Techno-economic evaluation of biomass conversion routes for power generation, in particular via gasification and fermentation – results from a feasibility study in Northeast Europe

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Introduction

Focusing efforts on the most purposeful conversion routes should significantly increase the probability of achieving policy set energy supply targets using biomass. Some main aspects to be dealt with in this context are: 1) assessment of the technical feasibility of various conversion technologies; 2) techno-economic evaluation of logistically and technically different manufacturing routes for biomass energy carriers; 3) assessment of favourable biomass-mixes considering regional, agricultural, technological, economic and environmental conditions; 4) analysis of potential technical, socio-economic and ecological impacts, benefits and risks at different levels; and 5) identification of recommendations and required RD&D steps for the successful implementation.

Approach

The present analysis results are part of a techno-economic evaluation study carried-out in a region located at the border between Poland and Germany (Grundmann et al., 2004). Location specific analysis is ensured by linking a regional databank with information among others of the plot specific biomass yields, land use distribution patterns and biomass potentials with a Geographic Information System (GIS) of the region. The impact of plant locations on techno-economic results is tested by selecting four different sites along a biomass gradient from North to South (Fig. 1). Feedstock cost analysis is carried out using the simulation model BIOMIX developed at the Department of Technology Assessment at ATB to derive minimal feedstock costs and/or, optimal feedstock mixes, as well as resources demand and shadow prices taking into consideration specific locations, conversion routes and plant characteristics (Fig. 2).

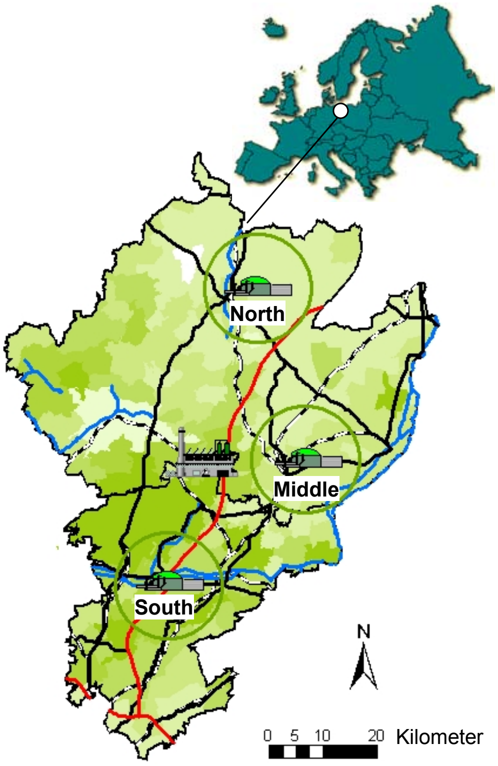

Fig. 1: Study Area and plant locations

Feedstock costs delivered by BIOMIX are used for further techno-economic scenario analysis. The susceptibility of the results to changing conditions is analysed within a sensitivity analysis. Cost optimal feedstock mixes are shown in table 1 for the analysed technologies, plants and locations.

Feedstock

Feedstock cost analyses are based on generally used crop production practices and supply chains in the region. The highest cost share in energy crop production are machine costs, followed by cultivation inputs i.e. seeds, fertilizer and plant protection agents (Fig. 3). This is the starting point for efforts to lower cost of energy crop production by reducing production intensities i.e. inputs and process steps.

Average energy crop production costs vary considerably in dependence of the land specific cultivation suitability and the chosen supply chain (Fig. 4 and 5). Square bales and chippings chains are cost efficient in case of biomass with a low moisture content. For wet biomass the silage chain is advantageous, because of low costs and good durability.

The cultivation of field woods can result in positive ecological effects due to among others relatively low gas emissions and high heavy metals accumulation in the trees. Even production costs are relatively low, the cultivation of field woods is rarely practiced in the region due to existing legal and economic obstacles. Similarly, “exotic” energy crops e.g. Miscanthus have not been adopted by farmers.

