

9 Economic and environmental evaluation of switchgrass production and utilisation.

9.1 Introduction

The economic and environmental evaluation of switchgrass will be based on three years of data. Since switchgrass is a perennial crop with a cycle of some 15 years extrapolations and assumptions have been necessary for the economic and environmental analysis. In Chapter 9.1 the economic and environmental analysis of switchgrass cultivation are presented. In chapter 9.3 the economic analysis of switchgrass utilisation for thermal conversion is discussed.

9.2 Cost price calculation of switchgrass

Introduction

Switchgrass has been evaluated as an alternative energy crop in Europe. Research in this area includes investigation of the cost price and yield with regard to switchgrass cultivation. In our case the cost price and yield of switchgrass was investigated for a period of 15 years based on available data or extrapolation of data. The resulting switchgrass cost price (price per tonne DM) was compared to the cost price for *Miscanthus* estimated in other studies.

Current studies show that switchgrass can be cultivated in different regions of Europe. In each region or country the yield and input parameters and therefore the cost price will differ. The inputs and associated costs were estimated individually for the 5 countries participating in the current EU switchgrass project. The participating countries are Italy, Greece, Germany, the Netherlands and the United Kingdom. The inputs, yields and cost price were calculated based on expected local farmer conditions. It should be taken into account that only 3 years of data are currently available for switchgrass in the current project therefore many parameters have been extrapolated from current data and literature.

Available cost information

In general the information provided by the five different countries was similar. Total costs were separated in direct costs (consumable goods) and labour / machine costs, both specified as costs in EURO's per hectare (EURO / ha). Direct costs are costs for consumable goods like seeds, herbicides, fertilisers, agrochemicals and pesticides. Labour and machine costs don't have the same meaning for all countries. Labour costs are for example explicitly mentioned in the German and Dutch data. For all other countries the labour costs are integrated in the costs for different activities. In Italian, Greek and UK data spraying costs are for example total costs that are required for carrying out the specific activity. Spraying costs on the German and Dutch cost specification are the costs to use machines. The labour costs are not ascribed to the activity spraying, but included in the total labour costs. Examples of labour and machine costs are costs for ploughing, using the power harrow, rotary cultivating, drilling, rolling, spraying, fertilising, irrigating, mowing, baling and transporting. The costs of land use are not taken into account, because the crops can be produced on non-productive land (that is polluted or that has other restrictions on use), where the costs of land use are assumed to be zero. Another difference is the way different countries calculated their costs. In all cases estimates were made of the required inputs under practical farming conditions and the current costs of these inputs in the respective countries. Differences in estimates of the required input and differences in the cost of these inputs can account for differences between countries. Some countries used the market prices they paid for products and services to grow switchgrass if these data were not available standardised prices or estimates were used.

Method of calculation

Two different methods are used to calculate the cost price of switchgrass. The first method obtains the total costs per tonne of dry matter (DM) by dividing the total costs (EURO / ha) by the total yield (tonne / ha). This method doesn't take into account that costs are made in different years. Because of inflation and the opportunity cost of money, the money spent in year 1 is worth more than money spent in year 15. The second method, that uses the Net Present Value (NPV) of the total costs, takes this into account.

If spending patterns are the same for all different countries, that means the distribution of the costs over the years is similar for all countries and consequently the results of both methods are similar. In our case the spending patterns are quite different. For example the start up costs for Greece are relatively high compared to the amount of money spent by Greece and the UK in all other years and to the amount spent by other countries in the first year. Greece and the UK also have relatively high start up costs compared to the costs in other years, but for Germany and the Netherlands the costs in the first year are similar to the costs in other years. Another difference in the spending patterns for different countries is that in some countries 'expensive' fertilisers are applied in some years.

Results

The total costs are separated in labour & machine costs and costs for consumable goods. Figure 1 shows the total costs over 15 years for the 5 European countries further specified as indicated above without taking the corresponding yield into account.

