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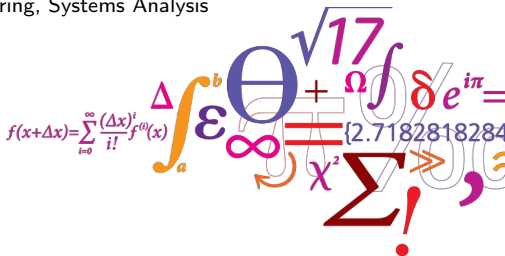
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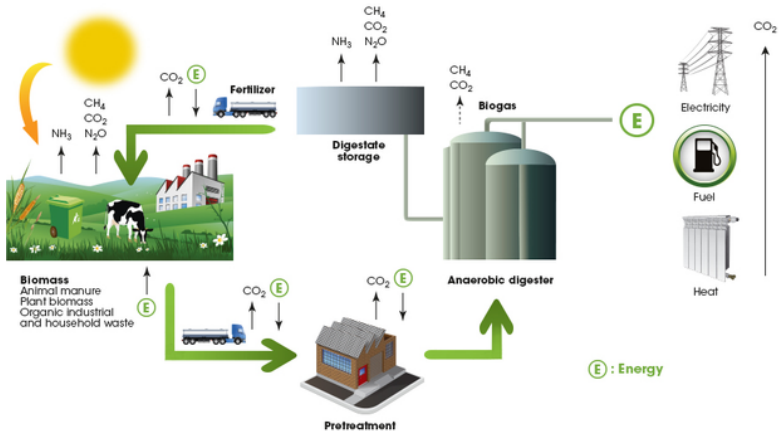
Ensuring Economically Feasible Biogas Projects by Optimisation of the Value Chain

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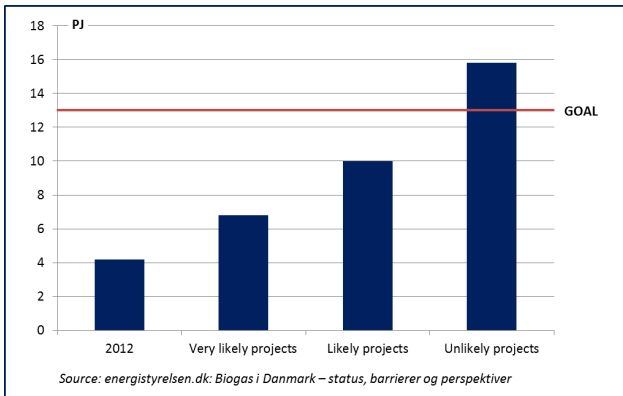


The system



Motivation for using biogas

- ▶ High share of wind energy \Rightarrow need of an alternative electricity source
- ▶ In 2020, 50% of all manure must be used for biogas production - corresponding to approximately 13 PJ



What is biogas?

Biogas is gas based on waste or other methane sources, e.g.:

- ▶ Animal manure
- ▶ Deep litter
- ▶ Household waste
- ▶ Waste water
- ▶ Energy crops

Biogas can be produced by:

- ▶ Thermal gasification
- ▶ **Anaerobic digestion**

Why biogas?

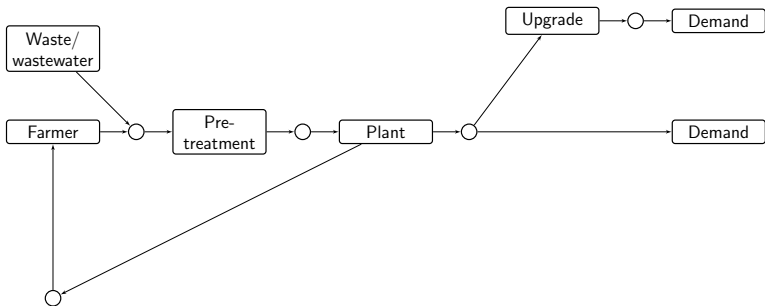
Biogas production has several advantages:

- ▶ Renewable energy - storage opportunities
- ▶ Reduction on GHG emissions
- ▶ Improved fertiliser
- ▶ Redistributions of nutrients
- ▶ Reduced smell

The plant level model

Objective:

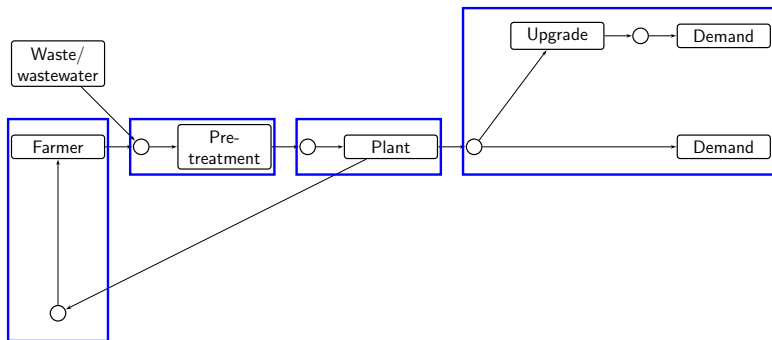
- ▶ Optimise the production of biogas while ensuring economic feasibility for all partners



The plant level model

Objective:

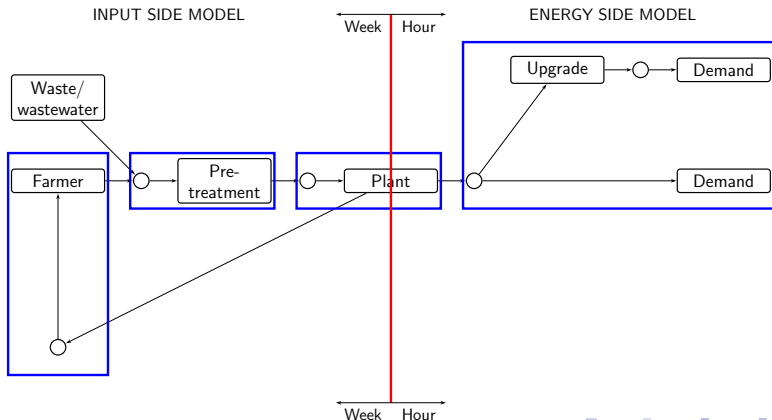
- ▶ Optimise the production of biogas while ensuring economic feasibility for all partners



The plant level model

Objective:

- ▶ Optimise the production of biogas while ensuring economic feasibility for all partners



Input side model

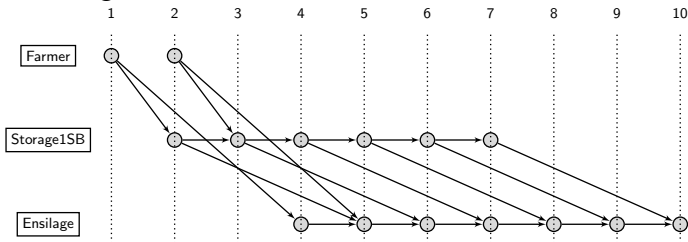
More complicated than the output side:

- ▶ Flow of different biomasses
- ▶ Both mass and energy potential must be accounted for:
 - ▶ Mass needed for capacities and fertiliser output
 - ▶ Energy potential needed for the final biogas yield - changes during storage and pretreatment

Flow model

- ▶ A 3D graph network: Dimensions are process p , time t and biomass potential e
- ▶ A variation of a minimum cost multi-commodity flow problem with node capacities

Small segment of the model - shown in 2D:



Variables

- ▶ x_a : Flow on arc a (arc defined by: (i, p, t, e, p', t', e'))
- ▶ c_p : Capacity of process p
- ▶ $u_{o,p}$: If p is owned by owner o
- ▶ $u_{o,p,o',p'}^{trans}$: If p is owned by owner o and p' is owned by owner o'
- ▶ $x_{o,p,o',p'}^{trans}$: How much is transported from process p owned by owner o to p' owned by owner o'

Objective and simple constraints

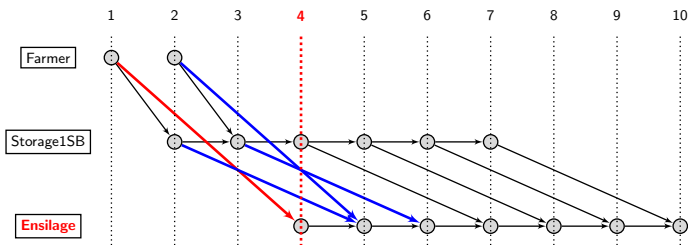
Objective:

$$\begin{aligned} \max Z = & \sum_{a \in \mathcal{A}^{plant}} (p^{gas} BMP_{ie} + p^{fert}) x_a \\ & - \sum_{a \in \mathcal{A}} OPEX_{p,p'} x_a - \sum_{p \in \mathcal{P}} CAPEX_p c_p \\ & - \sum_{(p,p') \in \mathcal{P}} \sum_{(o,o') \in \mathcal{O}} TRANS_{o,p,o',p'} x_{o,p,o',p'}^{trans} \end{aligned}$$

Simple(st) constraints:

