Ensuring Economically Feasible Biogas Projects by Optimisation of the Value Chain

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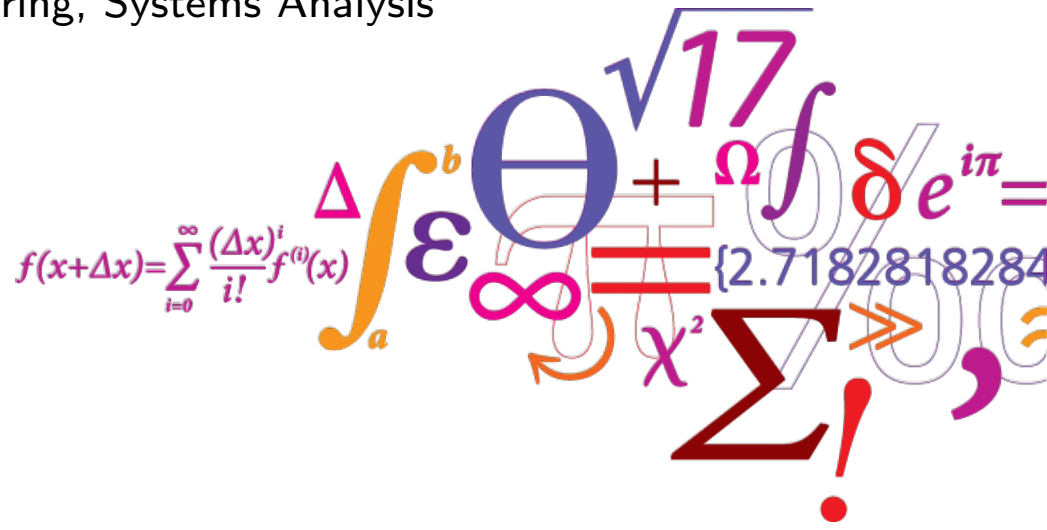
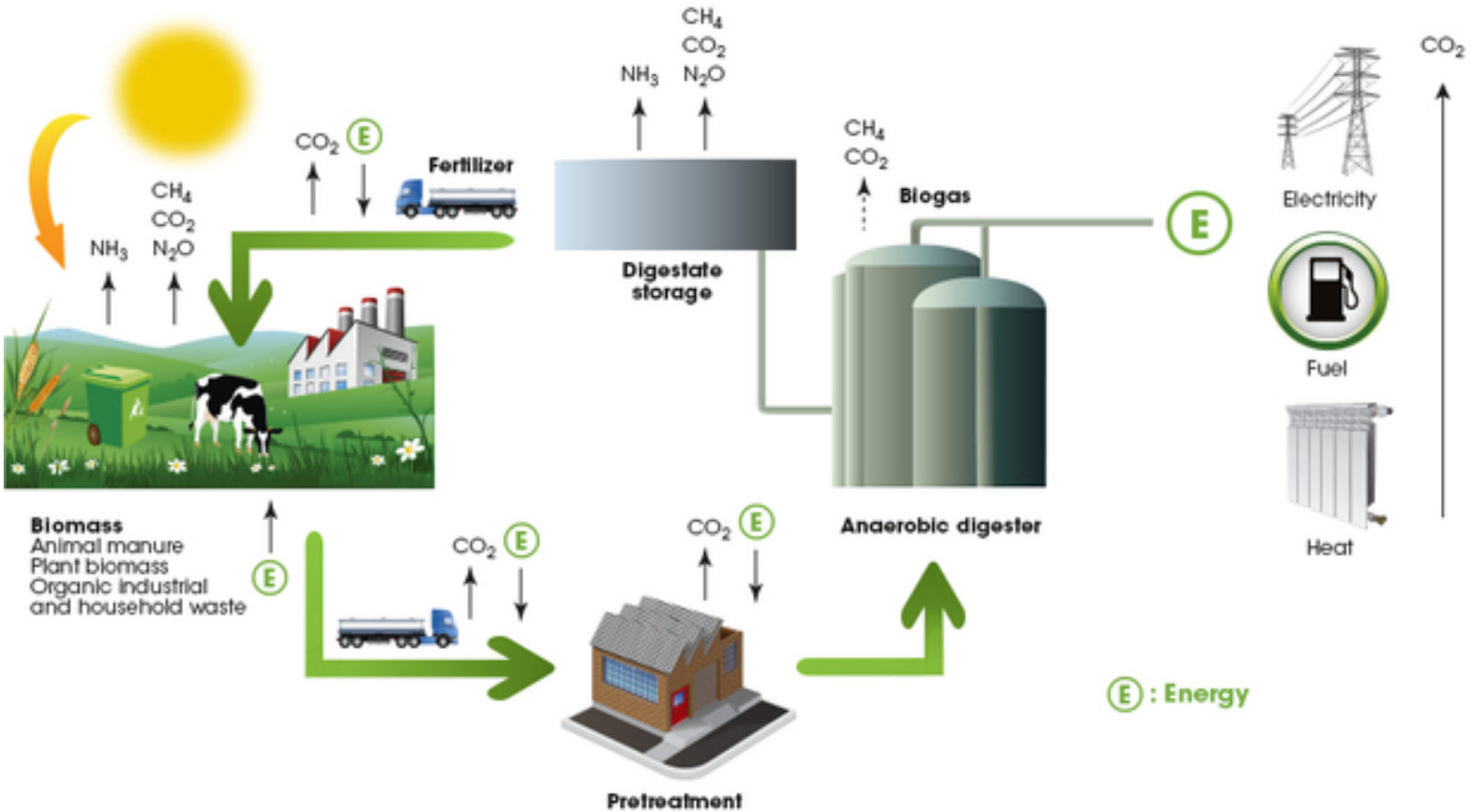