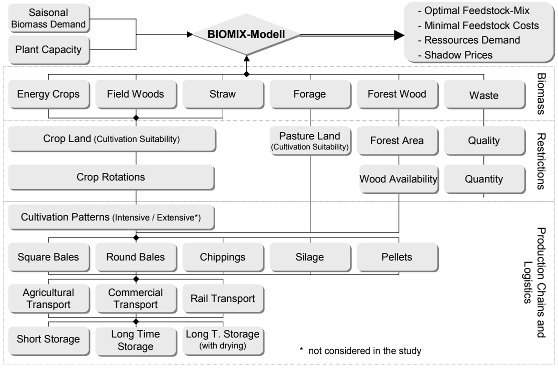

Fig. 2: BIOMIX – model structure

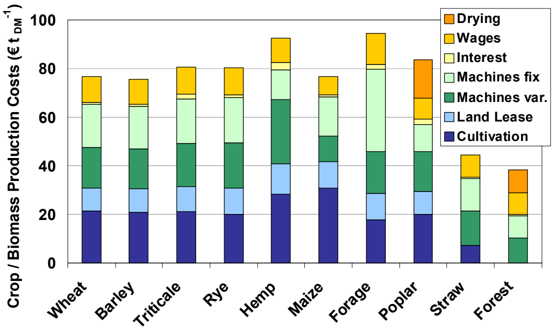

Fig. 3: Energy crops production costs

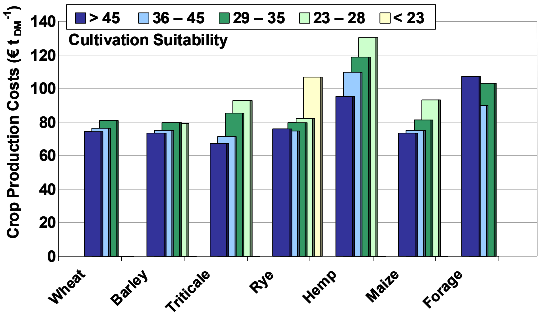

Fig. 4: Cost impact of cultivation suitability

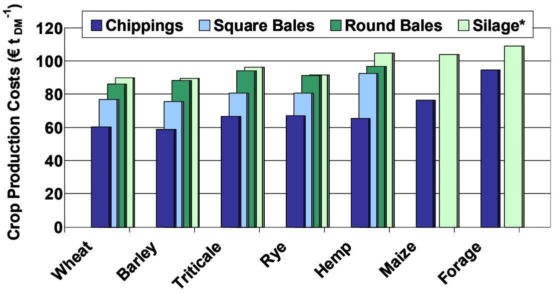

Fig. 5: Cost impact of supply chains

The environmental implications of energy cropping indicate a great variation of possible impacts (Tab. 1). This reinforces the necessity to develop crop rotations which combine positive effects and/or outweigh negative effects of the respectively gown energy crops.

Biomass conversion routes

Techno-economic analysis of anaerobe digestion routes is carried-out for slurry digesters with co-digestion of biomass and for dry-matter digesters. The analysed plants have installed capacities of 250 $kW_{el.}$, 500 $kW_{el.}$ und 2.500 $kW_{el.}$. Finally, the alternative of gas upgrading and gas feed-in is compared with the use of biogas in decentralized CHP-plants (Tab. 2).

Biomass gasification routes are analysed assuming two-stage gasification plants with a circulating fluidised bed and subsequent electricity generation using gas and steam driven power generators. The considered plant capacities range from 50 $MW_{th.}$ over 150 $MW_{th.}$ to 300 $MW_{th.}$. The analysis includes a case study for a 300 $MW_{th.}$ gasification plant with subsequent catalytic conversion via Fisher-Tropsch-synthesis for fuel production (BTL) (Tab. 1).

