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

Final Report

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1. Projektdaten

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<tr><td>Kurztitel</td><td colspan="2">GHG-SEBA</td></tr>
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<tr><td>Projektnummer</td><td colspan="2">A963628</td></tr>
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<tr><td>Projektpartner</td><td colspan="2">Universität für Bodenkultur Wien (BOKU) Vienna, Austria</td></tr>
<tr><td>Projektstart u. - Dauer</td><td>Projektstart: 01.09.2009</td><td>Dauer: 14 Monate</td></tr>
<tr><td>Berichtszeitraum</td><td colspan="2">[von 01.09.2009 bis 30.11.2010]</td></tr>
<tr><td colspan="3">Synopsis:
A techno-economic, geographically explicit optimization model has been developed to determine the potential for bio-energy production in Austria. A policy sub-model has been used to estimate the bio-energy potential under different policy scenarios while a more detailed model has been applied to assess the feedstock competition in the forestry market and draw conclusions for the economic and practical feasibility of biofuel production. Results indicate that a CO_2 tax is the most cost-effective way to reduce CO_2 emissions while biofuel policies may even generate positive net CO_2 emission. Biomass power production and biofuel production with CCS are ways to reduce significantly emissions. Short rotation plantations appear to be more effective than other crops if they are directed to heat and power production while it is less effective for 2nd generation biofuel production.</td></tr>
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2. Technisch-wissenschaftliche Beschreibung der Arbeit – Technical-Scientific Description of Project

2.1. Projektabriss (max. 3 Seiten) - Abstract

Austria faces stringent renewable energy targets in order to decrease its greenhouse gas emissions (GHG). By 2020, the share of energy coming from renewable sources should reach 34% of the Autrian energy production. To meet this target, the use of biomass for energy purposes will play a major role, and a strategic biomass use is essential. This project focuses on the economical feasibility for Austria to increase its bioenergy production with a particular focus on second generation biofuels.

The problem is aproached with a techno-economic, spatially explicit model (BeWhere) which optimizes the location, capacity and technology of bio-energy production plants. The full supply chain of the bio-energy production (from the collection of biomass to the bio-energy distribution to the consumers) is analyzed, and the cost of the chain is minimized. The BeWhere model has been developed within two complementary directions. A first model (BeWhere-Policy) has been developped towards an energy policy point of view, where biomass from arable areas and forest can be used for different energy purposes (transport, heat, power) through different technologies such as biofuels, pellets and district heating. The BeWhere-Policy model provides information on the share of different bio-energy commodities that will be produced under certain policy scenarios such as CO_2 emission taxes or biofuel targets. The second version of the model (BeWhere) focuses on a detailed assessment of second generation biofuels under particular consideration of transportation logistics and the competition for wood in the Austrian forestry market by existing woody based industries. The results will provide information on the economical feasibility to produce biofuel in Austria.

BeWhere is applied on a fine grid, considering all woody based industries of Austria, and the biofuel potential is analyzed under different scenarios with varying carbon cost, fossil fuel price and amount of wood demand. One paper compares different second generation fuel production technologies. Results indicate that methanol production plants are selected over ethanol

production plants when the availability of feedstock becomes scarcer. With today's wood consumption in Austria, and today's fossil fuel price, up to 14.4 PJ (4 TWh) of biofuel could be produced. Setting a carbon cost, forces the production of biofuel up to a limit of 40 PJ (11 TWh) biofuel, and an increase of the wood demand by 25% would limit the biofuel production to 20 PJ (6 TWh) only if poplar plantations is added into the system. Two locations are of high interest for the methanol production plants which are in the vicinity of Salzburg and Amstetten. These places are close to highways and train stations for logistic matters. Also, the production plant can deliver its residual heat to settlements. Ethanol production plants are mainly located close to areas of high heat demand due to higher residual heat from the production process.

BeWhere-policy is applied in two papers to assess (i) the cost-effectiveness of bioenergy policies and (ii) various options to reach the 10% target of renewable energy in the transportation sector as required by European energy policy. Results indicate that a CO_2 tax on all fossil fuels is the most cost-effective policy to reduce greenhouse gas emissions as well as substitute fossil fuels. A policy that indicates a certain percentage of biofuels in transportation is less effective because application of biomass for heat and power generation is less costly and saves more GHG emissions than the production of second generation fuels from woody biomass. With respect to the 10% target for renewable energy in the transportation sector, model results indicate that a mixture of first generation biodiesel and second generation methanol is optimal. Even electric mobility, combined with power production from biomass, may contribute to the targets. With respect to costs and land-use change, the second generation fuel methanol outperforms first generation ethanol that is costly and substitutes a lot of food and feed production. However, it has to be considered that even the optimal mix of biofuels in production imposes restrictions on the availability of the resource biomass in other energy sectors such as heat and power production and may therefore, in total, cause negative effects on the overall GHG emission balance.

2.2. Inhalte und Ergebnisse des Projektes (max. 20 Seiten) - Contents and Results of the Project

2.2.1. Ausgangssituation/Motivation des Projektes – Project Motivation

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. This study should indicate which consequences and effects have to be expected if the decision is taken to opt for the production of second generation biofuel in Austria.

2.2.2. Zielsetzungen des Projektes – Project Objectives

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.

2.2.3. Durchgeführte Arbeiten im Rahmen des Projektes inkl. Methodik – Effective Work in the Project Including Methodology

The project included mainly 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

Model Components

The data and the models used for the BeWhere model compound are presented in Figure 1. CropRota, EPIC [13] and PASMA [14] are used jointly to deliver spatially explicit supply curves for agricultural biomass. Soil, climate and management data as well as production costs and prices of agricultural products are necessary input for the model framework. The G4 model is used to spatially explicitly estimate the growth of forest biomass, relying on data of the Austrian Forest Inventory and Corine Landcover [15].

The heat demand is spatially explicitly estimated using data on buildings (type and age) [16] which is combined with average consumption values for such buildings. A detailed description of the methodology can be found in [17]. Demand scenarios for 2020 and 2030 are created by assuming rates for building retrofitting and for the demolition and new construction of dwellings. Spatially explicit estimations of population growth by ÖROK [18] are used to distribute growth of building areas spatially in Austria. Demand for power and transportation is linearly extrapolated from the historic trends [19], [20]. Performance data of bioenergy production technologies are taken from a literature review (see Paper 1) while GHG emission factors are mainly taken from Austria's National Inventory Report [21]. Schwarzbauer [22] provided estimates of supply elasticities of wood.

Model 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 a 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 (Figure 2). 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.

