A spatially explicit techno-economic assessment of green biorefinery concepts for Austria
Definition and Classification

"Biorefining is the sustainable processing of biomass into a spectrum of marketable bio-based products and bioenergy."

IEA - Task 42 Biorefineries

- IEA Task 42 Classification of Biorefineries ¹
  - Raw materials (agricultural-, forest- and aquatic biomass, biogenic residuals and waste materials)
  - Intermediates (Platform) (starch, proteins, fibres, press juice, biogas, syngas)
  - Processes (mechanical, thermochemical, chemical and biotechnological)
  - Products (food, feed, chemicals, materials, fuels, electricity, heat)

¹ Cherubini et al. (2009). Toward a common classification approach for biorefinery systems. Biofpr.
Green Biorefinery (GBR):
Two-platform (biogas and organic juice) biorefinery for
- bioenergy (electricity and heat),
- chemical building blocks (lactic acid and amino acids),
- biomaterials (fiber products) and
- fertilizer
from green biomass (fresh grass, grass silage, sugar beet leaves, ...)

Drivers for the green biorefinery concept in Austria
- Expected oversupply of grassland areas due to changes in agricultural policies and structures
- Alternative utilization for grassland biomass to preserve cultural landscape
- Employment opportunities for rural areas
# The Green Biorefinery

- Assessment of 3 GBR-Concepts and biogas as reference technology

<table>
<thead>
<tr>
<th>Feedstocks and products</th>
<th>GBR - Concept</th>
<th>Feedstock</th>
<th>Press juice</th>
<th>Press cake</th>
</tr>
</thead>
<tbody>
<tr>
<td>GBR_proteins</td>
<td>grass</td>
<td>feed proteins</td>
<td>feed</td>
<td></td>
</tr>
<tr>
<td>GBR_fibres</td>
<td>grass silage</td>
<td>feed proteins, biogas CHP</td>
<td>fibres for technical applications</td>
<td></td>
</tr>
<tr>
<td>GBR_amino_acids</td>
<td>grass silage</td>
<td>amino acids, lactic acid</td>
<td>Biogas CHP</td>
<td></td>
</tr>
<tr>
<td>Biogas</td>
<td>grass silage</td>
<td>Biogas CHP</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Biomass potential

- PASMA (Positive Agricultural Sector Model Austria)
  - economic potential of grass silage from temporary and permanent grasslands in Austria
  - accounts for land competition among livestock, bioenergy and food production
  - supply curves for all 35 Austrian NUTS-3 regions
# The Model (I) - Overview

## Input data

<table>
<thead>
<tr>
<th>Spatially explicit data</th>
<th>Techno-economic parameters for each green biorefinery concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Regional economic biomass potential (PASMA)</td>
<td>• Annualized capital costs</td>
</tr>
<tr>
<td>• 174 supply regions (20 * 20 km)</td>
<td>• Operating costs</td>
</tr>
<tr>
<td>• 79 potential sites</td>
<td>• Energy demand and costs</td>
</tr>
<tr>
<td>• Road-distance transportation costs</td>
<td>• Labour costs</td>
</tr>
<tr>
<td></td>
<td>• Product yields and prices</td>
</tr>
</tbody>
</table>

## Biorefinery supply chain optimization model

## Output

- Optimal locations and capacities
- Profits (costs and revenues of different green biorefinery concepts)
- Sensitivity of profits to varying input parameter values
- Key parameters contributing to model results uncertainty
The model (II) – Objective Function

\[ \text{Profit} = \sum_{\text{Sites, Products}} \text{ProductionVar}_{\text{Sites}} \times \text{ProductYield}_{\text{Products}} \times \text{ProductPrice}_{\text{Products}} - \text{Costs} \]  

(Eq. 1)

where

\[ \text{Costs} = \sum_{\text{Region, PriceLevel}} \text{SupplyQ}_{\text{Region, PriceLevel}} \times \text{FeedstockCost}_{\text{PriceLevel}} \times \text{IntPolVar}_{\text{Region, PriceLevel}} \]

\[ + \sum_{\text{Region, Sites}} \text{TransportVar}_{\text{Region, Sites}} \times \text{TransportationCost}_{\text{Region, Sites}} \]

\[ + \sum_{\text{Sites, Size}} \text{ChoiceVar}_{\text{Sites, Size}} \times \text{InvestmentCost} \times \text{AnnuityFactor} \]

\[ + \sum_{\text{Sites}} \text{ProductionVar}_{\text{Sites}} \times (\text{EnergyCost} + \text{LabourCost} + \text{OperationCost}) \]  