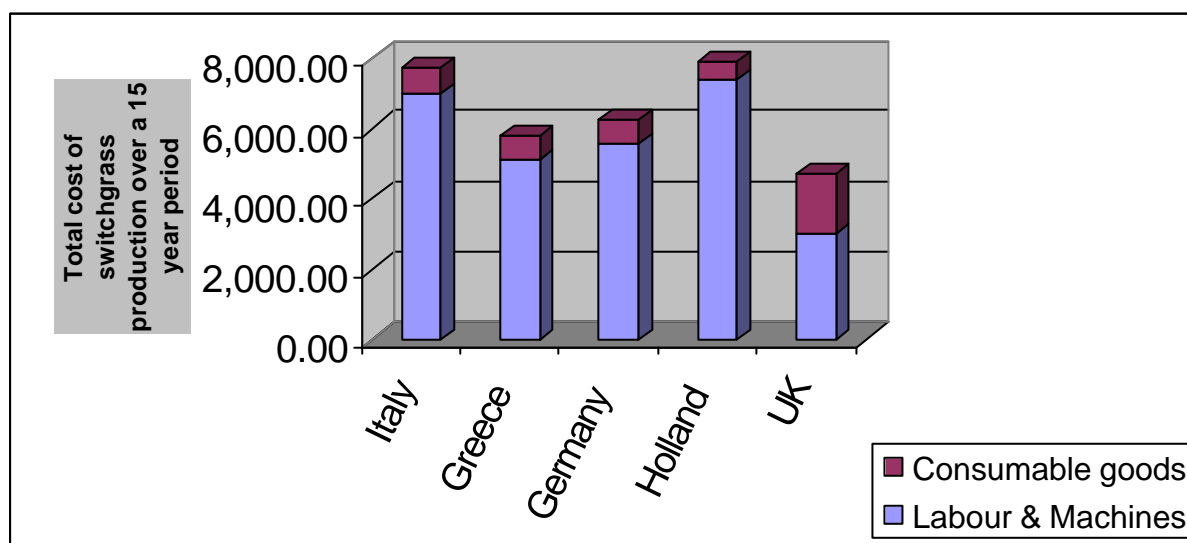


Figure 1: Total estimated costs over 15 years for switchgrass cultivation, in Euro per ha for 5 different countries in Europe.

In most countries the labour and machine costs are high compared to the costs for consumable goods, this agrees with the low input requirements for switchgrass (establishment by seed, low nutrient use and low pesticide use). Labour and machine costs are the highest in the Netherlands. This is explained by the fact that farms are relatively small and the labour costs per hour are very high. The size of German farms is comparable to Dutch farms, but labour costs per hour are lower. The total cost specification in the UK is different from the other countries. A relatively higher amount is spent on consumable goods. Farms in the UK are fairly large, labour and machine costs are low, and the price of (consumable) goods is high. Overall the costs in the UK are relatively low compared to all other countries. Greek labour is much cheaper than Italian labour, so the costs of different activities (labour and machine costs) are lower.

To be able to compare the costs of producing switchgrass for different countries the yield has to be taken into account. Figure 2 shows the estimated yield for all countries over 15 years.

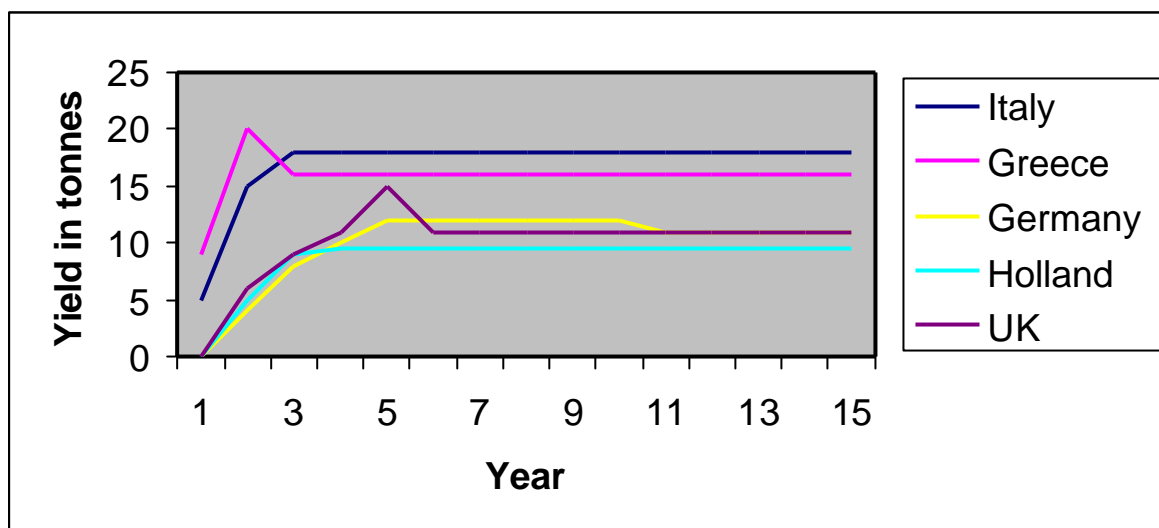


Figure 2: Estimated (extrapolated) yields over 15 years, in tonnes DM per ha per year for 5 countries in Europe.