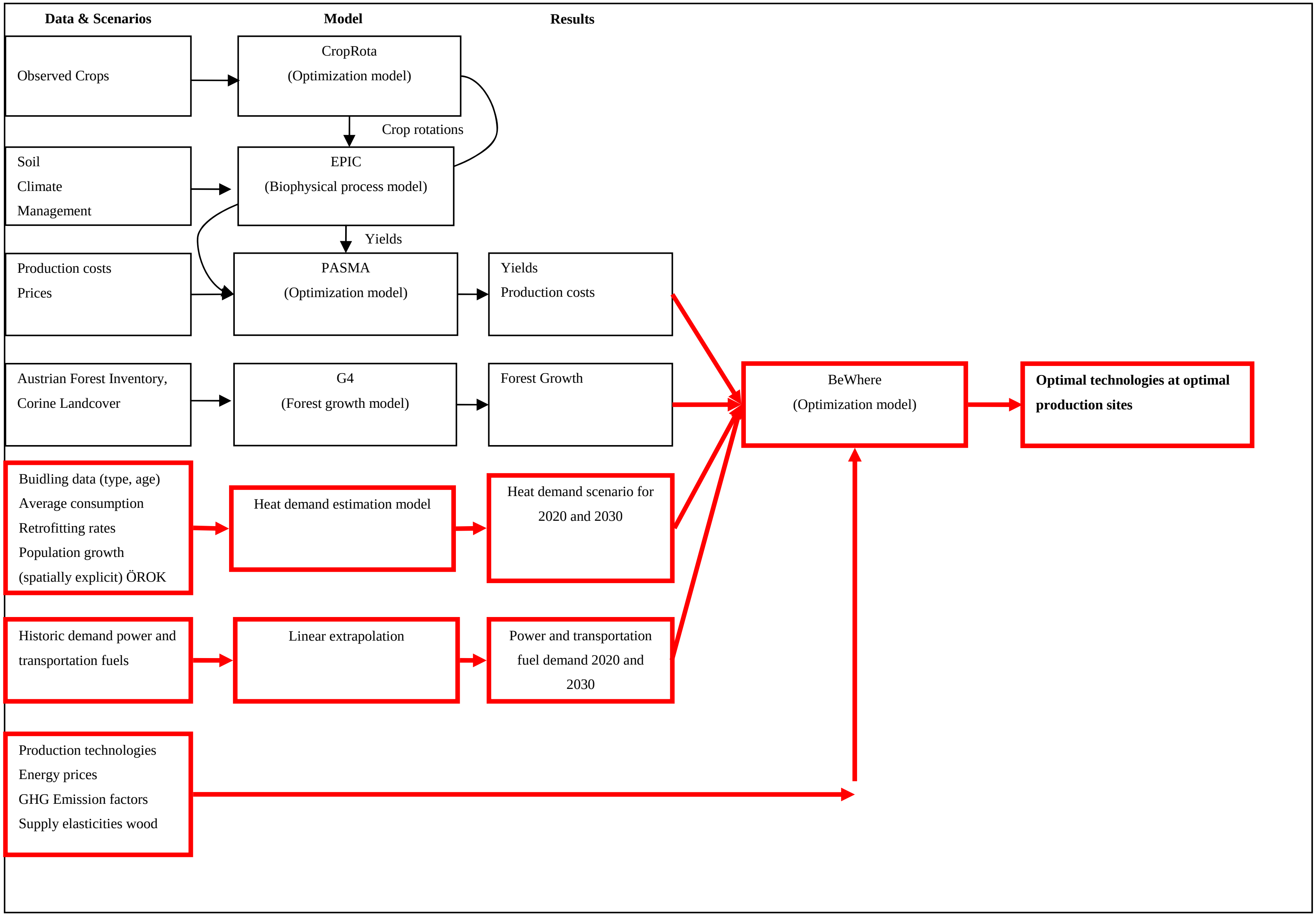

Figure 1: Integration of BeWhere with existing agro-economic model compound. In red: the model development in this project.

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.

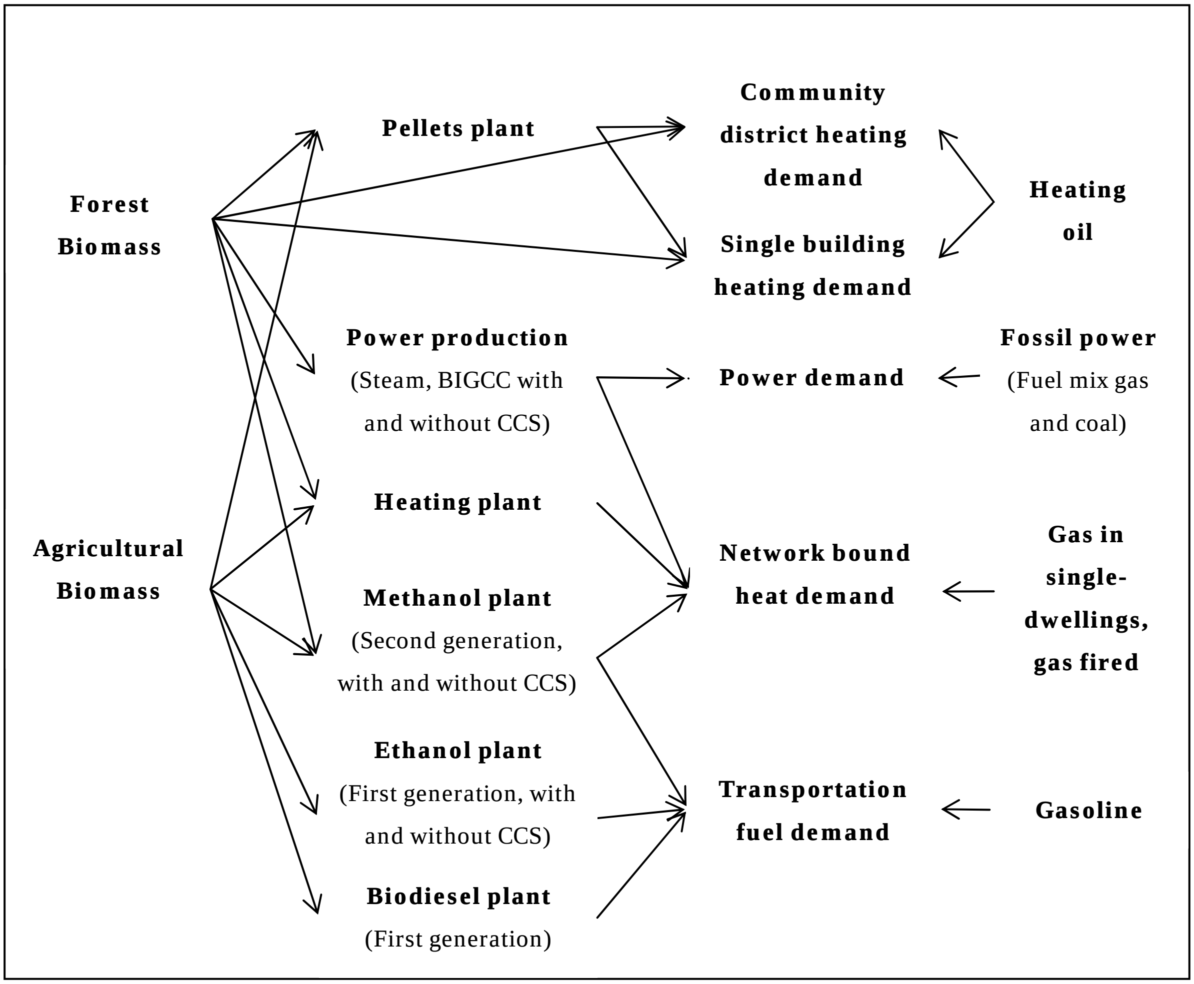

Figure 2: Diagram of the mixed integer programming model.

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.

Handling of Uncertainty

When assessing scenarios that forcast the far future, the role of uncertainty plays an important role, particularly if highly uncertain parameters such as technological developments and energy prices are necessary input parameters in the modeling process. In paper 2, a Monte-Carlo simulation of input parameters, as proposed in [23], was applied to (1) show uncertainty ranges of results and (2) conduct a global sensitivity analysis of parameters. Instead of assuming single values for the most uncertain input parameters, probability distributions were assigned to them. From these distributions, random combinations of parameter values were determined and the model was run for each of these parameter combinations. Instead of yielding a single result, probability distributions of results can thus be created, allowing insights into the uncertainty of model results. The approach also allows conducting a global sensitivity analysis of parameters, showing the influence of input parameters on the output. Due to the computational complexity of the Monte-Carlo simulations, the methodology was not applied to all research problems but was limited to paper 2. In paper 1, a different approach was taken: for some parameters (levels of policy instruments) a detailed study of the effects was conducted, while the effect of other parameters was assessed in a scenario analysis only. Full Monte-Carlo simulation of all assessed scenarios would have been computationally too demanding.

As a single instance of the optimization model takes minutes to solve and for both, the Monte-Carlo simulations and the scenario analysis, many thousand problem instances have to be solved, we implemented a version of the model for the Vienna Scientific Cluster [24] which allowed to speed up calculation of model results drastically as simulations can be run simultaneously on several processing nodes.

