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An optimisation model for supporting investment decisions in biorefineries: a European case study

Anna Panteli, [a] **Sara Giarola,** [b] Nilay Shah [a] *

[a] Chemical Engineering Department, Imperial College London, London, SW7 2AZ, UK
[b] Earth Science & Engineering Department, Imperial College London, SW7 1NA, UK

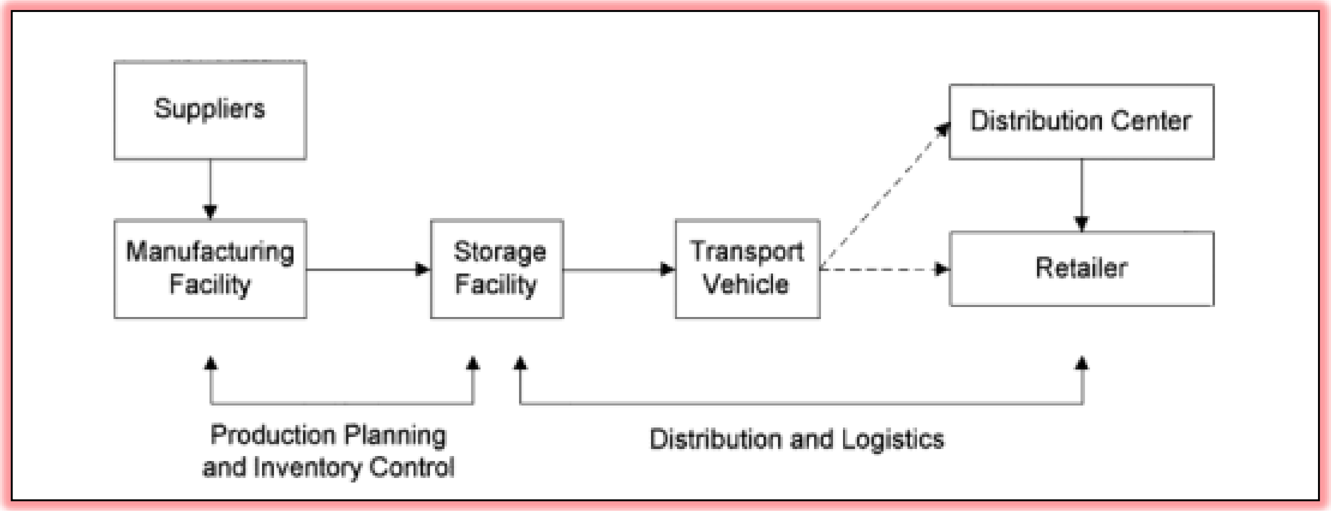
* Corresponding author (Nilay Shah). Tel.: +44 20 7594 6621; fax: +44 20 7594 6606.
E-mail address: n.shah@imperial.ac.uk

Outline

- Introduction
  - biorenewables supply chains optimisation
- Methodology
  - Mixed Integer Linear Programming (MILP)
- European case study — Organosolv-based biorefineries
- Concluding remarks

Supply chains in industry

A supply chain (SC) is an integrated manufacturing process wherein a number of various entities (e.g., suppliers, manufacturers, distributors, retailers) work together to convert raw materials into final products, and deliver them to customers. (Shah, 2005)

