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ASSESSMENT OF THE EXTERNALITIES OF BIOMASS ENERGY, AND A COMPARISON OF ITS FULL COSTS WITH COAL

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Abstract—This paper has assessed the externalities of biomass for electricity production, and compared them with those of coal. The effects studied have been those on human health, CO_2 balance, soil erosion, non-point-source pollution, and employment. The methodology used has been the one developed by the ExternE Project of the European Commission, which has been extended by CIEMAT to cover socioeconomic impacts. A more site-specific methodology for dealing with soil erosion and non-point-source pollution is also proposed. This methodology has been applied to assess the externalities of a proposed biomass power plant in Spain, and also to a hypothetical coal power plant in the same location. In spite of the high uncertainty involved in the assessment, results show that, when externalities are introduced into the cost analysis, the total costs of biomass electricity is lower than that of coal, under the assumptions used. © 1998 Published by Elsevier Science Ltd. All rights reserved

Keywords—Externalities, social costs, biomass, energy, methodology.

1. INTRODUCTION

Biomass energy faces several barriers for its widespread implementation, of which the most important may be its cost. However, this renewable energy source also presents several benefits, both socioeconomic and environmental, when compared to conventional energy sources.

From the socioeconomic point of view, energy crops are an alternative to traditional crops, and can be grown on set-aside lands, thus contributing to rural diversification, income, or employment increment. The substitution of imported fuels by biofuels may also increase national wealth, and improve the balance of payments.

With regard to environmental aspects, energy crops are neutral for CO_2 emissions that is, all the carbon dioxide emitted by biomass combustion was fixed by the same biomass during its growing period. Growing biomass in set-aside lands would also reduce erosion risk, which is specially important in Southern European countries.

The consideration of these benefits, on the same grounds as the financial costs, might make up for the lack of economic competitiveness. This is what is called "to internalize externalities".

Externalities are those consequences of a production process, imposed on society or the environment, which are not taken into account in the product price. They are produced whenever production processes, or consumers' utility, are affected by variables not controlled by themselves, but by other economic agents. These effects may be positive (external benefits) or negative (external costs).

The fact that these costs and benefits are not included in the price, and thus, not taken into account by the market, produces a market failure, as the price is the market assignment tool. This failure produces in turn an inefficient assignment of resources.

In order to correct this failure, externalities have to be incorporated in the product price, or internalized. The internalization of external costs is already encouraged by several institutions, such as the EU in its Green Paper on Energy, or Fifth Environmental programme.

Once external costs are internalized, the pros and cons of different energy options may be analyzed on the same basis, when trying to achieve contradictory objectives, i.e. economic and environmental. It will be possible to compare, for example, the environmental advantages of renewable energies with the lower generation costs of fossil fuels energy.

However, prior to this internalization, externalities have to be quantified and expressed in the same terms as prices that is, in monetary units. Here a methodology is presented for the assessment of the externalities of biomass energy in monetary units. The positive effect that the consideration of externalities may have on biomass energy competitiveness is shown by a comparison of its full costs with those of coal. In the following section, this methodology is briefly explained.

2. METHODOLOGY

2.1. *General aspects*

The quantification of externalities of energy has been attempted by several approaches. The first major effort was the "top-down" approach proposed by Hohmeyer.[9] This analysis is highly aggregated, being carried out at regional or national levels, with estimates of total quantities of pollutants emitted, and of the damages caused. This analysis is considered too simplistic for policy use, especially because it does not take into account the site dependence of the damages.

A second alternative is the "control cost" approach. This estimates damages by the cost of reducing emissions of the pollutants causing the damage, by arguing that the level of pollution abatement decided by regulators is the economic optimum. This method assumes that regulators possess perfect information on costs and damages, which is a rather untenable point of view.

These approaches have been considered to be insufficient for the assessment of externalities for their internalization. The methodology proposed in this paper for the assessment of the externalities of biomass energy is based on the one developed by the ExternE Project,[2] which has been running since 1992 under the funding of the European Commission. This methodology has been extended by CIEMAT, so that it may cover in a more precise way impacts more characteristic of biofuels, such as employment, or soil erosion.

The ExternE Project proposes the "impact pathway" or "bottom-up" approach for the assessment of the external impacts and associated costs and benefits resulting from the supply and use of energy. The analysis proceeds sequentially through the pathway, as shown in Fig. 1. Emissions or other types of burdens, such as soil eroded, are quantified and followed through to impact assessment and valuation. The approach thus provides a logical and transparent way of quantifying externalities. The analysis is site- and technology-dependent, given that damages vary considerably depending on the receptor affected. Thus, the study has to consider the impacts produced by an additional facility, located on a specific place.