Tab. 1: Environmental implications of energy cropping

	Grain	**Maize**	**Field Woods**	**Landscape Residues**
Soil erosion	+	-	+	++
Soil compaction	0	-	+	+
Soil fertility conservation	+	-	++	++
Plant protection agent applications	-	0	+	++
Fertilizer application intensity	0	0	++	++
Water resources demand	0	+	-	0
Nutrient leaching	0	-	++	++
Land resources demand	+	+	+	-
Nitrogen input intensity	0	0	++	++
Gas emissions	0	0	+	+
Biodiversity	-	-	+	++
Human health risk during storage	0	-	0	-

- : negative, 0 : no, + : positive, ++ : very positive

Tab. 2: Assessed technologies, plants and locations

		Co-digestion with slurry				**Dry-matter digestion**			**Gasification**
Plant Capacity	**($kW_{th.}$)**	**250**	**500**	**2.500**	**2.500$^{(*)}$**	**250**	**500**	**2.500**	**50 $MW_{th.}$**
Location: North (high biomass potential)									
Investments	(10^3 €)	535	1.050	3.590	3.750	380	670	4.450	38.000
Biomass Costs	(€ t_{DM}^{-1})	89	89	89	89	89	89	92	47
Total Biomass	(t_{DM} a^{-1})	454	908	4.537	4.537	1.156	2.311	11.286	39.258
Energy Crops	(t_{DM} a^{-1})	454	908	4.537	4.537	1.156	2.311	11.286	0
Forest Residues	(t_{DM} a^{-1})	0	0	0	0	0	0	0	0
Residues e.g. straw	(t_{DM} a^{-1})	0	0	0	0	0	0	0	39.258
O & M Costs	(10^3 € a^{-1})	166	322	1.237	2.925	218	379	2.045	9.057
Electricity Sales	(10^3 € a^{-1})	246	491	1.994	-	241	482	1.957	8.106$^{(**)}$
CHP-Sales	(10^3 € a^{-1})	277	553	2.303	-	302	604	2.564	10.036$^{(***)}$
Heat Sales$^{(****)}$	(10^3 € a^{-1})	39	79	395	-	39	78	388	-
Location: Middle (medium biomass potential)									
Investments	(10^3 €)	540	1.055	3.610	3.800	380	675	4.590	38.000
Biomass Costs	(€ t_{DM}^{-1})	83	83	87	87	84	84	87	52
Total Biomass	(t_{DM} a^{-1})	486	972	4.864	4.864	1.242	2.483	12.419	45.655
Energy Crops	(t_{DM} a^{-1})	486	972	4.864	4.864	1.242	2.483	12.419	2.384
Forest Residues	(t_{DM} a^{-1})	0	0	0	0	0	0	0	18.749
Residues e.g. straw	(t_{DM} a^{-1})	0	0	0	0	0	0	0	24.522
O & M Costs	(10^3 € a^{-1})	167	324	1.285	2.895	219	383	2.179	9.096
Electricity Sales	(10^3 € a^{-1})	246	491	1.994	-	241	482	1.957	8.106$^{(**)}$
CHP-Sales	(10^3 € a^{-1})	277	553	2.303	-	302	604	2.564	10.036$^{(***)}$
Heat Sales$^{(****)}$	(10^3 € a^{-1})	39	79	395	-	39	78	388	-
Location: South (low biomass potential)									
Investments	(10^3 €)	540	1.060	3.610	3.800	385	680	4.600	38.000
Biomass Costs	(€ t_{DM}^{-1})	98	98	101	101	104	104	102	52
Total Biomass	(t_{DM} a^{-1})	491	982	4.911	4.911	1.152	2.304	12.423	73.243
Energy Crops	(t_{DM} a^{-1})	491	982	4.911	4.911	1.152	2.304	12.423	0
Forest Residues	(t_{DM} a^{-1})	0	0	0	0	0	0	0	48.066
Residues e.g. straw	(t_{DM} a^{-1})	0	0	0	0	0	0	0	25.177
O & M Costs	(10^3 € a^{-1})	173	337	1.315	2.848	219	415	2.304	10.313
Electricity Sales	(10^3 € a^{-1})	246	491	1.994	-	241	482	1.957	8.106$^{(**)}$
CHP-Sales	(10^3 € a^{-1})	277	553	2.303	-	302	604	2.564	10.036$^{(***)}$
Heat Sales$^{(****)}$	(10^3 € a^{-1})	39	79	395	-	39	78	388	-

