THE ECONOMICAL AND ENVIRONMENTAL PERFORMANCE OF MISCANTHUS AND SWITCHGRASS APPLICATIONS IN EUROPE

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ABSTRACT: In this article the economical and environmental performance of switchgrass and miscanthus production and transportation chains in the European Union (EU25) are analysed. The analyses are done for the present situation (the base year is 2004) and for the year 2030. The economical performance refers to the costs of production (planting, cultivating, harvesting of miscanthus and switchgrass), storing and transporting. The environmental performance refers to the greenhouse gas emissions, primary energy use, and the impact on water resources, erosion and biodiversity. Projections to 2030 and beyond take into account changes in the yield of miscanthus and switchgrass, the plant scale, the technology, and the price of the inputs. Key variables that determine the costs are the harvesting system, storing system, transportation system, natural circumstances (soil profile, climate and consequently the yield level), labour costs, fuel costs, land costs and the scale of the processing facility. The focus in this paper is on the methodology; more detailed results will be generated in the near future.
Keywords: miscanthus, switchgrass, biochemicals.

1 INTRODUCTION

For the further development of policies aimed to increase the use of miscanthus and switchgrass for energy and material applications, more detailed and up-to-date information is required about the environmental and economical performance of miscanthus and switchgrass applications in the EU. In this study the environmental and economical performance of thirteen miscanthus and switchgrass applications in the EU25 is analysed and compared with the reference systems that use fossil fuels as feedstock. This is done for the year 2004 and for the year 2030. Key factors are the yield, harvest system, storage system, transport system, transport distance, farm size, plant size, type of technology and the price of land, labour, fuel and capital.

Results are available for the countries of the EU25, but are also available at a sub-national scale, but the focus in this paper is on the methodology and input data because it concerns ongoing work and final results have not been generated yet. The results allow for an assessment of the most promising miscanthus and switchgrass production and transportation chains and regions in the EU25. Results of this study are incorporated in the European Non Food Agriculture (ENFA) model, which is an integrative assessment model aimed to analyse the competitive economical potentials and the environmental impacts of major non-food options in the forest and agricultural sector in the EU[1].

2 METHODOLOGY

2.1 Selection of applications

Fourteen miscanthus and switchgrass energy and material applications are identified in the literature as (potentially) promising and these are included in this study: 1) Combustion combined heat and power (CHP), 2) Integrated gasification and combined cycle, 3) Indirect co-combustion with coal, 4) Small scale heating, 5) Gasification and co-combustion with coal, 6) Methanol, 7) Ethanol, 8) Hydrogen, 9) Fisher-Tropsch (FT) diesel, 10) Dimethyl Ether (DME), 11) Ethylene, 12) Poly Lactic Acid (PLA), 13) Poly Trimethylene Tetraphalate (PTT) and 14) Medium Density Fibreboard (MDF).

2.2 Economical performance

For each of these applications detailed bottom-up calculations are carried out for the different production and processing steps: production (planting, cultivating, harvesting of miscanthus and switchgrass), storing, transporting and converting the biomass into electricity, heat, material or fuel. The costs are compared with the reference chains, which are based on fossil fuels. The performance is expressed in t for material applications, in km for fuels, in kWhe for electricity and/or CHP and in J for heat only applications.

2.2.1 Biomass production

The costs of miscanthus and switchgrass production (€ od t^{-1}) are calculated using the discounted cash flow approach, based on the following equation [1]:

$$C = \frac{\sum_{i=1}^{i_t} \left(ecc_i \sum_{y=1}^{n} \frac{f_i(y)}{(1+dr)^y} \right)}{yld\ rot \sum_{y=1}^{n} \frac{f_{yld}(y)}{(1+dr)^y}}$$

C = costs of biomass (€ oven dry ton $(odt)^{-1}$)

[1] This research is an European Union Sixth Framework Programme funded project.

yld	=	yield of the energy crop (odt^{-1} ha^{-1} y^{-1})
rot	=	rotation cycle (y)
n	=	number of years of plantation lifetime (y)
ecc_i	=	cost of energy crop cost item (€)
$f_i(y)$	=	number of times that cost item i is applied on the plantation in year y (dimensionless)
dr	=	discount rate (dimensionless). A default interest rate of 7% is used as a default in this study
f_{yld}	=	binary number, harvest (1) or not (0) in year y (dimensionless)

Table I shows an overview of the cost items and the application of these during the plantation lifetime. This management system is applied to all EU25 countries, because the impact of variations in management is limited compared to the impact of differences in yields and the price of inputs (land, labour and fuel).