Overall the expected yields are highest in Southern European countries like Greece and Italy. The weather conditions in these areas are more favourable (longer growing season) than the conditions in Northern European countries like Germany, the Netherlands and the UK. For all Northern European countries the yield in the first year is low and probably not economical to harvest. In Greece and Italy in the first year economical yields are obtained. For Greece and the UK there is a peak in the yield at the beginning of the 15-year growing cycle. This is explained by the fact that for the first years actual data are given and for following years estimates are presented. For both Germany and Holland relatively lower yields are estimated than in the UK. The yield estimates presented here should be seen as preliminary. More accurate estimates can only be obtained from large experimental fields over a larger time frame (>10 years). Furthermore much optimisation of agronomic parameters is possible to optimise yields.

The following table reflects the cost prices of switchgrass for all five countries calculated in two different ways. Both total costs and total yields are incorporated in the calculations. The first method divides the total costs by the total yield. The second method divides the NPV of the total costs by the total yield. The interest rate was set to 4.93%⁸.

Table 1: cost price, in Euro per tonne DM

Country	Cost price (in Euros) per tonne (DM)	
	Method 1	Method 2 (NPV)
Greece	24	18
Italy	30	23
United Kingdom	31	23
Germany	42	31
Netherlands	62	45

Results for both calculation methods are similar because differences between cost prices in different countries are not substantial. Except for the difference between the UK and Italy. The production in Italy is a bit cheaper given method 1 and the results for both countries are the same given method 2. Greece is the cheapest producer of switchgrass, followed by Italy, the UK, Germany and the Netherlands. The Netherlands is by far the most expensive producer. Whilst the UK produces at the lowest costs, the

⁸ Interest rate 15 years, NL, 8-11-2001

production level is lower than the yield in Italy and Greece. This results in a lower total cost price for Greece and Italy. Although the cost price in Italy and the UK don't differ much.

The cost prices for switchgrass for the different countries mentioned above vary between 24 and 62 Euro per tonne DM. The most likely production costs for *Miscanthus* vary between 35 and 105 Euro per tonne DM for different EU countries (Walsh et al. 1997). The break even costs (worst case) for the Netherlands, without including any special incentives or subsidies, have been estimated between 82.78 and 187.86 Euro per tonne DM. In general environmental parameters that affect *Miscanthus* are similar to those mentioned for switchgrass. With *Miscanthus* requiring more input in establishment than switchgrass because *Miscanthus* is planted by rhizomes and switchgrass by seed. In comparison to *Miscanthus*, switchgrass seems cheaper to produce. But the cost prices are not comparable because of the differences in underlying assumptions. In each cost price calculation different cultivation procedure and combination of consumable goods are assumed. Another difference in the underlying assumptions is that the costs of land use are not taken into account in the cost price calculations for switchgrass, whilst these prices are included in the cost price of *Miscanthus*. The costs of land use will be high for The Netherlands for example, and can be reduced by using non-productive land (that is polluted or that has other restrictions on use). Because the costs of land use depend on the basic assumptions about the type of land and the area used, and also heavily differs from site to site, no assumptions can be made on the costs of land use in order to make a comparison. In order to make better comparisons in the future there is need for scaling up production field trials to determine actual commercial biomass yields and costs for switchgrass and other perennial grasses like *Miscanthus*.

Environmental effects

In this paragraph the environmental effects of growing switchgrass and *Miscanthus* will be examined. In order to do this the performance of the biomass crops on four different aspects: fertilisation, energy, irrigation and weed and pest control will be considered. Available data for switchgrass about the costs of irrigation, fertilisation, energy-use and weed and pest control in five European countries have been used in order to measure the performance of switchgrass for these aspects. Comparable information is not always available for all five countries for *Miscanthus*. The disadvantage of using costs as a measure of performance is that it is not known if high costs are caused by high prices of the consumable goods or the high application costs or the high amounts needed. When information about amounts is not available, the costs have been used as an alternative. The available information is compared with literature about the environmental performance of the two biomass crops. Table 2 shows the different costs on the aspects mentioned above for switchgrass. Information about energy use is not available and irrigation didn't take place in Northern European countries. Comparable information for *Miscanthus* is not available.