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

- transparency, to show precisely how results are calculated, the uncertainty associated with the results, and the extent to which the external costs of any fuel chain have been fully quantified;
- consistency of methodology, models, and assumptions, to allow valid comparisons to be made between different fuel cycles and different types of impact within a fuel cycle;
- comprehensiveness, in that it should at least identify all the effects that may give rise to significant externalities, even if some of these cannot be quantified in either physical or monetary terms.

These characteristics should be present at all stages of the assessment of externalities, which are shown in Fig. 2.

2.2. *Site and technology characterization*

As noted before, the assessment has to be site- and technology-specific, in order to allow for the bottom-up, marginal approach. Therefore, all the stages of the biomass fuel cycle have been assessed based on a 20 MW

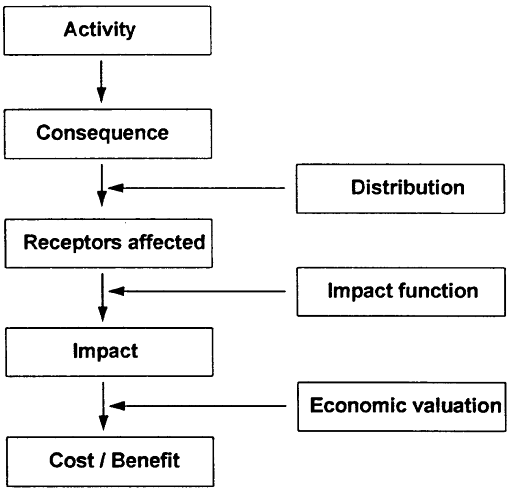

Fig. 1. Impact pathway.

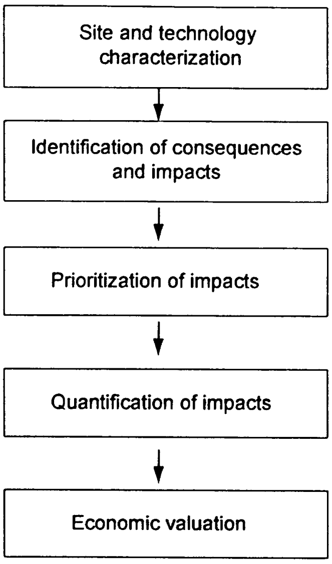

Fig. 2. Stages of the externalities assessment.

power plant located in Sanlúcar la Mayor, in Southern Spain, which will work 7500 h per year.

The technology selected for this power plant is fluidized bed combustion, as it is one of the most promising technologies for biomass combustion in the near future. The major burdens of this technology, such as the atmospheric emissions, liquid effluents, or solid residues, have been characterized.

The fuel used will be *Cynara cardunculus*, an herbaceous energy crop well adapted to Mediterranean conditions. This crop will be grown on 9300 ha of set-aside land, that is, agricultural land retired from production following the EU Common Agricultural Policy (CAP) guidelines. It is important to note that, under this policy, set-aside land should either be kept fallow, or be cultivated with some type of non-food crop. However, the current use in Spain is mostly to leave it fallow, or rather, as the CAP states, in good agricultural condition. This means, in practical terms, that farmers are required to till this land as if it were to be cultivated, and not to allow weeds to grow on it, the land remaining therefore bare. If the land was not tilled, or cared for, it would revert to semi-natural status, and that is not accepted in principle by the Ministry of Agriculture.

Regarding the site characterization, both the environmental and socioeconomic conditions of the area have been analyzed. Briefly, the area is rural, with high unemployment levels, especially in the agricultural sector.

This characterization has required the definition of the boundaries of the analysis, both for the activities and the receptors of the impacts. The temporal and spatial limits of the study have been designed to capture impacts as fully as possible, so it is unrealistic to fix a single time or space scale on all impacts. These limits depend on the nature and scale of the impact. For example, global warming impacts affect the whole world, and its effects should be traced for many years. On the other hand, erosion affects a more limited area, and its effects are not so long-term.

The comprehensiveness of the analysis has however been limited by the availability of data, and the uncertainty associated with the process.

