ACRP – GHG-SEBA –
Greenhouse Gas Reduction through Second Generation Biofuels in Austria

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1. Einleitung - Introduction

1.1. Aufgabenstellung – Problem Statement

Reducing climate change and increasing security of energy supply are among the main objectives of current European energy policy. One of the policies made to ensure that EU members meet the objectives is directive 2009/28/EC that regulates biofuel shares in transportation fuels. The directive is designed to save greenhouse gas emissions and decrease dependency on fossil fuels in the transportation sector. The former directive 2003/30/EC already contributed in the building-up of an increasingly strong biofuel production sector in Europe in the last ten years.

As a consequence of using large amounts of agricultural crops for energy production, a controversy has arisen with respect to the environmental and social impacts of biofuels [1-8]. Models, from which the results were partly confirmed by increasing prices of agricultural resources in 2008, forecast increases in prices for agricultural products due to biofuel policies. Those price increases may subsequently lead to (1) increases in food insecurity for the urban poor in developing countries where food takes a big share in household expenditures, (2) deforestation as land is cleared to increase agricultural production and to (3) increases in agricultural productivity. The third option allows producing more of the same commodity on the same amount of land. Second generation biofuels are one option to achieve higher productivity and therefore seem to be an attractive alternative to existing biofuels: they are expected to use land more efficiently than first generation fuels and therefore increase the output of biofuel per hectare of land [9], [10]. Second generation biofuel production technology is a new technology, that is still under development and only a few commercial installations are currently being built worldwide. Austrian biofuel production is currently based on biodiesel (4 TWh) and ethanol (0.6 TWh) [11]. However, the feedstock for biodiesel production is mainly imported and the expansion of ethanol production with Austrian agricultural resources will make the conversion of large amounts of agricultural land from food and feed to energy crop production necessary. At the same moment, woody biomass is already a very important resource for energy production (~8% of total energy consumption is supplied by wood, mainly for heating [12]) and further expansion of wood production in forests may be feasible. Second generation biofuel technology makes these resources accessible for biofuel production. However, second generation biofuels will have to be subsidized heavily to allow large scale introduction to the markets.

1.2. Schwerpunkte des Projektes – Main focus of project

The objective of this project is the assessment of economic potentials of second generation biofuels in Austria. Economic potentials for second generation biofuels are determined relative to other conversion paths of biomass in the energy sector. The decline in the production of competing agricultural products such as food and feed should also be shown. The amount of biofuels that are produced under different policy scenarios and the effects of technologies on the energy system, on overall greenhouse gas emissions and on land use is assessed. The further development of an existing bioenergy model, BeWhere, and the integration with existing agricultural models is a further objective of the project.

1.3. Einordnung in das Programm – Classification within the program

The ACRP call asked in Thematic Area 3 for integrated assessments of climate, energy and the economcy, particularly the role of technological change technological options such as CCS and biofuels. This project dealt with the integrated assessment of bioenergy technologies for climate change mitigation under consideration of biomass production in agriculture and forestry, the conversion of biomass to energy commodities and the distribution to final consumers. An economic optimization model was integrated with biophysical assessments of biomass productivity and was used to estimate climate change mitigation costs of bioenergy technologies and energy policies. The assessment of the performance of new bioenergy technologies, particularly second generation biofuels, in comparison to existing technologies was at the core of the project.

1.4. Verwendete Methoden – Used methodology

The project mainly included modeling work and the model application to the various research problems. We started from the existing bioenergy optimization model BeWhere. BeWhere is a techno-economic model, which optimizes the geographical location and capacity of bio-energy production plants by minimizing the cost of the supply chain. From this model, a new sub-model has been developed: BeWhere-Policy which is mainly used to comparatively assess bioenergy technologies and policies.

BeWhere policy description

The core component of the modeling framework is the mixed integer program (MIP) BeWhere. The model minimizes the costs of supplying Austria with transportation fuels, heat and electricity from either bioenergy or fossil fuels. It is static and simulates one year of operation. The year is split into two heating seasons to consider differences in heat demand between winter and summer. The current model version considers domestic biomass supply and energy demand and does not allow imports and exports of biomass or bioenergy commodities. The model determines which bioenergy plants (i.e. pellets, first generation ethanol or biodiesel, second generation methanol, BIGCC or BECCS, heating) of a specific size and specific location shall be built and which demand regions are supplied with bioenergy and/or with fossil fuels. Direct delivery of fuel wood from forest production sites to demand regions is possible. Each plant produces various energy commodities. They replace fossil fuels in heating, power generation, and transportation. By assumption, pellets and fuel wood are burnt in boilers of households or community heating networks, power is transmitted to the national grid, surplus heat is delivered to district heating networks and biofuels replace gasoline for transportation purposes. The objective function is minimized and consists of the costs of biomass supply from forestry and agriculture, biomass transportation (i.e. energy crops, forest biomass), plant investment annuities, district heating infrastructure annuities, investment annuities of heating furnaces, CCS costs, commodity transportation (i.e. fuelwood, pellets, transportation fuels) to consumers and the costs of the fossil reference technologies. Biomass supply curves endogenously determine the price of feedstock from forestry and agriculture, while prices of fossil fuels are given exogenously. Energy demand is defined exogenously by scenario assumptions. Taxes currently applied to both fossil and bioenergy fuels are not included in the model. A detailed description of the mixed integer program can be found in the appendix of paper 1.