Table 2: Estimated cost of different inputs for switchgrass, in Euro per tonne DM, for 5 different countries in Europe.

	Fertilisation	Weed and pest control	Irrigation
Italy	2,39	0,12	10,67
Greece	2,49	0,09	6,32
Germany	4,16	0,20	0
Netherlands	3,00	0,40	0
United Kingdom	9,60		0

Fertilisation

The costs of fertilisation for switchgrass range between 2,74 in Italy and 9,67 Euro per tonne DM in the Netherlands. It is not clear if higher costs of fertilisation in Northern European countries are either caused by the amounts applied or the costs for applying them. Fertilisers are applied each year in all countries except for the United Kingdom. In the UK fertilisers are only applied in year 5, 10 and 15. For Greece data on fertilising *Miscanthus* are also available. In comparison to switchgrass the cost per tonne DM for

fertilisation are higher for *Miscanthus*. The same amount of Nitrogen is applied, but costs for basic fertiliser that is only applied the first year are higher for *Miscanthus*. The costs in EURO per tonne DM are 4,27 and 3,97 for *Miscanthus* and switchgrass respectively.

Each of the crops will have different management regimes. The management regimes in different environments will also vary. The application of different fertilisers based on Christian and Riche (1999) is as follows: *Miscanthus* needs a yearly application of N, P₂O₅ and K₂O in the proportion 0:0:72 kg per ha. Furthermore it needs the fertilisers described above in the proportion 0:32:0 kg per ha every five years. switchgrass only needs the application of N, P₂O₅ and K₂O every five years in the proportion 0:28:78. Overall more fertilisers should be applied to *Miscanthus* in comparison to switchgrass. This is in line with the available price information for Greece on this subject.

Energy

The total energy ratio (energy output - energy input) of the establishment and production processes for both switchgrass and *Miscanthus* grown in the United Kingdom was calculated by Bullard and Metcalfe (2001). The main differences between switchgrass and *Miscanthus* is that *Miscanthus* requires extra energy inputs for the production of the rhizome starting material, whilst switchgrass can be seeded. In the production process of the rhizomes extra energy inputs are required for lifting, harvesting, grading and storing the rhizomes. This process requires extra machine equipment. Planting the rhizomes also requires specific machinery, whilst a standard cereal drill can be used for drilling the switchgrass seeds. The other energy input whilst the required energy inputs are higher for *Miscanthus* from year 4 onwards. The energy outputs are also much higher because of a higher yield in the years 4 to 20. This results in a higher overall energy ratio for *Miscanthus* compared to switchgrass.

Weed and pest control

In all countries the costs per tonne DM of weed and pest control for switchgrass are very low, except for the United Kingdom. Relatively a higher amount is spent on herbicides in estimated UK cost calculation. The fact that most countries spray only once in the first year is explained by the importance of effective weed control during establishment, which is well known for both *Miscanthus* and switchgrass. Specific herbicide applications or mechanical weed management methods will vary tremendously depending on site, weed burden and species composition (Bullard and Metcalfe, 2001). The need to control weeds in the first year may be a bit higher for switchgrass in comparison to *Miscanthus* since seedlings are smaller and may grow slower than tillers emerging from *Miscanthus* rhizomes. Mowing above seedling height may be used as a means of weed control in switchgrass. In later years the larger number of tillers in switchgrass compared to *Miscanthus* may make weed control measures less necessary in switchgrass than in *Miscanthus*.

The application of herbicides and agrochemicals in Booth, Walker and Cook (2001) is only specified as costs per input per year. The amounts needed are unknown.

Irrigation

Irrigation only takes place in Southern European countries. In Italy the costs for irrigating switchgrass are 10,67 Euro per tonne DM, this is much higher than the costs in Greece: 6,32 Euro per tonne DM. For Greece there is also information on the costs of irrigating *Miscanthus*, these are 12,63 Euro per tonne DM and even higher than the costs of irrigating switchgrass in Italy. This corresponds to observations in Italy and Greece that switchgrass requires less irrigation than *Miscanthus*. Despite a relatively high water use efficiency, *Miscanthus* has a high water demand (Walsh et al, 1997).

