivation is assumed to take place in the French region of Champagne-Ardennes, which contributes significantly to the national sugar production. It supplies the ethanol plant at Arcis-sur-Aube. The average yield during the early 1990ies was 67 t/ha (not including the soil attached to the beets).

Upon arrival at the sugar factory by truck, the beets are first washed, sliced, and then discharged into a scalding tank leading to the diffuser. There, the sugar is removed from the plant material by being dissolved in hot water. The sugar solution, called green juice, contains about 84% of water, 14.5% sugar and 1.5% of non-sugars. The latter are removed during a purification step using lime and carbon dioxide. Next, the sugar concentration in the syrup is increased to 60% by evaporating the water contained. Finally, the sugar is turned into a crystallised form at reduced temperature and pressure in vacuum pans.

To produce biofuels, ethanol is obtained half from green juice derived directly from beet processing during 3 months of the year (yield: 1.1 hl of ethanol per ton of beets) and half from 2^{nd} cycle green juice which is a by-product of making granulated sugar during 9 months of the

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[16] In California, there is an intensive debate on the question whether MTBE really leads to decreased emissions (cf., for instance, www.sedd.org or www.oxybusters.com). In addition, it is claimed that MTBE is meanwhile found in drinking water sources and leads to adverse health impacts itself.

[17] The data for this case study have been obtained from Cariolle (1995), Chauvel, Lefebvre and Castex (1985), ERM (1994), and FCB (year unknown). For more details, please refer to the case study report (Gosse et al. 1998).

year (yield: 0.2 hl/t). The plant at Aucis-sur-Aube produces some 300 000 hectolitres (hl) of ethanol per year. Altogether, sugar beets are estimated to have a potential of 3.8 million hl of ethanol per year, while the market potential in France is estimated to be about 10 million hl. ETBE is finally produced at a factory located at Dunkerque. To produce 1 t of ETBE, 0.47 t of ethanol and 0.53 t of isobutylen are used.

The transport activities considered for the production and use of ETBE are 25 km by truck for the sugar beets, 200 km by train for the ethanol and 100 km by truck for the ETBE.

Sorghums are tropical plants which have a C4-type photosynthetic metabolism. One has to distinguish between fibre sorghum, which has high cellulose fibre and low sugar content, and sweet sorghum with up to 40% sugar content in the stalks. At the European level, two commodities can be produced from sweet sorghum, alcohol and a lignocellulose raw material, the bagasse. The latter may be used for the production of cardboard, as pulp for paper industry or energetically by combustion. The crystallisation of and thus the alcohol production from sorghum sugar juice is difficult due to the low purity of the juice.

The case study analyses the farming of sweet sorghum in the Midi-Pyrénées region in Southern France as a complement to the farming of sugar beets in the Champagne-Ardennes region. However, this is a hypothetical case. Sweet sorghum is well adapted to Mediterranean conditions and might therefore replace some low quality vineyards on marginal production land, which is currently set-aside under EU regulations. In addition, the juice from sweet sorghum may be processed at existing vine-surplus distilleries. The steps of the fuel cycle are identical with those of the sugar beet case. As ETBE factory a facility at Feyzin is considered, which uses a process identical to the one at Dunkerque. The transport activities assumed for the production and use of ETBE are 5 km by truck for the sorghum, 350 km by train for the ethanol and 100 km by truck for the ETBE.

For the calculations shown below, it is assumed that the bagasse is used as energy supply in the sugar and distillation plant. In fact, there is even a surplus of energy from the bagasse, which is used to produce electricity that is sold to the grid. Thus, there are avoided emissions from fossil fuels which are credited to the ETBE production. This scheme replaces the allocation of impacts to different products by mass which is used in the case of sugar beets.

The ETBE is assumed to be added to standard gasoline supplied to private cars in France as a substitute for MTBE. The mix considered includes 17% of volume for ETBE and 15% for MTBE. All impacts are stated with respect to the transport service derived, which is measured in person-kilometres (p·km) to account for the number of persons transported and the distances travelled. In France, the average load factor of a private car is 2.01 persons.

2.7.2. Technical, economic and environmental data

As described in the previous section, the process of sugar production involves a number of by-products such as pulp as a residue after diffusion. Since some of these by-products are marketable goods, the emissions and environmental impacts of the whole production process have to be allocated among the different mass flows somehow (cf. Sec. 1.1). In the case of sugar beets, it has been decided to use mass allocation since not all of the products serve an energetic purpose. This decision is of course debatable and it has a significant impact on the quantitative results. However, it has to be stressed again that there is no optimal way of allocation.

A summary of the technical, economic and environmental data on ETBE and MTBE production and application can be found in Table 40. For more details, please, refer to the case study report (Gosse et al. 1998). Four different situations are distinguished: The use of ETBE

Table 40 Emissions, energy input, and costs of the production and use of ETBE and MTBE.

	17% ETBE from sugar beets		17% ETBE from sweet sorghum *		100 % Gasoline		15% MTBE	
	Production	Use	Production	Use	Production	Use	Production	Use
Emissions in g/(p·km)								
VOC	0.065	1.1	0.026	1.1	0.016	1.4	0.013	1.4
CO	0.012	7.1	0.0079	7.1	0.0083	7.7	0.0089	7
NO_x	0.05	0.49	0.033	0.49	0.036	0.48	0.043	0.49
PM	0.0044	&	0.00089	&	0.0022	&	0.0033	&
SO_2	0.27	&	0.24	&	0.06	&	0.29	&
CO_2-Equivalents **	35	78	15	78	19	95	19	95
Benzene		-8.1%		§		Reference		-11.1%
Acetaldehyde ***		+250%		§		Reference		-0.9%
Formaldehyde		-16%		§		Reference		+16%
1,3 butadiene		-3.8%		§		Reference		-1.7%
Primary energy in MJ/(p·km)	0.46	1.5	0.33	1.5	0.24	1.5	0.51	1.5
Costs in mECU/(p·km)	6.6	§	6.6	§	6.3	§	6.3	§

§ : Not applicable; & : Value not available. * It is assumed that the bagasse obtained as a by-product during sugar production from sweet sorghum is used energetically in the process itself. ** CO_2-Equivalents: CO_2 emissions from fossil energy sources plus weighted emissions of CH_4 and N_2O. *** Overall emissions are low.

from sugar beets and sweet sorghum as an oxygenate adder to gasoline, and as reference cases the use of MTBE as oxygenate adder and of pure gasoline.

Again, it is found that the emissions of the whole fuel cycle are dominated by the conversion stage. In general, the differences in emissions of the conventional air pollutants on which this study focuses are small (cf. Figure 18). All three oxygenate cases show small advantages in CO emissions and a disadvantage in SO_2 emissions. The ETBE has a benefit over both pure gasoline and MTBE with respect to VOC. One main reason for adding MTBE to gasoline was to reduce emissions of hydrocarbons. This is the case for benzene, acetaldehyde, and 1,3 butadiene. It is, however, not the case for formaldehyde. With ETBE, the picture changes somewhat. Now, there is an improvement in formaldehyde emissions, but a worsening with respect to acetaldehyde, however, at a low overall level.