Table I: Number of applications of various cost items included in the calculations over the miscanthus and switchgrass plantation lifetime of 15 year (M = miscanthus only; S = switchgrass only).

Cost item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Land rent	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Ploughing	1														
Harrowing	2														
Planting (M)	1														
Rolling (M)	1														
Drilling (S)	1														
Rolling (S)	2														
Fertilizing		2	1	2	1	2	1	2	1	2	1	2	1	2	1
Liming				1				1				1			
Sprayin g	1														1
Weed cult.	1	1													
Mowing	1														
Harvesting		1	1	1	1	1	1	1	1	1	1	1	1	1	1
Rotary cult.															2

For each of the cost items presented in Table I detailed calculations are included. The production costs change between the base year (2004) and 2030 as a result of technological changes (increases in efficiency) and changes of the price of cost items. A selection of parameters is discussed in more detail below.

Harvesting

The performance of nine harvesting machines is analysed based on a literature review. Two harvesting systems are selected based on the economical performance and also because these are presently being used for the production of miscanthus in the United Kingdom (the only place where commercial, large-scale production of herbaceous energy crops in the EU25 is currently taking place). These two harvesting systems are a self-propelled harvester-chopper, whereby the biomass is harvested and chopped and directly blow into a trailer, and a pull type harvester-baler, whereby the biomass is harvested and baled after which the bales can be collected.

Agricultural machinery

The costs of agricultural machinery are calculated following standard methodologies to estimate the costs of agricultural equipment [2, 3]. An example for a self-propelled harvester-chopper in Germany in 2004 is presented in Table II.

Table II: Cost calculation for a self-propelled harvester-chopper for Germany in 2004.

Fixed costs			Variable costs		
Purchase price (PP)	185	k€	Power	375	kW
Resale value (10% PP)	18	k€	Fuel[2]	83	l/h
Depreciation	5	y	Fuel price	0,88	€/l
Use	500	h/y	Fuel	73	€/h
Depreciation	67	€/h	Lubrication[3]	0,24	l/h
Repair and maintenance[1]	14	/h	Lubrication	3,4	€/l
Storage (1.75% PP y^{-1})	6	€/h	Lubrication	0,82	€/h
Insurance (0.5% PP y^{-1})	2	€/h	Other costs	0	€/h
General cost (3% PP y^{-1})	11	€/h	Labour[4]	1,1	h/h
			Labour price	28	€/h
			Labour	31	€/h
Fixed costs	100	€/h	Variable costs	105	€/h
Total costs			205	€/h	
Work capacity			0,29	h/ha	
Total costs			59	€/ha	

[1] Repair and maintenance costs (R, in € during total lifetime) = RF1 x PP x (h/1000) ^{RF2}, where RF1 = repair and maintenance coefficient 1 (0.03 h^{-1}), RF2 = repair and maintenance coefficient 2 (2.0), and h = lifetime (h).

[2] Diesel consumption (D, in l h^{-1}) = 0.222 x P, where P = maximum power (375 kWh).

[3] Lubrication consumption (L, in l h^{-1}) = 0.021 + 0.00059 x P.

[4] Labour costs are the labour price (€ h^{-1}) multiplied by the work capacity (h ha^{-1}) multiplied by 1.1 to account for various unproductive time required for travelling, servicing, lubricating, and training.

Yield

Data on the yield of miscanthus (in odt ha^{-1} y^{-1}) in 2004 are calculated using MiscanMod [4]. MiscanMod a spreadsheet model developed for the prediction of miscanthus yields that uses crop-specific parameters in combination with climate, land cover, and soil data. Results are shown in Figure 1. Switchgrass yields are assumed to be 80% of the miscanthus yield. More accurate yield estimates for miscanthus will become available in the future.