(Eq. 2)
Sensitivity analysis

- Sensitivity analysis
  - Monte-Carlo simulation with 500 model runs with feasible ranges for
    - product yields and prices
    - feedstock-, transport-, operation- and energy costs
    - discount rate and scaling factor
  - Regression analysis to assess the impact of single parameter variations
Results

- Biorefinery locations and capacities

The numbers below the plants indicate how often a certain plant location has been chosen (as percentage of all 500 Monte-Carlo simulation runs). Locations that have been chosen in less than 1% of all runs are not displayed.
Results

- Biomass utilization
Results

- Specific revenues

![Bar charts showing revenues for different products](chart.png)

Revenues (€ per t dm biomass input)
Results

- Specific costs

![Graph showing specific costs for different processes: Biogas, OBR_amino_acids, OBR_fibres, OBR_proteins. The x-axis represents capacity (1,000 t dm), and the y-axis represents costs (€ per tonne input). The graph includes cost elements such as feedstock, transport, energy, operation, personnel, and capital.]
Results

- Profitability
Results

- Sensitivity of GBR profits

- GBR Amino acids

- GBR Fibre

- GBR Protein

- Biogas
Conclusions

- Green biorefineries can offer a profitable utilization pathway for grass silage in Austria under favourable market conditions
- Profitability of green biorefineries is most sensitive to
  - market prices of organic acids and technical fibres
  - the development of separation and downstream costs
  - upscaling costs from pilot- to industrial scale
- Profitability of biogas plants is largely dependent on the current policy support schemes (feed-in tariffs)
- Sustainability assessment along the whole supply chain to demonstrate ecological sustainability of green biorefinery concepts
  - Intensification in cultivation and longer transportation distances
Outlook

- Climate mitigation potential of all GBR-Concepts
  - cultivation
  - transport
  - production
  - offset emissions (electricity, heat, organic acids, insulation material)
- Policy design to promote the material use of biomass
  - Feed-In-Tariffs
  - carbon price
  - investment subsidy
  - processing aid (premia per t utilized biomass)
Thank you for your attention

University of Natural Resources and Life Sciences, Vienna
Department of Economics and Social Sciences
Institute for Sustainable Economic Development

Stefan Höltinger, Johannes Schmidt, Martin Schönhart, Erwin Schmid
Feistmantelstraße 4, A-1180 Vienna
Tel.: +43 1 47654-3650
stefan.hoeltinger@boku.ac.at, www.boku.ac.at/454.html
### Classification of Biorefineries (IEA Task 42)

#### Raw Material
- **Agricultural biomass**
  - Oil crops
  - Starch crops
  - Sugar crops
  - Grasses
  - Wood
  - Woody biomass
- **Aquatic biomass**
  - Algae
- **Biogenic residual- & waste materials**
  - Agricultural and forestry residues (e.g. straw, manure, wood residues, fruit peel, slurry)
  - Biogenic residual materials from processing (e.g. whey, pulp, stillage, spent grains)
  - Biogenic waste materials (e.g. yellow grease, waste wood)

#### Platform
- Low molecular weight carbohydrates (e.g. lactose, sucrose)
- Polymeric carbohydrates (e.g. starch, inulin, pectin)
- Lignocellulose components (lignin/cellulose/hemicellulose)
- Proteins
- Plant fibres
- Vegetable oils, lipids
- Pyrolysis oil
- Press juice
- Biogas
- Syngas

#### Products
- **Materials**
  - Chemicals
  - Materials
  - Feedstuff
  - Foodstuff
- **Bioenergy**
  - Solid, liquid, gaseous sources of bioenergy
  - Electricity
  - Heat

#### Processes
- Physical, including mechanical processes
- Thermochemical processes
- Chemical processes
- Biotechnological processes
Transportation Costs

- Transportation Costs per t dm km$^{-1}$
The model (III) - Constraints

- Transport limited by biomass supply
  \[ \sum_{\text{Sites}} \text{TransportVar}_{\text{Region, Sites}} \leq \sum_{\text{PriceLevel}} \text{SupplyQ}_{\text{Region, PriceLevel}} \times \text{IntPolVar}_{\text{Region, PriceLevel, Region}} \]