The production of ETBE is energetically more efficient than the production of MTBE, but uses more energy than the production of pure gasoline (cf. Figure 19). The lowest energy input has the mix containing ETBE from sweet sorghum, which is due to the energetic utilisation of the bagasse by-product. Due to the general setting of the case study, only a small part of the energy needed to provide the transport service is contributed from renewable sources. This is also reflected in the emissions of CO_2-equivalents. The MTBE mix has the highest emissions, followed by pure gasoline and ETBE mix from sugar beets. The ETBE mix from sweet sorghum comes out best. However, the advantage is only in the order of 20%, which is small compared to the other case studies of the BioCosts project.

The production costs of ETBE from ethanol and MTBE were hard to come by, since these figures are treated as confidential by industry. Thus, the figures used must be regarded as rough estimates. Gasoline and the MTBE mix yield the same costs per unit of service, 6.3 mECU/(p·km). The two ETBE cases lead to 5% higher costs of 6.6 mECU/(p·km). This re-

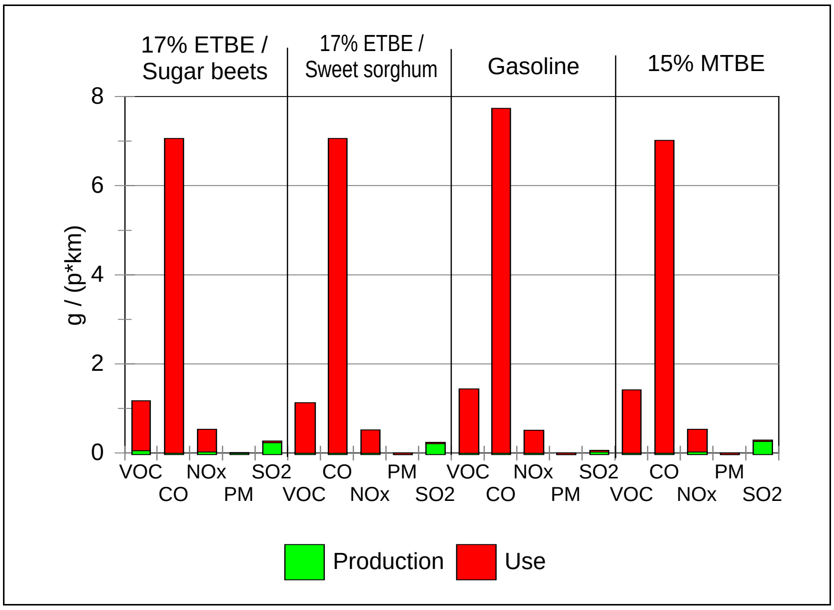

Figure 18 Emissions of air pollutants during production and use of ETBE-mix, gasoline and MTBE-mix for a transport application in g/(p·km).

sults is somewhat surprising as much higher costs would have been expected for ETBE. Thus, these figures should be cross-checked when data from other sources become available.

It should be stressed again, that the results stated for ETBE depend on the allocation mechanism used. As explained in the methodology section (1.3.3.1), it is not feasible to apply the EcoSense model to this case study. Hence, no monetisation of the environmental impacts was possible. The CO_2 abatement costs will be discussed below in Section 2.9 . Furthermore, since no appropriate investment costs could be obtained, no runs of the input-output model were possible. Hence, no indirect effects and no employment effects could be obtained.

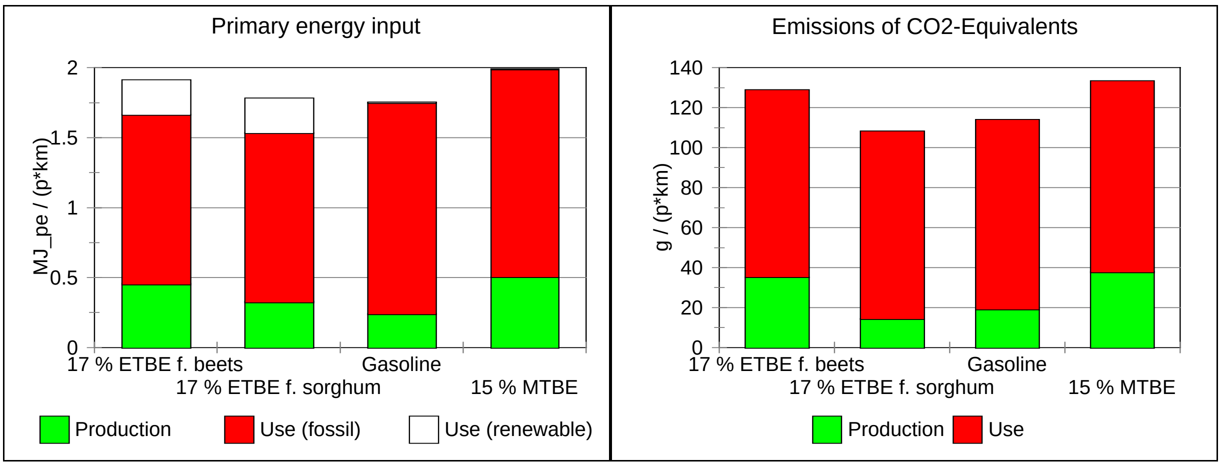

Figure 19 Primary energy input and emissions of CO_2-equivalents during production and use of ETBE-mix, gasoline and MTBE-mix for a transport application.

2.7.3. Other environmental impacts

In the French case study, soil erosion is not assessed due to a lack of data. The eutrophication of water balance shows that nitrate and phosphorus leaching during cultivation are negligible. The ETBE production may have impacts on the environment due to outputs of nutriments from the sugarhouse and the distillery. However, these impacts, which depend closely on local conditions, may be avoided by a reasonable control of effluents.

Potential problems caused by the leaching of nitrates and phosphorous during agriculture may be limited by the intermediate crops and by adjusting the use of fertilisers to the actual needs of the energy crops.

2.7.4. Socio-economic framework

Introduced in France by the Finance Law for 1992, the exoneration of biofuels from the internal tax on petroleum products has been confirmed by the 1993 Finance Law. It gives a fiscal advantage to esters of rape-seed (RME) and vegetable oils used as fuels or combustibles and to ethyl alcohol (ethanol) or derived products used as fuels, produced in pilot units as parts of experimental programs. At the moment, the tax exemption amounts to 0.35 ECU per litre of vegetable oil esters incorporated in either diesel fuel or domestic fuel and 0.50 ECU/l of ethanol incorporated in unleaded super gasoline or ethanol to make ether incorporated in unleaded super gasoline.

Moreover, the Finance Law for 1993 allows for "perennial progress conventions" between the State and industries to guarantee the amortisation of productions units of biofuels and integrate a progress margin by introducing an upper limit for the tax relief. Other measures are completing the system, e.g., the authorisation to incorporate 5% of RME in diesel fuel without an obligation to mention it at the pump and to use a blend up to 33% with monitored fleets. In addition, the ministry of agriculture participates in R&D actions.

An environmental protection act has laid down that as of 1st January 1995, the incorporation of oxygenate compounds, particularly those of agricultural origin, in petroleum motor fuels is encouraged in the frame of air quality protection. This measure was designed to encourage pilot projects in sensitive urban areas where pollution is characterised by large quantities of CO, unburned hydrocarbons and atmospheric ozone. The French Clean Air Act provides for compulsory incorporation of oxygenates in transport fuel as of 1 January 2000; a higher blend rate will be enforced for captive fleets (e.g. buses) in cities over 100 000 inhabitants.