Conclusion

In general switchgrass seems to perform a bit better than *Miscanthus* concerning the environment, because of the better performance of switchgrass on irrigation, low input for establishment and possibly lower

fertilisation. Not on every subject it is clear which perennial grass performs better because basic underlying assumptions were not always known and comparable. If only the energy inputs are concerned switchgrass performs better than *Miscanthus* on energy, but when the overall energy ratio is concerned *Miscanthus* performs better, because of the higher yields.

Literature

Bullard, M and P. Metcalfe, 2001. Estimating the energy requirements and CO₂ emissions from production of the perennial grasses *Miscanthus*, switchgrass and Reed Canary Grass.

Booth, E.J., K.C. Walker and P. Cook, 2001. A review of the potential of giant grasses for UK agriculture.
Christian, D. G. and A.B. Riche. 1999. Establishing fuel specifications of non-wood biomass crops,.ETSU B/U1/00612/REP.AEA Environment, Future Energy Solutions. Harwell, Didcot Oxon, OX11 0QJ,UK 64 pp.

Hallam, A., I.C. Anderson and D.R. Buxton, 2001. Comparative economic analysis of perennial, annual, and intercrops for biomass production.

Walsch, M., S. McCarthy, (Ed), and others, 1997. *Miscanthus Handbook*. Hyperion FAIR 3-CT96-1707.

9.3 Economic aspects of switchgrass utilisation for energy conversion

R. Siemons

BTG (Biomass Technology Group), Enschede, The Netherlands.

Approach

Economic cost items that are relevant when using switchgrass as a fuel include:

- Switchgrass growing and harvesting,
- Switchgrass preparation into suitable fuels,
- Storage and transportation,
- Adaptations to energy conversion equipment,
- Maintenance cost of energy conversion equipment,
- Conversion efficiencies of energy conversion equipment.

In general, costs are dependent on the specific processing chain chosen for generating electricity, heat, combined heat and power (CHP), or liquid fuels. However, for each end product, several processing routes can be conceived. As an example, two possible conversion chains for the generation of electricity from switchgrass are given in Table 1.

Table 1. Description of two possible conversion chains for switchgrass.

Chain 1	Chain 2
Switchgrass growing and harvesting	Switchgrass growing and harvesting
Baling and field storage	Baling and field storage
Bale transport to power plant	Liquefaction into bio-oil
De-baling and grinding	Bio-oil transport to power plant
Fuelling into a dedicated power plant for biomass-derived fuels	Fuelling into a co-firing boiler suitable for coal and biomass-derived fuels
Electricity generation	Electricity generation

So, not only are there several energy applications, the potential routes to produce the various end-products are also numerous. Van den Heuvel (1996) gave a broad, but still limited, review of potential processing routes. Of course, one could argue that an assessment should be based on currently available technologies; and this certainly limits the number of alternatives worth consideration. However, switchgrass, is not a biomass fuel of today, but a potential biomass fuel of the future, and, therefore, it seems to be more interesting to include future energy conversion technologies into the evaluation. A similar consideration applies for all other candidate European-grown energy crops, such as *Miscanthus*, reed canary-grass, and short rotation coppice. In the beginning of this investigation into the potential of switchgrass as an energy crop, it was decided to focus on a comparison with *Miscanthus*. Switchgrass and *Miscanthus* show large similarities in terms of the physical and chemical properties of the harvested products. This particularly applies to their moisture contents and to their ash contents. On the other hand, their contents of potentially corrosive elements such as potassium and chlorine are quite different. In view of these facts, and under the circumstance of uncertain conversion routes, an economic comparison at the level of the harvested products, rather than at the level of final products seems to be the most appropriate.

In the following analysis, the harvested products are assumed to be stored in stacked bales covered with tarpaulin, located in the field from where they were harvested. LEI-DLO prepared the production cost analysis of this product (see elsewhere in this report). This chapter reviews those data in view of energy applications.