2.3. *Identification of consequences and impacts*

All potential consequences and impacts of the fuel cycle falling within the boundaries of the analysis have to be identified. No impact that is known, or suspected to exist, but cannot be quantified, should be ignored for convenience. Moreover, it is recommended to highlight this gap for future research.

All this identification is done by means of the Accounting Framework, a matrix where all the activities, consequences, and impacts, are presented in a summarized way. This matrix gives a global view of the impacts, and helps avoid double counting.

In he case studied, a large matrix has been created linking activities, consequences and impacts of the biomass fuel cycle. Among the impacts identified, the following may be cited: impacts on public and occupational health, crops, forests, soils and groundwater, global warming processes, transport networks, visual amenity, employment, national economies, etc.

The full matrix may be found in the report on which this paper is based[1].

2.4. *Prioritization of impacts*

As mentioned before, all impacts of the fuel cycle assessed have to be identified. However, the large number of them make it unrealistic to assess all, even if it is assumed that all of them may be quantifiable

In fact, it can be shown that many of them will be negligible when compared to the rest, and others may be very difficult to quantify. Therefore, we may prioritize the impacts of the biomass fuel cycle, and assess only some of them. Based on expert judgement, and earlier evidence, some of the impacts may be expected to be the most relevant.

For the biomass fuel cycle, the following impacts seem more relevant: effects on employment, health effects caused by the atmospheric emissions of the power plant, erosion and non-point-source pollution due to the land cultivation, and global warming.

Other effects, which might be expected to be significant, such as the health effects due to air emissions of the biofuel transport, have been shown by previous studies[8] to be negligible, given that the emissions produced in this stage are less than 1% of the total emissions. For sulphur dioxide, emissions during transport are not negligible compared with those of power generation (as the emissions in this stage are very low), but the damages caused by this pollutant in the transport stage are dwarfed when compared to those caused by particulates or NO_x emissions from power generation.

Other impacts not considered, but which might have some importance, are those caused by the liquid effluents and solid residues of the power plant, or the visual amenity aspects of the energy crops. However, these impacts are very difficult to quantify.

Of course, due to assessing only some of the impacts, the results obtained may only be considered an underestimate of the total externalities produced by the biomass fuel cycle.

2.5. *Quantification of impacts*

The method used for the quantification of the impacts of the biomass fuel cycle is the "damage function" approach. This is a series of logical steps that have to be followed from the realization of an activity, through the consequences it produces, and finally to the monetary valuation of the impact it causes. This done for each activity and impact, so that additional effects can be accounted for separately, as the marginal approach requires. As noted before, interactions between different impacts have to be clearly identified in order to avoid double-counting, so as not to underestimate the impacts.

The application of the "damage function" to each of the impacts to be assessed is shown in the following sections.

2.5.1. *Employment*. One of the benefits to be taken into account in a biomass power plant is the effect it produces on job creation. Although job creation does not always mean a social benefit, positive externalities arise whenever unemployment levels are higher than the natural unemployment rate, and thus the employment generated by the power plant contributes to reducing the unemployment levels. If the economy has full employment, the new demand for jobs will only be realized through a decrease in other jobs, so there will be merely a change in the allocation of jobs, but not a net increase. In fact, job creation is considered a social benefit by most governments, since they devote considerable efforts to reducing unemployment.

A biomass project will create both direct and indirect jobs. Direct ones are those needed to build the plant, operate it, and grow the energy crop. Indirect jobs are those created in other sectors of the economy because of the indirect demand of goods and services generated by the project.

This indirect demand arises from two sources: first, the investment needed for the project stimulates economic activity through the multiplier effect; second, the economy is also stimulated by the increase in consumption produced by the increment in workers' income. By the multiplier effect we mean the demand produced in all sectors of the economy by an increment in the demand of one of these sectors, due to the interconnections existing between them.

This effect is estimated by input-output models. Using tables, we may calculate the amount of jobs needed from all economic sectors to produce a given amount of output, or demand, by each of them.

Direct jobs have been estimated based on real projects with similar characteristics, and also based on the crop labour needs. Indirect jobs have ben calculated by means of an input-output model created for the 1990 Spanish economy. Both the investments needed for plant construction, operation and maintenance, crop growing, and the consumption flows generated by the direct jobs, have been introduced into the model for the lifetime of the project. These values have been discounted for three different discount rates, 0%, 3%, and 10%, to reflect the uncertainty in this rate.