Model Applications

Having developed the models, we applied BeWhere-Policy on two different research problems which results are discussed in section 2.2.4:

(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 fuels 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.

BeWhere

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 loaction 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. Figure 3 presents the wood supply chain with considering all woody based industries in Austria.

The cost of the supply chain presented in Figure 3 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.

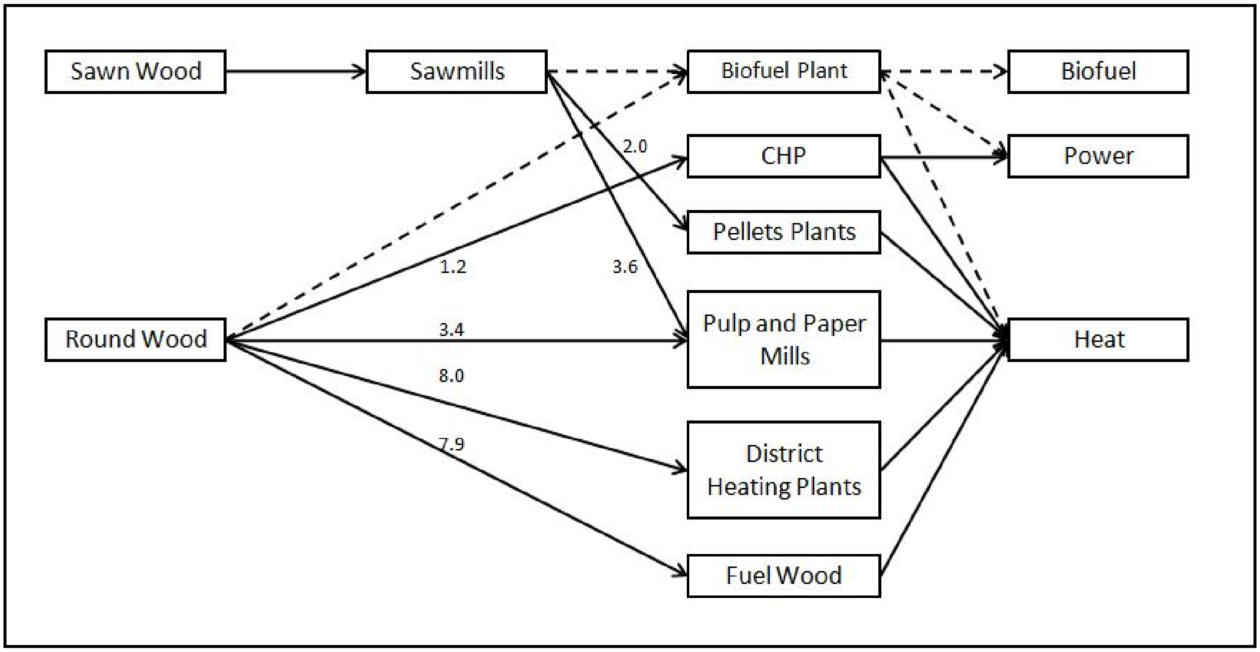

Figure 3: Forest wood conversion route. The dashed lines are potential routes if the amount of biomass is sufficient after meeting the wood demand from the actual woody based industries. The numbers (in million m^3) represent the amount of wood necessary from each actual woody based industry [9].

The upgraded version of BeWhere also incorporates a full road and railway network for Austria. The distance from one grid point to another grid point is calculated by finding out the shortest distance travelled by combining truck and train. Both biomass and biofuel can be transported by truck or train. It can only be transported by truck if the distance travelled is below 200 km. For longer distances, the combination of truck and train is possible if the a railway network allows it. It is not possible to travel by train for distance lower than 150 km. Those calculations are made in a GIS software.

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. This version of the model is applied in paper 3.

The differences between the two models (BeWhere and BeWhere-Policy) are presented in Table 1.

	BeWhere-Policy	BeWhere
Modeling of biomass economics	Supply curves	Fixed shares of available biomass, including forest industry residuals Fixed production costs
Competition with other bioenergy technologies	Full competition between all modeled technologies (heat, power and fuel production)	Current biomass consumption for energy production (heat, power and fuel) is assumed to be fixed Biofuel production is "additional"
Logistics	Euclidian distances between two grid points	Actual road and railway network allows transportation by truck and/or train
Technologies	All main bioenergy technologies (heat, power, fuel). Allows modeling of CCS	Second generation biofuels No CCS
District heating	Spatially explicit estimation of heating demand, Costs of district heating infrastructure	Only partly integrated, Uses results from BeWhere-Policy
Spatial resolution (possible)	Low	High
Sensitivity Analysis and Uncertainty	Paper 1: Scenario analysis Paper 2: Global sensitivity analysis (Monte-Carlo simulation)	Local sensitivity analysis

Table 1: Main differences between BeWhere-Policy and BeWhere.

2.2.4. Beschreibung der Ergebnisse und Meilensteine – Description of Results and Milestones

This section summarizes the results of the three papers that are attached to this report. A detailed report on the assumptions made in the studies and an extensive discussion of the results can be found in these papers. In this report, we briefly discuss the most important results. We first show results of comparing two competing second generation biofuel production technologies (Gasification vs. Hydrolysis and Fermentation) and subsequently compare first and second generation fuels with electric mobility, heat and power production. The effect of energy policy instruments on the deployment of bioenergy technologies and the resulting GHG emissions and fossil fuel substitution are discussed in an own section while spatially explicit results of the modeling efforts are presented at the end of this section.

Introduction to Second Generation Biofuels

In comparison to first generation biofuel which rely on agricultural crops, second generation biofuels can use woody biomass that is either supplied from forestry, from residuals from the wood industry or from the production of lingo-cellulosic feedstock on arable land. Second generation biofuels have a higher overall biomass to fuel efficiency, which makes them attractive in comparison to the first generation. The drawbacks are that the technology is currently costly. Also, very large production units are necessary to be competitive with fossil fuels. In this project two second generation biofuel technologies have been considered, which are methanol from gasification and ethanol from hydrolysis and fermentation. The gasification technology produces more than twice as much biofuel as the hydrolysis and fermentation technology. However, the later technology creates more income from the production by-products such heat, power and biogas. The key performance parameters of the two technologies are summarized in Table 2.

Table 2: Key factors for the production of methanol and ethanol [25-28].

Key factors	**Unit**	**Methanol (Gasification)**	**Ethanol (Hydrolysis and Fermentation)**
Fuel efficiency	$GJ_{biofuel}/GJ_{biomass}$	0.58	0.243
Heat efficiency	$GJ_{heat}/GJ_{biomass}$	0.08	0.176
Power efficiency	$GJ_{electricity}/GJ_{biomass}$	-	0.085
Biogas efficiency	$GJ_{biogas}/GJ_{biomass}$	-	0.132
Base plant size	$MW_{biomass}$.	388	100
Investment cost	M€	505	100
Operation cost	€/$GJ_{biofuel}$	6.13	11.0

Box 1: Main assumptions in the three articles attached to the report

Main assumptions Paper 1

- The year 2030 is studied. Substantial learning effects until year are assumed for all technologies.
- No trade of biofuels and biomass.
- Heat demand declines due to efficiency gains by 32%, power demand increases by 25% and transportation demand increases by 12%.
- Oil price at 65 € bbl^{-1}, other prices accordingly.
- Full competition between *all* bioenergy technologies.
- Existing taxes on fossil fuels are not regarded.
- Indirect land use change effects of increasing agricultural biomass production not considered.

Main assumptions Paper 2

- Year 2020 is studied. Substantial learning effects for that year are assumed for all technologies.
- No trade of biofuels and biomass.
- Heat demand declines due to efficiency gains by 32%, power demand increases by 15% and transportation demand remains constant.
- A minimum of 80% of 2008 levels of biomass heat production is preserved.
- Existing taxes on fossil fuels are not regarded.
- Indirect land use change effects of increasing agricultural biomass production not considered.