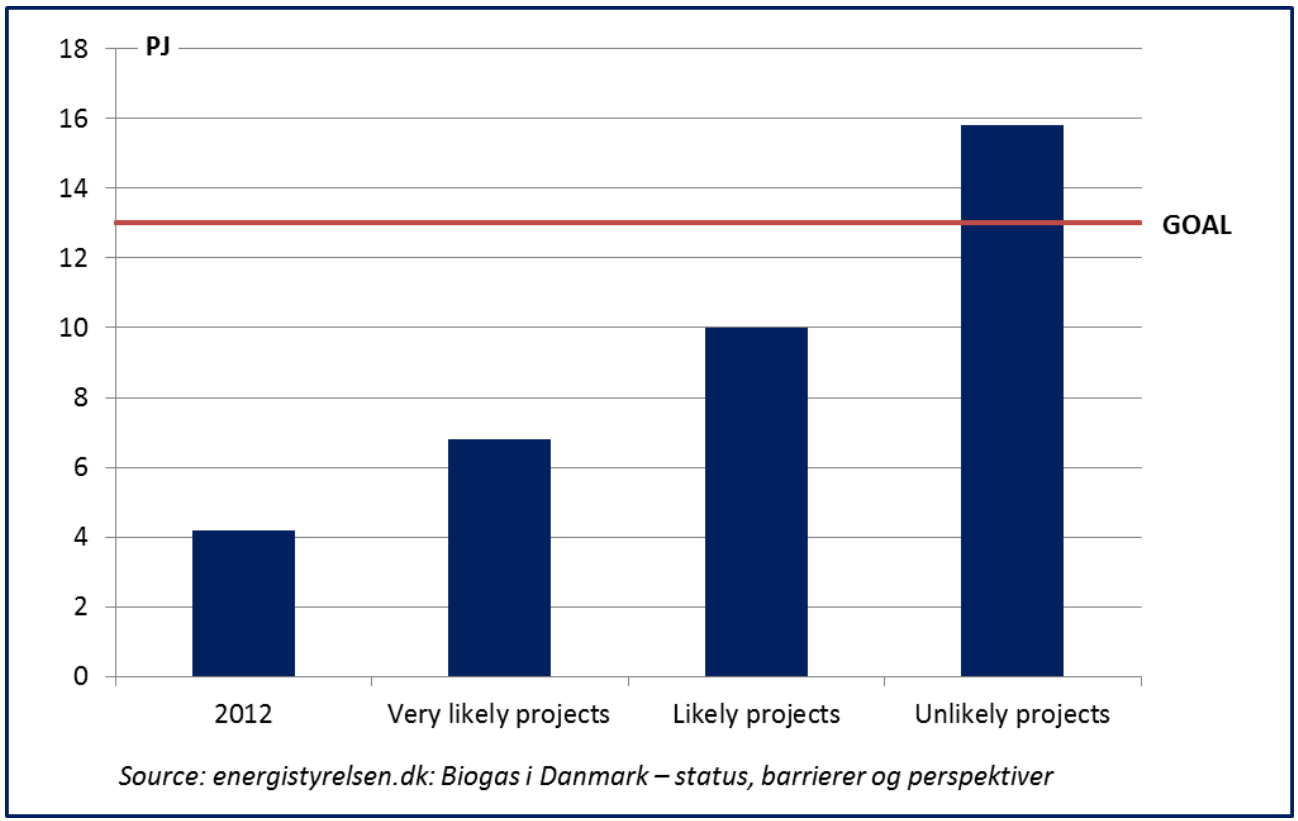
DTU Management Engineering
Department of Management Engineering

The system


CH_4
CO_2
NH_3 N_2O
CO_2 E
Fertilizer
CH_4
CO_2
NH_3 N_2O
Digestate storage
CH_4
CO_2
Biogas
E
CO_2
Electricity
Fuel
Heat
Biomass
Animal manure
Plant biomass
Organic industrial and household waste
E
CO_2 E
CO_2 E
Anaerobic digester
Pretreatment
E : Energy

Motivation for using biogas

- High share of wind energy ⇒ 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?