By running the model, the increment in production caused by this demand in each economic sector has been estimated. This increment has then been translated into value added and then into jobs through regression analysis. These analyses are not as complex as they should have been due to the lack of data, but they do provide a good estimation.

In addition to this data problem, input-output analysis presents other shortcomings. It is only valid for static analysis, as it is based on relationships established for a certain year (1990, in our case). Moreover, the model only accounts for official economic transactions, but not for the "underground" economy, which may be important in some cases.

The remaining problem is the monetary valuation of the jobs generated. This valuation will depend on the economic conditions of the region, the political environment, the social value of jobs, etc. The ideal way of valuing jobs would be to measure the willingness to pay (WTP) of society to have new jobs, as this is a consistent measure for the further internalization of externalities into prices. However, no such values have been estimated yet for Spain, so an alternative approach has been used, one based on the "avoided cost" approach.

This approach has attempted to value jobs by the expenses avoided in unemployment subsidies, since that is really a benefit for the government, and ultimately, for society. However, this should be considered as a lower limit, as it does not include other sociological aspects of unemployment. In fact, if we consider the value of jobs for governments, by looking at their expenses in job promotion, we obtain values ten times higher. Although this is also not a precise value, it may provide an upper limit for the estimation.

2.5.2. *Health effects*. The effects on health considered for our analysis have been those caused by the atmospheric emissions produced during the power generation stage. These emissions are 640 gNO_x/MWh, and 160 g/MWh for particulates. SO_2 emissions have been considered to be negligible for this stage.

The emissions generated for the rest of the stages of the biomass fuel cycle have been estimated, especially those produced during biofuel transport, but they have been found to be negligible when compared to the power generation emissions, as has been shown by other studies.[8] These emissions also present the problem of being quite complex for their atmospheric dispersion modelling.

The first step for the assessment has been the modelization of the dispersion of the pollutants considered. This has been done with atmospheric dispersion models, which take into account meteorological or topographic factors. Two dispersion models have been used, ISC for the local range, and WTM for the regional range. These models are well accepted for regions where topography is not too complex, such as the area studied. The models are included in EcoSense software, developed by IER (University of Stuttgart).

Once the pollutant concentrations affecting the receptors are known, the effects they produce may be estimated through dose-response functions. These functions link pollutant concentrations with different health impacts, such as asthma attacks, bronchitis, or even mortality. They are usually obtained with epidemiological studies carried out in small areas, so their transferability has to be carefully examined.

A complete list for the dose-response functions linking air pollutants (such as particulates, SO_2, and ozone) and health impacts may be found in the ExternE report.[2] Only functions for particulate matter have been used, since ozone has not been modelled, and SO_2 emissions were considered negligible.

The second part of the assessment is the monetary valuation of the impacts. This is a difficult task, because it should not take into account only the cost of illness or death to the health systems, but also the associated pain and suffering. This is even clearer for the cost of mortality, or rather, the value of human life.

This value should be calculated as the WTP to avoid the risk of death. Several figures have been produced in Europe and the USA using direct or indirect valuation methods. The value established in the ExternE Project[2] has been 2.6 MECU, and that has been the one used in this study. The values assigned by ExternE to other health impacts have also been used.

2.5.3. *Global warming*. Among the major benefits of biomass systems is that they are CO_2-neutral, or may even be carbon sinks.

The steps for the assessment of this externality include the determination of the net CO_2 emissions of the biomass fuel cycle, and the monetary valuation of its impact.

The carbon emissions of the whole biomass fuel cycle have been estimated. Biomass cultivation, transport, and power generation are activities with a net release of carbon to the atmosphere. However, the growing of the energy crop fixes carbon from the atmosphere, by the photosynthetic process. The net balance of CO_2 for the fuel cycle will depend on its characteristics.

In the case of the biomass fuel cycle studied, the CO_2 emissions during biomass cultivation and transport amount to 1385 t/yr. In the power generation stage, 204,000 t/yr of CO_2 are released, which come from the carbon contained in the biomass. Since this carbon has been previously fixed from the atmosphere, it can be considered then that no net emissions are produced.

In addition, it must be noted that only a part of the plant is harvested, part of it staying in the soil as roots and part of the stem. The carbon stored in such parts then partly decomposes, partly is incorporated into the organic matter of the soil, thus constituting a carbon sink.

In the present assessment, we have assumed that the carbon stored in the soil will equal that released during cultivation and transport, so that the biomass fuel cycle may be considered to be neutral, or even a carbon sink. Further research is under way to determine this aspect.