Main assumptions Paper 3

- All positions and wood demand of the already existing woody based industries are considered.
- Forest market of 2007 is simulated.
- No trade of biofuels and biomass.
- Fixed heat demand.
- Existing taxes on fossil fuels are not regarded.

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

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. We included electric mobility as it is generally considered as superior to biofuel production with respect to land use efficiency [29]. Seven scenarios are compared: in scenarios S5, S10 and S15 the optimization model freely choses which technologies are used to reach a share of 5%, 10% and 15% of renewable energy in transportation, respectively. Additionally, four scenarios assess the attainment of a share of 10% of renewable energy in transportation, fixing the technology to first generation ethanol (*eth*), second generation methanol (*meth*), second generation synthetic natural gas (*sng*) and electric mobility, fuelled by electricity produced in biomass plants (*emo*).

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 4). 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).

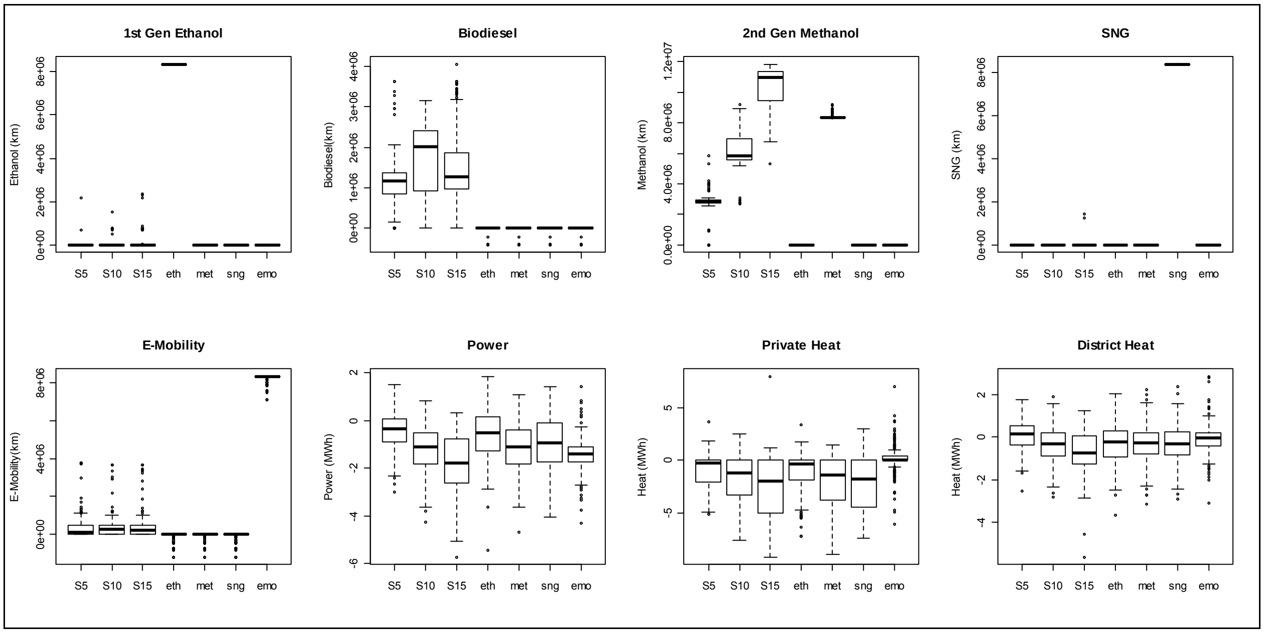

Figure 4: Bioenergy technology mix in the year 2020 for different scenarios. The figure shows the difference to the baseline scenario without policy intervention. (Source: Paper 2)

Land use of ethanol production is significantly higher compared to all other options. As shown in Figure 5, 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).

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 [30], 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 5 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 6 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 7 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.

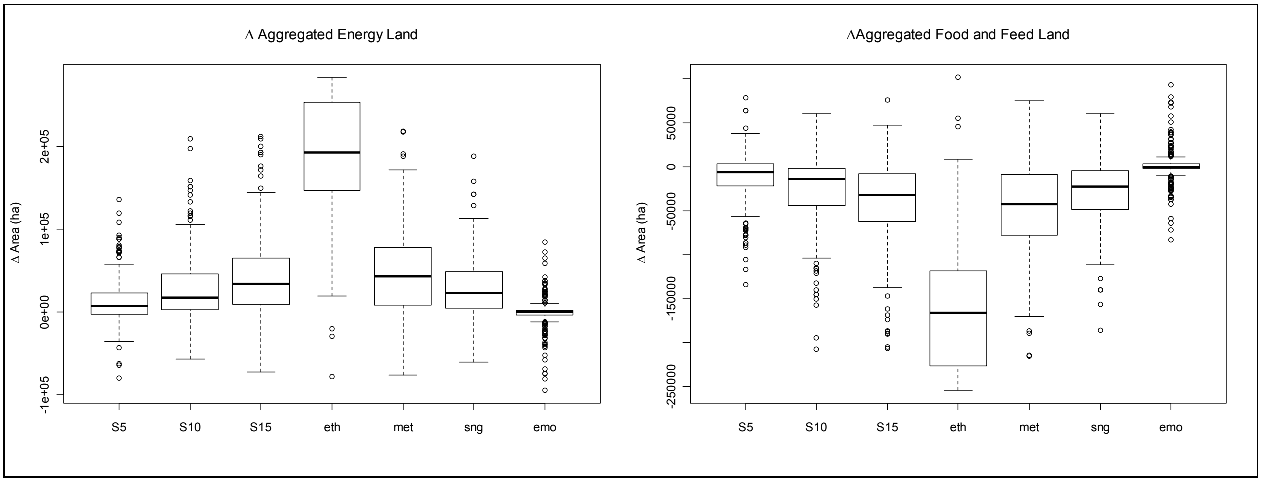

Figure 5: Land use for the year 2020 for different scenarios. The figure shows the difference to the baseline scenario without policy intervention. (Source: Paper 2)

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 8 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.

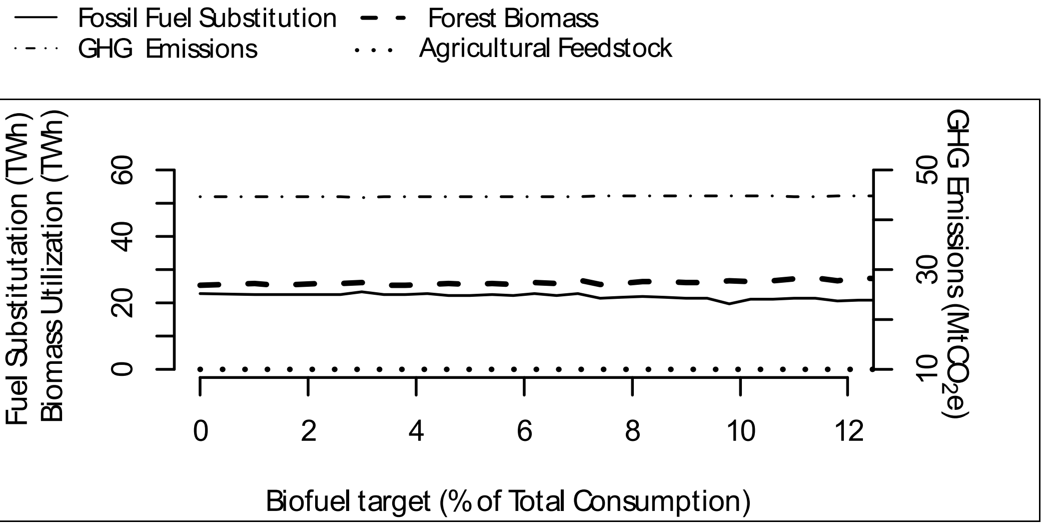

Figure 6: Fossil fuel substitution, GHG emissions, forest biomass utilization and utilization of agricultural feedstock in a scenario of increased biofuel production for the year 2030. (Source: Paper 1)