Methodology

Cost calculation

The primary purpose of the analysis is to derive the production costs of switchgrass fuel in terms of Euro per energy unit (Euro/GJ). The energy unit selected is the net calorific value at constant pressure (NCV_p) as defined in ISO 1928 (1976). Although defined for solid mineral fuels, the definition equally applies to solid biomass fuels. In some technical and economic analyses of energy conversion processes the gross calorific value (GCV), defined by the same ISO standard, is more suitable. However, an arithmetical conversion between the two types of calorific value is possible if the fuel moisture and hydrogen contents are known. That is, according to the following expression:⁹

$$GCV_p [MJ/t] = NCV_p [MJ/t] + 21825.86 \times H + 2442.2 \times m,$$

where H is the hydrogen content - not bound as H_2O - of the fuel, and m is the fuel's moisture content. The formula applies for any type of analysis basis (wet; dry; or dry and ash free), provided that the same basis is consistently applied. According to the referred ISO standard, the gross calorific value is determined at constant volume (GCV_v) for an analysis sample. Based on that measurement, the NPV_p is then calculated for the state of the analysis sample, defined by its hydrogen content (H_{Rw}), oxygen content (O_{Rw}) and moisture content (m_{Rw}), from:¹⁰

$$NCV_{pRw} [MJ/t] = GCV_{vRw} [MJ/t] - 21211 \times H_{Rw} - 77.48 \times O_{Rw} - 2442.2 \times m_{Rw}$$

In reality, the moisture contents of both switchgrass and *Miscanthus*, when baled and piled, are expected to be about 10-20%. Arithmetical conversion of the calorific values to the any actual moisture content proceeds by using the following equation:

$$NCV_{pAw} [MJ/t] = NCV_{pRw} [MJ/t] \times \frac{1 - m_{Aw}}{1 - m_{Rw}} + 2442.4 \frac{m_{Aw} - m_{Rw}}{1 - m_{Rw}}.$$

where the subscripts R and A denote the fuel condition in the reference state (R) and in the actual condition (A), respectively. The equation applies to fuel properties expressed on a wet basis. This is indicated by means of the subscript w.

Productivity data for energy crops such as switchgrass are usually given on a dry-matter basis, i.e. t_0 /(ha.yr). The dry matter is also the usual basis for the determination of production cost, i.e. they are normally expressed in terms of Euro/ t_0 . Since switchgrass is not utilised in the dry form, a recalculation must be made to adjust for the actual moisture content. This proceeds by means of the following equation:

$$C_{MA} [Euro/t_A] = C_{MR} [Euro/t_R] \times \frac{1 - m_{w,A}}{1 - m_{w,R}},$$

where C_{MA} is the production cost per tonne at the actual moisture content as utilised, and C_{MR} is the production cost per tonne at the reference moisture content. If the reference moisture content is 0%, and the actual moisture content is 20% on a wet basis, then the equation becomes:

⁹Based on ISO 1928 (1976). For the expression to apply, the unit of the calorific values is in MJ/t, and the contents of hydrogen and oxygen, as well as the moisture content are expressed as fractions.

¹⁰Based on ISO 1928 (1976). The subscript R denotes the state of the analysis sample, which is taken as the reference state.

$$C_{MA} [\text{Euro}/t_{20}] = C_{MR} [\text{Euro}/t_0] \times (1 - 0.20).$$

Thus, to determine energy equivalent costs for practical moisture contents, given dry-matter production costs, proceeds as follows:

$$C_{EA} [\text{Euro}/\text{GJ}] = \frac{C_{M0} [\text{Euro}/t_0] \times (1 - m_{Aw})}{NCV_{pRw} [\text{MJ}/t] \times \frac{1 - m_{Aw}}{1 - m_{Rw}} + 2442.4 \frac{m_{Aw} - m_{Rw}}{1 - m_{Rw}}} \times 1000.$$

By making use of the subscripts E and M, the energy basis and the mass basis of the unit costs (C) are distinguished. The applicable parameter values are reported in the next Section.

Other economic issues

In the introduction, it was explained why the economic value of a fuel does not only depend on its unit energy value. Other determining factors include utilisation issues like required adaptations to energy conversion equipment, and associated maintenance cost of energy conversion equipment. Especially fuel properties with regard to corrosion are very relevant. Fuels of a particular corrosive nature make additional investments into less vulnerable equipment necessary, and also result in increased maintenance costs. These increased costs of fuel utilisation can be translated into reduced fuel values. Quantification depends, however, on the applicable conversion technology.

For this generic study a single assumption with regard to the utilisation technology would be inappropriate. This issue is therefore merely illustrated with an example, to show the relevance of the matter. The example compares the utilisation of wood and straw in non-CHP district heating plants. Straw is a well-known corrosive fuel, due to its high contents

of alkaline matter. The example was selected in view of the availability of data. Since no such data are available for switchgrass, the example should be interpreted with care.