- ▶ Flow: includes mass loss for each process
- ▶ Input: what biomasses are available in each time step
- ▶ Maximum biomass type: restrictions on e.g. percentage energy crop of total mix

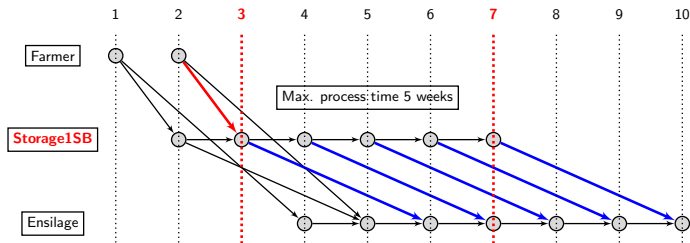
Capacity constraint



$$\sum_{\text{all red edges}(p,t)} x_a + \sum_{\text{all blue edges}(p,t)} x_a \leq c_p$$

$$\forall p \in \mathcal{P}, t \in \mathcal{T} | (p, t) \in A^{in}$$

Process time



$$\sum_{\text{All red edges}(i,p,t,e)} x_a \eta_{i,p,t} \leq \sum_{\text{All blue edges}(i,p,t,e)} \frac{x_a}{(\eta_{i,p,p})^{(t'-t)}}$$

$$\forall i \in \mathcal{I}, p \in \mathcal{P}, t \in \mathcal{T}, e \in \mathcal{E} \mid (p, t, e) \in A^{\text{diff}}$$

Ownership constraints

- ▶ One owner per process:

$$\sum_{o \in \mathcal{O} \mid (p,o) \in \mathcal{PO}} u_{o,p} = 1 \quad \forall p \in \mathcal{P}$$

- ▶ Same owner for consecutive processes:

$$u_{o,p} + 1 \geq u_{o,p'} + u_{o,p''}$$
$$\forall o \in \mathcal{O}, i \in \mathcal{I}, (p, p', p'') \in \mathcal{P}^i \wedge p' < p < p''$$

Transportation constraints

- ▶ If two processes are owned by different owners:

$$u_{o,p,o',p'}^{trans} + 1 \geq u_{o,p} + u_{o',p'}$$
$$\forall \{(p, p') \in \mathcal{P}^{comb}, (o, o') \in \mathcal{O} \mid (p, o), (p', o') \in \mathcal{PO}\}$$

- ▶ Amount transported between different owners:

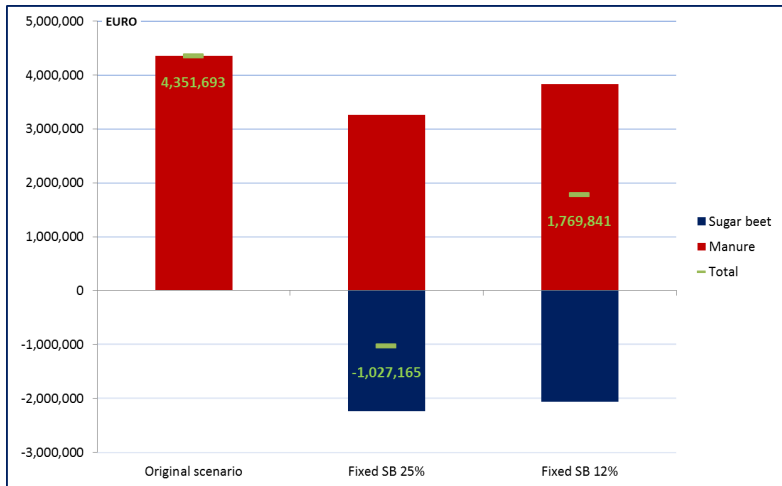
$$x_{o,p,o',p'}^{trans} \geq \sum_{a \in \mathcal{A}(p,p')} x_a - M(1 - u_{o,p,o',p'}^{trans})$$
$$\forall \{(p, p') \in \mathcal{P}^{comb}, (o, o') \in \mathcal{O} \mid (p, o), (p', o') \in \mathcal{PO}\}$$

Results

Case considers co-digestion of sugar beet (SB) and pig slurry (PS).