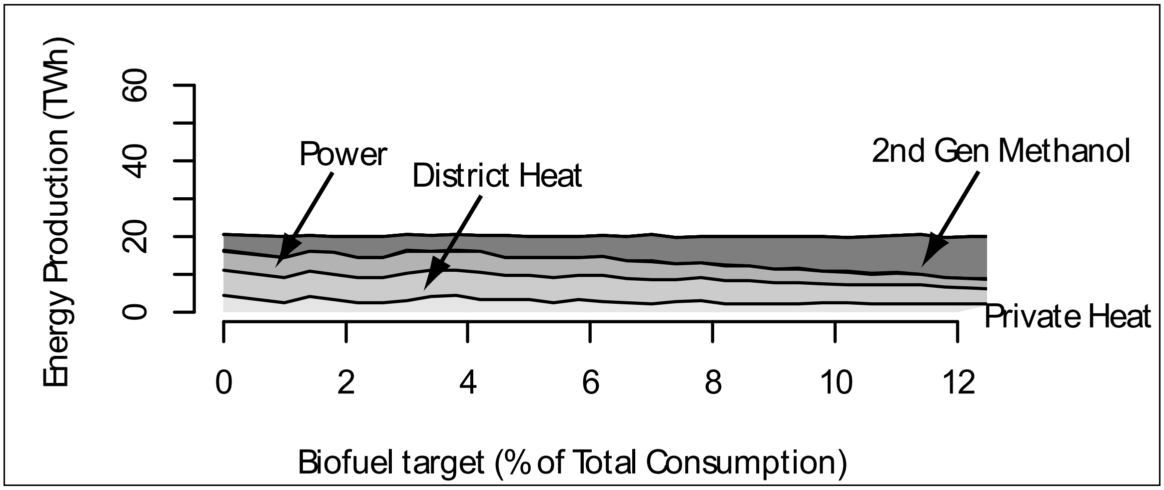

Figure 7: Technological mix with a biofuel policy for the year 2030. (Source: Paper 1)

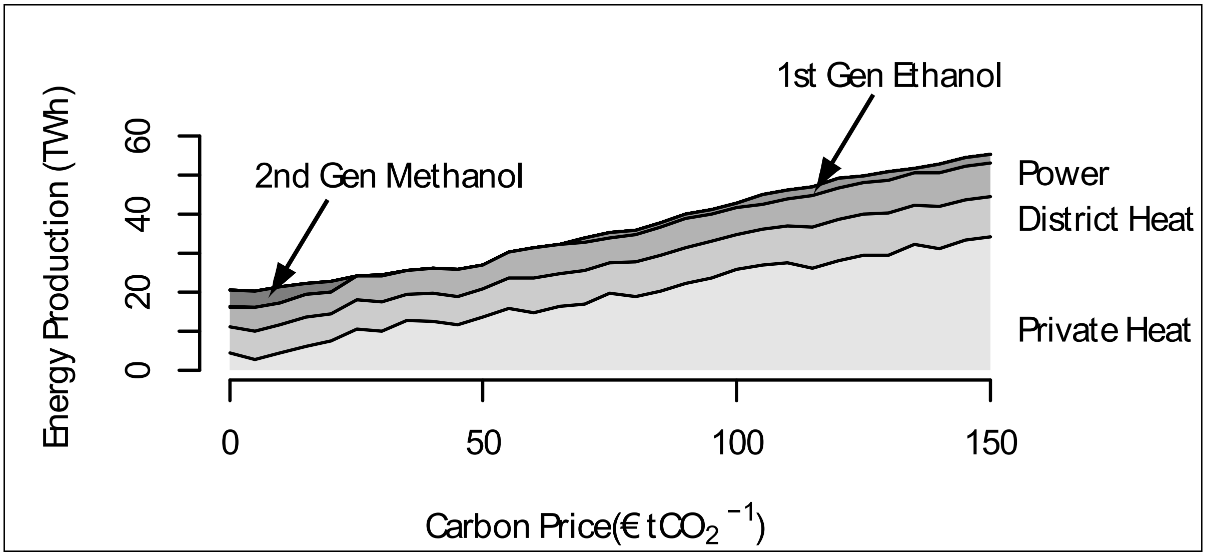

Figure 8: Technological mix when a carbon tax of different levels is assumed for the year 2030. (Source: Paper 1).

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 9). 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.

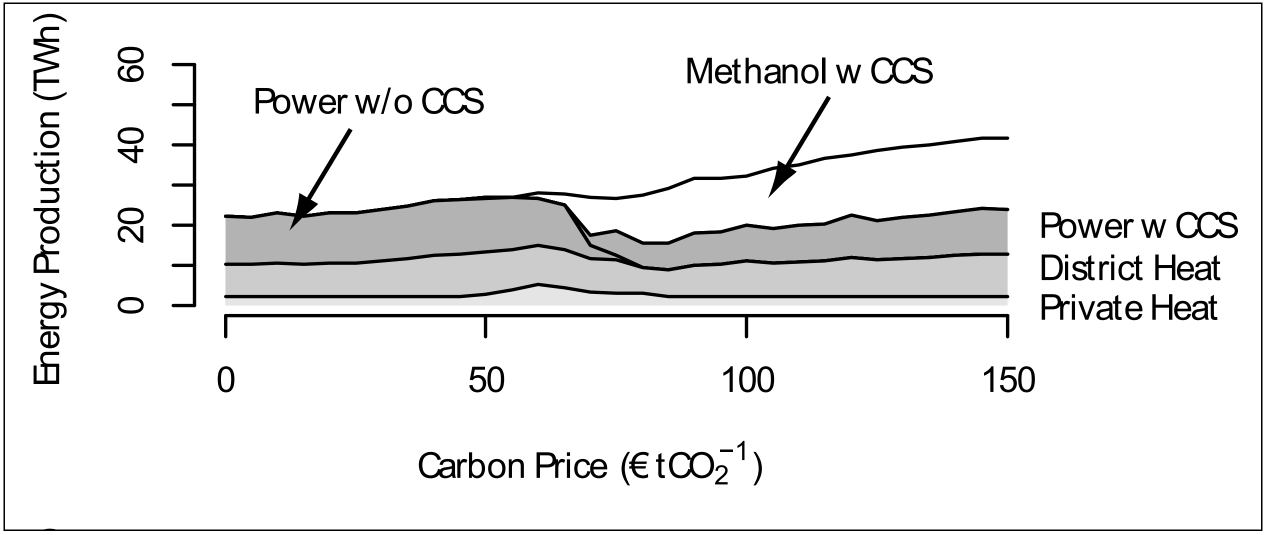

Figure 9: Technological mix when a carbon tax of varying levels is assumed for the year 2030 and CCS is available. (Source: Paper 1).

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 [31]:

- 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 [32]. 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 10). 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}.

