Biofuel production in Austria considering the use of waste heat: a study on costs and potentials of greenhouse gas reduction

Biogene Treibstoffproduktion in Österreich unter Berücksichtigung der Verwendung von Abwärme: eine Analyse der Kosten und Treibhausgasreduktionspotentiale

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Zusammenfassung

Die Biotreibstoffproduktion mit Technologien der zweiten Generation verspricht geringere Treibhausgasemissionen im Vergleich zu Technologien der ersten Generation. Die Kosten, Emissionen und optimale Standorte von Biomassekraftwerken, die diese neuen Technologien verwenden, werden mit Hilfe eines linearen Integer- Optimierungsmodells für Österreich abgeschätzt. Holz aus der Forstproduktion und von Kurzumtriebsanlagen geht als biogener Rohstoff in das Modell ein. Einnahmen durch den Verkauf der Nebenprodukte Wärme, Strom und Biogas, die in der Treibstoffproduktion entstehen, werden ebenfalls berücksichtigt. Die Modellresultate zeigen, dass der Ausstoß von Treibhausgasemissionen in Österreich durch den Einsatz von Biotreibstoffen um 2%-3,5% verringert werden kann. Allerdings ist nur die Fermentierungstechnologie in der Lage, Treibstoffe zu konkurrenzfähigen Kosten zu produzieren, weil höhere Erlöse durch den Verkauf der Nebenprodukte erzielt werden können.

Schlagworte: Biotreibstoffe, Abwärme, Facility Location Problem, Treibhausgase

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Summary

Biofuel production through second generation technology is expected to lower greenhouse gas (GHG) emissions significantly in comparison to first generation biofuels. A spatially explicit mixed-integer programming model has been built to assess costs, emissions and optimal locations of biofuel production plants in Austria. The model can choose between forest woods and short rotation poplar as possible feedstock as well as between fermentation and gasification technologies. Revenues from selling heat, power and biogas as by-products of biofuel production are considered in this analysis. The results of the model indicate that biofuel production allows a decrease in GHG emissions by 2%-3.5% of total Austrian GHG emissions. They also indicate that only biofuels from the fermentation technology are competitive to fossil fuels due to higher revenues from by-products.

Keywords: biofuels, waste heat, facility location problem, greenhouse gases

1. Introduction

Decreasing dependency on non European oil, climate change mitigation and rural development were until recently the main drivers of biofuel production in Europe (BERNDES and HANSSON, 2007). For these reasons, the European Union set the goal to replace a share of 5.75% of fossil gasoline with biofuels by 2010 and to increase this share to 10% by 2020 (EUROPEAN COMISSION, 2007). In the 2007 edition of the government program, the Austrian government set an even more ambitious goal to reach a 20% share by 2020. However, biofuels are criticized for various reasons. The greenhouse gas (GHG) balance of biofuels is - depending on the kind of feedstock used - at most equivalent or even worse than the one of fossil fuels. The use of fertilizers and land conversions due to feedstock production generates large amounts of GHG emissions (ZAH et al., 2007; SEARCHINGER et al., 2008). Other critics state that producing biofuels from food crops increases food prices which affects mainly the urban poor in developing countries negatively (MÜLLER et al., 2007; GOMEZ et al., 2008). Second generation biofuels produced either through gasification or fermentation are a promising alternative to the problems caused by first generation biofuels which are mainly produced from food crops. Second generation technologies