As for the monetary valuation of the emissions, several models have been developed in the last years, to assess the damage caused by CO_2 emissions. These models analyze the impacts that a rise in global temperatures caused by CO_2 emissions would produce on the sea level, agriculture, ecosystems, human population, and the global economy.

In our analysis, the results provided by the Climate FUND model[4] have been used. This model proposes a range from 0.52 to 13.17 ECU per t of CO_2 emitted depending on the scenarios considered and on the discount rates used (from 0 to 10%).

Although we consider these values as the best available, using them adds great uncertainty to the valuation of carbon fixation or small carbon emissions. It is difficult to assume that the damage caused by CO_2 emissions at the large scale will be the same as those from the small amounts emitted, even less that they may equal the benefits of CO_2 fixation. More complex models should be used in these cases.

2.5.4. *Soil erosion*. Soil erosion is one of the effects that biomass cultivation has on the environment, without its being accounted for in the production cost. It is always a cost, although it may be a relative benefit when compared to an alternative land use.

If the alternative land use is another plant cover, the changes in erosion rates will be quite small, so there would be no point in considering this effect. However, as we mentioned before, the most popular alternative for set-aside lands in Spain is to keep them fallow, with the requirement of tilling them at least once a year. This means that the land is bare for most of the year, specially during the rainy season.

Therefore, if we consider this alternative, the cultivation of the energy crop will be a relative benefit, since plant cover will contribute to a reduction in soil erosion processes.

The factors to be considered to determine the amount of soil eroded in both cases are the rainfall, and soil and crop characteristics. All these parameters have been characterized for the area studied, and fed into the EPIC model[5] for the quantification of soil loss. This model was developed by the US Dept. of Agriculture to determine the relationship between erosion and productivity for the US and has been widely used for assessing soil degradation.

Once erosion rates have been estimated, the damage caused has to be put in monetary terms. These damages include the loss of arable soils, the loss of water quality, or the siltation of stream beds and reservoirs.

The first two aspects are not considered to be externalities. The loss of soil productivity because of the removal of its upper layer is a cost internalized by the farmers, as it is included in land prices, or crop management decisions. The loss of water quality at a small scale will not produce an increment in water cleaning expenses.

Therefore, the only damages valued have been those caused by siltation. The soil removed is assumed to settle into stream beds and reservoirs downstream from the fields, causing an alteration of their flow or storage capacity. The removal of these sediments implies some costs, which will be taken as a proxy for the damages of soil erosion. As mentioned before, the best way of dealing with this valuation would be to use measures of the WTP of the society to avoid these effects. However, no such values are available.

2.5.5. *Non-point-source pollution*. The use of fertilizers produces effects on the environment, which may be considered as externalities. The main mode of action is water, specially runoff, because of its mobility and of the significant amount of pollutants which it receives directly. Through water surpluses, pollutants are usually spilled in sewage networks or groundwaters.

Fertilizers such as nitrogen or phosphorus cause eutrophication of water. The effect of pesticides is not so clearly determined, although they are acknowledged to have many side-effects, and many of them are toxic for humans or animals.

Thus the first step in the assessment of the damages caused by the fertilizers and pesticides is to determine the amount leached into groundwaters. This has been done with the EPIC model.

The economic valuation of the impacts of these pollutants is very difficult. No studies have been published on the assessment of the damage caused by these pollutants to human health or the environment. However, there are some studies which measure the willingness to pay to reduce pollutant concentrations in water. Here we will use the value obtained by Silvander and Drake[7]. They interviewed 1,000 people in Sweden, obtaining WTP values from 0.47 to 3.35 ECU per kg of N leached. Unfortunately, no similar studies have been found for other fertilizers or pesticides, so no valuation has been possible for their effects.

As mentioned before, due to the local nature of this study, the extrapolation of the values obtained to other environments is highly controversial. However, it is expected that it may provide an indicative range for the damages assessed.

3. RESULTS

The application of the methodology described above to the biomass fuel cycle has given the following results, by impact category. It is seen that, according to the methodology proposed, the results show only marginal impacts (that is, additional impacts produced by the implementation of the biomass fuel cycle). This is the case, for example, of health effects, or global warming effects. This shows that the alternative situation has to be considered, to determine the net additional effects with and without the project implementation. Hence, while no atmospheric pollution would be produced without the implementation of the project, the alternative use of set-aside land would produce larger erosion effects, and these must be considered.