The yields are assumed to increase between 2004 and 2030 at a rate of 0.10 odt ha^{-1} y^{-1}, which is equal to 0.76% of the present average yield in the EU25. This equals a yield increase of 21% from 2004 to 2030, from 13 odt ha^{-1} y^{-1} to 16 odt ha^{-1} y^{-1} for miscanthus and from 10 odt ha^{-1} y^{-1}

to 12 odt ha^{-1} y^{-1} for switchgrass.

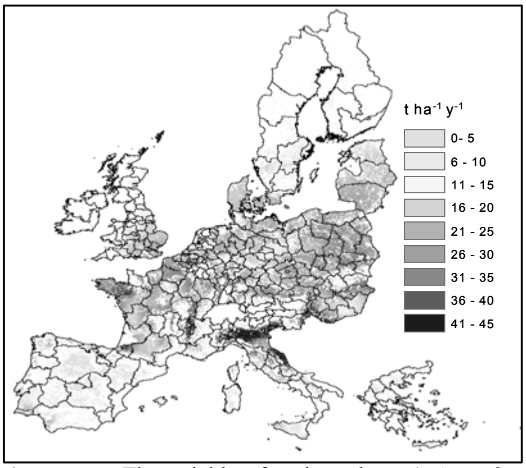

Figure 1: The yield of miscanthus (*Miscanthus x giganteus*) production on arable land in the EU in 2004 (in odt ha^{-1} y^{-1})

Fertilisation

There is no consensus on optimum fertilizer application rate. We use the amount of nutrients in the biomass that is harvested as a proxy for the optimum fertilizer demand. The same approach is used for lime. For nitrogen fertilisation the atmospheric deposition is subtracted.

2.2.2 Biomass processing

The processing of biomass includes the storage, transportation and conversion into energy and material applications. For all three steps detailed cost calculations are included.

Storage

The biomass is stored at the farm during six months after which the biomass is transported to the processing facility. The costs of six storage options are compared based on a literature review. The results indicate that storage using existing farm buildings is one of the cheapest options available. This storage system is also included in the main results.

Transportation

Three transportation modes are considered in this study: truck, train and inland ship (five types of inland ship are included). Truck is generally the preferred transportation mode, because of the versatility of truck transportation and because truck is the cheapest option, applied when the transportation distances are limited, as is the case in this study where transportation distances from farm to plant are generally below 100 km. Yet, after densification (e.g. pelletising) train and ship transport can be economically efficient compared to truck transport in case of long distance transportation (the costs of densification are high compared to the limited reduction in costs per km when shifting from truck to train or ship).

The costs of transportation are split into (un)loading costs and transportation costs, and also into capital, fuel and labour costs. The transportation distance is a function of the size of the processing unit, the area of agricultural land that is available for biomass production and the yield level. The transportation costs are also a function of the density of the transported biomass (chopped, baled or pelletised) and the (country—specific) price of fuel and labour. Note that the costs of (un)loading are substantial (50% or more in the case of the transportation of chopped miscanthus by truck), which means that differences in transportation distances have a limited impact on the total costs of transportation costs.

Biochemicals

The production costs of biochemcials are calculated using aggregated data from the literature [8, 9]. The data cover the production of biochemicals using fermentable sugars as feedstock. Data are given for now and for the future, based on differences in types of technology. For all three products a scale of 100 kt output is assumed, which is considered a suitable plant scale [8]. This plant scale is taken for both for the present situation and the future situation.

The costs of the production of fermentable sugars based on miscanthus and switchgrass is based on a recent study on the production of fermentable sugars from corn stover [10]. The data include pre-processing of the biomass. We assume that each biochemicals plant produces its own fermentable sugars, so the scale of the production of fermentable sugars is matched with the scale of the production of the biochemicals. Additional cost reductions can be achieved by increasing the scale of production of fermentable sugars, which are than delivered to different plants that produce biochemicals that are located close by (despite the higher biomass transportation costs).

The reference systems for ethylene and PTT are conventional ethylene and PTT production from oil and for PLA the reference system is polyethylene terephthalate (PET) made from oil. The costs of the reference system are expected to increase as a result of increases in the costs of oil.