- Production limited by supply and capacity
  \[ \sum_{\text{Sites}} \text{ProductionVar}_{\text{Sites}} \leq \sum_{\text{Region}} \text{TransportVar}_{\text{Region, Sites}} \quad \forall \text{ Sites} \]
  \[ \sum_{\text{Sites}} \text{ProductionVar}_{\text{Sites}} \leq \sum_{\text{Size}} \text{ChoiceVar}_{\text{Sites, Size}} \times \text{Capacity}_{\text{Size}} \quad \forall \text{ Sites} \]

- Maximum one plant per site (Binary)
  \[ \sum_{\text{Size}} \text{ChoiceVar}_{\text{Sites, Size}} \leq 1 \quad \forall \text{ Sites} \]
The model (IV) - Nomenclature

<table>
<thead>
<tr>
<th>Subscripts</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Region</td>
<td>174 supply regions</td>
</tr>
<tr>
<td>Sites</td>
<td>79 potential facility sites</td>
</tr>
<tr>
<td>Size</td>
<td>6 potential capacities (10,000-300,000 t dm year(^{-1}))</td>
</tr>
<tr>
<td>PriceLevel</td>
<td>11 feedstock price levels</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variables</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ProductionVar</td>
<td>production at each site (tdm)</td>
</tr>
<tr>
<td>TransportVar</td>
<td>transportation quantity from each supply region to every GBR site (tdm)</td>
</tr>
<tr>
<td>ChoiceVar</td>
<td>binary decision variable whether to build a GBR of a certain size at a certain site</td>
</tr>
<tr>
<td>IntPolVar</td>
<td>interpolation variable (value between 0 and 1) – for the selection of price levels in between of the predefined points on the supply curve</td>
</tr>
<tr>
<td>ProductionVar</td>
<td>production quantity at each GBR site (tdm)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ProductYield</td>
<td>product yield for each product (per t dm input)</td>
</tr>
<tr>
<td>ProductPrice</td>
<td>price for all products (€ ( \text{kg}^{-1} ))</td>
</tr>
<tr>
<td>SupplyQ</td>
<td>biomass supply for a supply region at a given price level (t dm)</td>
</tr>
<tr>
<td>FeedstockCost</td>
<td>feedstock cost for all price levels (€50-150)</td>
</tr>
<tr>
<td>TransportationCost</td>
<td>transportation cost from each supply region to every GBR site (€ t(^{-1}) dm)</td>
</tr>
<tr>
<td>InvestmentCost</td>
<td>investment costs for the base size of a given GBR (€)</td>
</tr>
<tr>
<td>EnergyCost</td>
<td>energy costs for processing one t feedstock (€ t(^{-1}) dm)</td>
</tr>
<tr>
<td>LabourCost</td>
<td>labour costs for processing one t feedstock (€ t(^{-1}) dm)</td>
</tr>
<tr>
<td>OperationCost</td>
<td>operation costs for processing one t feedstock (€ t(^{-1}) dm)</td>
</tr>
</tbody>
</table>
Results

• Uncertainty analysis

![Graph showing relative parameter contribution to profit uncertainty for different parameters such as white protein revenues, transportation costs, scaling factor, personnel costs, operation costs, livestock feed revenues, lactic acid revenues, investment costs, fibre revenues, feedstock costs, energy costs, electricity revenues, and amino acid revenues for Biogas, GBR_amino_acids, GBR_fibres, and GBR_proteins.]
• Simplified process overview GBR demo plant Utzenaich (AT)
GBR_Proteins

- Process overview GBR Havelland (GER)

Felder, Grassland
Alfalfa, Grass, Lychee
Harvest
40,000 t (TS: 20%)

Dampf

Filtrat

Biogasanlage

Feuchtfraktionierung
Press

Press-Saft

Filtrat

Milchsäure/Lysin
Fermentation

Membran Separierung

Protein Separierung

Protein Koagulation

Dekantierung Separierung

Trocknung

Futterprotein

Kosmetikprotein

Einzelzellbiomasse

Milchsäure/Lysin

Separierung

Aufreinigung

Silage Futter

08. 10. 2013
Stefan Höltinger
• Process overview GBR-Brensbach (GER)
Outlook

- GHG-mitigation potential of GBR-concepts