allow the use of a wide range of different biogenic feedstock and transform the whole crop to fuel instead of converting the grain only (BRIDGWATER, 2006). They therefore perform better in terms of GHG emissions in comparison to first generation plants (ZAH et al., 2007). Furthermore, competition to food production could be minimized if large scale production shifts from food crops to energy crops are avoided (GOMEZ et al., 2008).
This paper assesses the costs of second generation technologies - gasification and fermentation of biomass - using the biofuel model BeWhere developed by LEDUC et al. (2008a). BeWhere analyzes the whole supply chain from biomass production to delivery of the final product and seeks to find optimal locations of biofuel plants. Heat, power and biogas are considered as energy by-products of the biofuel production. Selling them increases the profit of biofuel plants. Also, total GHG emissions can be further decreased by substituting fossil fuels in diverse energy sectors. Using waste heat for district heating purposes is considered in former version of BeWhere. However, it was simply assumed that heat can be sold to the market at a fixed price. This paper introduces an add-on to BeWhere which allows the spatially explicit assessment of waste heat use for district heating. Costs of this application as well as effects on total emissions and on optimal plant locations are analyzed for the case of Austria.

2. Methods and Materials

A spatially explicit mixed-integer programming model has been built to find the optimal location and size of biofuel plants by minimizing the costs of the full supply chain. The supply of biomass is restricted in each supply region. Plants are modeled using energy balance equations, combined with capacity constraints for production. A vehicle fuel demand and a heat demand constraint, which considers competition between bioenergy and fossil fuels, is defined for each demand region. The objective is to minimize the overall costs in order to fulfill the demands for heat and vehicle fuel. The cost function includes costs for the supply of biomass, operation and investment in plants, transportation of biomass and biofuel and investment costs for district heating networks. Evaluating the model by solving the optimization problem generates the optimal locations of production plants and the optimal supply regions. The basic model is presented in detail in LEDUC et al. (2008a), though the version used in this paper contains an add-on which explicitly models the use of the waste heat for district heating purposes. The supply chain consists of biomass production, biomass transport to biofuel plants, production of biofuels and by-products and distribution of biofuels and heat to consumers.

Forest woods and short rotational poplar are considered as feedstocks. Spatial distribution of forestry yields is estimated with increment curves from Assman's yield table (ASSMAN, 1970) and a net primary production map from RUNNING (1994). This is calibrated with the observations from the national forest inventory of Austria (SCHADAUER, 2004). Harvesting costs are a function of tree size (which depends on site quality and rotation time) and the slope. The slope is calculated using a 30x30m digital elevation map from the SRTM (shuttle radar Topography mission) (NASA, 2008). The dimension of the harvested wood used for bioenergy has a diameter below 15 cm. Competition with paper and chipboards is not taken into account in this study. The long rotation periods of around 100 years and the fact that wood residuals from felling remain in the forest support sustainable use of the biomass resources. Short rotational poplar yields are estimated using the biophysical process model EPIC (SCHMID et al., 2006). A share of 10% of arable lands is assumed to be available for poplar plantations. Short rotation poplar management leads to a slightly increase in soil organic carbon stocks compared to crop production on average. The spatial distribution of gasoline consumption is estimated by combining a population map with average consumption values for Austria.

Concerning the biofuel production, two technologies are considered: gasification and fermentation. Table 1 shows the efficiencies of converting biomass to various products for the two technologies. While the delivery of power and biogas is not modeled in detail - it is assumed that they can be sold on the market at a fixed price - the use of waste heat for district heating is handled spatially explicit. Spatial distribution of private and commercial space heating and warm water consumption is estimated. The model combines data on Austrian dwelling areas and on employees based on the census of 2001 with average consumption per square meter of living area and per employee.

Tab. 1: Efficiencies (%) for converting biomass into fuel and by-products

Product	Gasification	Fermentation
Fuel	50.0	29.3
Heat	5.0	23.4
Power	0.0	12.7
Biogas	0.0	18.3