Bewhere Description

The original version of the model has been kept and the focus was to determine the optimal positions of the biofuel production plants depending of the scenario studied. The model has been improved by considering the whole Austrian wood market: the actual location of the already existing wood industries, such as combined heat and power plants (CHP), pellet plants, pulp and paper mills, district heating plants and personal fuel wood consumption, are included into the model. These industries are main competitors for the feedstock with possible bioenergy plants, and the residuals from sawmills can help meeting the wood demand of those industries. The cost of the supply chain presented is minimized. The wood demand from the woody based industries has to be met. If there is sufficient amount of feedstock available, additional biofuel production plants can be selected by the model.

1.5. Aufbau der Arbeit - Structure of work

The work has been accomplished in three scientific papers. Paper 1 presents in details the BeWhere-Policy model, and studies the different policy scenario in order to decrease GHG emissions whithin the energy sector. Paper 2 compares second generation biofuels with various other options of introducing renewable fuels to the transportation sector including first generation biofuels and electric mobility from biomass power production for the year 2020. In order to make the results from paper 1 and paper 2 more consistent with the actual forest market in Austria, paper 3 presents the feasibility of those results on a finer grid as presented above.

2. Inhaltliche Darstellung – Content

Having developed the models, we applied BeWhere-Policy to two different research problems:

(i) Different energy policies, such as a CO_2-tax and a biofuel policy, were assessed for the year 2030, under special consideration of Carbon Capture and Storage in paper 1. The effect of the policies on GHG emissions and fossil fuel substitution was compared.

(ii) We compared different transportation technologies such as first and second generation biofuels and electric cars with respect to land use, greenhouse gas emissions and fossil fuel substitution for the year 2020. The assessment of uncertainties was a special focus in paper 2.

The BeWhere model was applied to the following research problem:

(iii) From the results of (i) and (ii), the potential for second generation biofuel has been analyzed by considering the whole Austrian forestry market. Knowing the wood demand of the existing forestry based industries; the economic potential for biofuel production was assessed under different policy scenarios.

3. Ergebnisse und Schlussfolgerungen – Results and conclusions

Cost-effective Application of Biomass for Heat, Power and Fuel Production (Paper 1 and Paper 2)

According to model results, an optimal mix of renewable fuel technologies consists of second generation methanol, biodiesel and some amount of electric mobility (see Figure 1). The results clearly indicate that second generation biofuels are less costly and use less land than first generation ethanol, even if by-products of first generation biofuels such as Dried Distillers Grains with Solubles (DDGS) are regarded. Biodiesel technology can provide biofuels at lower costs and higher land use efficiency than ethanol. However, land characteristics and crop rotations limit the amount of feedstock (i.e. rapeseed and sunflowers) that can be produced in Austria. Model results indicate an absolute limit of around 0.5 TWh of domestic biodiesel production (without considering imports of biomass).

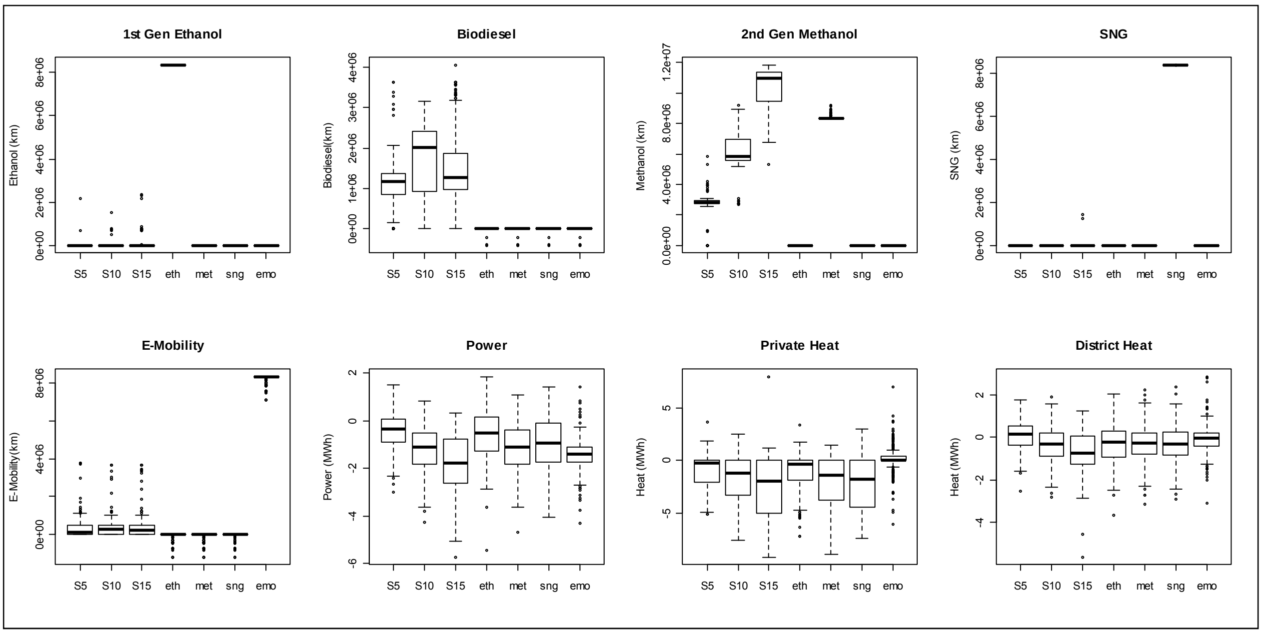

Figure 1: Bioenergy technology mix in the year 2020 for different scenarios. The figure shows the difference to the baseline scenario without policy intervention. (Source: Paper 2)