Location: Middle

		Gasification & Power Generation						**BTL**
Plant Capacity	**($MW_{th.}$)**	**150**	**150**	**150**	**300**	**300**	**300**	**300**
Energy Crops	**(%)**	**10 %**	**20 %**	**30 %**	**10 %**	**20 %**	**30 %**	**10 %**
Investments	(Mio. €)	82	82	82	135	135	135	182
Total Biomass	(10^3 t_{DM}^{-1})	126	118	117	315	267	254	445
Energy Crops	(10^3 t_{DM}^{-1})	0	0	0	79	28	4	79
Forest Residues	(10^3 t_{DM}^{-1})	23	0	0	135	86	49	135
Residues e.g. straw	(10^3 t_{DM}^{-1})	103	118	117	101	153	201	101
Biomass Costs	(€ t_{DM}^{-1})	53	49	47	61	55	51	61
O & M Costs	(10^6 € a^{-1})	23,3	22,2	21,6	49,3	47,1	45,2	56,5
Power Sales	(10^6 € a^{-1})	25,2$^{(**)}$			52,9 $^{(**)}$			-

$^{(*)}$: gas upgrading; $^{(**)}$: regulated electricity price: 84 € MWh^{-1} and $^{(***)}$: 104 € MWh^{-1} $^{(****)}$: 100 % heat use (price: 20 € MWh^{-1}); BTL : **B**iomass **t**o **L**iquid; DM: Dry-Matter

Anaerobic digestion

The state of the art of co-digestion technologies is comparatively high. Biomass co-digestion with slurry is already practiced by a number of farmers in the study area. Economic results are positive taking as a basis regulated prices for electricity of 159 € MWh^{-1} for plants up to 500 $kW_{el.}$ and 129 € MWh^{-1} for plants up to 5 $MW_{el.}$ (Fig. 6). Further, results show that economies of scale have a greater impact on electricity production costs than plant location in the analysed case.

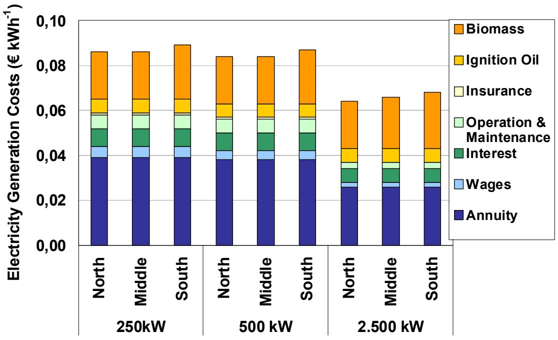

Fig. 6: Electricity production costs in anaerobe co-digestion plants

In contrast to electricity generation there is no regulated price system for upgraded biogas. The cost analysis results show that without regulated prices gas upgrading for feeding the natural gas pipeline grid is unprofitable. The results also indicate that to reach profitability, upgraded biogas would have to be remunerated with at least 0,50 € m^{-3} (Fig. 7).

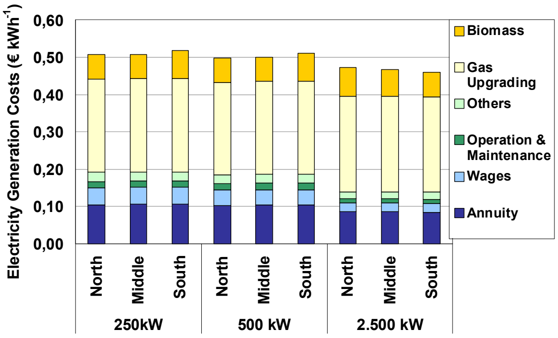

Fig. 7: Costs of upgraded biogas from anaerobe co-digestion plants

Since there are no best practices available for the anaerobic digestion of biomass with high dry matter contents, a number of uncertainties cannot be discarded while conducting a techno-economic evaluation. Nevertheless, taking as a basis the above mentioned electricity prices, dry matter digester plants can be run profitably, even with cost-deviations of up to 25 %. The profit shares decrease notably in case of large scale plants due to over-proportional feedstock cost increases and lower guaranteed electricity prices.