2.8. Summary of the Economic Performance: Internal Costs and Employment Effects

The services provided by the two transport applications are unique. These two case studies can neither be compared with each other nor with the electricity and heat producing case studies as far as economic performance is concerned. Thus, this summary comprises only the electricity and heat producing case studies.

2.8.1. Internal costs

The internal costs of the different facilities considered in the BioCosts project are summarised in Figure 20. The abbreviations used are explained in Table 41. Only two biofuel cases

Table 41 Abbreviations for case studies.

Case study	Biomass case	Reference case
Forestry residues, Nässjö, Sweden	s1-o	s1-r (coal)
Mangualde, Portugal		
Case 1: Forestry residues	p1-o	p1-r (fuel oil)
Case 2: Short-rotation coppice	p2-o	p2-r (fuel oil)
Biogas, Hashöj, Denmark	dk-o	dk-r (natural gas)
Gasification of forestry residues, Värnamo, Sweden	s2-o	s2-r (coal)
Gasification of short-rotation coppice, Eggborough, UK	uk-o	uk-r (coal)
Rape-seed oil, Weissenburg, Germany	d1-o	d1-r (diesel fuel)

have lower costs than their reference cases at current fossil fuel prices. These are the industrial CHP facility at Mangualde, Portugal, (p1: 3.0 mECU/kWh) and the CHP plant at Nässjö, Sweden (s1: 19 mECU/ kWh). Both are using forestry residues as a fuel, which are obtained at low cost. Not surprisingly, it may thus be concluded that the utilisation of residues has a clear economic advantage over other forms of biomass.

The gasification schemes (s2, uk) are dominated by the high investment costs of the conversion equipment, which is somewhat astonishing since the innovative part is the gasification equipment that is included in the fuel costs. Being integrated facilities, it is sometimes hard to distinguish which part of the equipment belongs to which fuel-cycle stage. However, there should be room for significant reduction of costs for these demonstration facilities.

The biogas fuel cycle in Denmark (dk) is relatively expensive, but not much more expensive than its reference case. The high cost level is partly due to the decentralised character of

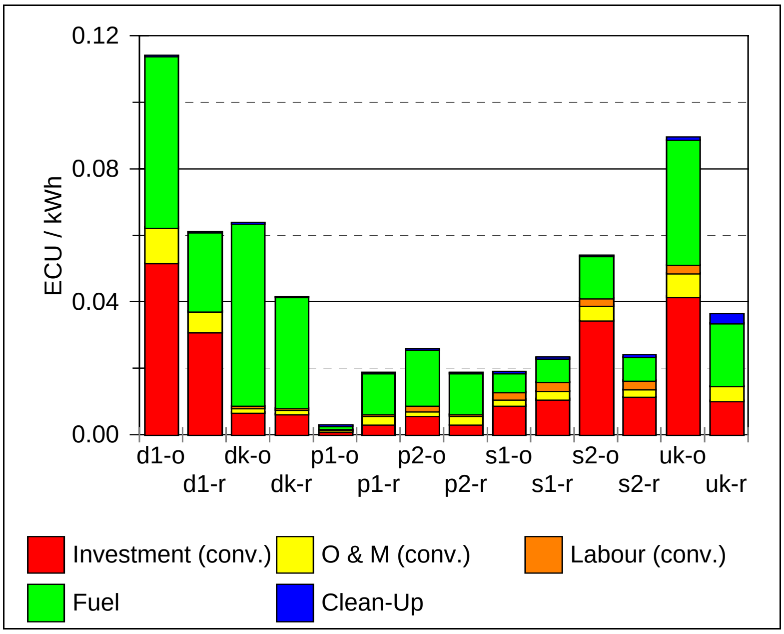

Figure 20 Energy production costs of the BioCosts case studies producing heat and electricity. Costs of the conversion stage are split into investment, operation & maintenance and labour.

the installation and partly to natural gas being the most expensive fossil fuel. The additional cost for biogas is owed to the early phase of biogas technology development. The second Portuguese case (p2) involving short-rotation coppice has the potential of becoming economic if the costs of biofuel production can be reduced or if fossil fuels are becoming more expensive. The rape-seed oil case (d1) does not seem favourable, even when one considers much longer hours of operation, since the potential for cost reduction is limited.

It should be stressed again, that the cost figures stated here are not the ones relevant for business calculations as those would include taxes and would probably use a different allocation of costs among heat and power. Thus, the figures given represent an economic rather than a business view.

2.8.2. Employment effects

In Figure 21, the employment effects, stated for the different case studies in the respective sections, are summarised. The figure shows specific employment with respect to energy production costs and to the amount of energy supplied. The latter is necessary if one wants to determine possible large scale effects when biomass contributes an increasing share to the European energy supply. However, these data have to be interpreted with care since the different case studies are at very different stages of development and their costs and efficiencies vary widely.

For rape-seed farming (d1), the direct data obtained seemed unrealistic. Thus, an EMI-model run was made where the production cost of rape seeds was fully allocated to the agricultural sector of the economy. This led to much higher employment impacts, as one would expect for a still rather labour intensive agricultural activity. However, as discussed above, 65% of this impact has to be allocated to the press cake residue. Consequently, the labour intensity of the rape-seed oil fuel cycle is only slightly higher than the intensity of its reference case in monetary terms (cf. Figure 21). This result is due to the fact that rape-seed oil production is much more costly than diesel production because it is more labour intensive, and to the fact that the extraction of the mineral oil does not take place in Germany. On the other hand, in physical terms, the labour intensity of the rape-seed oil fuel cycle exceeds that of the diesel

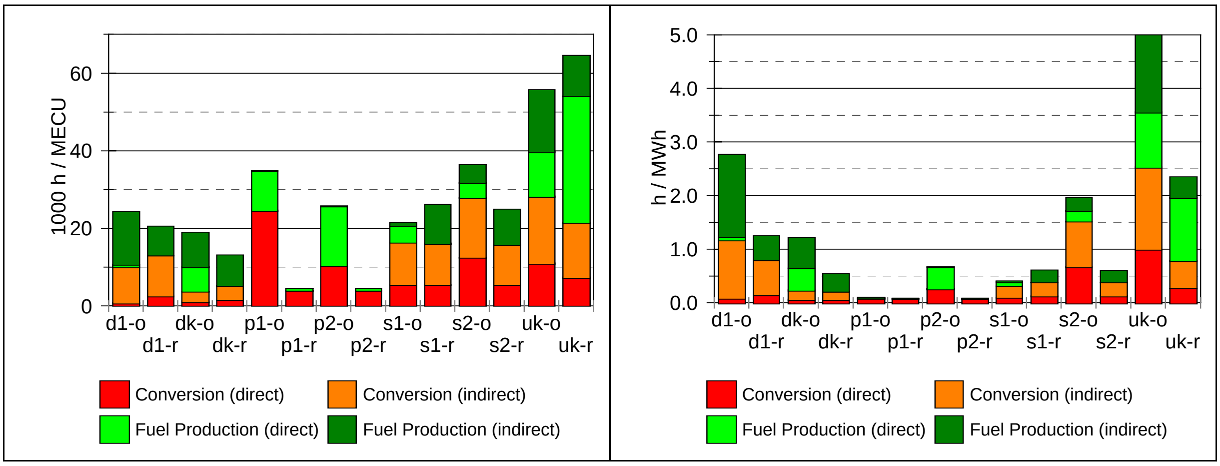

Figure 21 Specific employment effects of the BioCosts case studies producing heat and electricity with respect to production costs (1000 h/MECU) and energy output (h/MWh). Abbreviations are defined in Table 41.

fuel cycle by more than a factor two, since the energy efficiencies are comparable. Thus, if the same energy services are to be supplied, the biofuel cycle would need more labour. However, since it is also much more expensive, this would not be the only economic effect. The excess cost would have to be saved at some other place and lead to decreasing employment in the respective sector of the economy (see discussion at the end of this section). Finally, it has to be noted that the large share of indirect effects on the conversion stage is caused by the peculiar operation schedule of the CHP plant. If one assumes 5 000 instead of 1 260 full-load hours of operation, this share is reduced to about the same size it has in the Danish case (dk), which is reasonable since the equipment is comparable.