Land use of ethanol production is significantly higher compared to all other options. As shown in Figure 2, first generation ethanol causes a decline of land used for food and feed production of more than 150.000 ha on average (i.e. more than 10% of total available agricultural land) in comparison to the baseline scenario, already including positive land use effects due to by-products. Second generation methanol has a significantly lower impact of around 25.000 ha. The reason is simple: productivity of ethanol per hectare of land is lower than that of second generation fuels. The model results show that the average productivity per hectar is for ethanol at 29,400 km_{car} ha^{-1}, while methanol yields on average almost 44,100 km_{car} ha^{-1}. Biodiesel yields on average 35,000 km_{car} ha^{-1}. Additionally, the use of forest resources is not possible for the production of first generation fuels. Therefore, up to 27% of Austrian agricultural land has to be dedicated to the production of energy crops to substitute 10% of fossil transportation fuels with ethanol. From all transportation options, electric mobility shows by far the lowest land use change due to the superior conversion efficiency of 221,111 km_{car} ha^{-1}, i.e. 5 times the efficiency of second generation fuels. It has to be regarded in this context, that electric mobility is still a very expensive technology and that there remain serious technical obstacles to the large scale introduction (i.e. range and battery charging time).

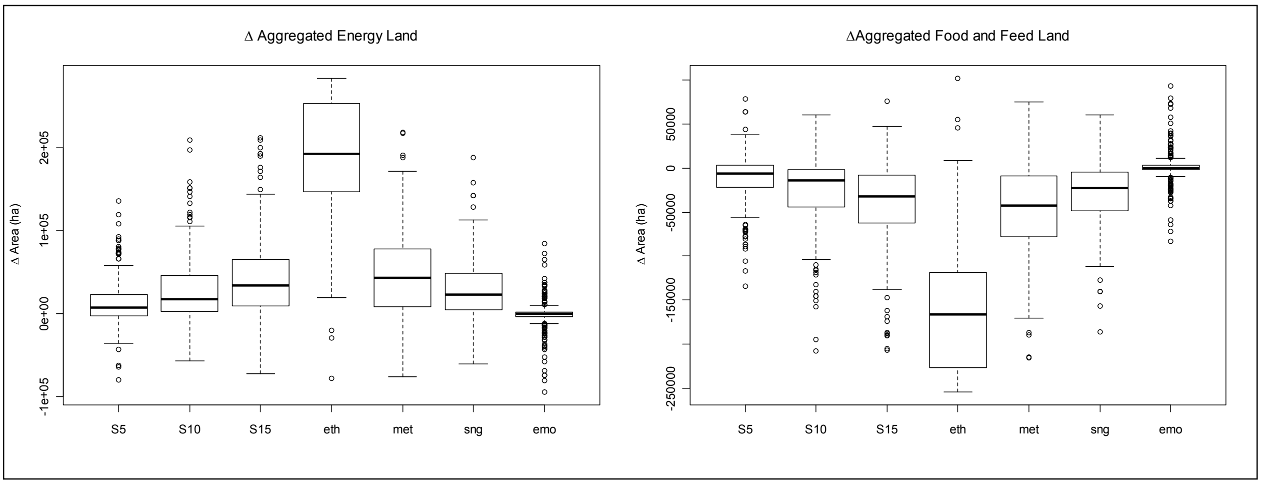

Figure 2: Land use for the year 2020 for different scenarios. The figure shows the difference to the baseline scenario without policy intervention. (Source: Paper 2)

The fact that second generation fuel production is able to use forest wood may, however, lead to the situation that inefficient first generation biofuels save locally more GHG emissions than more efficient second generation fuels. The simple reason is that first generation biofuels can only expand on agricultural land, while second generation fuels may compete for lingo-cellulosic feedstock on existing (forestry) markets. Market feedbacks will increase prices and production of heat and power from biomass may decline therefore – in total, less fossil fuel is substituted than without the introduction of biofuels. Guidelines for GHG emission accounting that do not consider indirect land use change, such as the current guidelines of the UNFCCC [13], would therefore conclude that the expansion of bioenergy production on agricultural land reduces GHG emissions while the expansion of second generation biofuel production will reduce heat and power production from biomass and in consequence increase total GHG emissions due to additional fossil fuel utilization.

For this reason, the assumption on the adaptation rates in the energy sector has very relevant implications for model results: if, as assumed in paper 2, the minimum of biomass heat production is fixed to 80% of 2008 levels, land use change as shown in Figure 2 has to be expected. However, if it is assumed – as done in paper 1 - that the whole biomass that is currently used for heating and power production may be used by other sectors, biomass production will not be increased drastically in the simulated scenarios and an expansion of biomass production on agricultural land will not occur to a large extent. Figure 3 reports how much agricultural biomass and biomass from forestry is produced in the biofuel scenario in paper 1 at varying levels of biofuel shares. No increase in biomass production is observed for higher shares of biofuel production. This is explained by Figure 4 that shows the technologies deployed at various level of biofuel production: heat and power production from biomass declines while biofuel production increases at the same rate. An extension of the provision of biomass is not necessary in that case because forestry biomass is deviated from heating and power to biofuel production. This substitution effect is clearly limited: if resource needs of second generation biofuel production exceed those of the previous levels of resource consumption of power and heat production, i.e. if all of the heat and power production is substituted by biofuel production, total biomass production will have to increase anyhow.