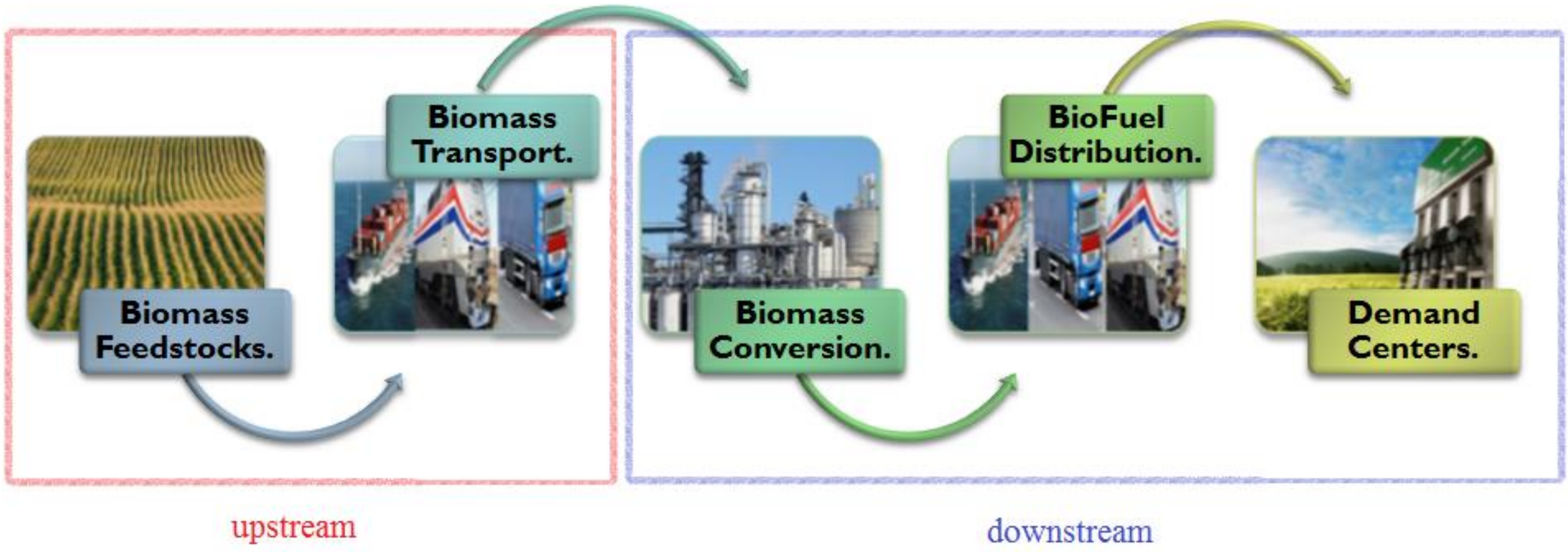


Beamon, 1998

- ❑ meet customers' orders
- ❑ effective inventory management
- ❑ maximise economic performance or minimise costs

Extending SCs to renewables

Suppliers → biomass growers
Manufacturers → biorefineries
Final Product Distributors/retailers



Fossil vs renewable-based infrastructures

Fossils:

- ✓ Highly developed infrastructures — electricity and gas delivery to consumers at high efficiencies and low costs
- ✓ Large, centralised, continuous generation and processing coupled with national and continental scale pipeline and cable distribution networks

Renewables:

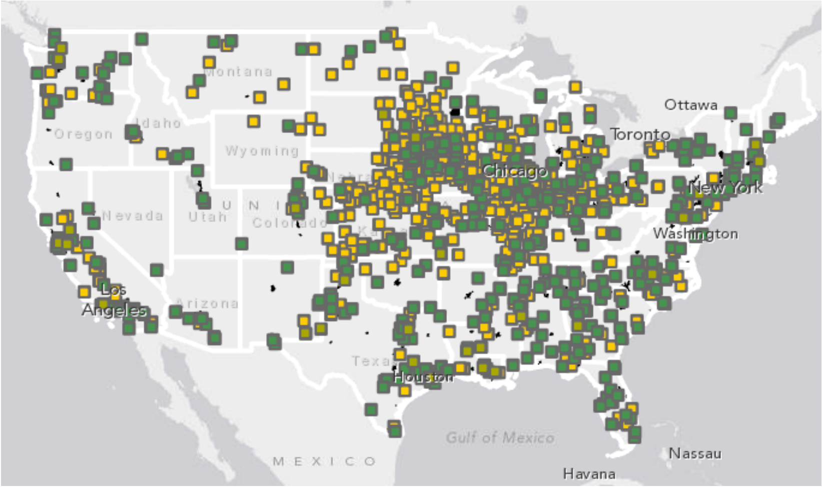
- ❖ Integration of spatially and temporally distributed sources of primary energy (wind, solar, biomass, etc.)
- ❖ Decentralisation of energy infrastructures, overcoming inefficiencies in co-ordination, complex logistics and economies of scale

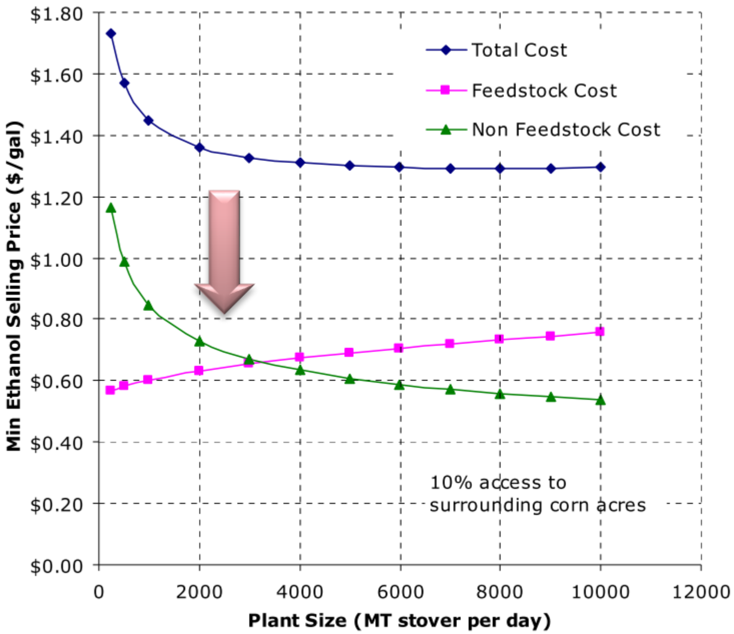
Biorenewables supply chains: plant scale