However, this alternative situation has not been assessed, for employment impacts. In this case, they should not be considered as net, but gross effects, since capital resources are limited, and their utilization for this project would prevent them being used for other projects which in turn would generate a different amount of employment. In order to assess the net employment effects, a plausible investment alternative should be assessed, as has been done for a coal power plant later in the paper.

3.1. *Employment*

Direct employment has been estimated on an average figure of 81 jobs for the whole fuel cycle. This figure comes from the extrapolation of job figures for similar projects incorporating power plant construction, and its operation and maintenance. In the case of biomass production, the labour required has been estimated baaed on the crop cycle requirements, following the crop management scheme proposed by J. Fernández, University Politécnica of Madrid. Jobs of transport have been estimated based on the amount of biomass and transport distance. Thus 225 jobs are for construction, 25 for plant operation, 23 for biomass cultivation, and 24 for biomass transport.

The amount of indirect jobs generated has been calculated using the input-output model for the Spanish economy. The annual averaged demand for the model was, for the 0%, 3% and 10% discount rates, 5995, 4388, and 2709 kECU respectively. The resulting indirect employment generated by this demand ranged from 42 to 91 jobs, depending on the discount rate used.

The following monetary values have been used: 2000 ECU/yr for agricultural jobs, and 4132 to 12,119 ECU/yr for other jobs. This resulted in a total figure of 460 to 1852 kECU/yr, or 3.06 to 12.35 mECU/kWh.

As noted before, this could be considered a lower limit for the benefits of job creation. If we use estimates from government job promotion schemes, the figure increases to 27,983 to 39,130 kECU, which is a much larger figure than the one proposed before. However, this figure is also more uncertain.

3.2. *Health effects*

The effects of particulate matter on human health have been determined by means of the dose-response functions proposed by the ExternE Project. Their monetary valuation is also based on the ExternE values.

The resulting values ranged from 290 to 683 kECU per year, that is, 1.93 to 4.55 mECU per kWh. The range is determined by the confidence interval of the dose-response functions, but it can not be considered as a confidence interval for the value itself, as there are other uncertainty sources which have not been accounted for. The major uncertainty is the value of life, as the mortality effect dominates the results.

It should be noted that only particulate matter emissions from power generation have been assessed with the rest being considered negligible or too difficult to determine. Therefore, the above value should be considered an underestimate for the total health damages.

3.3. *Global warming*

As noted before, the assessment of this externality requires the determination of the net CO_2 emissions of the whole biomass fuel cycle. These net emissions have been estimated to be zero, or even negative. However, the negative values are still controversial, since the role of biomass crops as carbon sinks has not yet been widely recognized. Thus the value adopted here for the whole fuel cycle will be zero, as we assume that the carbon fixed in the soil will compensate the CO_2 emissions of other fuel cycle stages. Therefore, it is considered that there is no damage due to global warming from the biomass fuel cycle.

3.4. *Soil erosion*

The amount of soil removed because of the cultivation of *Cynara carduncullus* was estimated at around 1.12 t per ha and year, according to the Universal Soil Loss Equation (USLE).

It was considered that the most realistic alternative in the biomass power station area for the set-aside lands used for the energy crop was that they should be kept fallow, being bare for most of the rainy season, as they have to be tilled in autumn.

The soil eroded for the fallow land alternative was estimated from the USLE, noting that all factors of the equation remain constant, except the crop factor. The crop factor for *Cynara* cultivation is 0.01, while for fallow lands it is 1. Therefore, the soil eroded on the same land cultivated with *Cynara*, when kept fallow, will be 100 times higher or 112 t/ha.yr.. Then the relative erosion avoided by the energy crop cultivation is 111 t/ha.yr..

The cost of this erosion, based on the cost of sediment removal, has been estimated at 8 to 17 ECU/t of soil.[6] This results in an annual figure of 7879 to 17,493 kECU per year, or 52 to 116 mECU/kWh.

This value is quite high, but it must be noted that the land is bare most of the rainy season, and that the erosiveness of the area studied is quite significant. The transparency of the methodology allows for a different assessment based on other environmental conditions.

3.5. *Non-point-source pollution*

The total amount of nitrates leached into water has been estimated at about 18,000 $kgNO_3$ per year, using the EPIC model. Applying the figure provided by Silvander and Drake,[7] the resulting damage of this leaching is estimated at 8 to 60 kECU per year, or 0.06 to 0.4 mECU/kWh.