Cost-effective CO_2 Emission Reduction

In order to determine an optimal technological portfolio with respect to CO_2 emission reduction under consideration of all available bioenergy technologies, paper 1 applies a uniform CO_2 tax on all energy consumers. Figure 5 reports the technologies that are deployed in such a case: biofuel production plays a minor role while mainly heat production, and to a smaller extent, power production is expanded. The main reason is the high cost of biofuel production compared to relative low GHG emission savings and low fossil fuel substitution relative to heat and power production. Minimizing competition with existing bioenergy technologies by employing first generation fuels that do not rely on lingo-cellulosic biomass may reduce competition for forestry products. However, the performance of first generation fuels (i.e. production of fuel per hectare) is worse than that of second generation fuels which implies very high land use. If the same land is used for producing heat and power from lignocellulose, more fossil fuels can be substituted than from the production of first generation ethanol. Two facts explain this: production of lignocellulose yields more biomass per hectare than starchy crops and conversion efficiencies from biomass to fuel are higher for second generation methanol.

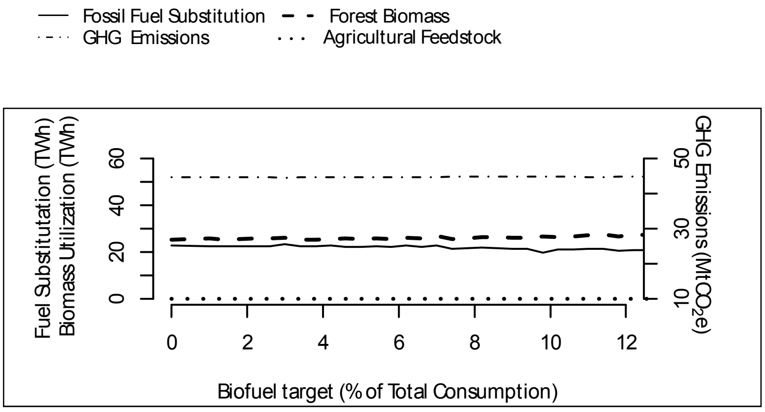

Figure 3: Fossil fuel substitution, GHG emissions, forest biomass utilization and utilization of agricultural feedstock in a scenario of increased biofuel production for the year 2030. (Source: Paper 1)

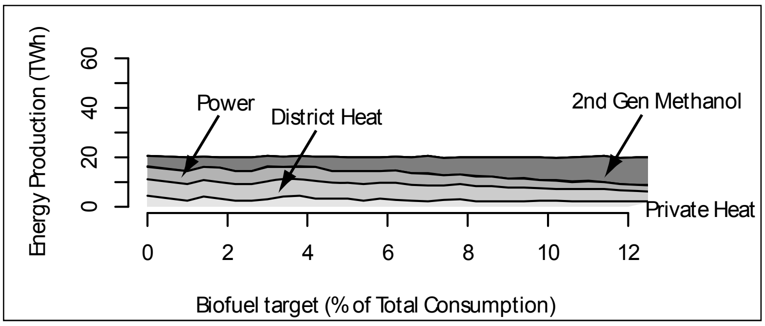

Figure 4: Technological mix with a biofuel policy for the year 2030. (Source: Paper 1)

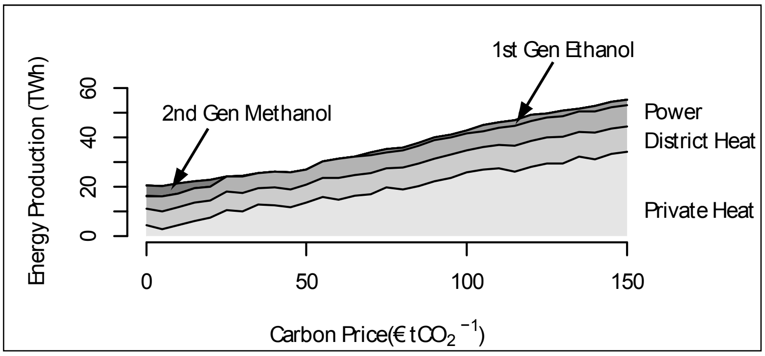

Figure 5: Technological mix when a carbon tax of different levels is assumed for the year 2030. (Source: Paper 1).

Carbon Capture and Storage

If CCS is allowed in the technological portfolio, second generation biofuel production, particularly methanol production, gains importance: in the transportation sector, other low carbon technologies are rare and very costly. Combining methanol production with CCS allows achieving very low emissions for transportation fuels at relative low costs: in the methanol production process, relative pure CO_2 streams are produced that can be easily captured and stored. CCS is deployed at CO_2 prices of above 60 € tCO_2^{-1} and methanol production and power production share a similar share of energy production in that case (see Figure 6). CCS also introduces a trade-off between GHG emission reduction and fossil fuel substitution: a carbon tax reduces both indicators at almost the same rate if CCS is not available. The availability of CCS allows very significant reductions of GHG emissions, however, fossil fuel substitution is rather low because plants with CCS operate with reduced conversion efficiencies.