Biofuels

Data about the production costs of biofuels are mainly derived from the Well to Wheel (WTW) study carried out by the Joint Research Centre (JRC) of the European Commission and the representing bodies of the oil industry (Concawe) and car industry (EUCAR) in Europe [5]. This is the most recent and detailed study we could find that includes data on both costs and greenhouse gas emissions. The data are supplemented by data from other sources where necessary [6, 7]. An example of the cost calculation of methanol production in the EU25 in 2004 and in 2030 is shown in Table III. The costs of the conversion of the miscanthus and switchgrass biomass into fuel is assumed the same for the countries in the EU25, only the costs of the biomass differs between countries. The scale is assumed to double between now and 2030, from 400 to 2000 $Mwth_{input}$ [6]. As a result of efficiencies of scale the costs decrease.

Data about the costs and the fuel efficiency of vehicles are derived from the WTW report [5], supplemented by data from other sources [6]. The reference system is based on conventional gasoline and diesel production and use. The costs of the reference system are expected to increase as a result of an increase in the price of oil.

Table III: Technological and economical performance of the conversion of miscanthus and switchgrass biomass to methanol in 2004 and in 2030.

		2004	2030
Plant scale	MW	204	1020
Load	h/y	8000	8000
Feedstock	kodt/y	640	3200
Feedstock	MWhth input	400	2000
Fuel conv. eff	%	50	50
Capex	M€	264	980
Capital charge	%	12	12
Capital charge	M€/y	32	118
Oil cost factor[1]	-	0.05	0.05
Oil price	€/bbl	25	50
Capital charge	M€/y	33	123
Opex	M€/y	17	69
fixed	M€/y	12	44
net energy & chemicals[2]	M€/y	5	25
Default oil price	€/bbl	25	25
Oil cost factor	-	0.032	0.032
Oil price	€/bbl	25	50
Opex costs	M€/y	18	72
Total annual costs	M€/y	51	195
Capex costs	€/GJ	5.5	4.1
Opex costs	€/GJ	2.9	2.4
Distribution & retail	€/GJfuel	0.1	0.1
Distribution infrastruct. costs	€/GJfuel	0.6	0.6

[1] Oil Cost Factor (OCF) is included that describes the correlation between the oil price and the price of petroleum fuels. The costs are multiplied with the relative increase in the oil price (an oil price of 25€/barrel is used as default) and the OCF. An example: an oil price of 50€/barrel equal a oil price increase of a factor 2, which is multiplied with an OCF of e.g. 0.1, which result in a cost increase of 2 x 0.1 = 0.2 or 20%, in case of a base year oil price of 25 €/bbl.

[2] Net energy & chemicals costs include the credits from electricity production.

Bioenergy

Data on bioenergy applications are taken from a study of the Organisation for Economic Co-operation and Development (OECD) and the International Energy Agency [11]. For all applications goes that the costs decrease due to increases in efficiency and/or increases in scale that result in lower capital costs. The performance of the reference chains is expected to increase due to changes in the price of feedstock (oil, gas, coal). The costs of nuclear, wind, hydro and solar energy as well as the costs of carbon capture and storage (CCS) are also shown for reasons of completeness. No distinction variation between countries is included due to a lack of data, but differences are likely limited compared to differences in the miscanthus and switchgrass production.

2.3 Environmental performance

Four environmental parameters are included: primary energy use, greenhouse gas emissions, water use, soil erosion and biodiversity. The latter three are analysed using existing literature; work on these issues is ongoing and therefore not further discussed in this paper.

Primary energy use

The primary energy use includes both the direct use of energy carriers during the production, transportation and processing of the biomass and the use of energy during the production of inputs (chemicals and capital goods). Calculations are carried out for both the bioenergy applications and the reference chains.

Greenhouse gas emissions

Similarly to the primary energy use, the greenhouse gas emissions include both the direct emissions from fossil fuel combustion during the production, transportation and processing of the biomass and emissions during the production of inputs. Also fertilizer-induced nitrous oxide (N_2O) emissions are included. Results are available for both the bioenergy applications and the reference chains.

3 RESULTS

Some (preliminary) results of the costs calculations are presented below. At this moment more detailed resutls are being prepared and these will be published in the form of four journal articles.