However, this value would probably be lower in Spain, since due to the lower public concern, for non-point-source pollution, the willingness to pay values would probably also be lower.

3.6. *Summary of external costs and benefits of the biomass fuel cycle*

The results estimated above are presented in Table 1. Costs are shown with negative signs, and benefits with positive ones. Note that these results are gross effects, which should be compared with an alternative, in order to obtain the net benefits. This is attempted in the following section.

Table 1. Externalities of a 20 MW biomass power plant

	kECU/yr	mECU/kWh
Employment	+460 to +1852	+3.06 to +12.35
Health effects	–290 to –683	–1.93 to –4.55
CO_2 fixation	negligible	negligible
Soil erosion	+7879 to 17,493	+52 to +116
Non-point-source pollution	–8 to –60	–0.06 to –0.40

Table 2. Externalities of a 1050 MW coal power plant

	kECU/yr	mECU/kWh
Employment	+2860 to +13,130	+1.10 to +5.05
Health effects	−21,866 to −51,584	−8.41 to −19.84
CO_2 fixation	−2080 to −41,860	−0.8 to −16.1
Soil erosion	–	–
Non-point-source pollution	–	–

3.7. *Externalities of the coal fuel cycle*

These have been assessed following the same methodology as for the biomass fuel cycle, so that results may be directly comparable. The assessment has been carried out for a 1050 MW coal power plant, located in the same site. The coal used for this plant will be imported, and hence no mining activities will be considered.

The annual averaged demand introduced into the input-output model has been from 7141 to 11,468 kECU (from 10 to 0% discount rate). The atmospheric emissions estimated for the power plant are 301 g/MWh for particulates, 1180 g/MWh for SO_2, and 1015 kg/MWh for CO_2. No impacts have been assessed for soil erosion or non-point-source pollution, since no such impacts apply to this fuel cycle.

As has been done for the biomass fuel cycle, only those impacts considered most relevant have been assessed. Impacts on crops, or on ecosystems, are negligible when compared to health effects. The resulting externalities are shown in Table 2. It is seen that the external costs of the coal fuel cycle are much higher, and its benefits lower, than for the biomass fuel cycle. Lower employment effects are mostly because the coal is imported. This produces an outflow of capital from Spain to other countries, this capital being removed from indigenous employment generation. This is reflected in the lower domestic demand per energy unit of the coal fuel cycle, and so in the lower indirect employment generated in Spain. In addition, direct employment per electricity unit produced is much lower for imported coal than for biomass.

Table 3. Social cost of electricity from biomass and coal (mECU/kWh)

	Biomass	Coal
Private cost	115.39	57.26
External cost	−50.11 to −126.36	4.16 to 34.84
SOCIAL COST	−11.0 to +65.3	61.4 to 92.1

4. CONCLUSIONS

This paper presents a methodology for the quantification of the externalities of biomass energy systems, as a first step toward their internalization. The methodology, developed by the ExternE Project, and extended by CIEMAT, offers several advantages.

Its major advantage is that it produces a set of comparable figures for the external costs and benefits of the different fuel cycles. Although these figures should still be considered subtotals, because of the difficulties existing in the quantification and valuation procedures for some effects, a first analysis can be carried out, comparing the results for the fuel cycles assessed.

The costs and benefits of biomass and coal fuel cycles examined in this paper show that the external costs of biomass are much lower than those of coal.

If these costs are introduced into the private cost of electricity, that is, if they are internalized to reflect the true social cost of these energy sources, it may be seen that the social cost of electricity from biomass is then lower than that of coal (Table 3). These figures should not be taken as absolute values, because of the uncertainties involved, and the existence of other externalities which cannot be yet valued. However, this is considered to be a first good approximation for the estimation of social costs.

In spite of the uncertainties underlying the analysis, it appears, when externalities are taken into account, that the social costs of producing electricity from biomass are lower than that of electricity produced from imported coal. This would then mean that prices for biomass electricity should be lower than those of electricity from imported coal, which in turn would imply that the demand for biomass electricity would be larger than for imported coal electricity. This is clearly not the current situation, so the internalization of the externalities into electricity prices would significantly change the market, by promoting a larger implementation of biomass energy.

The above conclusions would require that the conditions on which this analysis has been carried out are maintained unchanged. If these do change then new assessments should be undertaken with the ExternE methodology providing a powerful tool for that.

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