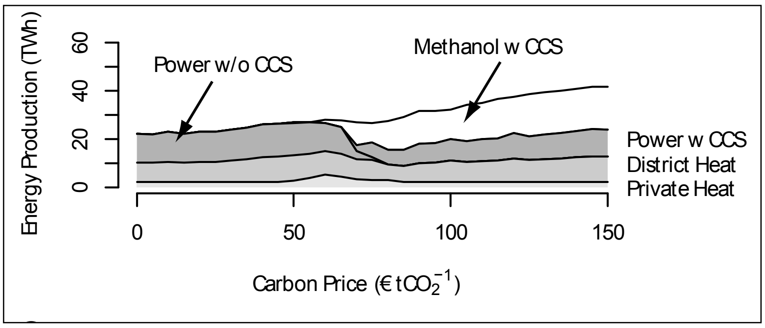

Figure 6: Technological mix when a carbon tax of varying levels is assumed for the year 2030 and CCS is available. (Source: Paper 1).

Bioenergy Policies

Rapidly increasing the share of biofuels in particular and bioenergy in general needs political intervention if energy prices are too low to incentivize the deployment of additional production capacities. Two set of policies are available for that purpose [14]:

- The first kind of policies penalizes the use of fossil fuels and thus internalizes some of their external effects. In the context of climate policy, emission trading schemes (ETS) and a CO_2 tax are mainly discussed. The EU ETS is a working implementation of such a scheme while a CO_2 tax is currently employed in some European countries.
- Technology specific subsidies are used to incentivize further development of technologies that are currently far from being competitive on the market. Policies of the first kind would have to be introduced at very high levels to make such technologies competitive. Direct subsidies to such technologies may help to quickly bring down costs of the technologies due to learning effects. Feed-in tariffs for biomass power plants as well as the current European biofuel policy can be considered to belong to this category of policies.

In Paper 1 we assess the effectiveness of energy policy instruments in achieving GHG emission reductions and fossil fuel substitution for the year 2030. The analysis was restricted to bioenergy technologies. We exogenously assumed learning effects for all technologies.

The analysis clearly demonstrates that the biofuel policy has to be regarded ineffective. Even with second generation biofuel technology, effects of the policy with respect to GHG emission reduction and fossil fuel substitution are negligible because the policy mainly incentivizes the substitution of heat and power production by biofuel production but still causes additional costs. The biofuel policy has, besides climate and energy targets, also the objective of creating additional income for European farmers [15]. However, this objective could be better aligned with objectives of climate and energy policy if the production of lingo-cellulosic feedstock by agriculture is promoted and the feedstock is converted to heat and power instead of fuels. Our analysis suggests that this is less costly and has more effects on the substitution of fossil fuels and on the reduction of GHG emissions than the biofuel policy. This even holds if significant demand declines due to efficiency gains in the building sector are assumed.

The most effective policy instrument for achieving low CO_2 emissions and fossil fuel substitution is the CO_2 tax. Losses in cost-effectiveness of the EU ETS are significant because some important sectors, like the private heating sector, are excluded from the scheme (see Figure 7). A trade-off between the two policy objectives of reducing GHG emissions and substituting fuels exists if CCS is available. Fossil fuel substitution declines with the introduction of CCS at CO_2 prices above 60 €tCO_2^{-1}.