The Danish biogas case study (dk) is also similar to the rape-seed oil case (d1) in the fact that it exhibits higher employment than its reference case due to fuel production. However, the specific labour input for fuel production is smaller than in the German case, because biogas production is not an agricultural activity but carried out in an already very efficient way. The fuel substituted is Danish natural gas, which is fully produced within the country. It may well be that the labour necessary to produce this gas is underestimated here, because no direct figures were available. EMI results on fossil fuel production in Denmark include substantial uncertainty, because there are no separate economic sectors for the oil, gas and coal industries in the Danish input-output tables used here.

For the Portuguese case studies (p1 and p2), no indirect effects could be calculated due to the missing input-output table. Direct effects show a significantly higher specific employment for the biomass case compared to the reference case with respect to production costs. This may be due to the fact that, especially in Case 1, the production costs are very low. If based on the energy produced, the employment benefit for Case 1 vanishes almost completely, while we still have an advantage of biomass in Case 2, which is due to fuel production.

For the use of forestry residues in Sweden (s1-o), we find 20% lower employment than for the reference case (s1-r) using Polish coal. The employment effect for the fossil fuel was again determined by feeding the fuel costs into the energy sector of the Swedish economy in the EMI model. If the direct labour input for coal production in Poland had been used, the difference would have been much larger. However, all case studies only include the economic performance in the country in which the facility is located. The result stated is due to the use of residues which need only little labour input for collection and chipping and to the higher energy output of the biofuel version of the plant.

The gasification scheme in Sweden (s2), which is compared to the same reference case as the residues fuel cycle (s2-r=s1-r), needs more labour input than the fossil fuel case since this scheme involves much more effort for fuel preparation. In addition, it must also be considered that the technology has high investment costs at the moment, that result in high employment figures in EMI runs which are probably overestimated. Since these costs are likely to decrease as the technology matures, employment figures will fall accordingly.

The same is true for the gasification scheme in the UK (uk). Here, however, the reference case has higher employment figures than the biofuel case in monetary terms since it considers the use of UK coal, which is produced within the same country and for which productivity is low compared to other economic sectors. In addition, the specific employment figures are higher than those of other case studies since only electricity is produced.

It may be concluded that the use of biofuels has some benefits over using fossil fuels with respect to employment, if there is a substantial effort for preparing the biofuel, which is nevertheless carried out efficiently and if it substitutes imported fuels. The benefits are however small. In addition, the labour input into biofuels will have to decrease during continuing efforts to improve the economic efficiency of the respective fuel cycles.

For Germany, it has been estimated that supplying 5% of its energy demand from biomass would involve some 60-120 thousand jobs (ZEW 1998). These jobs would not be created in addition to existing jobs, but would mostly substitute other jobs. First, the jobs for operating the reference technology would be void. Second, if the biofuel technology is more expensive than the fossil fuel technology, the extra money spent would not be available for other purposes as, for instance, consumption and jobs in the respective sector of the economy, e.g. in the production of consumer goods, would be lost. All in all, there is probably a small positive net effect for using renewable energy sources. It will however not contribute significantly to solving the employment problems which European countries face today (LTI-Research Group 1998).

2.9. Summary of Environmental Impacts: Emissions, Energy Input, External Costs, and Global Warming

This section serves to compare the environmental impacts of the case studies among each other. Differences between the biomass fuel cycles and their reference cases have already been interpreted in detail in the respective sections of this report. It should be noted that all figures are given with respect to the total energy output of the facilities, that is the sum of electricity and heat. For the UK case study, emission values are in general higher than in the other cases since it is the only one producing electricity only and therefore has a lower overall energy efficiency than the other case studies.

Figure 22 shows the emissions of conventional air pollutants and CO_2-equivalent emissions for all biomass-to-electricity (and heat) case studies. The highest VOC emissions are found for the industrial CHP installation in Portugal (p1-o and p2-o) with results between 0.4 and 0.8 g/kWh. The fuel-cycles applying oil-driven engines (d1-o, d1-r, p1-r, p2-r) lead to VOC emissions between 0.1 and 0.2 g/kWh which are mainly attributable to the conversion technology. The VOC emissions of the biogas fuel cycle (dk-o) as well as the UK gasification scheme (uk-o) and its reference case (uk-r) also lie in the latter range. However, they are determined by fuel production rather than by the conversion process. The use of natural gas in a Danish CHP unit (dk-r) and all Swedish case studies (s1-o, s1-r, s2-o, s2-r) have very small VOC emissions well below 0.05 g/kWh.

The oil-driven engines in Germany (d1-o, d1-r) and in Portugal (p1-r = p2-r) have by far the highest NO_x emissions of all case studies. It should be stressed again, that this results is not related to the application of biofuels, but determined by the technology. This problem may be reduced by adding appropriate flue gas cleaning equipment. The Swedish case studies show that it is possible to keep NO_x emissions of biomass fuel cycles at very low levels.

There is a substantial benefit in low SO_2 emissions for all biofuel case studies since there is almost no sulphur in the fuel and the contributions of fossil fuels during biofuel production are low. The only exception is biogas competing with natural gas (dk), since the latter does hardly contain any sulphur either.

A number of biomass cases exhibit rather high CO emissions (d1-o, d1-r, p1-o, p2-o, uk-o), which again is more related to the technology than to the fuel. The high emission level is probably due to less demanding emission standards or little attention paid to this problem. The UK gasification scheme, for example, has probably not been optimised in this respect since it

