Conceptual Model

Ida Græsted Jensen and Nina Juul

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This report serves as a general introduction to the conceptual model for the value chain in biogas production.

Method/Systems analysis (Juul et al. [2])

Systems analysis consists of different types of tools supporting decision making. Chang et al. [1] have suggested grouping these into two categories; system assessment tools and systems engineering tools. In general, system assessment tools focus on assessing how existing systems performs. These tools include, for example, material flow analyses and life-cycle assessment (LCA). Systems engineering tools focus on the design (engineering) of future systems, and these include, for example, cost benefit analyses and economic optimisation.

It is beneficial to work with both types of models. However, we will focus on evaluating the design of future solutions. This both in terms of future solutions for running and/or expanding existing systems as well as investments in new systems. Hence, we will focus on systems engineering models. To be more specific, we will work with economic optimisation modelling.

Economic optimisation

Economic optimisation is a part of mathematical optimisation. Mathematical optimisation is about maximising or minimising a function - typically subject to a number of constraints. Economic optimisation focus on, e.g. profits or costs. A lot of economic optimisation problems can be expressed in terms of linear or integer variables and consequently be solved using mathematical programming methods.

In some cases, the model can be expressed as a deterministic model. These cases are restricted to models where the future is known (or assumed known), i.e. the input and output including prices. However, economic optimisation will typically contain some amount of uncertainties which can be dealt with using stochastic programming. On short term, these uncertainties can be concerning, e.g. prices. On long term uncertainties will typically be on, e.g. investment costs and demand.

When a problem has been expressed in mathematical terms, the problem can be solved using mathematical programming methods. The solution to the problem will be a set of values of the variables leading to the optimal solution to the problem, e.g. least costs or maximising social welfare.

The value chain model

The objective of the economic model in BioChain is to reduce the cost of the value chain as well as ensuring benefits for each stage of the model as far as possible. In doing this, the cost of each part of the chain will be evaluated to ensure that the problem becomes feasible for all partners in the project. The ownership structure is highly relevant in this context and a part of the model will be to enable analyses of different ownership structures, investigating the consequence of changes in the structure. This can, e.g. be done by grouping the different processes in the model to a single owner and test for feasibility for this owner. The model will enable analyses on different types of regulation by changing specific model elements.

Flexibility in the model is given by the input mix, end-use mix and the variation in technologies used in the model. The degree of importance of these will be evaluated by analysis. The placement of, e.g. pretreatment and separation might be included as decisions in the model, but as this might make the model too extensive, simple analysis on the best placement of these processes might be the solution.

Decisions

The value chain of biogas production can be explained by a sequence of processes. This sequence is shown in Figure 1.

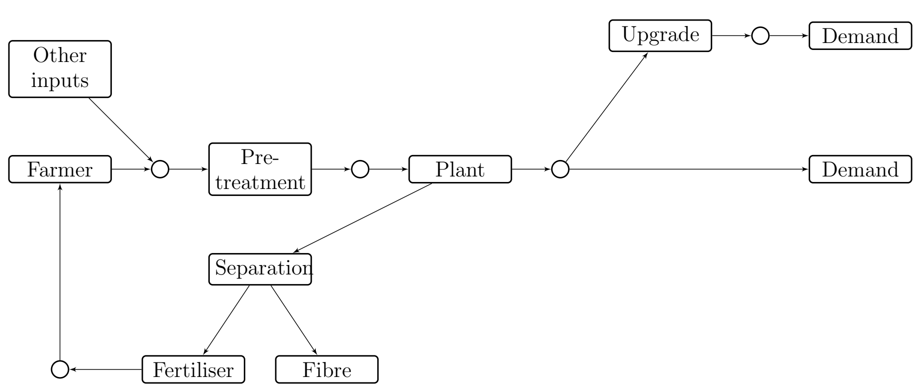

Figure 1: The value chain system

In each step, different inputs are present. These consist of different types of input from the farmer, namely, manure and biomasses, or other input sources, e.g. household waste, waste water, or industry waste. In the following, all these will be covered by the term ”input”.

The circles in Figure 1 are inserted to simplify the figure and represent a possible sequence of storage - transport - storage (or parts of the sequence).

The model consists of two types of decisions, namely, short term and long term decisions. The short term decisions correspond to decisions made on a daily/hourly basis, e.g. how long the feasible hydraulic retention time is. The long term decisions are decisions made to ensure the best production facilities for the future, e.g. the size of the biogas reactor. Hence, in this model investment decisions (including size) are only performed on a long term basis while most other decisions are both short term and long term decisions.

Storage

Storage is included in the model by adding a time/storage constraint for each of the storages. Storages will both serve as storage for input and output and in principle they have two functions; seasonal storage (primarily input) and short term storage. Both types of storage serve to ensure the possibility for steady production as well as enabling the use of biogas when prices are high.