Source: LEDUC et al., 2008a; LEDUC et al., 2008b

The methodology was adapted from DORFINGER (2007). Heat has to be transported to district heating consumers using an extensive pipeline network. The costs of the pipeline network mainly depend on the distance between the plant and the demand, and on the demand density in the settlements. Areas of high heat demand are assumed to be supplied at lower unit costs than low demand areas. Estimations of costs of heat distribution networks based on the heat density or population density give a wide range of costs (SCHIFFER, 1977; KONSTANTIN, 2007). Therefore a sensitivity analysis is used to determine the influence of network infrastructure costs on the costs of the final product.
GHG emissions are compared with those created in a non biofuel scenario. All transport emissions from the biomass production sites to the end consumers are considered. It is assumed that fossil fuelled trucks are used for all transportation means. CO_2 emissions from burning biofuels are assumed to be totally recycled in biomass production. To estimate emission reduction through substitution of fossil transport, power and heating fuels, emission factors which represent the current Austrian fuel mix are taken from the Austrian National Inventory Report.

3. Scenarios and Results

Three different scenarios were used to assess costs, emissions and optimal locations. The base scenario (S1) represents current prices and district heating infrastructure costs taken from SCHIFFER (1977). It is compared to a scenario without heat use (S2) to assess the influence of selling heat on costs, emissions and plant positions. A second district heating scenario (S3) assuming lower infrastructure costs for the pipeline network (KONSTANTIN, 2007) is modeled to test sensitivity of the results to this parameter. In all scenarios 5.75 TWh of biofuels are produced. A total consumption of 100 TWh of fuels is assumed for Aus-

tria, a slight increase to the consumption of 96 TWh in 2006 (BITTERMANN, 2007).
Table 2 shows the results of the model for all combinations of technologies, feedstock and scenarios. The cost column gives a comparison of fossil fuel costs with biofuel costs, assuming a cost of 0.6 € per liter for fossil fuels. Emission savings are shown as share of total Austrian emissions in 2006. The last column gives the distance (in millions of km) that a 20 ton truck has to drive to deliver the biomass to the plants and the biofuel to the gas stations. Gasification of poplar (forest wood) needs 22% (46%) of the available biomass. Fermentation uses a higher share of 38% (78%) of biomass due to lower conversion efficiency of biofuel.

3.1 Costs

Producing biofuel from fermentation is in all scenarios cheaper than producing from gasification due to higher revenues from by-products.

Tab. 2: Model results

Technology	**Feedstock**	**Scenario**	**Costs** (% of gasoline costs, 1 liter=0.6 €)	**Emission Savings** (% of total Austrian emissions)	**Distances** (Biomass and biofuel transport in million km)
Gasification	Poplar	S1	118	1.9	11
		S2	124	1.9	10
		S3	116	1.9	11
	Forest Wood	S1	142	1.9	25
		S2	146	1.9	24
		S3	140	1.9	26
Fermentation	Poplar	S1	72	3.2	23
		S2	81	2.8	13
		S3	59	3.3	17
	Forest Wood	S1	112	3.2	49
		S2	129	2.8	43
		S3	100	3.4	48

Source: own calculations

Producing biofuel from poplar is cheaper than producing from forest wood due to lower production costs and due to a decrease of around 50% in transportation distances. A combination of fermentation and poplar is competitive to fossil fuels in all scenarios. Production of biofuel from forest wood by fermentation is competitive in scenario S3, which assumes low district heating infrastructure costs. In all other scenarios, biofuel production is not profitable. Use of waste heat has a significant influence on the costs of biofuel from fermentation. Comparing scenarios S1 and S2, costs go up by 13% (14%) for fermentation of poplar (forest wood). Due to lower heat yields in gasification, the influence of heat on costs is less: costs rise by 4% (3%) in the no heat scenario using poplar (forest wood) as feedstock. In S1 the parameters for the cost function of the district heating infrastructure are estimated from the results in SCHIFFER (1977) while in S3 results from KONSTANTIN (2007) are used. The average heat distribution costs in the model decrease by 40% in S3 due to this parameter change. This decreases the costs of the biofuel from fermentation of poplar (forest wood) by 18% (11%) and makes fermentation of forest wood profitable. Low district heating infrastructure costs are therefore a relevant factor in making biofuel production competitive.