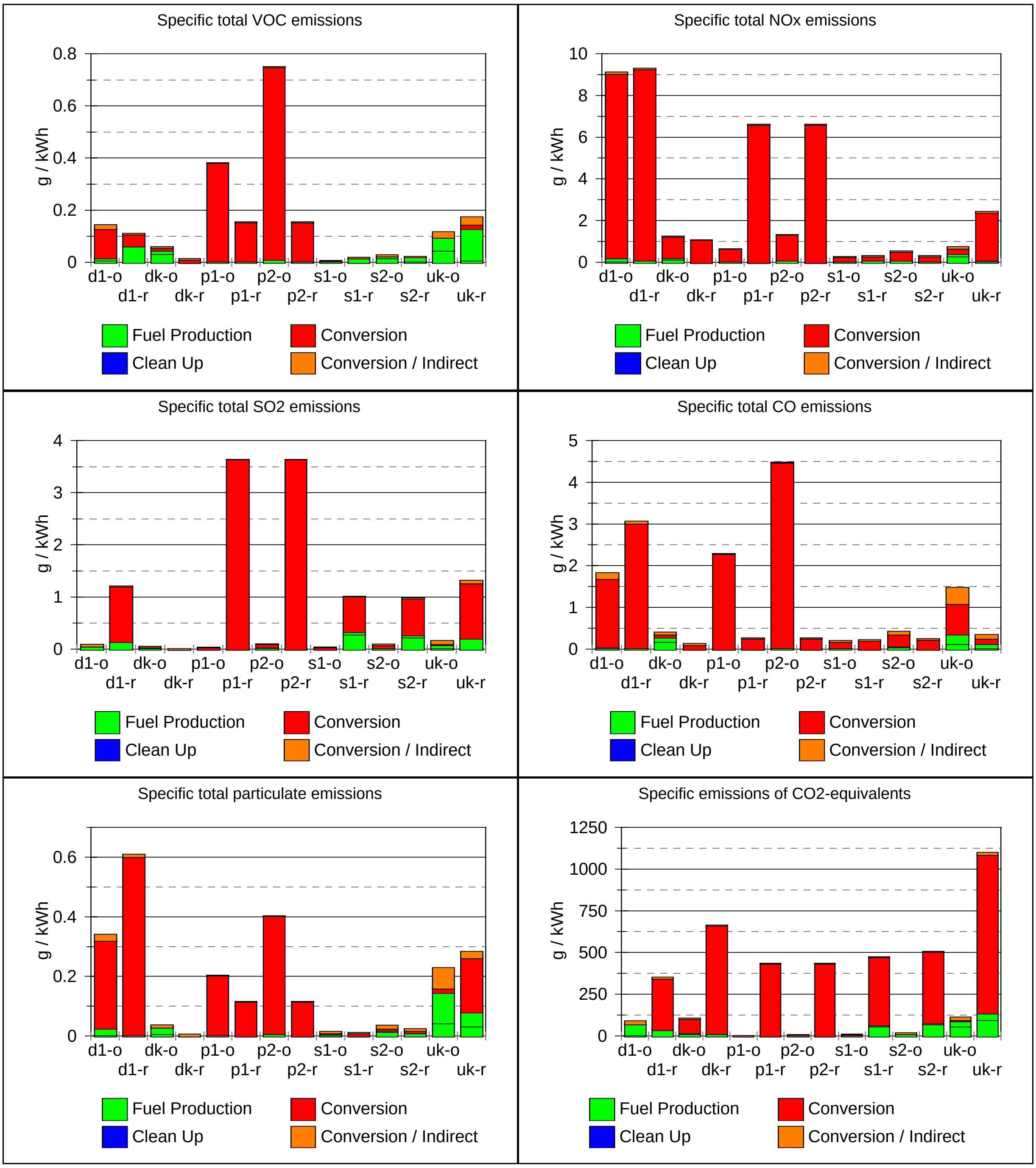

Figure 22 Summary of the total specific emissions of air pollutants of the BioCosts case studies, which produce heat and electricity. Abbreviations are defined in Table 41.

is a demonstration unit. As the other case studies show, there is no technical reason which prevents lower CO emissions if this is made an objective. The same is true for particulate emissions, which are low in the Scandinavian cases, but rather high for all other installations.

Finally, Figure 22 clearly illustrates how the emission of CO_2-equivalents can be reduced by using biomass instead of fossil fuels, typically by a factor of 10 or more. Only the rape-seed oil (d1) and the biogas case (dk) deviate somewhat. In the later case, the reduction is only by a factor of 6 due to methane emissions of the internal-combustion engine, which might be

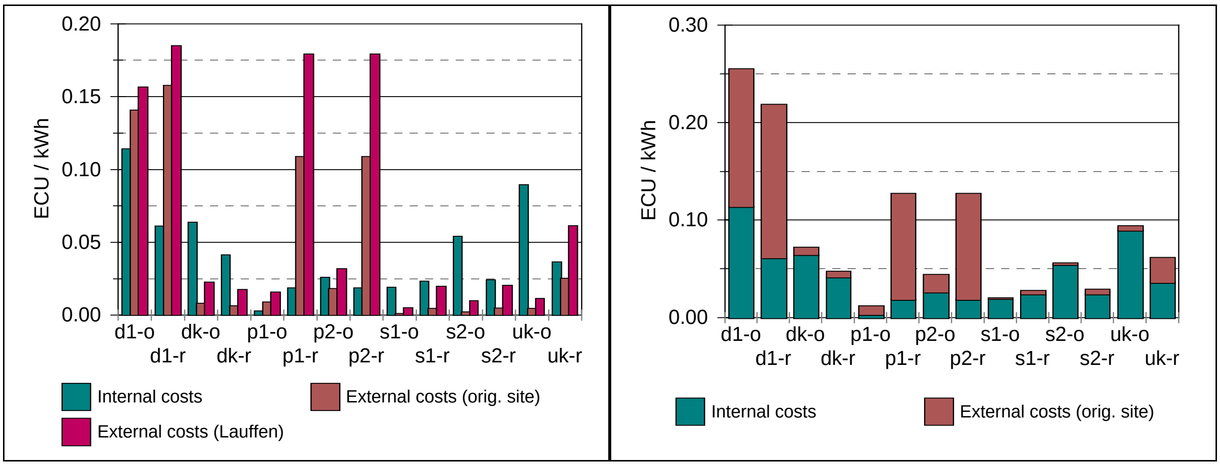

Figure 23 Internal and external costs of BioCosts case studies at original site and at Lauffen, Germany.

avoided if a turbine was used instead. This would also help to reduce NO_x emissions. For the rape-seed oil, emissions are only reduced by a factor of 4 since the production of fertilisers requires substantial amounts of fossil fuel.

Figure 23 compares the internal and external cost figures derived in this study. External costs refer to human-health impacts by air pollutants exclusively since it has been concluded that these effects are by far the most important ones. External costs are stated for the original site of each technology and also for the hypothetical case in which the technologies were moved to Lauffen in Germany. There are huge differences in the external costs of the different case studies ranging from below 1 to above 150 mECU/kWh. In most cases, with the exception of biogas versus natural gas, we find a benefit for the biofuel application. The most favourable options are the use of forestry residues directly or via gasification in Sweden (s1-o, s2-o). For a number of cases, external costs are of the same magnitude as internal costs. This is especially true for all oil-driven engines and for coal-fired power plants placed in the UK or Germany. Of the biomass fuel cycles, this is – next to the rape-seed oil engine – only the case for the two Portuguese facilities. Finally, it should be noted, that the Portuguese Case 2 is the only facility which would be made economic by internalising the external costs calculated.