Imbalance between biomass availability and energy demand sites

Biomass (e.g. corn stover) spread across a region

Trade-off — collection distance vs economy of scale





http://www.usda.gov/energy/maps

Aden et al., 2002

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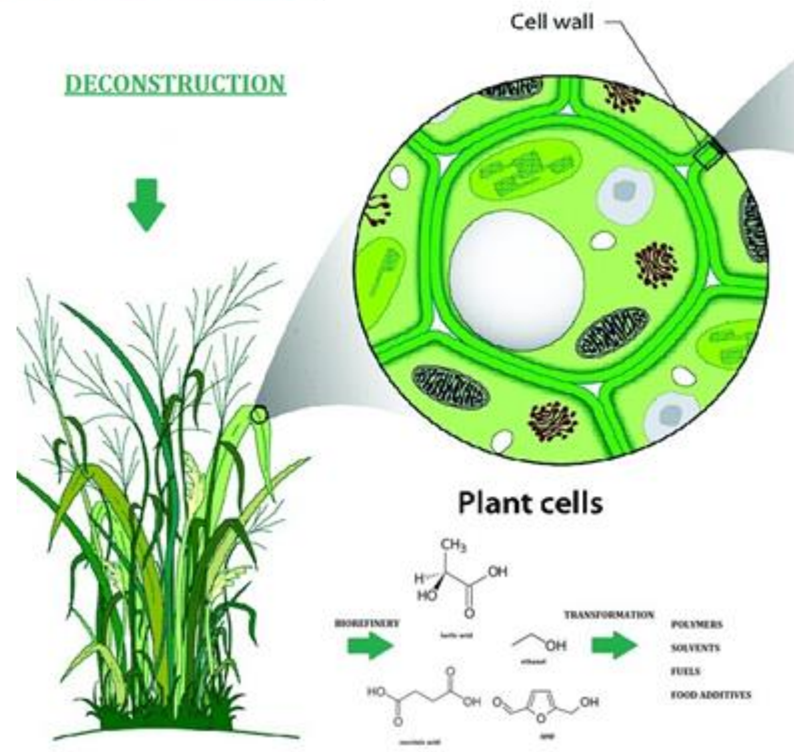
Biorenewable supply chains: time


- ❑ Seasonality of biomass
  - ✓ straw: in summer – autumn
  - ✓ wood: in winter
- ❑ Continuous biomass supply
  - ✓ storage
- ❑ Biomass quality endangered as time passes since harvest
- ❑ Pretreatment
  - ✓ biomass fractionation into cellulose, hemicellulose, lignin
  - ✓ highest cost share



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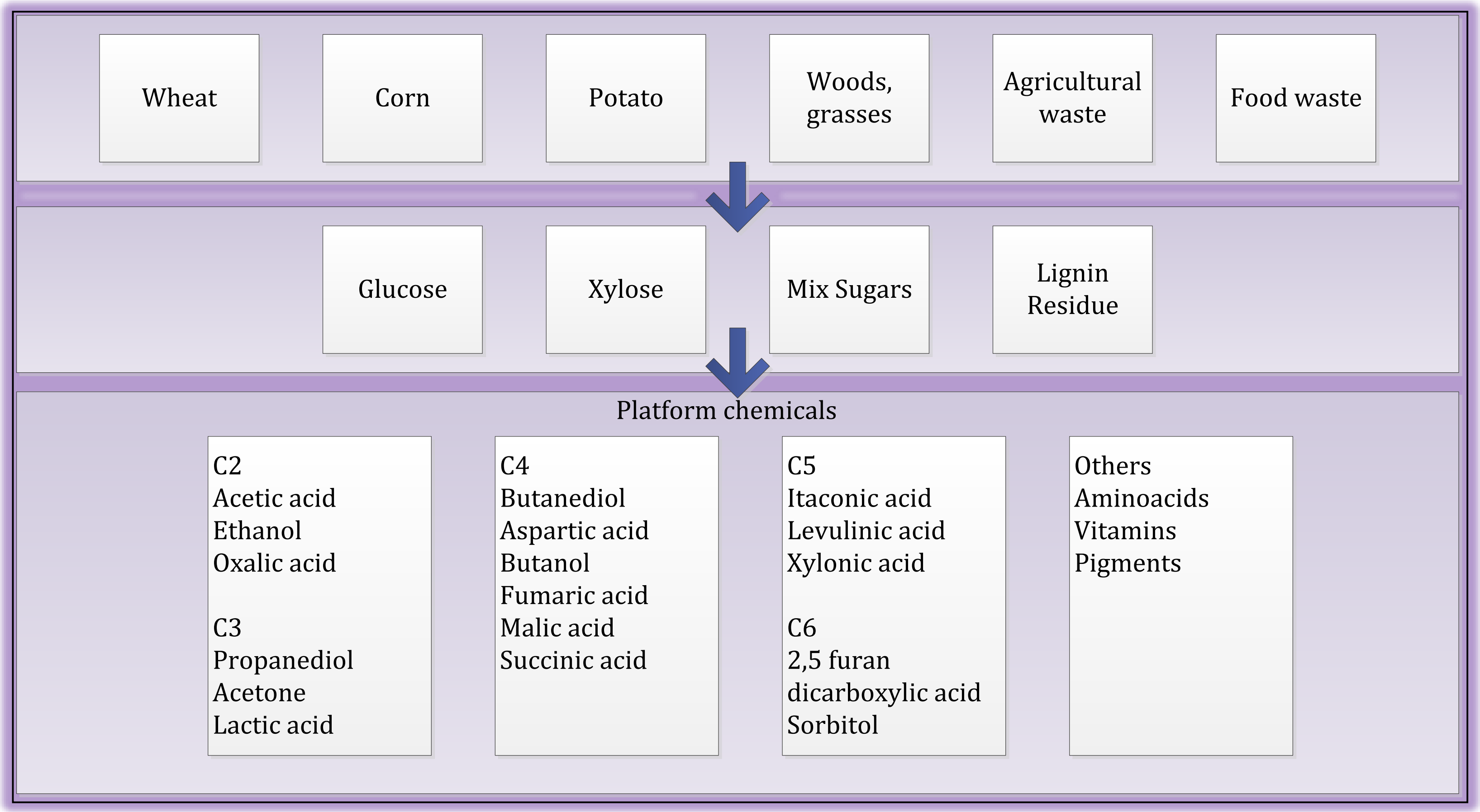
Potential biomass conversion routes