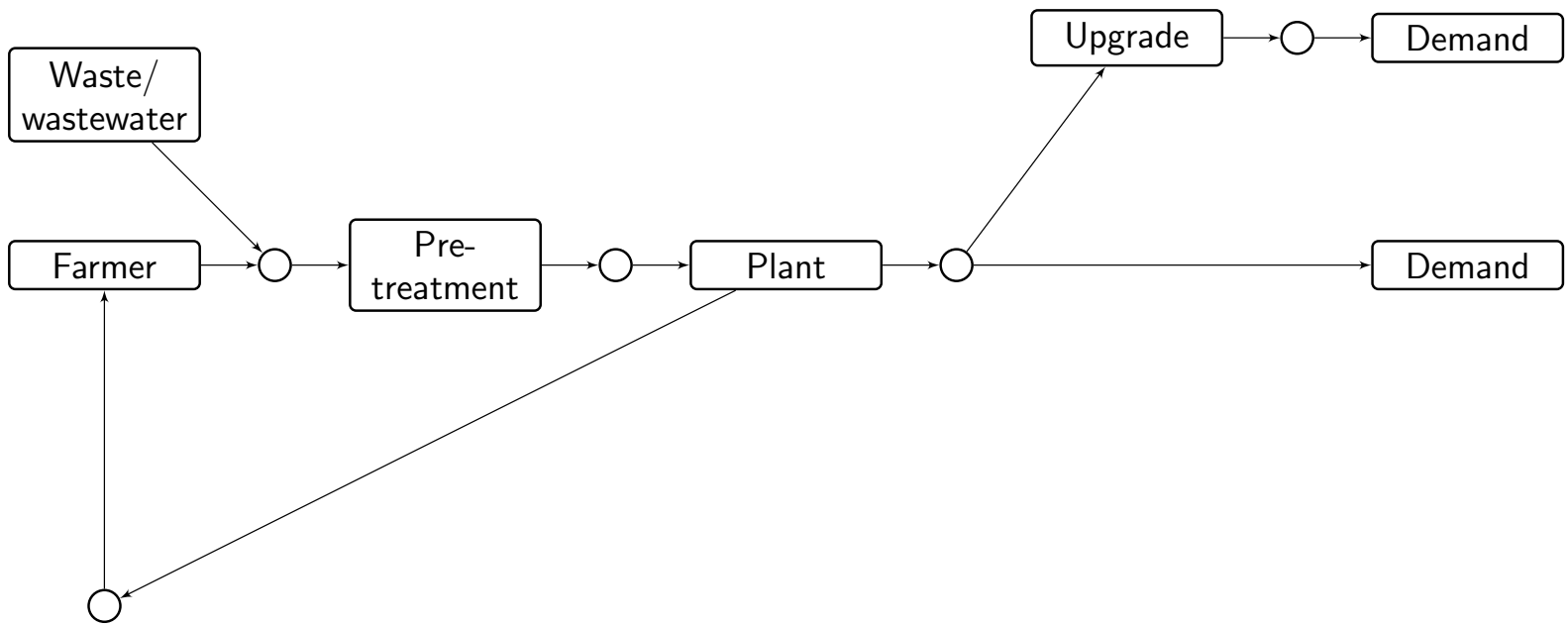
Biogas production has several advantages:

- 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



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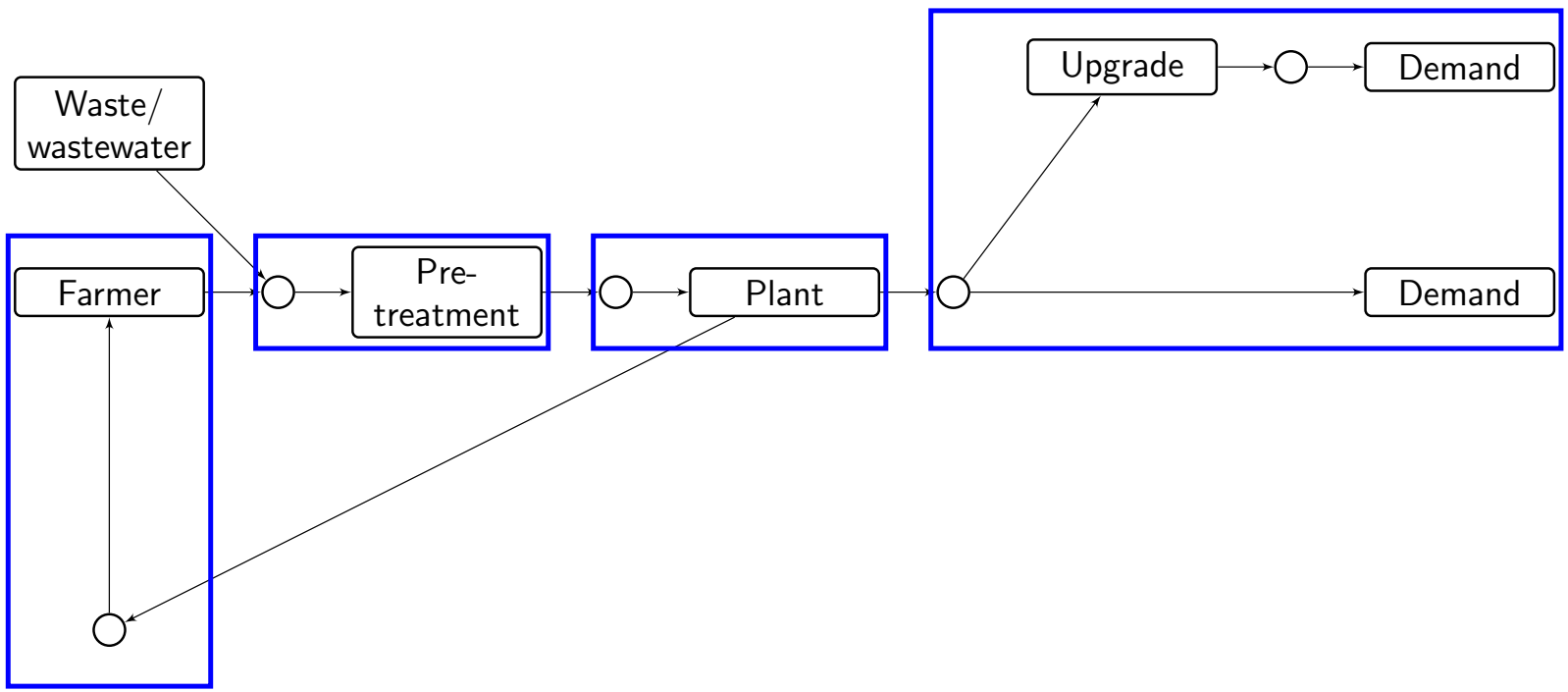