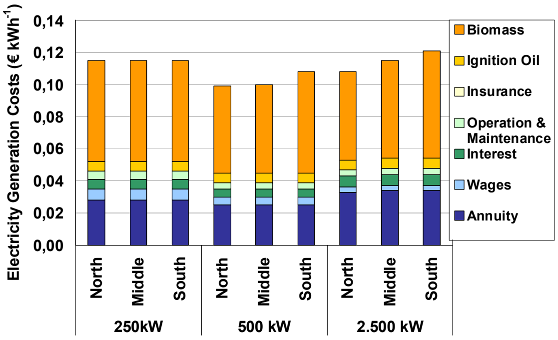

Abb. 8: Electricity production costs in anaerobe dry-matter digesters

Thermo-chemical gasification and Fischer-Tropsch-synthesis

An increasing application of thermo-chemical biomass gasification is anticipated as a consequence of the prospected increasing use of Fisher-Tropsch-fuels e.g. in combustion engines for transportation. Large-scale capital-intensive biomass gasification plants are being envisaged in the study area as pilot projects for scale-up and feasibility tests. The analysis is therefore carried-out on the basis of medium-term technology development projections.

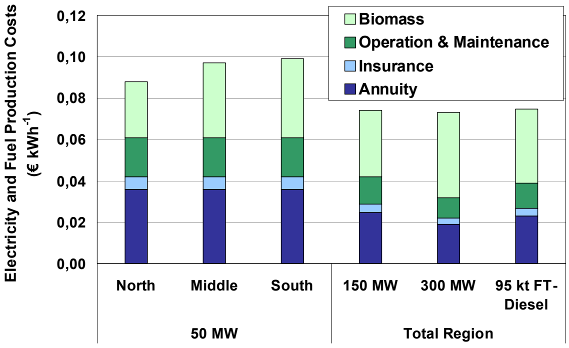

Fig. 9: Electricity and fuel costs in biomass gasification and FT-synthesis plants

These plants are characterised by large scale, centralized biomass procurement logistics and processes. The decentralized biomass conversion via flash-pyrolysis and centralized pyrolysis-oil gasification is technically feasible, but economically and ecologically disadvantageous. The main reasons for this are high toxic contents in the pyrolysis-oil and lower thermal efficiencies due to calorific losses during partial conversion. The economic results of large-scale biomass gasification plants are highly vulnerable to changing prices and feedstock availabilities, since feedstock costs represent 30 % to 50 % of the final product costs (Fig. 9). The subsequent catalytic conversion of generated gas into Fischer-Tropsch-fuels adds value to the final product with costs of 0,80 € l^{-1} (Fig. 9).

Conclusions

Feedstock related uncertainties represent the main economic risk factor, especially for large-scale conversion units and centralized biomass logistics. Therefore, short-term preferences are based on economic advantages of conversion routes suitable for a wide range of low cost biomass inputs. In the studied case regarded conversion routes do not compete for the biomass in the region, since digester plants make use of energy crops with high moisture contents, while gasification plants are basically fed with straw and wood. In the regarded case the profitability of energy crop production is achieved only on the basis of regulated price systems. Yield and cost variations indicate that considerable potential for improvements exists e.g. by selecting crops and crop rotations according to the suitability of the land and optimising supply chain management. Further advances are expected as middle to long-term results of ongoing RD&D, including new crop varieties and “new” energy crops, as well as improved cultivation technologies. Improving the competitiveness of biomass production e.g. through infrastructure activities, RD&D and other incentives, substantially improves the profitability of biomass to power conversion.

References

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