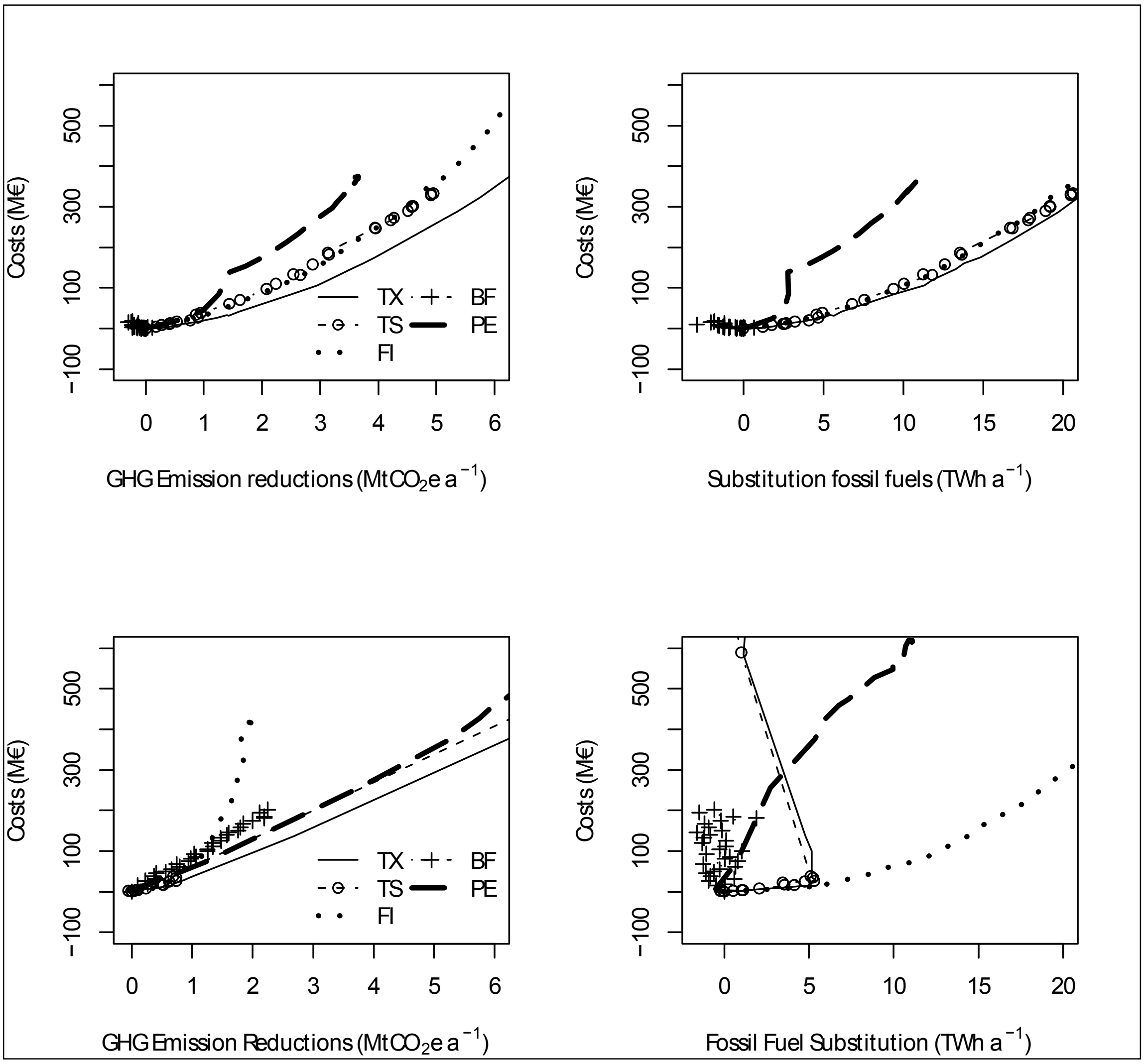

Figure 7: GHG emission reductions (left) and fossil fuels substituted (right) in relation to costs in the scenario without CCS (upper) and with CCS (lower).

Assessing Second Generation Biouels (Paper 3)

Assessing the second generation biofuel potential in Austria can only be achieved if one takes into account the already existing forestry market. Therefore, the location and the wood demand of the forest industries that already exist (pulp and paper mills, saw-mills, CHP, district heating plants…) are implemented in the BeWhere model. With varying external factors to the supply chain such as the wood demand (100% refers to the actual situation), a CO_2 cost, and the fossil fuel price, the second generation biofuel (ethanol and/or methanol) potential is estimated for Austria.

Gasification vs. Hydrolysis and Fermentation

The biofuel production costs for the two technologies are presented in Figure 8 for both methanol (left) and ethanol (right). The biofuel cost corresponds to the sum of the costs from transportation, feedstock, biofuel production, and income from carbon subsidies. As the wood demand increases the biofuel cost increases too: the transportation distances for collecting the feedstock increases as the wood demand is increasing. The methanol cost varies within a range of 5 €/GJ, whereas the ethanol cost varies within a range of 7 €/GJ. The latter is indeed very sensible to income from the by-products, such as residual heat. For a wood production of 100%, a methanol cost between 15 and 20 €/GJ can be reached whereas the cost of ethanol can reach 19-28 €/GJ.

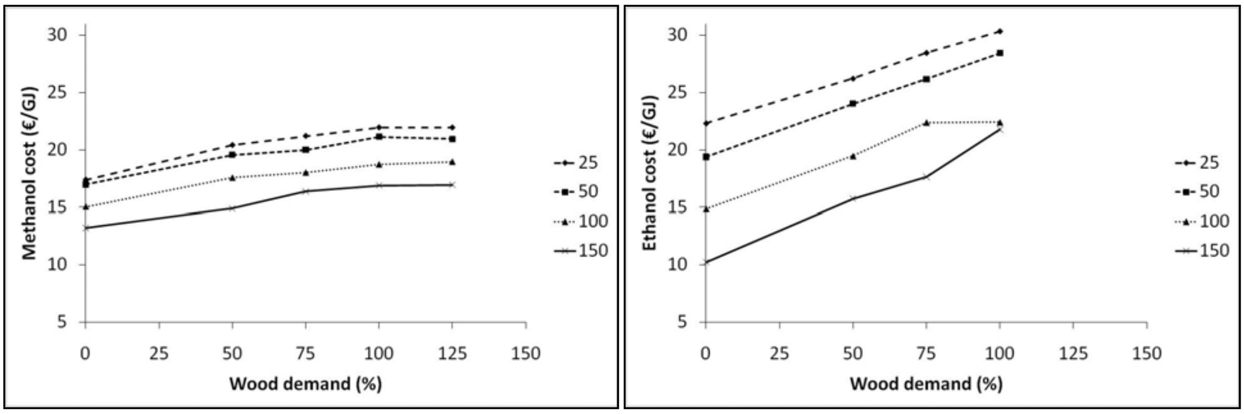

Figure 8: Influence of the wood demand on the methanol cost (left) and ethanol cost (right) for four carbon cost scenarios (fossil fuel price 20 €/GJ, feedstock used: forestry wood and poplar plantations).