Kamm et al. (2010)

Integrating SCs and technology superstructures

- SC models
  - ✓ Capacity planning of processing facilities
  - ✓ Geographical locations of plant sites
  - ✓ Logistics
  - ✓ Seasonality and biomass pre-processing

- Technology superstructure models
  - ✓ synthesis blocks representing functional modules in the process and contributing to the objective functions (Yuan and Chen, 2012)

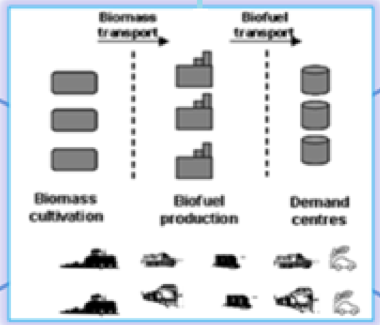
Methodology framework

Biomass availability
- local crop yields assessment
- seasonality
- competitive uses appraisal

Logistics characterization
-transport mode type
- rail, truck, barge

-infrastructure network quality
- unitary transportation cost
- local transportation link density and access

LCA of the SC nodes



Product Demand
-promising product portfolios
-deterministic demand

CAPEX and OPEX
-biomass conversion process
- storage
-densification processes
- drying

Mixed Integer Linear Programming Model (MILP)
- Objective function
- Mass/energy balances
- Regional specific constraints

Model formulation

<u>Economic objective function</u>:

$$OBJF = \sum_t TP_t \ , \forall t \in T$$

- where: t is one-month period $(t \in T,\ T = \{1,\ldots,12\})$

  TP_t is the net profit of the network at time t [€]

- $TP_t = Rev_t - TC_t \ , \forall t \in T$

  Rev_t are the revenues at time t [€/month]

  TC_t is the total cost (capital and operational) at time t [€/month]

- *Decision variables*: planning (location and size of biorefinery, storage facilities, crop sites) & operational (optimal logistics, biomass mix)
- *Mass balances*: biomass & product
- *Logical constraints (e.g. maximum of one facility to be established per cell at time t)*