Elaboration

Basic technical data for the determination of unit energy costs are given in Table 2.

Table 2.

Reference states (analysis sample)		
μ_{Rw}	23.70%	Measured
H_{Rw}	4.37%	Measured
O_{Rw}	32.69%	Measured
GCV_{vRw}	14294 MJ/t	Measured
NCV_{pRw}	12763 MJ/t	Calculated
Actual state (utilisation state)		
μ_{Aw}	20%	Assumed
NCV_{p20w}	13263 MJ/t	Calculated

Elsewhere, in the reporting of this project, the production costs (C_{M0} [Euro/ t_0]) for switchgrass are analysed and compared with the production costs for *Miscanthus*. They are reviewed in Table 3. This table also shows the resulting energy values (C_{E0} [Euro/GJ]).

Table 3.

Case	Greece	Italy	United Kingdom	Germany	Netherlands
C_{M0} (Euro/t ₀)/a	18	23	23	31	45
C_{E20} (Euro/GJ)	1.09	1.39	1.39	1.87	2.71

a/: Source LEI-DLO

To illustrate the effect of corrosiveness on fuel value, a 2 MW non-CHP district heating plant was considered for two fuel types: wood and straw. In terms of corrosiveness, switchgrass is similar to wood. *Miscanthus*, on the other hand, shows rather detrimental specifications. Straw is one of the least attractive fuels in terms of corrosiveness.

Table 4.

Content (mass %, dry basis)	Wood	<i>Miscanthus</i>	Straw	Switchgrass
Cl	0.01%	0.22%	0.42%	0.07%
K	0.15%	0.49%	1.30%	0.01%
Ca	0.77%	0.23%	0.31%	0.03%

Economic performance data on wood and straw-fuelled systems were reported in two Danish studies,¹¹ and these are taken for our elaboration. General parameter values are shown in Table 5.

Table 5.

Boiler capacity /a	2 MW
Conversion efficiency /a	100%
Annual energy /a	11200 MWh before distribution loss/yr
=	11200 MWh before conversion loss/yr
=	0.040 PJ ₀ /yr
Project duration /a	20 yr
Discount rate /b	10%

a/ Wood for energy production (technology, environment, economy), Centre for Biomass Technology, Denmark, 1999.

b/ This study.

Specific parameter values are given in Table 6. The table also shows how the difference in fuel quality can be expressed in terms of Euro/GJ. The resulting difference in value is about 1 Euro/GJ. This appears to be a quite relevant issue, if straw is concerned. It is uncertain to which extent this consideration will apply to switchgrass.

¹¹Serup, Falster, Gamborg *et al.* (1998) and Serup, Falster, Gamborg *et al.* (1999).

Table 6.

Cost item	Wood /a	Straw /b
Capital (Euro), (differing ones only)		
Heating plant	896,000	1,186,000
Annualised capital costs	105,244	139,307 Euro/yr
=	2.61	3.46 Euro/GJ
Operating costs (Euro/yr), (differing ones only)		
Maintenance, heating plant	17,000	26,000
Electrical power consumption	11,000	9,000
Other costs	9,000	10,000
Total operating costs (differing ones only)	37,000	45,000 Euro/yr
=	0.92	1.12 Euro/GJ
Grand total differing costs	3.53	4.57 Euro/GJ

a/ Wood for energy production (technology, environment, economy), Centre for Biomass Technology, Denmark, 1999.

b/ Straw for energy production (technology, environment, economy), Centre for Biomass Technology, Denmark, 1998.

References

ISO 1928 (1976), Solid mineral fuels - Determination of gross calorific value by the calorimeter bomb method, and calculation of net calorific value, International Standards Organisation.

Serup, H., Falster, H. *et al.* (1998), Straw for energy production (technology, environment, economy), Centre for Biomass Technology (for the Danish Energy Agency)

Serup, H., Falster, H. *et al.* (1999), Wood for energy production (technology, environment, economy), Centre for Biomass Technology (for the Danish Energy Agency)

Van den Heuvel, E. (1996), Biomass conversion routes for agricultural crops in Europe; Analysis within the context of sustainable solutions for both the agricultural and energy generation sector, BTG for Novem (EWAB 9606), Novem, Utrecht.