Influence of CO_2 Price

As the CO_2 cost increases, the biofuel cost decreases. This is due to the income from CO_2 permits or CO_2 tax exemptions. If those incomes were not considered in the cost, the biofuel costs would remain constant whatever the carbon cost applied as the biofuel production does not change for different CO_2 cost scenarios (see Figure 9).

The influence of a CO_2 cost on the biofuel production is illustrated by Figure 9, left side. Setting a CO_2 cost over 25 €/t_{CO2} imposes the production of biofuel. With a CO2 cost applied, the production of biofuel is limited to 40 PJ for a wood demand up to 100%. Over that limit, the biofuel producion decreases. Figure 9, right side, presents the share of methanol produced at a certain wood demand and CO_2 cost. Until a wood demand of 75%, there is as much methanol as ethanol produced. For a wood demand of 100%, the share of methanol produced is between 71-90% depending on the CO_2 tax imposed, and it reaches a share of 100% for a wood demand of 125%: as the feestock becomes scarcer, it becomes more interesting to invest in methanol as the overall efficiency is greater than the ethanol efficiency.

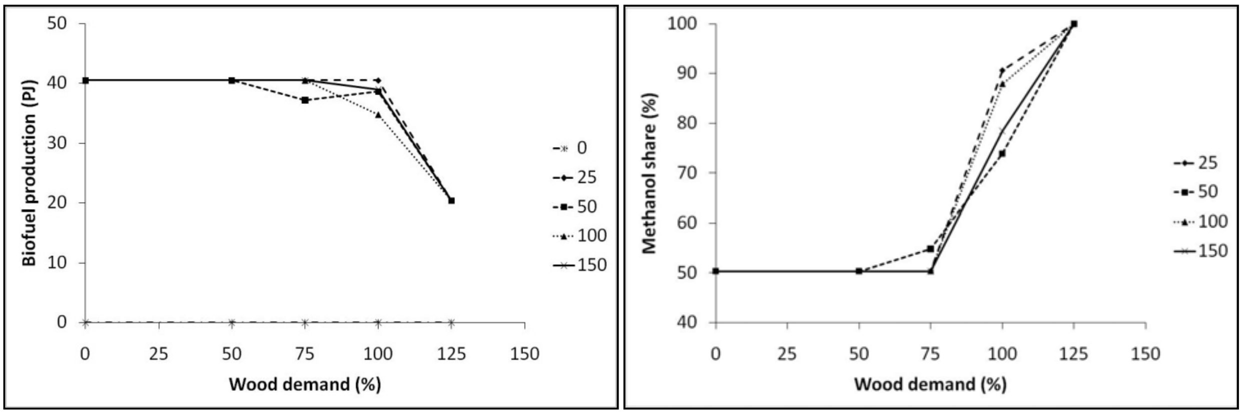

Figure 9: Left: influence of the wood demand on the biofuel production; right: influence of the wood demand on the methanol production, for four carbon cost (€/t_{CO2}) scenarios. (Fossil fuel price 20 €/GJ, feddstock used: forestry wood and poplar plantations).

Optimal Locations and Scales

Figure 10 presents the optimal locations in respect with their number of appearance for methanol production plants (first row) and ethanol production plants (second row), with the use of forestry wood only (left side) and foresty wood with poplar plantations (right side). Three categories can be defined: the locations that appear for 1-10% of the runs, 11-25% of the runs, and the locations that appear for 26-40% of the runs and constantly (100%) for ethanol and methanol production plants respectively.

For the methanol production plants, two points are of interest (appearance equals to 100%), one is located in the vicinity of Salzburg, and the other one close to Amstetten. These cities can be supplied by residual heat from the production plants; they are also close to a highway and railway, which facilitates feedstock and biofuel transportation through the country. Adding poplar plantations as an energy feedstock does not influence the results on the locations.

For the ethanol production plants, the main area of interest is around Vienna. The demand for residual heat plays a major role in the location of the ethanol production plant. The production of residual heat is higher when producing ethanol than when producing methanol; therefore the ethanol production plant should be located closer to areas of higher heating demand.