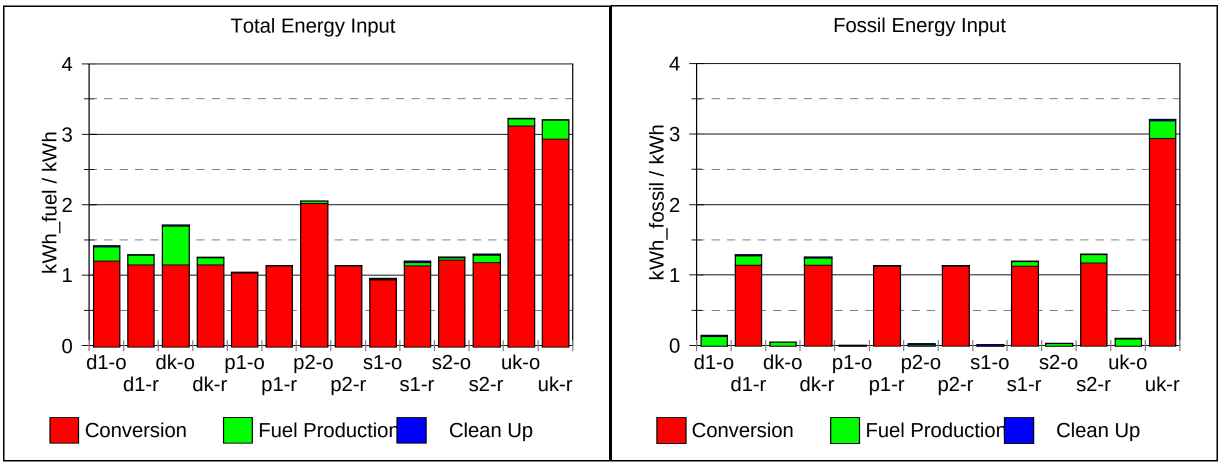

Figure 24 Specific total and fossil energy input of the BioCosts case studies.

Figure 24 displays the total and fossil energy input for all case studies. The total energy input per kWh of energy output is a measure of the overall energy efficiency. The two UK facilities and Case 2 of the Portuguese study have rather low conversion efficiencies, in the first case because only electricity is produced and in the second case because not all the potential energy produced can be utilised in the company and the surplus cannot be sold. The fuel production stage uses significant amounts of energy only for rape-seed oil and biogas production. While in the latter case, renewable energy from the facility itself is applied, fossil fuel is used in the former case. Thus, the relative reduction in fossil fuel consumption is much lower for rape-seed oil than for the other cases. This is relevant on the one hand with respect to the protection of non-renewable resources and, on the other hand, will also be reflected in the discussion of global warming below.

Table 42 and Figure 25 indicate the CO_2-abatement costs of the different case studies, including the two transport applications. Abatement costs are defined as the ratio of the specific cost difference over the difference of specific emissions of CO_2-equivalents. When based on internal costs only, the cost difference is implicitly attributed to CO_2 reduction exclusively. Therefore, we also indicate CO_2 abatement costs if external costs of conventional air pollutants at the original site and at Lauffen are taken into account. For case studies where biomass has an advantage over the reference case with respect to conventional pollutants, CO_2 abatement costs are decreased.

As discussed in Section 1.3.4, the BioCosts team views CO_2 damage cost estimates as too uncertain to be directly included in the external cost figures produced here. Therefore, in Figure 25, we compare the CO_2-abatement costs of the different case studies to damage cost estimates from literature. One of the lowest estimates found is the one by Nordhaus (1991) using his DICE model. He obtains a figure of 1.8 ECU/t CO_2 (7.3 US-$/t C). As Azar and

Table 42 CO_2-abatement costs of the biomass fuel cycles as compared to their references cases.

	Short name	CO_2-abatement cost in ECU/t CO_2-equivalent, based on:		
		Internal costs	Internal plus external costs at orig. site	Internal plus external costs at Lauffen
Electricity and heat case studies				
Forestry residues, Nässjö, Sweden	s1-o	-9.3	-17	-41
Mangualde, Portugal				
Case 1: Forestry residues	p1-o	-36	-270	-410
Case 2: Short-rotation coppice (SRC)	p2-o	17	-200	-330
Biogas, Hashöj, Denmark	dk-o	40	43	49
Gasification of forestry residues, Värnamo, Sweden	s2-o	61	55	40
Gasification of SRC, Eggborough, UK	uk-o	54	33	3.3
Rape-seed oil for CHP, Weissenburg, Germany	d1-o	190	130	130
Transport case studies				
RME for transport, Germany	d2-o	100		
17% ETBE mix for transport, France				
– ETBE from sugar beets				
– versus 15% MTBE mix	f1-o	81		
– versus pure gasoline		no reduction		
– ETBE from sweet sorghum				
– versus 15% MTBE mix		14		
– versus pure gasoline		58		

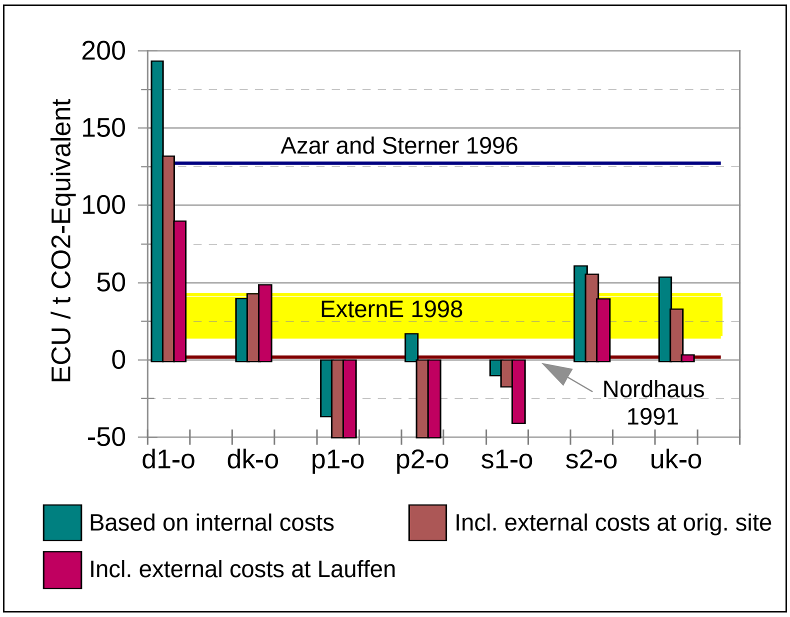

Figure 25 CO_2 abatement costs of biomass-to-electricity case studies with and without considering damage to human health by conventional air pollutants; including damage cost estimates by Nordhaus (1991), Azar and Sterner (1996) and ExternE (CEC 1998, Eyre et al. 1997).

Sterner (1996) point out, this result is mainly due to using a rather high discount rate of 3% even for long-term damage, no equity weighting and a low retention time of CO_2 in the atmosphere. With the same model, but different assumptions on the three issue listed, Azar and Sterner reach values up to 127 ECU/t CO_2. In the ExternE project, calculations with the FUNDS model yielded a range of 15-42 ECU/t CO_2 (CEC 1998, Eyre et al. 1997).

For the BioCosts case studies, three categories can be distinguished. First, there are case studies which have negative CO_2-abatement costs since they are economically more efficient than there reference cases (p1-o, s1-o). Hence, for them we have a classical win-win situation under prevailing economic conditions. Second, we have case studies with very high abatement costs, which include the two rape-seed oil cases (d1-o and d2-o). Provided that the financial resources for mitigating global warming will be limited, these case studies would not belong to first choice options. Third, we have the remaining case studies (dk-o, p2-o, s2-o and uk-o) which have medium range abatement costs that are more or less within the ExternE damage cost range.[18] These are the ones which are most interesting candidates for future R&D support and market introduction programs. Also, it has to be stressed that three cases (p2-o, s2-o, uk-o) provide two benefits at the same time, mitigation of global warming and a reduction of human health impacts from conventional pollutants. Only in the case of biogas versus natural gas in Denmark (dk-o), mitigating global warming has to be paid for with a limited increase of impacts from conventional pollutants.