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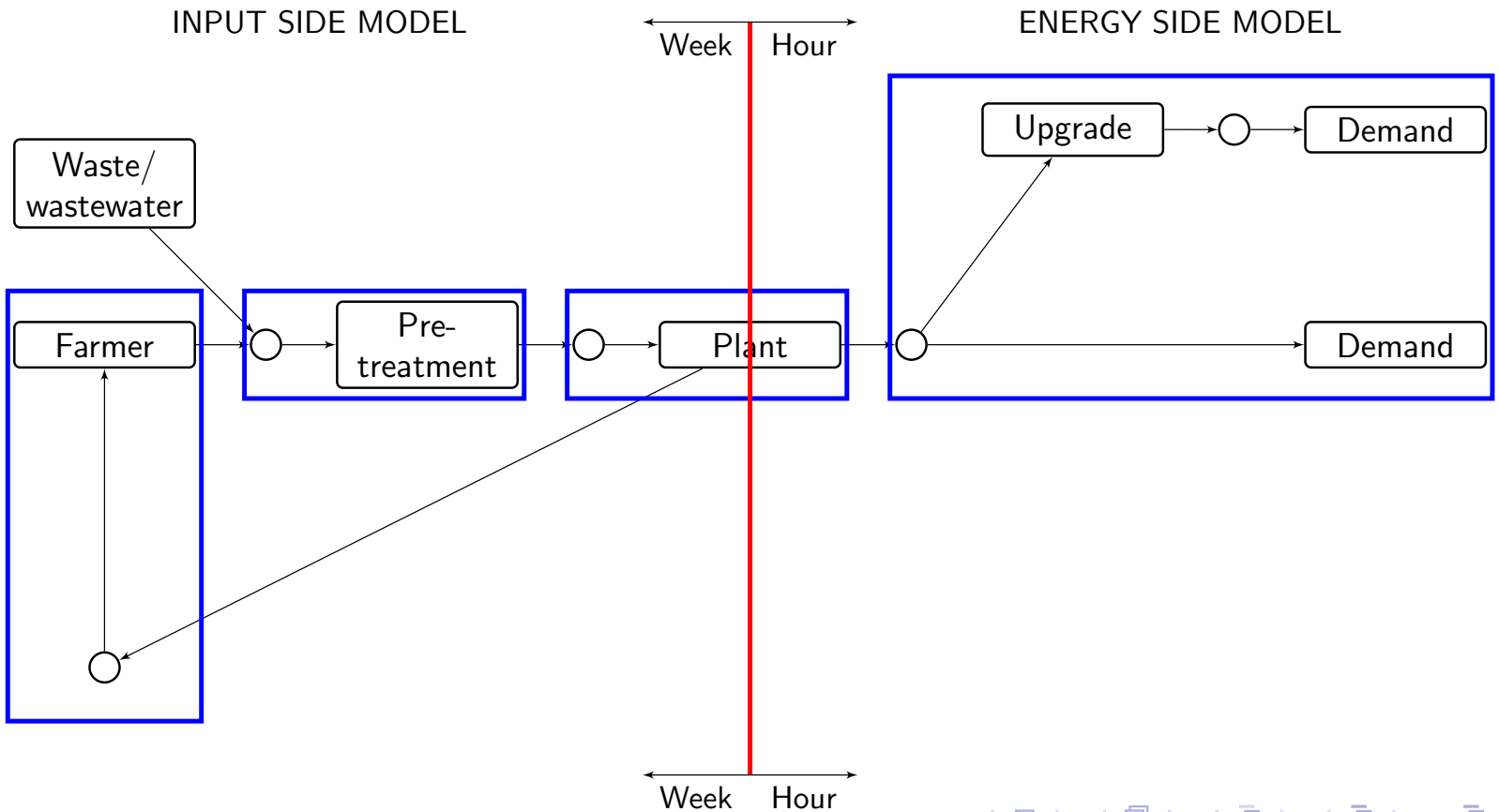


Input side model

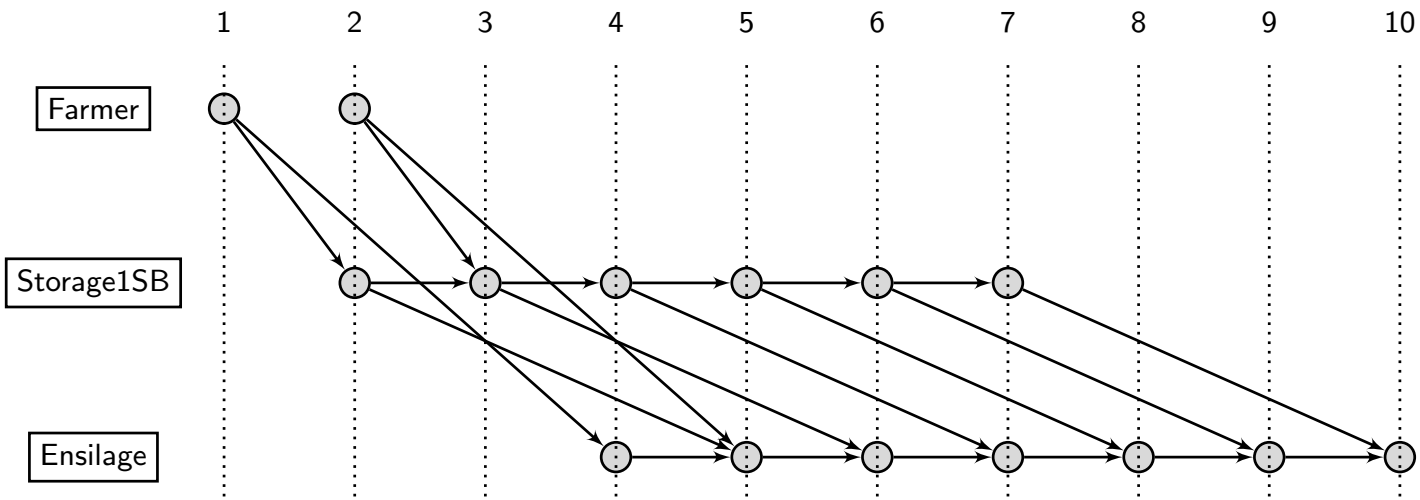
More complicated than the output side:

- 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
- $u^{trans}_{o,p,o',p'}$: If p is owned by owner o and p' is owned by owner o'
- $x^{trans}_{o,p,o',p'}$: How much is transported from process p owned by owner o to p' owned by owner o'

Objective and simple constraints

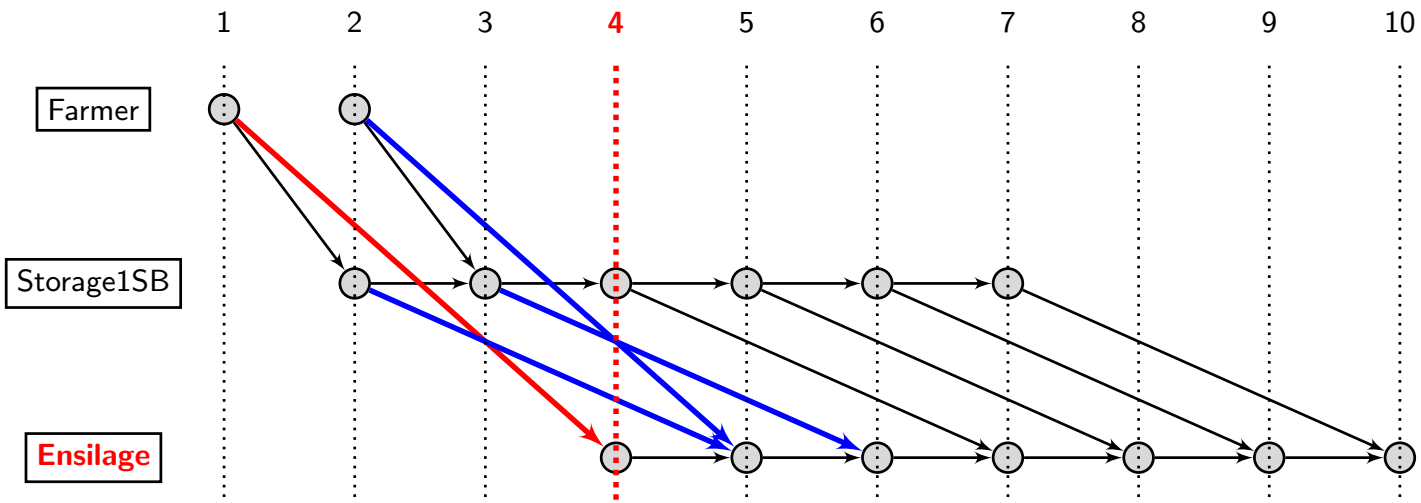
Objective:

$$\max Z = \sum_{a \in \mathcal{A}^{plant}} (p^{gas} BMP_i e + p^{fert}) x_a - \sum_{a \in \mathcal{A}} OPEX_{p,p'} x_a - \sum_{p \in \mathcal{P}} CAPEX_p c_p - \sum_{(p,p') \in \mathcal{P}} \sum_{(o,o') \in \mathcal{O}} TRANS_{o,p,o',p'} x^{trans}_{o,p,o',p'}$$

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

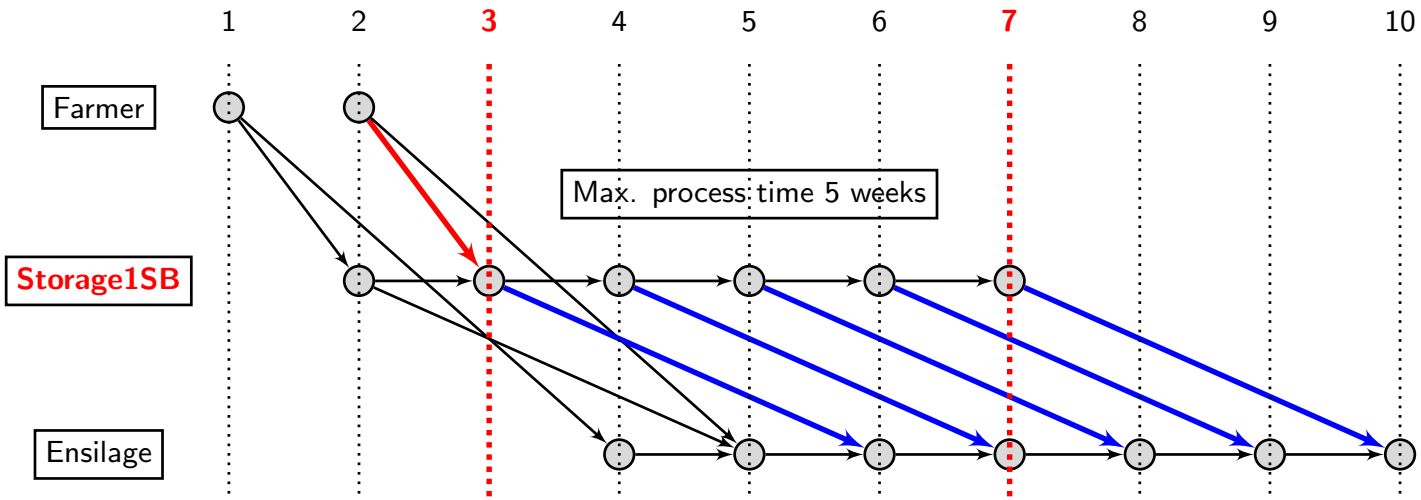
Capacity constraint



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

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

Process time



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

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

Ownership constraints

- One owner per process:

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

- 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:

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

- Amount transported between different owners:

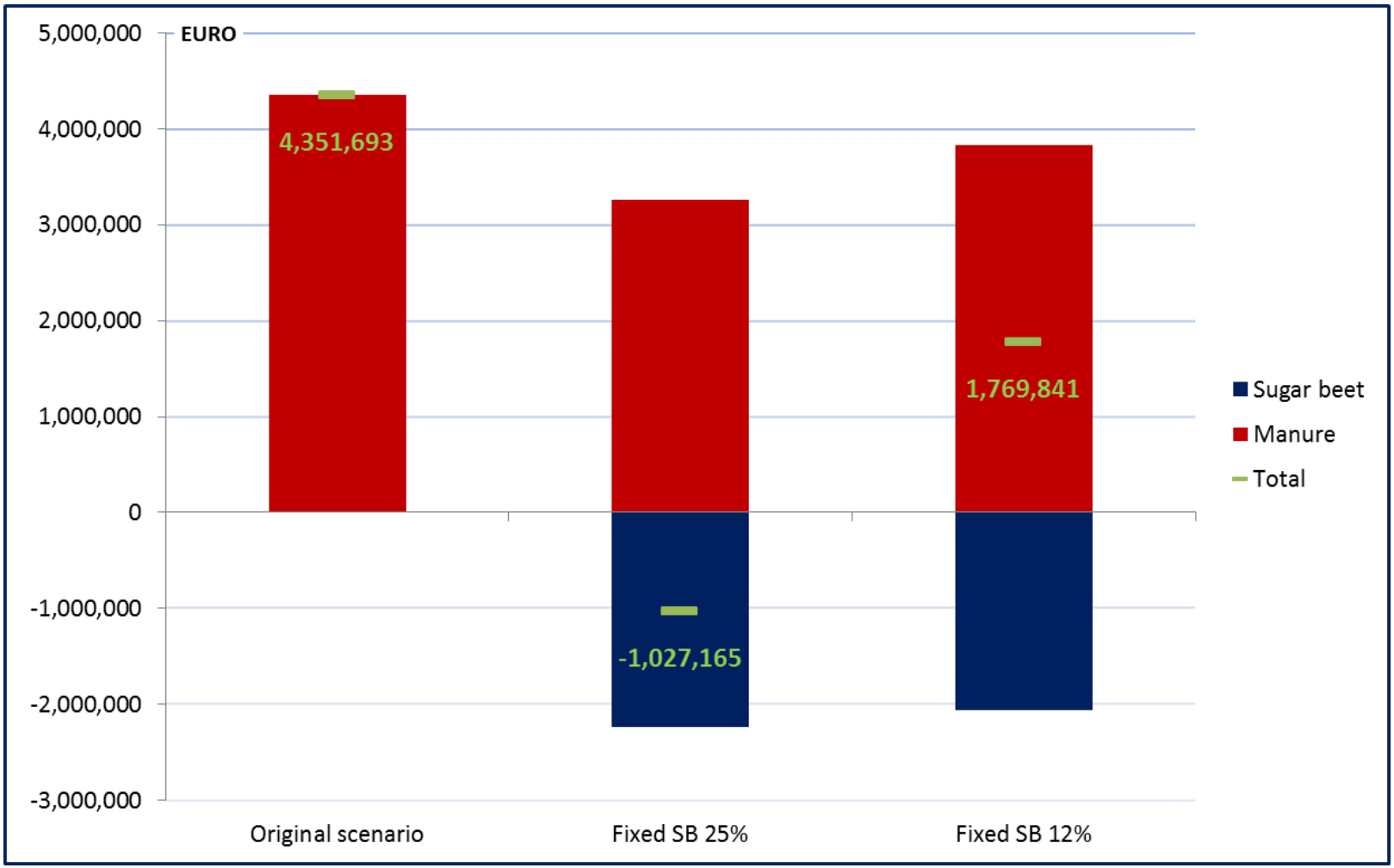
$$x^{trans}_{o,p,o',p'} \geq \sum_{a \in \mathcal{A}(p,p')} x_a - M\,(1 - u^{trans}_{o,p,o',p'})$$
$$\forall\{(p,p') \in \mathcal{P}^{comb}, (o,o') \in \mathcal{O} | (p,o),(p',o') \in \mathcal{PO}\}$$