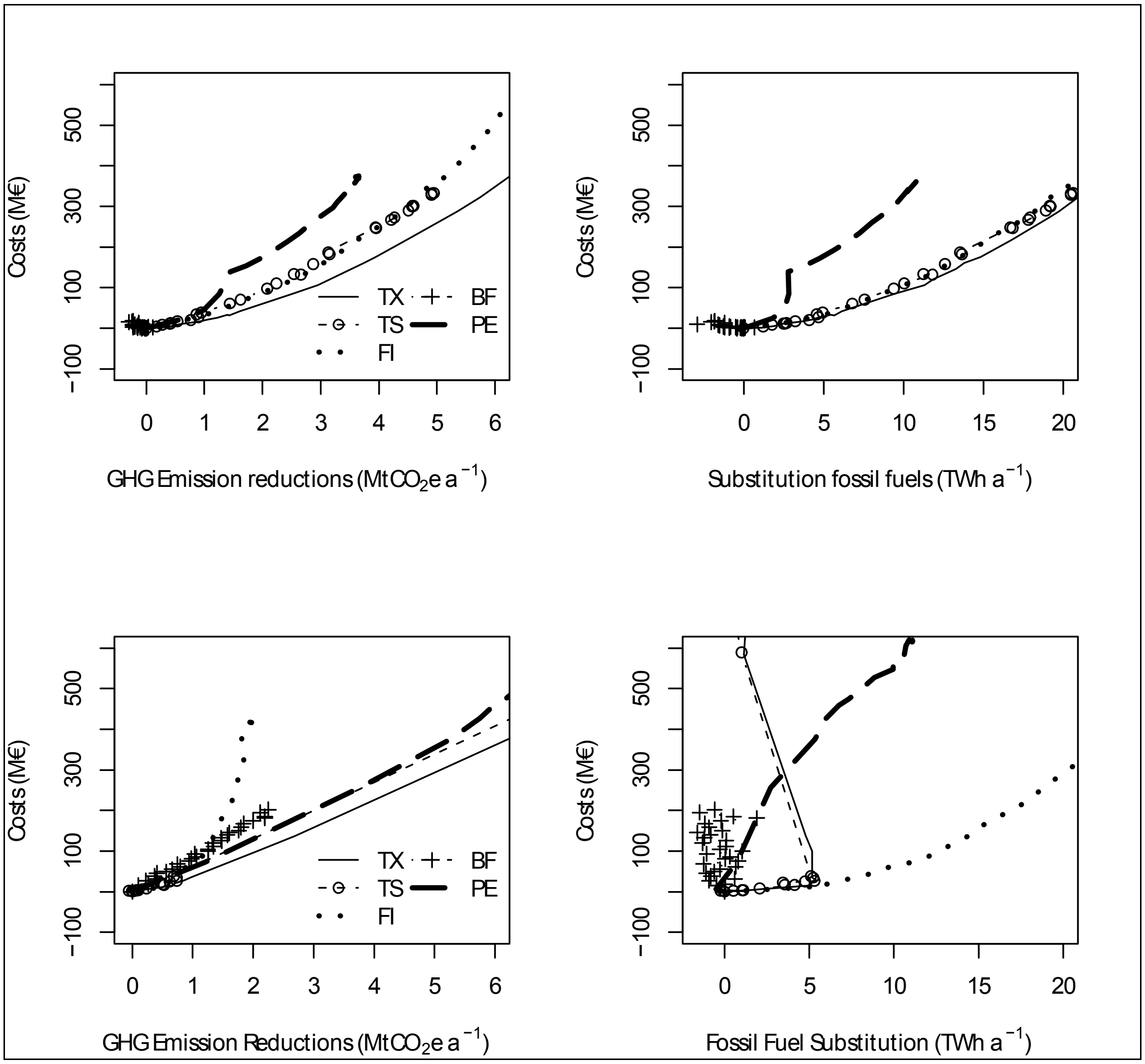

Figure 10: GHG emission reductions (left) and fossil fuels substituted (right) in relation to costs in the scenario without CCS (upper) and with CCS (lower).

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 11 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.

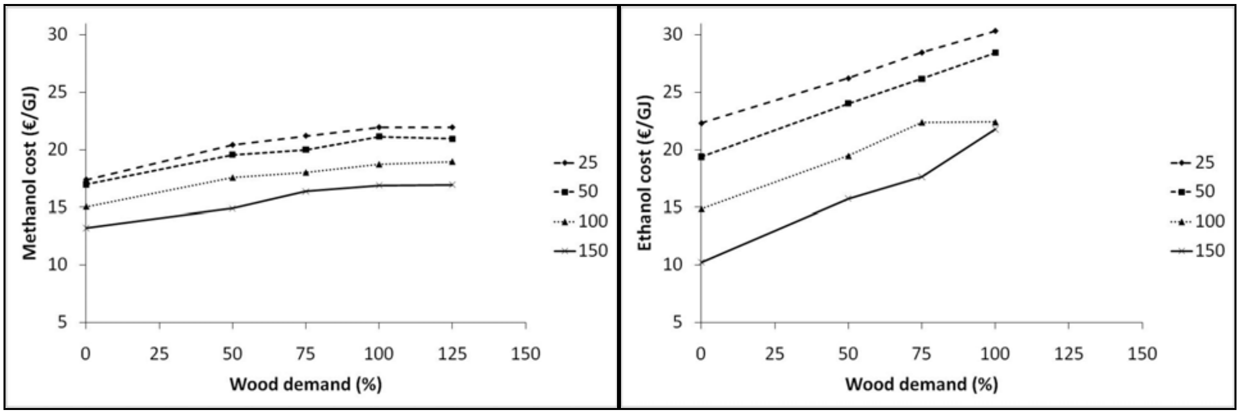

Figure 11: Influence of the wood demand on the methanol cost (left) and ethanol cost (right) for four carbon cost scenarios (fossil fuel price 20 €/GJ , feedstock used: forestry wood and poplar plantations).

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 12).

The influence of a CO_2 cost on the biofuel production is illustrated by Figure 12, 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 12, 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.

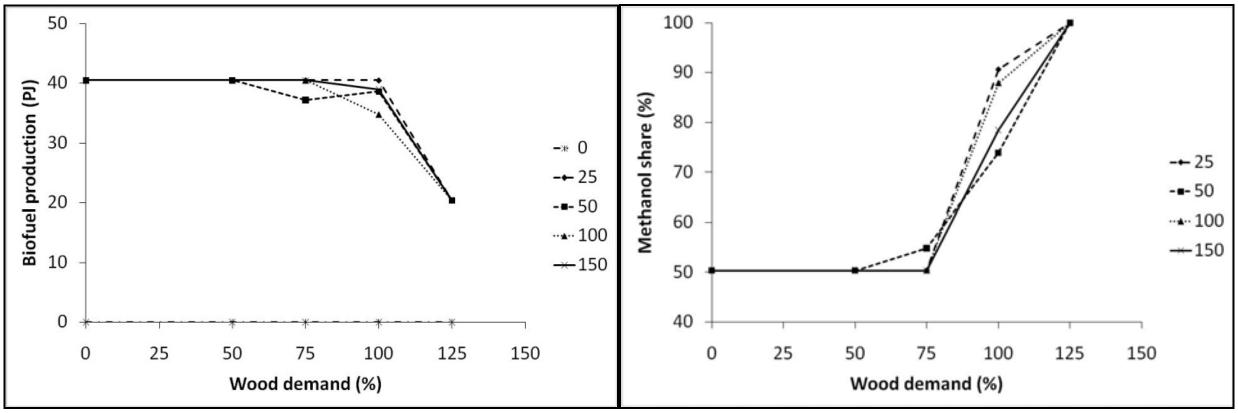

Figure 12: Left: influence of the wood demand on the biofuel production; right: influence of the wood demand on the methanol production, for four carbon cost (€/t_{CO2}) scenarios. (Fossil fuel price 20 €/GJ, feddstock used: forestry wood and poplar plantations).

Optimal Locations and Scales

Figure 13 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.