3.1 Costs of biomass production

The costs of miscanthus production (excluding storage and transportation) in the EU25 in 2004 varies between 35 and 95 € odt^{-1}, see Figure 2. A key determinant is the yield level, as shown in Figure 2. Other important variables are the price of land and labour. The costs of chopped miscanthus are lower than the costs of baled miscanthus, but the density of chopped miscanthus is lower and consequently the transportation costs are higher. Most applications use chopped or smaller biomass particles, so chopped miscanthus is included as default production system.

3.2 Costs of biomass processing

Table IV shows the costs of transportation (data are based on 100 km transportation, which is below the distance required for most applications), storage (stor.) and (un)loading (load.) in six countries in the EU25 of chopped miscanthus.

The results also indicate that pelletisation of miscanthus, which costs in Western-Europe some 30-51 € odt^{-1}, is not an economically attractive option to reduce the transportation costs (at least not for the default 100 km distance included). Based on the data above we assume the production and transportation of chopped biomass as the preferred delivery chain.

Table IV: The costs of transportation (transp.; 100 km by truck), storage, (stor.), and (un)loading (load.) of chopped miscanthus in the EU25.

€/odt	Storage	Loading	Transportation
Austria	8.1	9	10
Estonia	6.4	5	6
Germany	8.6	10	11
Italy	7.9	8	9
Slovakia	6.7	5	7
United Kingdom	8.6	9	11

Biochemicals

Table V shows the costs of biochemicals compared to the reference system in 2004 and in 2030. The costs are expected to decrease due to gains in efficiency and increases in yield of miscanthus production. The costs of the reference chain are expected to increase as a result of increasing oil prices; results for the reference chain for the year 2030 have not (yet) been calculated.

A crucial factor in the comparison are the capital costs of reference system. The costs of petrochemically produced PET are calculated to be ca. 1500 €/t, while in reality the market value is ca. 1200 €/t. The difference is the result of the capital costs, which are very low in reality, because plants have already been depreciated. In Table V the market values of the reference products are given. These data show that some biochemicals can be produced at competitive prices.

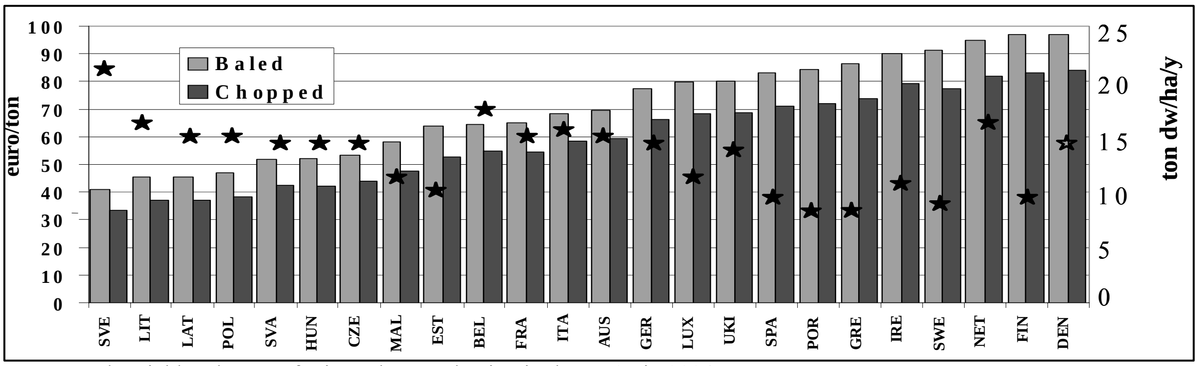

Figure 2: The yield and costs of miscanthus production in the EU25 in 2004.

Table V: The costs of ethylene, PLA and PTT production from miscanthus in different European countries comapred to the costs of the reference system (€/t).

Biochemical	Ethylene		PLA		PTT	
year	2004	2030	2004	2030	2004	2030
Austria	1742	1324	1607	1421	1197	1100
Czech Republic	1572	1194	1546	1374	1159	1076
Germany	1808	1375	1633	1440	1213	1110
Italy	1724	1310	1602	1416	1194	1098
Poland	1523	1156	1528	1360	1148	1068
Slovenia	1477	1120	1508	1345	1135	1060
United Kingdom	1791	1362	1627	1436	1210	1108
Reference product	Ethylene		PET		PTT	
year	2004	2030	2004	2030	2004	2030
	724	-	1226	-	1204	-

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