3.2 Emissions

Emission savings from biofuel use are in the range of 1.9% to 3.4% of total annual Austrian emissions in the different scenarios. Biomass and biofuel transportation emissions do not decrease these results significantly. The trucks emit 0.5% to 1.5% of emission savings. Heat use has a significant influence on emission reductions in the fermentation scenarios. Without using waste heat, emission savings are decreased by 13%. However, emission savings per unit biomass are lower for heat than for biomass since the current heating system stock emits generally less GHG per unit of final energy than combustion engines do. The reason is that renewable forms of energy and natural gas are major fuel sources in heating. In case of gasification, emission savings by using waste heat for district heating are negligible.

The model does not account for emissions in the feedstock production. While it can be assumed that forest wood production has insignificant emissions, poplar production may create carbon debts due to fertilizer use and land use conversion (ZAH et al., 2007; SEARCHINGER et al., 2008).

3.3 Locations

Due to different energy yields of fermentation and gasification, more plants are needed when using fermentation (8) than when using gasification (4). Figure 2 shows the optimal locations for plants in scenarios S1 and S2. The plants using poplar as feedstock are located in the east of Austria since poplar production and gasoline demand are concentrated there. Forest wood production is distributed more equally over Austria and therefore plant positions can be also found in the west. Comparing heat and no heat scenarios, a shift of locations in direction of heat demand centers can be observed. These results are backed by the fact that total truck transportation distances are decreased in the no heat scenarios. For gasification of poplar (forest wood), total transportation distances decrease by 7% (6%) if no heat is considered. For fermentation, transportation distances decrease by 40% (12%). These results indicate that longer transportation distances for biomass and biofuel are necessary if plants are placed closer to heat demand centers.

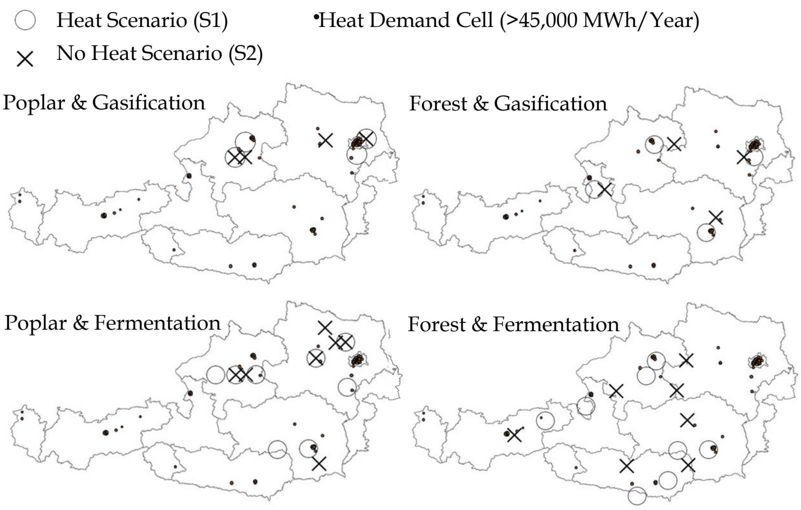

Fig. 2: Plant locations in the heat scenario S1 and the no-heat scenario S2 for all combinations of technology and feedstock. Source: own calculations

4. Conclusions

The analysis shows that the biomass production potential and current biofuel yields allow for attaining the current Austrian biofuel targets using second generation technologies in combination with woody feedstock. Still, only fermentation technology is currently competitive in production costs. The use of by-products of fermentation, especially heat, decreases costs considerably. In Austria, there is a lot of potential to use waste heat from biofuel plants for district heating.
Increasing the biofuel share significantly above 5.75% is only possible through either using expensive gasification technology or introducing poplar as feedstock. Poplar production in large plantations has several drawbacks which are not yet covered by the model. Emissions from land use change as well as fertilizer and pesticide uses in production may offset emission savings. Moreover, competition for the land has to be taken into account in future model versions.

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