The case study on production and application of ETBE in France does not fit into the three categories described so far without further discussion. First, is has to be noted that the values

[18] Considering the uncertainties of all the figures involved, it cannot be concluded with sufficient precision that some of the abatement cost figures are definitely above or below the ExternE damage cost range even though the figures stated would indicate this.

stated are more uncertain than for the other case studies. Assuming that ETBE replaces MTBE, we find abatement costs of 81 ECU/t CO_2 if ETBE is produced from sugar beets and 14 ECU/t CO_2 if it is derived from sweet sorghum. The reason for this difference is mainly the use of the bagasse as energy supply in the latter case. While the first figure would clearly place this case study in the group of non-favourable options, the second figure is quite promising. The interpretation of this result is not straight forward. On the one hand, one may conclude that the energy use of the bagasse is crucial for the viability of this biofuel scheme. On the other hand, this result illustrates the large influence of the allocation mechanism. If the bagasse were not used, CO_2-abatement costs would increase to 23 ECU/t CO_2. Furthermore, as the continuing debate in California shows, there is no consensus that the use of MTBE has benefits in the first place. Therefore, to indicate the effect of adding oxygenate compounds to gasoline on the emission of CO_2-equivalents, we try to calculate abatement costs with respect to pure gasoline. In the case of sugar beets, however, we find no reduction, but a 13% increase in CO_2-equivalent emissions. For sweet sorghum, abatement costs increase to 58 ECU/t CO_2. This sensitivity analysis is not made to suggest that oxygenate compounds should not be used at all, but to demonstrate the trade-off between their alleged benefits and their contribution to global warming.

2.10. The Role of Biomass in the EU

The potential for the different technologies assessed in the BioCosts project has been stated in the respective sections above. Here, we discuss the general role of biomass in a future EU energy system.

The "true" present contribution of biomass to the primary energy demand in EU-15 is 3.5%, 90% of which is derived from forestry residues (Chartier 1996). This corresponds to about 55% of the total renewable energy supply. The share of the primary energy demand is expected to increase to 4-7% up to the beginning of the next century. In the long run, biomass could even become the largest single source of energy supply (LTI-Research Group 1998). Currently, the use of biomass is predominantly for heat supply (1 500 PJ/a), while electricity generation amounts to only 55 PJ/a.

In the White Paper on renewable energy sources (CEC 1997), the European Commission aims at doubling their share from 6 to 12% in 2010.[19] The largest contribution is foreseen to come from biomass, the use of which would triple from 1 900 to 5 600 PJ/a in this period.

The White Paper states that at most 10 million ha of land will be available for energy crops within the next 15 years, which would allow for obtaining some 1000 PJ/a of energy. The availability of land will depend on the integration of the countries of Central and Eastern Europe into the EU and on future world market trends. In addition, the demand for food products from Southern Mediterranean countries will be an important factor. Finally, assuming that providing 1100 PJ/a of energy crops for heat and power would require about 6.3 million ha, it seems rather optimistic to expect that 750 PJ/a of liquid fuels can be derived from the remaining 3.7 million ha. Even with optimistic assumptions about the production of ethanol (not ETBE) from sugar beets, we estimate that only half as much net energy could be derived from that area (details may be found in the working paper by Scrase and Bauen 1998).

[19] The different figures on the current share of biomass are due to different forms of accounting in different studies. Often, municipal solid waste and its incineration are counted under the heading of biomass.

In this context, it should also be noted that traditional crops, especially for liquid fuels, are technologically least challenging but receive much financial support presently. However, they are not the most promising in terms of net energy production and overall environmental impacts.

Moreover, we do not agree with simply adding urban and industrial waste to renewable energy sources. First, much of this waste is not renewable in the sense that a more sustainable economy would try to diminish the amount of waste produced as much as possible. Second, municipal waste contains materials which do not stem from renewable sources such as plastics. Therefore, only organic waste from households and food industries collected separately should be regarded as a renewable resource. At least, only the biomass part of the total heating value of the waste should be counted as renewable.

Wood will remain the most important biomass resource for energy purposes. Forestry by-products constitute an abundant resource, amounting to about 2 000 PJ/a. It should be exploited with priority, especially considering the environmental benefits of the respective fuel cycles found in the BioCosts project.

The main obstacle to the use of biomass is the fact that it is in most cases more expensive than fossil fuels. There are a number of exceptions, though. First, if a cheap residue is available, its use may be economic as the Portuguese case study of the BioCosts projects shows. In addition, if a country has a determined policy towards improving the quality of the environment, it can make the use of biomass, at least in the form of residues, economically attractive. The case of Sweden shows how environmental taxes can be used successfully to this end. The set-aside land scheme of the EU, on the other hand, is regarded as too unreliable by farmers for long-term decisions.

Mostly, biomass for energy is considered a high risk investment for which it is hard to obtain financing. Nevertheless, further targeted R&D can be expected to reduce the cost of energy from biomass due to increased efficiency of fuel production, especially for energy crops, but also for residue collection and treatment. The two other most important obstacles are the reluctance of potential actors to go ahead with the use of biomass and the resistance from the traditional energy sector in some EU countries.

Part III: Conclusions

Even when considering the uncertainties involved in the quantitative results of the BioCosts project, there are a number of conclusions which are well founded since they are supported by several indicators and more or less independent of the methodology chosen.

The energy use of biomass can have significant environmental advantages compared to the use of fossil fuels if it is organised appropriately.

First of all and beyond doubt, biofuels are an important option to reduce net emissions of CO_2. Most of the biomass fuel cycles investigated have a clear advantage over fossil fuels regarding their contribution to global warming. However, the contributions are of different size and importance. In general, the advantages turn out to be larger and more cost efficient for solid and gaseous fuels than for liquid fuels.

The picture is more differentiated for conventional pollutants, such as NO_x, SO_2, CO, VOC and particulate emissions. While there is always an advantage of biomass with respect to SO_2, there are cases where some of the other emissions are higher for the biomass fuel cycle than for the application of fossil fuels. However, in well managed cases, the difference is either small or emissions occur at low levels anyway. Concerning external costs from human health impacts of the pollutants listed, there is an advantage of biomass when compared to coal and oil, but a (small) disadvantage compared to natural gas. Remaining problems, regarding for instance NO_x or CO emissions, are mostly due to the technology applied and not due to the fact that biofuels are used as feedstock. Solutions to these problems are mostly available or seem feasible, but are not yet standard technology. Therefore, they should be tackled by carefully targeted R&D.

The emission inventories are dominated by the energy conversion stage of the fuel cycle while the clean-up stage has virtually no visible impact. The contribution of fuel production – though small in general – is the larger the more complicated the fuel preparation process is.

If the strong implicit focus of ExternE on human health impacts, which is due to the exposure-response functions and economic valuations in the EcoSense model, prevails, reduction of NO_x has to become a major policy target. This does not only hold for biomass, but also for fossil fuels since NO_x emissions depend on the conversion technology in the first place. There are a number of technological options for reducing NO_x emissions available at moderate costs. Therefore, when introducing new technologies, low NO_x emissions should be an important criterion.