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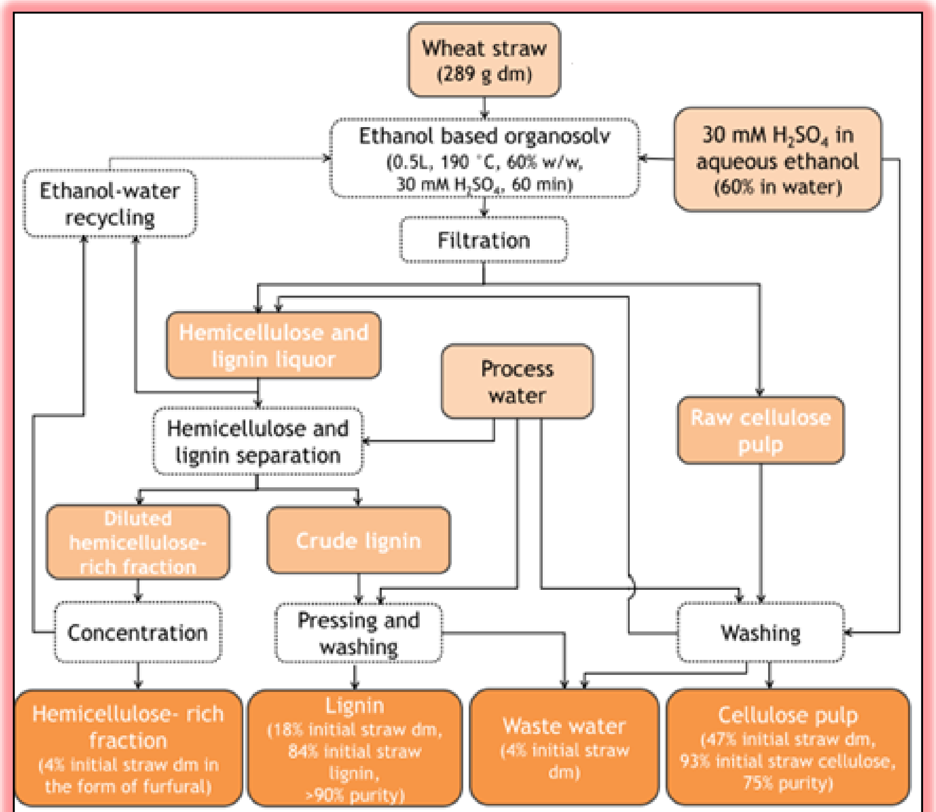
Organosolv Pretreatment



(van der Linden et al., 2012)

Organosolv size (kt of dry biomass)	Unit Production cost (€/t)	Capital Investment (M€)
Small (150)	105	230
Medium (325)	80	345
Large (500)	72	450

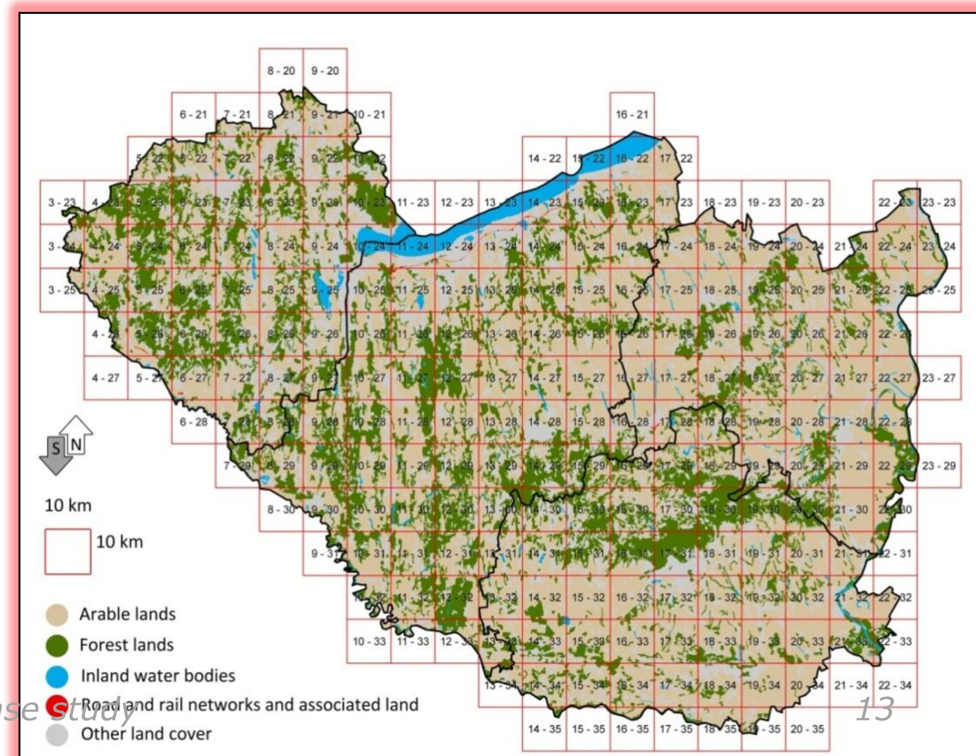
Biomass type	Cellulose (t/tdm biomass)	Hemicellulose (t/tdm biomass)	Lignin (t/tdm biomass)
Winter wheat	0.505	0.228	0.267
Winter barley	0.52	0.23	0.26
Corn stover	0.51	0.23	0.26

Local energy system analysis

Full second generation supply chain in the South-West of Hungary:

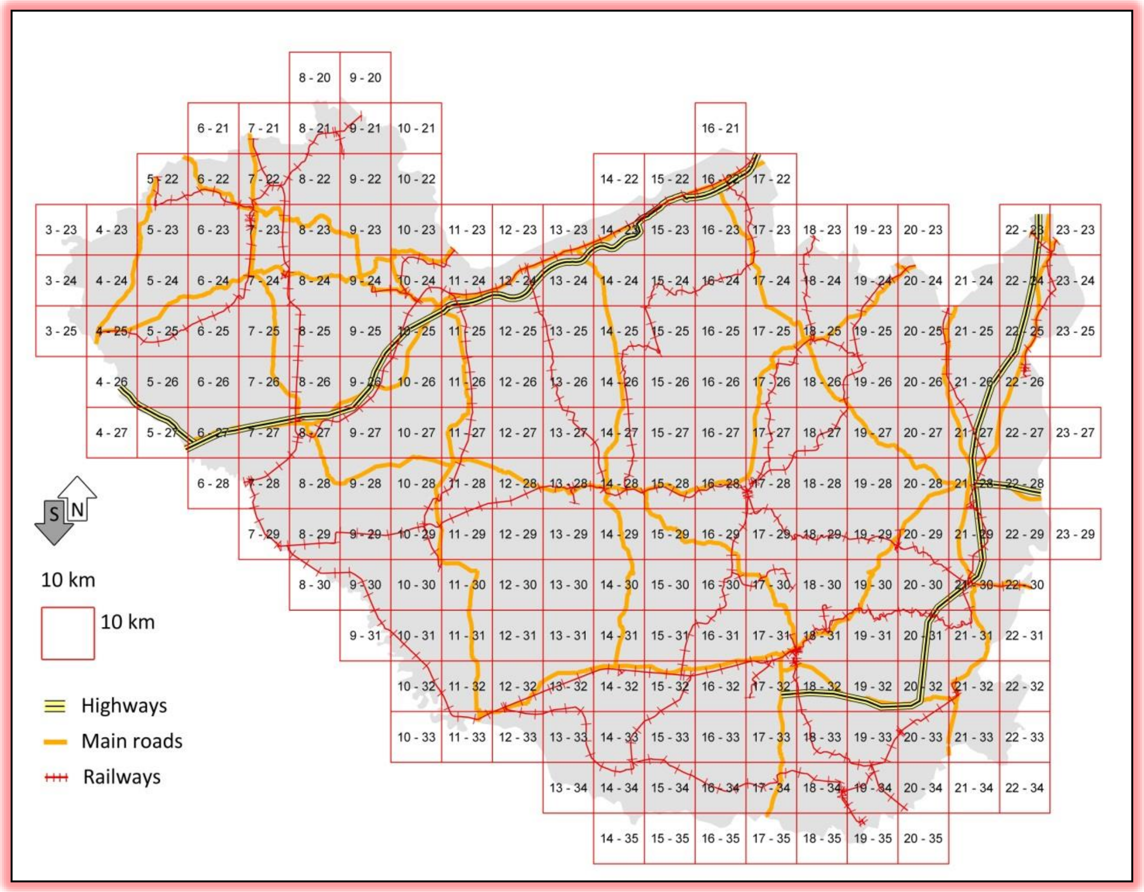
- minimum 13,000 t of cellulose on regional basis
- 587,000 ha (arable land)

Biomass	Yield (t of dry/ha)	Cost (€/t of dry biomass)
Wheat	3.66	40
Barley	3.81	40
Corn stover	8.05	43



Transport infrastructure

- Actual transport distance
  - ✓ tortuosity factor
  - ✓ cell-to-cell straight-line distance
- Unit transport cost
  - ✓ 0.5 €/t/km



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Case study description

- Hungarian case study of an Organosolv-based SC:
  - ✓ Set of products (cellulose, hemicellulose and lignin).
  - ✓ Set of candidate processes
  - ✓ Set of transportation modes (trucks)
  - ✓ Set of potential geographical sites (102 cells of 225 km^2 each)
  - ✓ Potential, spatially explicit availabilities of the raw material (winter wheat straw, winter barley straw and corn stover for July-October)
- Goal:
  - ✓ Determine the size and location of plants, storage and cultivation sites, the feedstock mix and the logistics
  - ✓ Fulfil the demand over the entire planning horizon
  - ✓ Maximisation of net system profit