Results

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

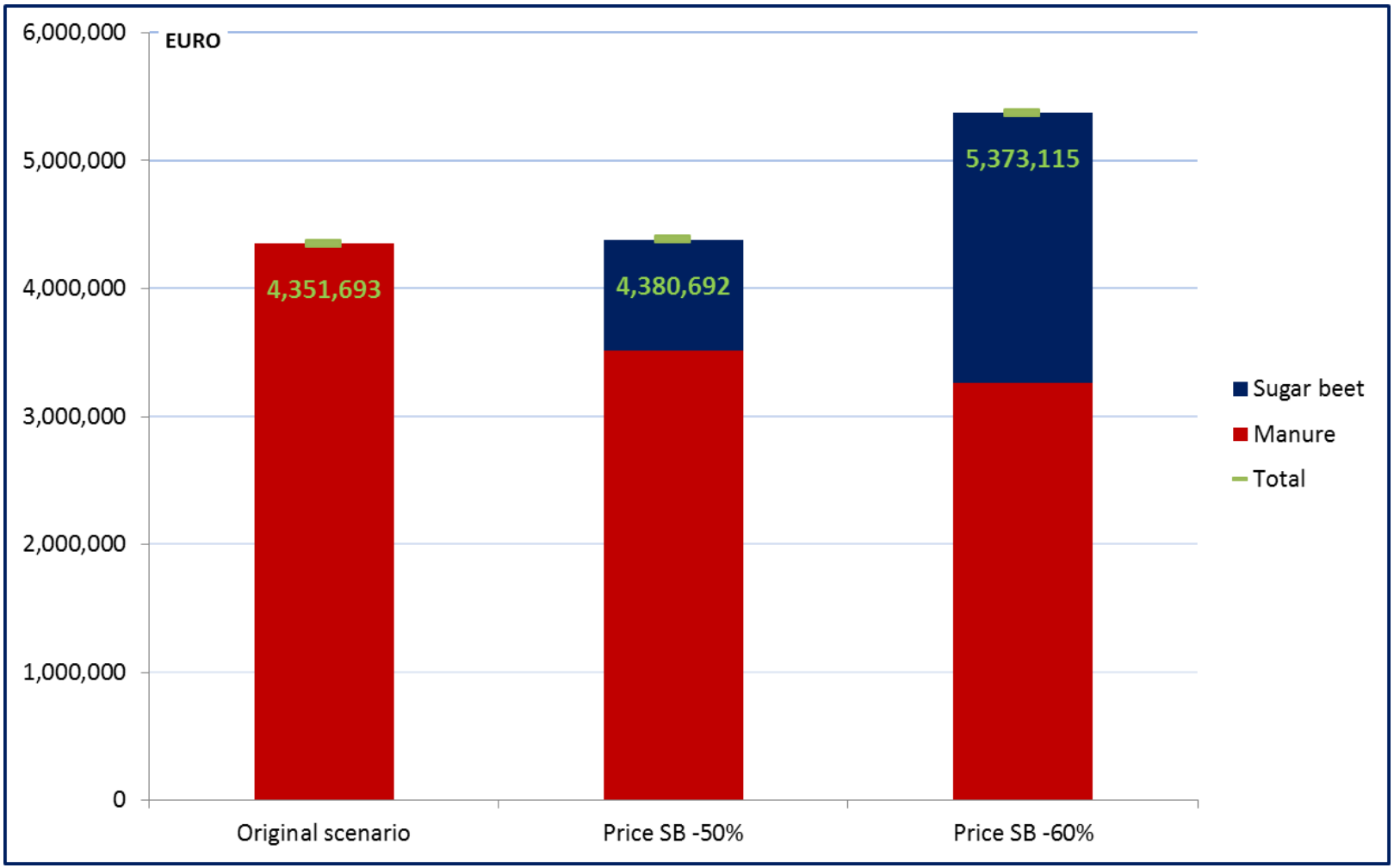
- All cost functions are linear
- Data is preliminary - the costs of each process is partly being determined in the BioChain project

Fixed amount of SB



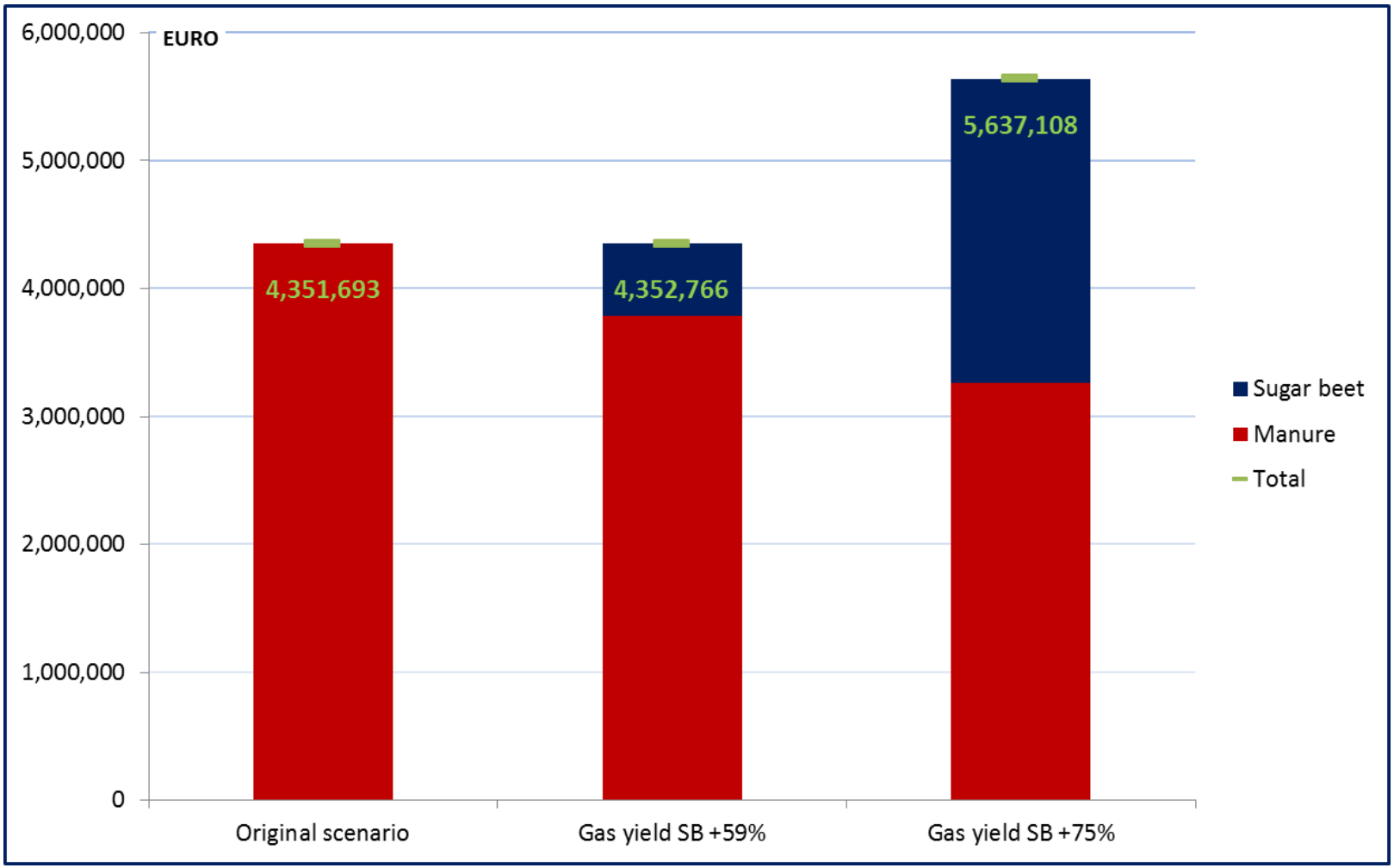
- Negative net income with SB up to maximum level