There are several other, mostly qualitative benefits and damage that accompany the energy use of biomass. First, the use of forestry residues may contribute to reducing acidification levels in the forest. Especially in Sweden, this is regarded as valuable and expresses itself in a high willingness-to-pay demonstrated by the wide acceptance of relevant environmental taxes.

Second, the use of biomass residues may contribute to solving waste problems which is illustrated by the production of biogas from animal slurry and the use of sewage sludge for fertilising short-rotation coppice.

Concerning impacts on biodiversity, water and soil quality, we have found negligible marginal effects in our case studies. This may change, however, if these fuel cycles are implemented at a larger scale. Adverse consequences may be avoided if the technologies are introduced carefully and if possible negative impacts are counteracted right from the beginning. For instance, energy crops should not be planted in areas which are or should be nature reserves, but in re-designated agricultural areas. Furthermore, the use of fertilisers has to be adapted to the actual uptake of the plants, and pesticides have to be applied sparsely. It may be worthwhile to examine in how far guidelines and a tax on fertilisers, pesticides etc. could promote such a behaviour.

Possible future competition for resources and land should be taken seriously at an early stage. Otherwise, developments such as the increasing share of organic farming in Denmark may erode the potential of biomass. Changing the diet towards less meat consumption, on the other hand, may contribute significantly to increasing the area available for energy crops.

It may also be concluded that it is important to involve local stakeholders at an early stage. This may help to ensure appropriate definition of and compliance with good practice guidelines and to preserve rural amenity, thus avoiding local resistance to the new technologies.

The combined production of heat and power has substantial advantages over separate production of these commodities if demand and supply can be brought into phase. With respect to the use of biomass, this is not only an issue of rational use of energy, but also of making optimal use of the scarce land resources available for energy purposes. Gas turbines and combinations of boilers and steam turbines are clearly preferable compared to combustion engines which exhibit considerable problems with emissions of NO_x and methane. However, it should be noted that installing engines may be an economic necessity if one wants to realise cogeneration potentials in areas with low demand densities. Thus, there is a trade-off between energy efficiency and mitigation of global warming on the one hand and health impacts of conventional pollutants on the other hand.

Furthermore, there is an advantage of using residues compared to energy crops and of perennial woody crops over annual crops. This is due to the effort for growing of annual crops and to the complex fuel preparation processes involved in converting biomass into a convenient biofuel.

The advantages of liquid biofuels are less clear than for solid and gaseous fuels (and sometimes non-existent) as their production requires substantial amounts of fossil energy. The example of using the bagasse by-product as energy source in the process indicates that further integration of the production processes might improve the picture.

The different case studies revealed a broad range of energy production costs. Two case studies were found to be economic at present fuel prices, mainly because the feedstock is available at low cost. The other case studies are up to 50% more expensive than their reference cases. Bringing down the internal costs of the promising biomass fuel cycles should be an important objective of R&D strategies at national and EU levels.

For a number of technologies, including biogas and gasification of forestry residues and short-rotation coppice, the CO_2-abatement costs are in the same range as the damage cost estimates of ExternE for global warming. Combined with external costs from health impacts of conventional pollutants, we see a clear incentive to pursue the application of the biomass technologies.

This is even more the case if one adopts the notion of strong sustainability as a policy guideline. In this case, the higher costs of biofuels and other renewable energies may be regarded as payments for an insurance against damage to the environment in general and the risk of global climate change in particular.

Nevertheless, market-based incentives should be used to support the market introduction of biomass-to-energy applications in order to select the most favourable application. Such incentives could be fuel taxes or emission taxes which may be justified as an internalisation of external costs. However, reflecting the large uncertainties of the external cost concept, the levels of such taxes should be determined by the objectives pursued rather than the external costs calculated. This principle is called standard-price approach in economics and is well in line with the concept of strong sustainability. An alternative instrument for implementing a standard-price approach are tradable permits as they are foreseen in the Kyoto protocol on global warming.

Not surprisingly, calculating external costs with the EcoSense model revealed a crucial dependency on the site chosen and, consequently, the population density in the area hit by the exhaust plume. Thus, this methodology may be helpful when siting energy conversion facilities. However, its use for a general assessment of technologies is limited.

The energy use of biomass will most probably not lead to a decrease in employment. It may even contribute moderately to additional employment. However, improvements in efficiency necessary for economic reasons may also reduce the labour input into biomass fuel cycles. Thus, the energy use of biomass should not be regarded as a substantial contribution to solving the unemployment problem. Nevertheless, there may be local benefits in rural areas.

With respect to socio-economic frameworks, the case studies examined indicate a number of issues which are essential for the success of biomass fuel cycles:

- First, it has to be demonstrated that the technology is mature and has environmental benefits.
- Then, economic conditions must be favourable. This can be influenced decisively by government policies.
- Within such constraints, entrepreneurs should be left as much freedom as possible to organise the fuel cycle efficiently.
- However, their efforts have to be closely monitored and made subject to tight environmental standards in order not to trade in advantages for one environmental problem (e.g. global warming) against disadvantages for others, e.g., impacts on human health by air pollutants.
- The existence of determined groups of local people who want to promote innovative solutions is essential. Local benefits are crucial to guarantee local support of new technologies.
- The frameworks established have to be easy to understand, non-bureaucratic and reliable for substantial periods.

All in all, we emphasise that carefully chosen and well managed biomass fuel cycles can provide an important, if not indispensable contribution to a sustainable future energy system for the European Union.

Part IV: Annexes

Nomenclature

a :	Year
BIG/CC :	Biomass integrated gasification / combined-cycle (gas and steam turbine combustion)
CFB :	Circulating fluidised bed (-combustion)
CFC :	Chlorofluorocarbon
CH_4 :	Methane
CHP :	Combined heat and power(-plant)
CO :	Carbon monoxide
CO_2 :	Carbon dioxide
CVM :	Contingent valuation method
DG :	Directorate General
ERF :	Exposure-response function
ETBE:	Ethyl tertiary butyl ether
g / (p·km):	grams per person-kilometre (i.e. per kilometre travelled by 1 person)
g / (t·km):	grams per tonne-kilometre (i.e. per ton of a good transported over 1 kilometre)
h :	Hour
ha :	Hectare (1 ha = 1000 m^2)
hl :	Hectolitre (1 hl = 100 l)
I/O :	Input-output (-model)
kg :	Kilogram
kWh:	Kilowatt-hour
LCA :	Life-cycle analysis
mECU :	Milli-ECU
MJ :	Megajoule
MTBE:	Methyl tertiary butyl ether
MW :	Megawatts
MWh :	Megawatt-hour
N :	Nitrogen
Nm^3 :	Norm cubic meters (cubic meters of a gas at norm conditions, 15^{o}C, 1013 HPa)
N_2O :	Nitrous oxide
NO_x :	Nitrogen oxide
odt :	Oven-dry tonne
PM :	Particulate matter
RME :	Rape-seed oil methyl ester
SO_2 :	Sulphur dioxide
t :	Tonne
TSP :	Total suspended particulates
VOC :	Volatile organic compounds
VLYL :	Value of life years lost
VOSL :	Value of a statistical life
YOLL :	Years-of-life-lost
WTA :	Willingness-to-accept (compensation)
WTP :	Willingness-to-pay

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Remark: Internal documents of the BioCosts project are shown in italics.

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