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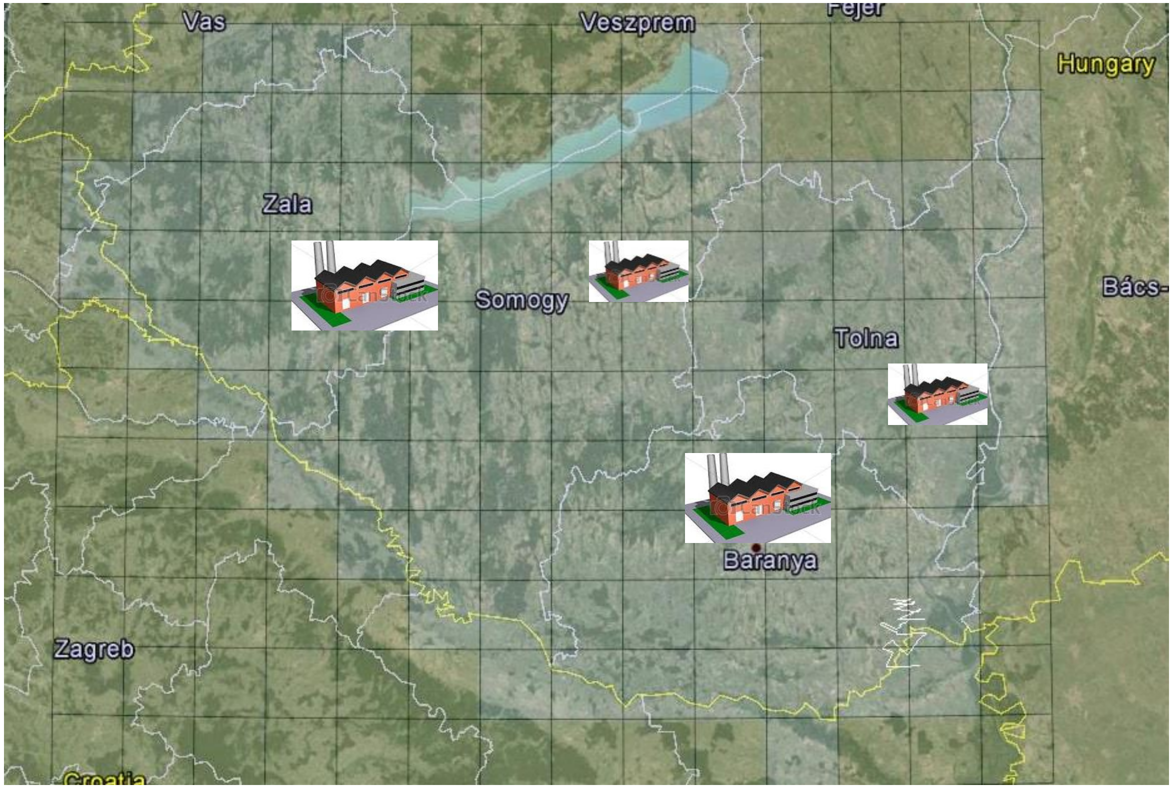
Supply chain configuration

- Process facilities
  - ✓ 2 medium (325 kt pa)
  - ✓ 2 large (500 kt pa)
- Biomass crop widely distributed
- Storage on-fields

