The Green Biorefinery Concept: Optimal plant locations and sizes in Upper Austria

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***Abstract* - The green biorefinery concept promoted in Austria aims at utilizing grass silage to produce bioenergy, biomaterials and organic acids (i.e. amino acids and lactic acid) and to preserve grassland areas in Austria. We have developed a mixed integer programming model that integrates spatially explicit biomass supply, heat demand, and biorefinery plant data. The model maximizes the constrained profits of green biorefineries by selecting the optimal plant locations and sizes in Upper Austria. Model results reveal that four to five biorefineries can be established to optimally utilize the available biomass potential in Upper Austria. The selected biorefinery locations are mainly affected by the regional amount of biomass supply and heat demand. The plant sizes range from 20,000 to 40,000 tonnes of dry matter grass silage per year. The profitability is mainly determined by the variable production costs and amino acid prices.**

INTRODUCTION

The current fossil fuel based economy is supposed to be transformed into a low-carbon bio-based economy in the coming decades due to concerns about climate change and energy security. Biomass will be essential for the production of fuels, materials, and chemicals (Dale & Kim, 2006). However, there is a large dispute about the contribution of biomass in a sustainable energy and material mix. Especially the effects of biofuels on world food prices have attracted much attention in the public discussion since the last food crises. Industries depending on biomass feedstock, as for instance the pulp and paper industries, have raised their concerns about policies that promote bioenergy and claimed that priority should be given more to biomaterials.

Biorefineries aim at efficiently converting biomass into a wide a range of marketable products including food and feed, materials, biofuels, chemicals, electricity and heat (de Jong et al., 2010). Furthermore, the biorefinery concept contributes to climate change mitigation, allows the reduction of waste streams, and preserves long term soil fertility by sustainable land use practices.

The green biorefinery concept is promoted in Austria. It focuses on the use of grass silage, because surplus grassland areas are expected to increase in the near future due to structural changes in agriculture (BMVIT, 2009). Positive side-effects of grassland management are the preservation of typical cultural landscape and biodiversity as well as the reduction of greenhouse gas emissions from land use changes. Currently, research focuses on improving the biorefinery processes as recovery rates and product yields are essential to guarantee the viability of the green biorefinery concept (Mandl et al., 2011). The whole supply chain has to be considered to assess the competitiveness of biorefineries as well as the regional value added and impacts. Therefore, the article aims at finding the most competitive locations and plant sizes of green biorefineries considering the whole supply chain in Upper Austria. Furthermore, a model parameter sensitivity analysis is performed to assess how transport and capital costs affect the economic profitability compared to other factors such as feedstock and operating costs as well as product prices.

METHODS

A spatially explicit, mixed integer programming model has been developed to select optimal plant locations and sizes for green biorefineries in Upper Austria. The model reveals the trade-off between economies of scale of plant sizes and the diseconomies of scale of biomass transport.

The major limitations of larger biorefineries are the biomass supply, the transport costs, and the regional heat demand. Therefore, spatially explicit biomass supply and heat demand data is essential to determine the optimal size and locations. Since one of the main arguments for promoting the green biorefinery concept in Austria is to provide an alternative utilizations paths for grassland areas. Therefore, only biomass from these areas is included in the analysis. Their geographic distribution is considered by using Corine land cover data. Based on this data, the biomass supply is calculated for all raster cells using a 5 km^2 raster grid. For the calculation of the transport costs, it is assumed that all biomass from one raster cell is available at the raster centroid. After the biomass is processed in a biorefinery, the digestate from the biogas plant is assumed to be transported back to the field of origin, to close the nutrient cycle.

Besides transportation costs, capital costs determine the optimal plant size of green biorefineries as well. So far, green biorefineries have been realized only on pilot or demonstration scale. Therefore, no calculations and data of green biorefineries are available at industrial scale. The investment costs

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are based on estimations of different publications and therefore uncertain. The model computes results for one operating year. Therefore, it is necessary to distribute the total investment costs over the lifetime of a biorefinery plant. The annuity method is applied by assuming an economic lifetime of 15 years and an interest rate of 6 %.

Spatial explicit heat data is included from Schmidt et al. (2010). The data provides an estimate of the heat demand for each 1 km^2 raster grid in Megawatt hours (MWh) for the summer and winter periods. The model seeks to maximize the total biorefinery supply chain profits in the model region by selecting the optimal biorefinery locations and sizes from 15 preselected locations and 4 possible sizes.

Results and Discussion

A scenario analysis reveals that five biorefineries are selected to optimally tap the calculated biomass potential of 109,279 tonnes dry matter of grass silage per year (Figure 1). The size of the points indicates the annual biorefinery capacity and the coloured area shows the supply region for each biorefinery location. The most frequent realized biorefinery capacity is 20,000 tonnes dm per year. Location B7 is the only exception with a capacity of 30,000 tonnes dm.

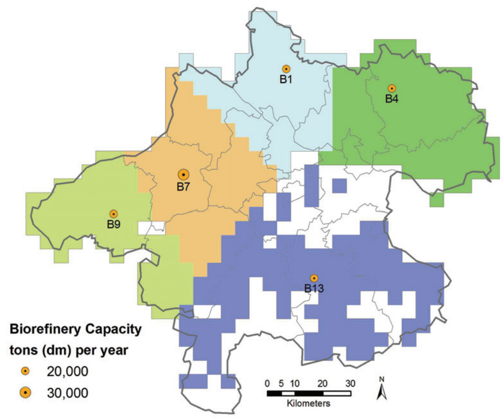

Figure 1. Biorefinery capacities, locations and biomass supply regions in the baseline scenario.

The optimal plant size of biorefineries is determined by the trade-off between capital costs, transport costs, and the heat demand. Specific capital costs decrease with increasing biorefinery size, favouring the largest possible plant size. Depending on the regional biomass supply and the realized plant size, average biomass transport distances range from 25 to 35 km. The annual profits per tonne dm input vary between 90.82 and 102.11 € for the different biorefinery locations in the baseline scenario.

A model parameter sensitivity analysis is performed for the following parameters: biomass supply, transport costs, capital costs, scaling factor, downstream costs and amino- and lactic acid prices. For each of these parameters the effect of a 20 % increase and a 20 % decrease has been assessed.

Decreasing transportation costs, increasing capital costs or applying a lower scaling factor shows similar effects on the realized biorefinery capacity and the average transport distance. In all these cases, capital costs become relatively more important compared with the transportation costs. Therefore, the average biorefinery size increases by 25 % from 22,000 tonnes dm to 27,500 tonnes dm and the average transport distance by about 20 %. Higher regional biomass supplies also increase the biorefinery capacity, but without significantly affecting the transport distances. Contrarily, lower regional biomass supplies do not substantially affect the realized biorefinery sizes much, but the transport distances increase by about 20 %. Decreasing average biorefinery sizes have been modelled for none of the assessed parameter changes. Concerning the average profits per tonne dm biomass, the influence of transport and capital costs is far lower than the impact of changing downstream costs and the amino acid prices. For instance, 20 % lower amino acid prices reduce the profits by 60 %.

Conclusion

The green biorefinery is a promising concept to provide a sustainable utilization pathway for green biomass. The analysis reveals that four to five biorefineries with annual capacities from 20,000 to 40,000 tonnes can be realized to utilize the calculated biomass potential of about 110,000 tonnes of dry matter grass silage in Upper Austria. Due to the capital intensive separation technologies, small decentralized biorefinery plants are unlikely to be competitive compared to larger plant sizes.

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