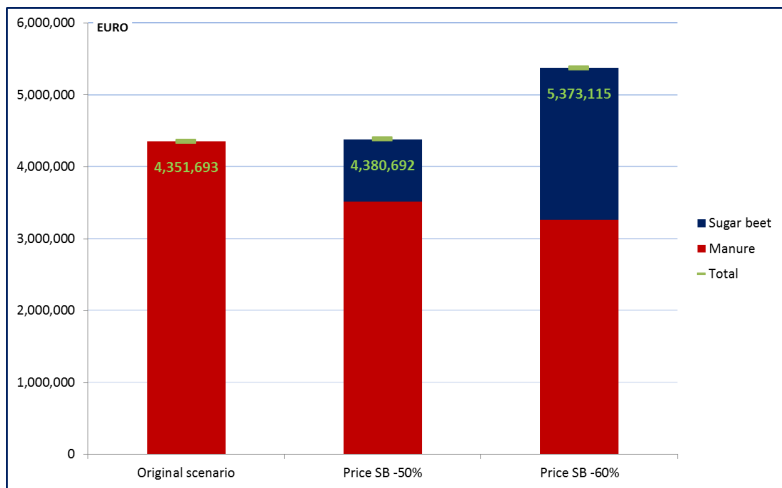
- ▶ All cost functions are linear
- ▶ Data is preliminary - the costs of each process is partly being determined in the BioChain project

Fixed amount of SB



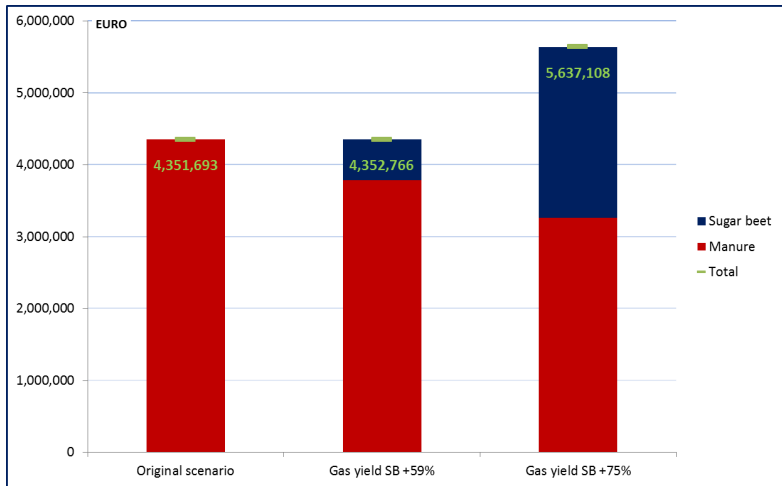
- ▶ Negative net income with SB up to maximum level

SB price decreased



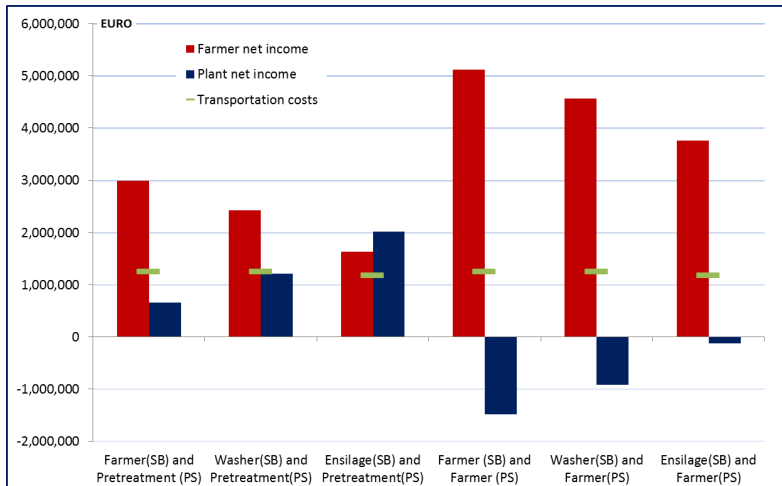
- ▶ Price of SB needs to be lower to make co-digestion profitable

SB gas yield increased



- ▶ Uncertainty on the gas yield of SB can make co-digestion profitable

Income for farmer and plant - different ownerships



- ▶ Ownership of each process is highly relevant for partners in the project

Next step

- ▶ Data on the input side must be validated
- ▶ Constraints for feasibility of ownership included
- ▶ Detailed restrictions on the plant, e.g. seasonal variation
- ▶ Transportation more detailed included
- ▶ CAPEX and OPEX included as piece-wise linear functions

Is it really worth the effort?

Today in Denmark:

- ▶ Existing biogas plants typically have long time contracts on price of output, i.e. the variation on prices might not be used in practice
- ▶ Existing biogas plants cannot control what the biogas is used for due to the ownership structure

Is it really worth the effort?

Today in Denmark:

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- ▶ Existing biogas plants cannot control what the biogas is used for due to the ownership structure

This will hopefully change over the next years!