SB price decreased



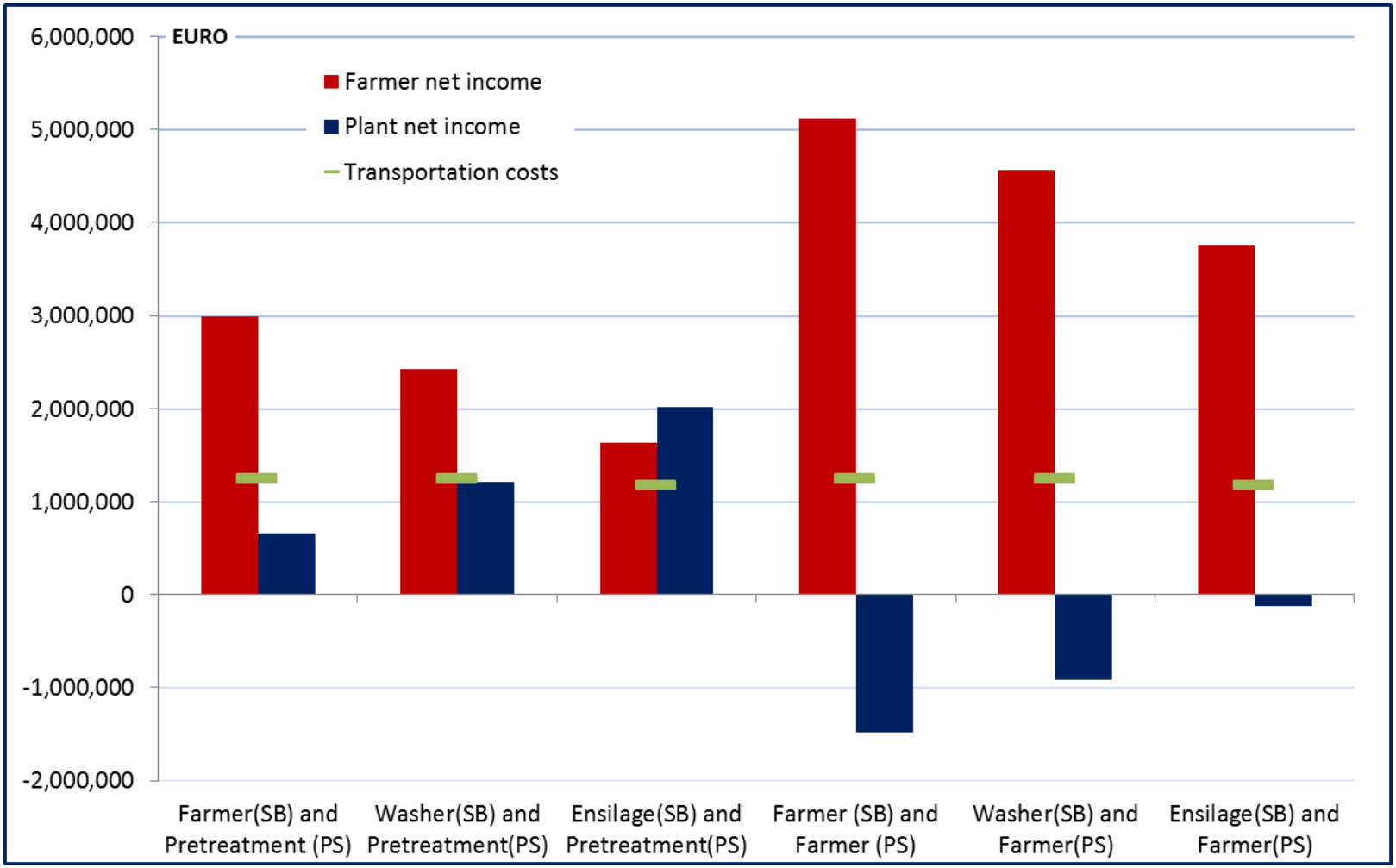
- Price of SB needs to be lower to make co-digestion profitable

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

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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!