As storage appears everywhere in the model, the following questions are to be considered at each step of the model:

- Should we invest in storage at this level?
- How large should the storage be?
- Should the storage be before or after the treatment? (not relevant for the farmer)
- For how long should the inputs/biogas be stored?

Transport

Transportation will be handled by an average distance to the farmers, a kilometre price for delivering or picking up the different types of e.g. biomass or fertiliser, and a pickup cost. The exact routing of vehicles and planning of deliveries will not be included in the model. The kilometre price will be dependent on the amount of input needed as this will influence the size of the maximum radius in which the collection takes place. The size of the radius will affect the kilometre price as less time will be spent on loading input to the truck but more time spent on driving. The kilometre price is also affected by the type of input, as the vehicles used for transportation depend on the type of input. Different types of vehicles will have different loading times and different maximum speed.

The farmer and other inputs

The first part of the chain resembles the input from a farmer or other inputs. At this point of the model, the decision to be made is:

- How much of each accessible input should be send for pretreatment?

Pretreatment

Transportation to the pretreatment facility might be present depending on the type of input used and the placement and type of pretreatment. For some types of inputs, the pretreatment will be done at the source, e.g. when harvesting and, therefore, the transportation to a pretreatment facility will not be included, neither will the storage possibilities. The pretreatment can be skipped for some of the available input types while for others it is a necessity. The decisions in this step are:

- What type of pretreatments should be invested in?
- What type of pretreatment (if any) should be used for each input type?

Biogas plant

After the pretreatment, the input is transported to the biogas plant. Here the retention time will also give a storage opportunity in the biogas reactor. The decisions in this step are:

- What type of plant technologies should be invested in?
- How large should the biogas reactor be?
- What types of input should be used in the biogas reactor?
- For how long should the input stay in the biogas reactor?

Separation

The digestate from production can be separated or used directly as a fertiliser at the farms. If the digestate is separated a fibre fraction is available. This fibre fraction should get an additional treatment or sought to be sold. For e.g. Maabjerg, the fertiliser will be send back to the farmers. Decisions to be taken in this step are:

- Should there be an investment in a separation facility?
- How much of the digestate should be separated before sending it back to the farmer?

End-use/Biogas

The biogas will be transported either directly to a demand site or to an upgrading facility. The demand can be either from CHP plants, transport, or industry. If upgrading is chosen, transportation must be made to the new demand sites which would normally be the gas grid or for use in transportation. At this step, the decisions to be taken are:

- What investments should be done for upgrading, delivering biogas for CHP plants etc.?

- Where should the biogas be sold?
- How much of the biogas should be used for self-consumption?

Assumptions

The model of course contains a number of assumptions and a lot of these are placed at the end-use. Among others:

- The end-use, e.g. the CHP plant is a price taker and not price maker. This means that whatever is sold will not affect the price of, e.g. electricity.
- The CHP plants already exist, i.e. only investments for connecting the biogas plant to the CHP plant is needed.
- Whatever is produced can be sold at the market. This is only justified if the assumption of biogas production only being beneficial when inputs are available within a rather short radius (e.g. max 50 km) holds.

Uncertainties

The value chain has a large amount of uncertainties. The most important uncertainties are chosen and shown in Table 1. In the table, decisions are divided into the short term and long term decisions. As it can be seen, the number of uncertainties handled using stochastic programming is small. This is due to data availability and the effect the stochastic decisions will have on increasing solution time. Uncertainties not handled using stochastic programming will be investigated using sensitivity analysis.

We are aware that there are high uncertainty in input prices. These prices are correlated with, e.g. choice of crops on the field (assumably based on prices and demand and varies from year to year), demand for these crops, and, thus, the choice of crops for biogas production. Thus, many uncertain factors are part of this price, and we expect this to be more stochastic than what historical prices can resemble. Furthermore, this will make the model too extensive. Therefore, uncertainties on input prices most likely will be considered by making sensitivity analysis.

Area of risk	Type	Short term Stoc.	Short term Sens.	Long term Stoc.	Long term Sens.
Input, quantity	Biomass		x		x
	Manure		x		x
	Level of dry matter		x		x
Input, price	Input		x		x
Output, quantity	Biogas output	x			x
Output, price	Energy price	x		x	
	Treated Manure		x		x
	Nutrients		x		x
Opex	Transport		x		x
	Daily O&M		x		x
Investment	Interest rate				x
	Access to loan				x
	Actual investment costs				x
	Investment support				x

Table 1: The identified uncertainties in the system and how these will be handled both for short term and long term decision

References

[1] N.B. Chang, A. Pires, and G. Martinho. Empowering systems analysis for solid waste management: Challenges, trends, and perspectives. *Critical Reviews in Environmental Science and Technology*, 41(16):1449–1530, 2011.

[2] Nina Juul, Marie Münster, H. Ravn, and M. Ljunggren Söderman. Challenges when performing economic optimization of waste treatment: A review. *Waste Management*, 33(9):1918–1925, 2013.