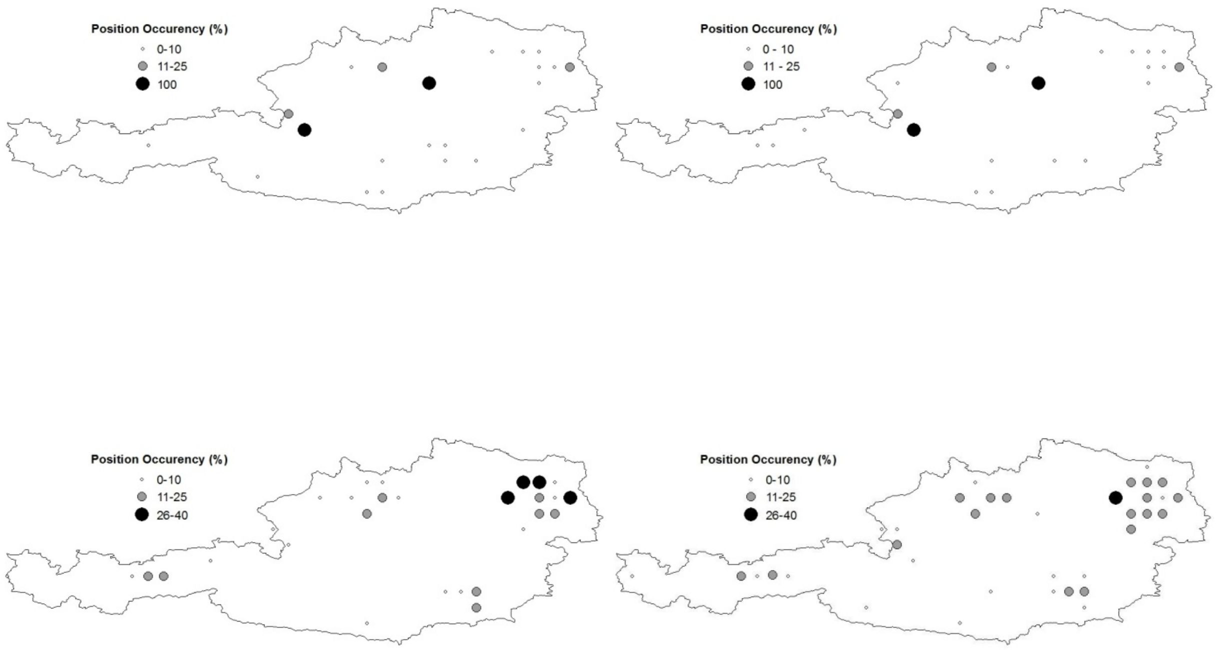

Figure 13: Positions of the production plants selected from the 210 simulations (from top to down, and left to right: 1. methanol with forest only; 2. methanol with forest and poplar plantations; 3. ethanol with forest only; 4. ethanol with forest and poplar plantations.

Milestones:

M1.1: Plausible Ranges for prices and quantities for supply curves for all nine Austrian states. Fulfilled with paper 1 (August 2010).

M1.2: Review of elasticities in the forest sector, definition of plausible value ranges for elasticities. Fulfilled with paper 1 (August 2010).

M1.3: Locations and the wood consumption of Austrian sawmills, biomass CHP and DH plants, of the pulp-and-paper industry and of other wood based industries, imports of wood and biofuels. Fulfilled with paper 3. (October 2010)

M1.4: Bottom up model for the estimation of the spatial distribution of wood consumption of private households. Fulfilled with paper 3. (October 2010)

IR: Interrim report summarizing the work so far. Fulfilled with interim report.

M2.1: Optimization model updated validated and calibrated. (August 2010, October 2010). Fulfilled with paper 1, 2, 3.

M3.1: Sensitivity and Scenario Analysis completed, Policy recommendations derived. Fulfilled with paper 1, 2, 3.

M4.1: Publications in non-scientific journals, scientific publications submitted.

- Publication in “Nachwachsende Rohstoffe”
- Paper 1 submitted to Energy Policy
- Paper 2 accepted at World Renewable Energy Congressin Linköping, Sweden
- Paper 3 has been submitted to Biomass and Bioenergy

1st of December 2010: evaluation workshop that took place at IIASA.

2.2.5. Beschreibung der eventuellen Schwierigkeiten bei Erreichung der geplanten Ziele – Description of Difficulties in Attaining the Objectives

Project progress was fast in general due to the already established partnership between IIASA and BOKU. In some areas, project progress was very effective and we were able to integrate more details into modeling and analysis than planned. However the model feature that was planned in the proposal could not be delivered due to methodological difficulties. Eventually, the decision was made to develop two model versions instead of one to account for these difficulties.

The integration of economic modeling of biomass supply with the modeling of spatially explicit supply by wood industries was not feasible. A fully consistent, spatially explicit model of the Austrian wood energy sector would have to consider all biomass flows between forests, wood industries and bioenergy industries under different economic conditions and explicitly integrate the competition for the whole resource wood, including sawnwood and industrial wood, in the model. However, a full blown model of the Austrian forestry sector is far off the scope of this project.

We therefore decided to apply two different approaches:

- BeWhere-Policy assumes a supply curve for forest wood and does not consider residuals from wood industries. This may decrease the quality of spatially explicit results because important wood supply points (forestry industries) are not considered. However, the approach allows estimating prices of wood consistently with historic developments in the sector.
- BeWhere uses a different approach: the total amount of wood available for bioenergy production is a fixed share of the sustainable harvesting potential within a cell. Costs for the wood remain constant within a cell and vary between cells only because of changing production costs due to different slopes of the terrain. Additionally, a fixed share of forest industry residuals is made available for bioenergy production at a fixed price. This approach allows a better estimation of optimal production sites because biomass supply centers are included in the analysis. However, market feedbacks due to increased biomass utilization are not covered by the modeling approach. Additionally, the fixed share of biomass made available for bioenergy production has to be chosen arbitrarily.

Although the approaches are fundamentally different, results with respect to production potentials and costs are similar. However, spatially explicit results do diverge between the two model versions.

2.2.6. Beschreibung der „Highlights“ des Projektes – Description of Project Highlights

There are several achievements in the project which were not planned in the project proposal. Throughout the project, BeWhere was integrated with an existing agro-economic modeling compound. Thus, agricultural biomass resources as well as additional biomass technologies can now be handled by the model. Comparisons of first and second generation biofuels were only possible due to this approach. The inclusion of Bioenergy with Carbon Capture and Storage technology (BECCS) for biofuel production as well as for power production into the model was a further development step not planned in the project proposal. The model therefore currently contains a set of the most important current bioenergy technologies such as biomass heating, power production and first generation fuels and it also contains those bioenergy technologies, that are expected to become relevant in the near future such as second generation biofuels and BECCS.

To enhace the complete road and railway network for Austria was not planned from the beginning. But this stage was necessary for the accuracy of the results. Austria is a very heterogenous country with flat areas on the north east and very montaneous areas in the rest of the country, which can make transportation of feedstock and biofuel difficult and expensive if the wrong assuptions are made for transportation. A full connection between roads and railwasy was then completed in order to find out the least transportation distance between any two grid points of the grid. Setting up a proper methodology and implementing the distance results into the model took an unexpected 4 month of work.

There is however a drawback to enlarging the model to that extent: the computational complexity of the model grows drastically with the increased amount of features. At the same moment, a significant number of model runs was necessary to complete all scenario and sensitivity analysis. Running the model on a single computer would have slowed down the analysis enormously. We were able to adapt the model to run it on the Vienna Scientific Cluster (VSC) which now allows running several model runs concurrently and thus speeding up model analysis significantly. The implementation of BeWhere on the VSC was not planned; actually VSC only became available after the project had started already.

2.2.7. Beschreibung und Begründung der Unterschiede zum ursprünglichen Projektantrag – Description and Justification of Differences to Original Project Proposal

The differences to the original project proposal are described in section 2.2.5 as well as their justifications.

2.3. Schlussfolgerungen zu den Projektergebnissen (max. 5 Seiten) – Conclusions to Project Results

This section briefly summarizes conclusions from the project with respect to the methodology and the results. Extensive conclusions can be found in the attached papers.