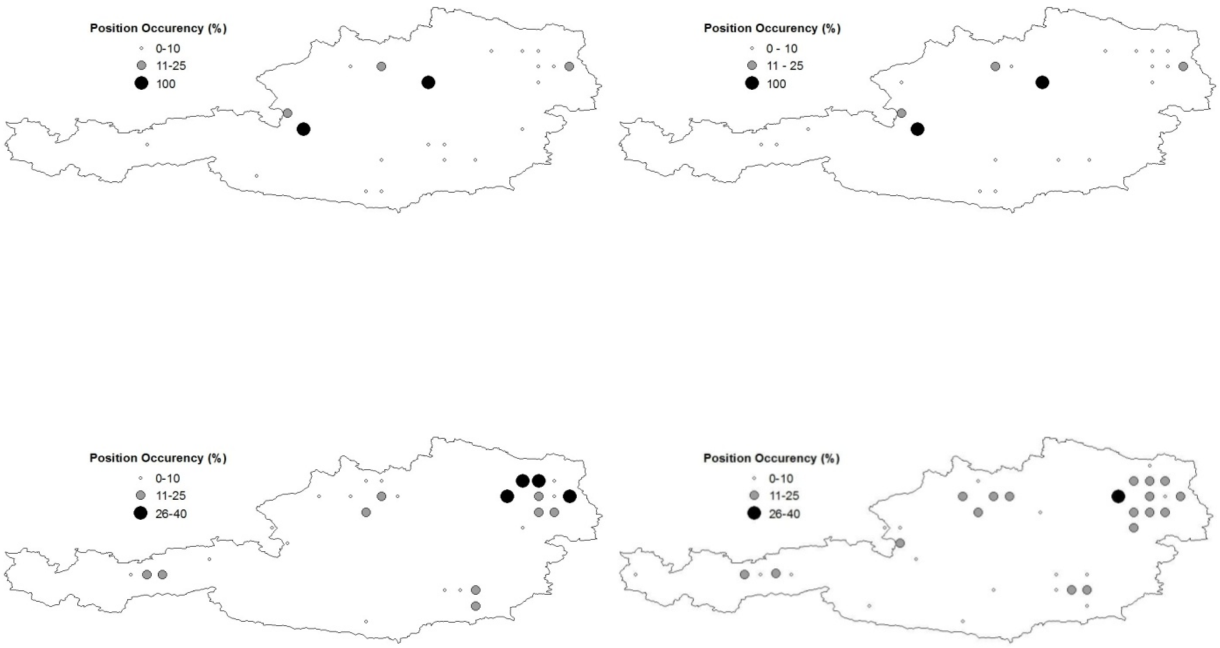

Figure 10: Positions of the production plants selected from the 210 simulations (from top to down, and left to right: 1. methanol with forest only; 2. methanol with forest and poplar plantations; 3. ethanol with forest only; 4. ethanol with forest and poplar plantations.

4. Ausblick und Empfehlungen - Outlook and Recommendations

We want to emphasize that many of the conclusions and policy recommendations rely on assumptions on the technological performance of bioenergy technologies. These assumptions are based on an extensive literature review of existing and yet to be developed bioenergy technologies. It is, however, inherent to the problem that *future* performance data of technologies is unknown. All conclusions and policy recommendations are therefore based on what is currently known about technological details.

Efficiency gains of second generation fuels over first generation ethanol are significant: per hectare yield of biofuel on agricultural land are estimated to be 50% above those of first generation fuels. Biodiesel is more efficient than ethanol. However, total domestic production potentials for the feedstock are limited at a very low level. If the biofuel policy is therefore continued, a switch to second generation fuels will reduce total land use of the biofuel policy at lower costs. At the same moment, the biofuel policy as a whole – independent if second generation fuels are considered or not – seems to be ineffective in reaching objectives of climate and energy policy. If second generation biofuels are available, competition for woody biomass will increase and biomass heating and power production will therefore increasingly be switched to rely on fossil fuels, which is, in terms of GHG emission reduction and fossil fuel substitution, ineffective. If biofuel production otherwise relies on first generation biofuels only, large scale land use change has to be expected if the feedstock is produced domestically. A highly land use efficient solution can be provided by electric mobility that is fuelled by biomass power production. However, technical barriers to the large scale introduction of electric mobility are still significant. In the light of huge up-front investment costs in an industry such as second generation biofuel production, it therefore seems to be advisable to still wait on further technological developments before deciding to subsidize the technology. There is one long-term technological development that may make second generation biofuel production very attractive with respect to GHG emission reduction: CCS. If CCS is introduced at large scale in Europe, it would certainly be introduced for the power sector first. However, CCS in combination with biofuel production is a cheap and effective way of reducing GHG emissions because (i) costs of CCS are cheaper than in power production and (ii) fossil fuels used in transportation do not allow for CCS while fossil fuels combusted in power plants do. Both, biomass power production and biofuel production with CCS are effective ways of reducing GHG emissions therefore.

With respect to the resource base, it has to be emphasized that in principle the conversion of woody biomass to heat and power is more effective in reducing GHG emissions than the production of transportation fuels. An expansion of this resource base from forestry or agriculture should therefore mainly be directed to these conversion chains. Demand limitations will most certainly constraint the deployment of additional biomass resources in these sectors later than constraints in biomass supply. If agricultural policy seeks to increase the agricultural production of energy products for reasons of rural development - which always has to be considered in the light of competition for land by food and feed crops production - the project results conclude that short rotation plantations are more effective than other crops if the feedstock is directed to heat and power production. A redesign of the biofuel policy in the light of these results seems to be indicated.

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6. Anhang - Attachment

Paper 1:

Schmidt, J., Leduc, S., Dotzauer, E., Schmid, E. 2011. Cost-effective policy instruments for greenhouse gas emission reduction and fossil fuel substitution through bioenergy production in Austria. Energy Policy (Submitted).

Paper 2:

Schmidt, J., Gass, V., Schmid, E. 2011. Land use, greenhouse gas emissions and fossil fuel substitution of biofuels compared to bioelectricity production for electric cars in Austria. World Renewable Energy Congress 2011, Linköping, Sweden.

Paper 3:

Leduc, S., Schmidt, J., Dotzauer, E., How can Austria Increase its Biofuel Production? Submited to Biomass and Bioenergy.