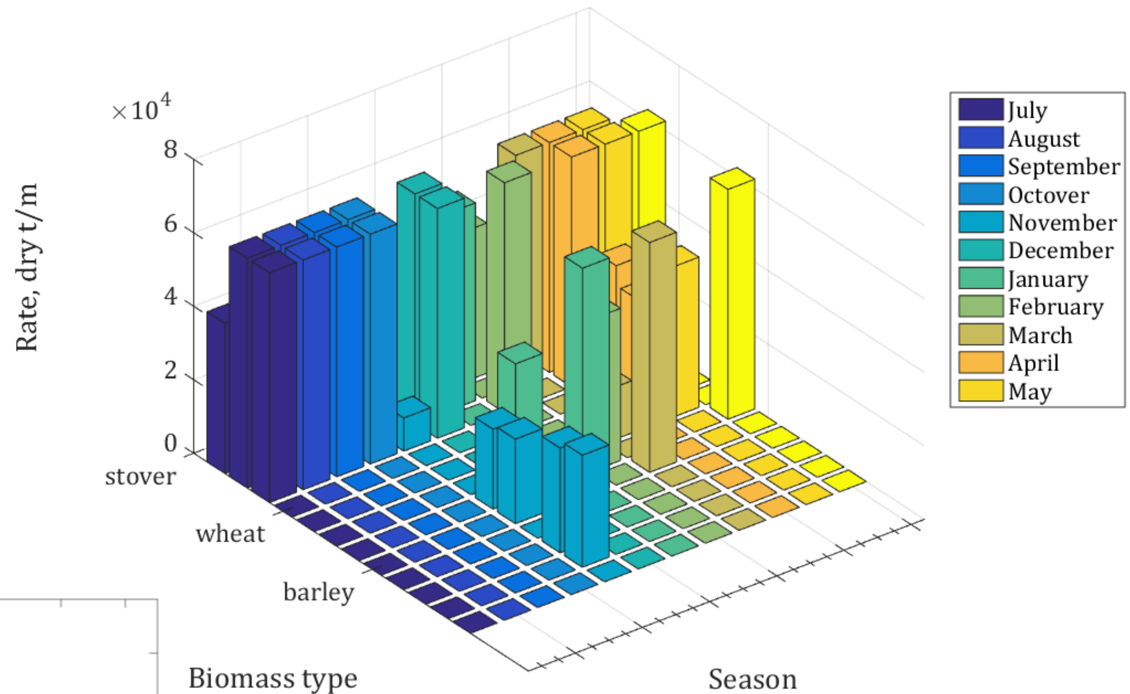


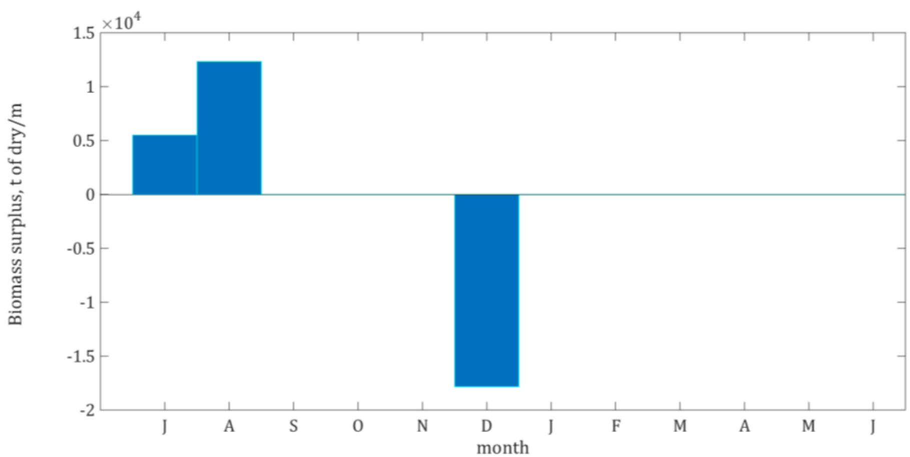
Biomass provision

Feedstock mix

- 77% corn stover
- 19% winter wheat straw
- 4% winter barley straw

Storage on fields





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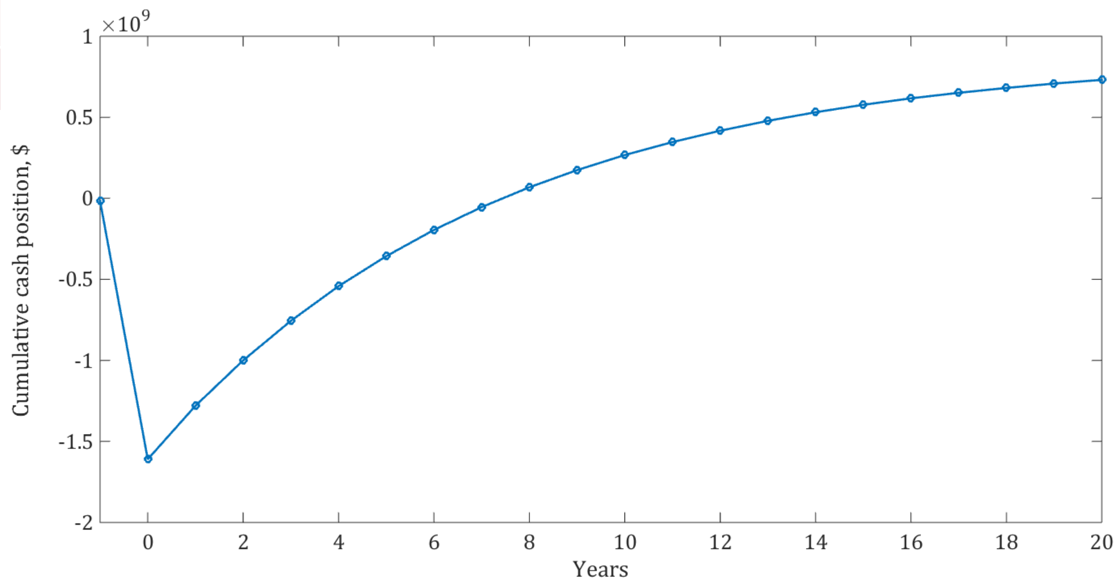
Results: investment profitability

Item	Value [€/y]
Total Operating Cost	$4.56 \cdot 10^8$
Annualised Investment Cost	$1.64 \cdot 10^8$
Cost Breakdown	
Biomass	22%
Processing	39%
Transport	22%
Storage	17%

- ❑ 20 years lifetime
- ❑ 15 % discount rate
- ✓ Net Present Value (NPV) = 730 M€
- ✓ Internal Rate of Return (IRR) = 23 %

- ❑ Market for product not available as yet
- ❑ Product price subject to uncertainty



Concluding remarks

- Optimisation models represent a powerful tool to shed light on the development of novel production systems
- They could support the development of biorefining systems and allow
  - ✓ screening product portfolios and alternative configurations
  - ✓ investigating technical feasibility of production systems
    - evaluating key performance indicators (e.g. costs, emissions) for process technology superstructure with a portfolio of selected biobased products and platform chemicals
    - analysing key source of uncertainties (e.g. technological yields, capital and operating costs) and their evolution over time

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Questions?

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