Methodology

We use an integrated modeling approach, combining biophysical models for the estimation of plant growth with bottom-up models for the estimation of demand and an energy system model. The integrated bottom-up approach allows linking an economic approach with biophysical conditions and with the built infrastructure. Our methodological approach models the whole bioenergy supply chain from biomass production to energy consumption in a bottom-up way. We think that this approach is unique and allows showing effects along the whole chain. Most other models in this context focus on either the supply or the demand side and do not integrate all aspects along the supply chain. The following aspects of integration are of particular relevance:

- Biophysical conditions determine biomass productivity. Although biotechnology may enhance biomass growth, there are still fundamental restrictions to plant growth that are determined by the environment, i.e. soil and climate. Our approach links those biophysical conditions with agricultural modeling which in turn is linked to a bioenergy production model.
- The agricultural model also allows showing substitution effects of bioenergy production in agriculture. Although this does not allow estimating carbon effects of indirect land use change, it allows estimating how much of biomass production increases are due to efficiency gains and how much of biomass production is increased due to land use change.
- Biomass logistics are of importance due to high transportation costs and should therefore be considered.
- The bottom up estimation of heat demand is a relevant issue because heating is one of the main applications of biomass in energy production. Future estimations of heating demand should somehow relate to the currently built infrastructure because there is a long lag in the adaptation of buildings. Additionally, the spatial concentration of heating demand

plays a crucial role in deciding if network bound heating (i.e. gas or district heating networks) can be considered economic or not.

We do not account for trade in our model, neither of biomass nor of biofuels. The model therefore may give inconclusive estimations of bioenergy costs and the effect of policies. This approach was chosen to show the effect of bioenergy policies if supply would be domestic only. Indirect effects of global bioenergy production may be of major magnitude, particularly indirect land use change. The effect of Austrian policy only is, however, in almost all cases negligible due to the size of the country. Additional biomass resources could certainly be imported without any major distortions on world agricultural markets. Including imports in a national model would result in a high import rate of bioenergy resources, particularly of biofuels. A domestic production of biofuels would not take-off if imports are allowed. Such a modeling approach would not have been able to inform on domestic potentials of second generation biofuels at all. It would also shift the problems associated with bioenergy, particularly the reliance on a limited resource, to other global areas and would not be very informative on domestic effects.

There are several enhancements to our analysis that are possible but that are out of the scope of this project:

- Currently, exogenous scenario assumptions are made on the deployment of low carbon technologies outside of the bioenergy production sector. Endogenously integrating these technologies, particularly building retrofitting, photovoltaic, wind and water power, would allow showing interdependencies between these technological options in a more explicit way.
- A consistent economic framework for biomass production, including agriculture and forestry, still has to be developed. PASMA can be extended to account for forestry also and results of the G4 model could be used as input to PASMA for that purpose. However, major research and modeling efforts are necessary to make this happen.
- Currently, higher harvests from forests are not accounted for as reduction of carbon stock in forests. A full model of the carbon cycle in forests would be necessary to give estimates on this effect. The G4 model is principally able to do so, however, additional analysis is still necessary to integrate results.

A general drawback of a modeling approach that is locally limited to one country concerns the calculation of GHG emissions: while our model is able to show substitution effects of bioenergy production in agriculture, the global effect of the replacement of domestic production of food and feed on deforestation and the conversion of land with high carbon stock to agricultural land in general cannot be consistently calculated with such an approach. GHG emission calculations reported in the project are therefore valid when compared to GHG emission accounting rules in the Kyoto protocol because the guidelines provided by UNFCCC assume zero emissions for biomass combustion. The real net GHG emission effect can, however, not be accounted for.

Conclusions and Policy 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.

2.4. Arbeits- und Zeitplan (max. 2 Seiten) – Work and Time Plan

The work and time plan has been achieved acording to the milestones (see section 2.2.4).

2.5. 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.

Report 1:

Schmidt, J., Sylvain, L. 2010. Biotreibstoffe der 2.Generation – Potentiale. Nachwachsende Rohstoffe (58).

3. Kosten - Costs

3.1. Kostentabelle für die gesamte Projektlaufzeit - Table of costs for whole project

Kostenkategorie	**Förderbare Gesamtkosten lt. Vertrag**	**Kumulierte Kosten in der Projektlaufzeit**	**Antragsteller**	**Partner 1**
Personalkosten	96,885	106,031	61,295	44,736
Investitionen				0
Reisekosten	9,400	0	0	0
Sach- und Materialkosten				0
Drittkosten				0
Total	106,285	106,031	61,295	44,736

3.2. Kostenbeschreibungen für die ganze Projektlaufzeit – Description of Costs for Whole Project

Applicant – IIASA

IIASA costs were totally comprised of staff costs. The IIASA team was comprised of Mr. Florian Kraxner, Dr. Aoki Kentaro and Dr. Michael Obersteiner and was lead by Dr. Sylvain Leduc. All scientists contributed in the course of 2009 and 2010 except for Dr. Aoki who only contributed to the work in 2010.

Partner 1

Costs of partner 1 were totally allocated to payroll costs. Partner 1 employed Dr. Johannes Schmidt from April 2010 to October 2010 for 32 working hours / week and Dr. Martin Schönhart from July 2010 to September 2010 for 32 working hours / week and in October 2011 for 24 working hours / week.

3.3. Kostenumschichtungen – Redeployment of Costs

IIASA shifted all travel costs to personnel costs Partner 1 shifted 2,000 € from traveling costs to personnel costs. Budgeted/anticipated travel costs did not accrue as project meetings were held on site or at the partner site.

BOKU were able to hold all project meetings locally in Vienna or Laxenburg, therefore traveling expenses did not accrue. We decided to shift traveling costs to personal costs therefore.

4. Verwertung – Dissemination

Scientific Dissemination

The scientific dissemination of research results is guaranteed by the submission of Paper 1 to Energy Policy (currently under review after revisions). Additionally, paper 2 was submitted and successfully accepted at the *World Renewable Energy Congress* in Linköping, Sweden. The paper will be presented there in May 2011. Paper 3 has been submited to Biomass and Bioenergy.

References:

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).

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.

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

Dissemination to Stakeholders

A short article on project results was published in "Nachwachsende Rohstoffe". Subsequently, the "IEA Bioenergy Task 39: Commercialisation of Liquid Biofuels" and the "Technologie- und Förderzentrum im Kompetenzzentrum für Nachwachsende Rohstoffe (TFZ)" in Germany showed interest in project results. The project report will be provided to them after publication.

On December 1st, we organized a three hour workshop for stakeholders at the IIASA in Laxenburg. The methodology and most important results of the project were discussed with staff members from IIASA and from the Austrian energy agency. A main point of discussion was how GHG emissions caused by indirect land use change (ILUC) could be considered in the Austrian study. The utilization of generic parameters that translate domestic land use change in GHG emissions abroad was deemed to be much too inaccurate. An alternative approach was also suggested: decreased exports or increased imports of agricultural products induced by increasing agricultural biomass production could be used as input to global land use change models (as developed at IIASA) to determine ILUC. However the large uncertainties in the modeling process would not allow drawing conclusive results from this approach, particularly because Austrian agricultural production is almost irrelevant on world markets.

References:

Schmidt, J., Sylvain, L. 2010. Biotreibstoffe der 2.Generation – Potentiale. Nachwachsende Rohstoffe (58).

5. Ausblick – Future Work

The model can further be developped into different directions:

- Currently, exogenous scenario assumptions are made on the deployment of low carbon technologies outside of the bioenergy production sector. Endogenously integrating these technologies, particularly building retrofitting, photovoltaic, wind and water power, would allow showing interdependencies between these technological options in a more explicit way.
- A consistent economic framework for biomass production, including agriculture and forestry, still has to be developed. PASMA can be extended to account for forestry also and results of the G4 model could be used as input to PASMA for that purpose. However, major research and modeling efforts are necessary to make this happen.
- Currently, higher harvests from forests are not accounted for as reduction of carbon stock in forests. A full model of the carbon cycle in forests would be necessary to give estimates on this effect. The G4 model is principally able to do so, however, additional analysis is still necessary to integrate results.
- A coupling with real options modeling is necessary in order to predict the right time to invest in a certain type of bio-energy technology. Giving the uncertainty of the investment costs and prices of energy comodities, such a coupling would give more strength to the model results and their reliability.

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