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Ecological evaluation of biogas feedstock from intercrops

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The production of biogas from renewable resources is a common technology for combined heat and power provision. Small scale plants represent de-centralized energy supply for communities and are an important part of regional development and de-central usage of renewable resources.

To avoid conflicts with the food- and feedstock provision the usage of main crops as main source for biogas production should be avoided. Intercrops are planted on agricultural fields between the periods for main crops and may be used to provide biogas feedstock fields besides main crops. This biogas can be used in decentralized biogas units to produce electricity and heat. Beside the energetic usage of intercrops possible positive side effects are analysed. The usage of intercrops instead of mulching has a potential to decrease emissions of nitrates to water and nitrous oxide to air. Especially emission reduction of nitrous dioxide, a potent greenhouse gas, is part of the analysis.

For the calculation of environmental effects of agriculture with intercrops the ecological evaluation method of the Sustainable Process Index (SPI) is used (Narodoslawsky et. al., 2008).

1. Introduction

Intercrops are planted beside main crops e.g. wheat, corn or triticale between the main crop periods. Intercrops however can also be used to increase yield per hectare besides improving soil quality. Intercrops have the potential to increase biological nitrogen fixation and rebuilding of humus. This would decrease usage of mineral fertilizers which results in a lower ecological pressure. Taking intercrops from the field may decrease this positive effect. This has to be balanced with the potential positive impact of providing energy from intercrops, if they are to be used as substrate for biogas production. For an economic analysis of different possible biogas production scenarios the well known method of the process network synthesis (PNS) (Friedler et. al., 1995; Halasz et. al., 2005, Friedler, 2009) is used. PNS is able to calculate different concepts of using fields most efficiently and also indicate if biogas should be used centralized or decentralized based on economical values.

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2. Process Network Synthesis (PNS)

Process Network Synthesis is a method to find an optimal technology pathway out of a complex technology network (maximum structure). The main aim is to find a network consisting operations of processes technologies to transform raw materials into products (including energy). This method allows the optimisation of process structures as well as energy and material flows. Time dependencies like resource availability (e.g. harvesting of renewable resources) as well as product or service demand (e.g. varying heat demand for district heating over the year) are part of the optimisation. The input necessary for this optimisation includes mass and energy balances, investment and operating costs for the technologies considered, costs for resources and utilities, prices for products and services as well as constraints regarding resource supply and product/service demand.

3. Intercrops

To get raw data about soil effects a set of intercrops combined with common main crops are planted on 3 different locations in Austria. Climatic differences between the locations are used to get specific yield data for planting different kind of intercrops. One target is to increase economic output per hectare and simultaneously improve soil quality through intercrops.
Typical planting rotation is to grow the winter type of main crops (e.g. wheat, rape, etc.) and after harvesting the regeneration period starts. This period is used to plant intercrops. Decreasing effects of soil erosion, loss of nitrate and simultaneously increased yield per hectare and year are an argument for planting intercrops. After the intercrop period the main crop period starts again instead of taking a break between the main crop phases without planting anything on the acre.

4. Case study

First step of analysis was a PNS network with all possible biogas feedstock from regional providers. Several locations for biogas plants are chosen and virtually interlinked with the PNS-Solver. Transport distances are taken into account through slightly different raw material prices for each provider group of substrates.
Second step was the calculation of an ecological footprint through SPI out of the optimal solution from PNS.

4.1 Economic evaluation - PNS

Figure 1 illustrates the maximum structure from PNS of a case study from Bad Zell in Upper Austria. Every possible connection between substrates, production technology and products are illustrated. This results in a very complex maximum structure for optimisation. Detailed information about the maximum structure is listed below:

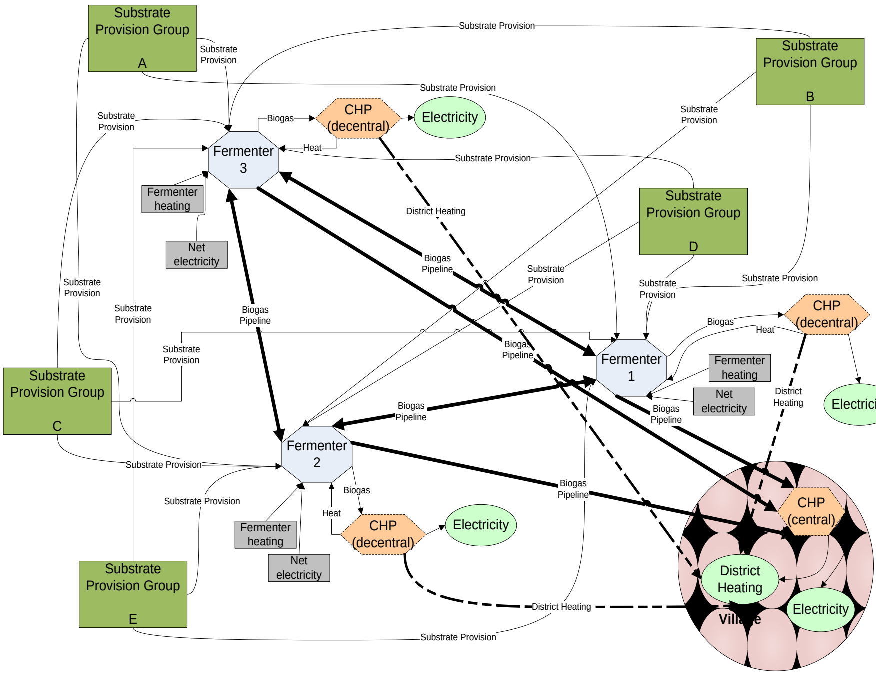

Figure 1: PNS - Maximum Structure

I. There are many small farmers in Bad Zell who can provide different substrates. These providers of main crops, intercrops and manure are grouped to simplify transport situations. Each provider group has a specific transport distance to each fermenter and they are able to supply every fermenter every possible substrates (corn, grass silage, intercrops and manure).

II. Three possible locations for a biogas fermenter are chosen. For every location also three different sizes are available (80 kW_{el}, 160 kW_{el} and 250 kW_{el}).
   - A biogas fermenter including a combined heat and power unit (CHP) could be possible. It can sell electricity to the grid, provide heat for the fermenter (for free) and additionally selling heat for the central district heating grid (DHG). To sell heat to DHG additional pipelines would be required which increases investment costs.
   - Another option for PNS would be to install a biogas fermenter excluding a CHP unit with the possibility to transport the biogas (through a biogas pipeline) to one of the others including a CHP unit or transporting it to the central CHP unit. In this case investment costs are lower for a fermenter but an additional heating for the fermenter is required (in this case a wood chip burner)

III. Because of high priced DHG-pipelines there is also the possibility to transport biogas to a centralized CHP unit (with a higher capacity) which produces electricity (for the grid) and heat (for DHG). An advantage of transporting the biogas is the low price for biogas pipelines.

All available scenarios are part of the maximum structure. PNS is used to get an optimized structure out of Figure 1 with the highest revenue. Transport situation (e.g. distances between provider groups) is taken into account through different transport prices for each route.
Out of the maximum structure PNS calculates several possibilities how to link these production options. Figure 2 illustrates which provider groups and how many substrates are taken for the optimal solution. Not every provider group is part of the final solution due to different transport distances. Only one fermenter (biggest size) excluding CHP chosen and biogas is transported through biogas pipelines to a centralised CHP. Because heat can be sold to villages DHG it increases the overall revenue although biogas pipelines are needed. Although main crops (corn) are used, intercrops are part of the optimal structure. Therefore it makes sense for farmers to plant intercrops on their fields.

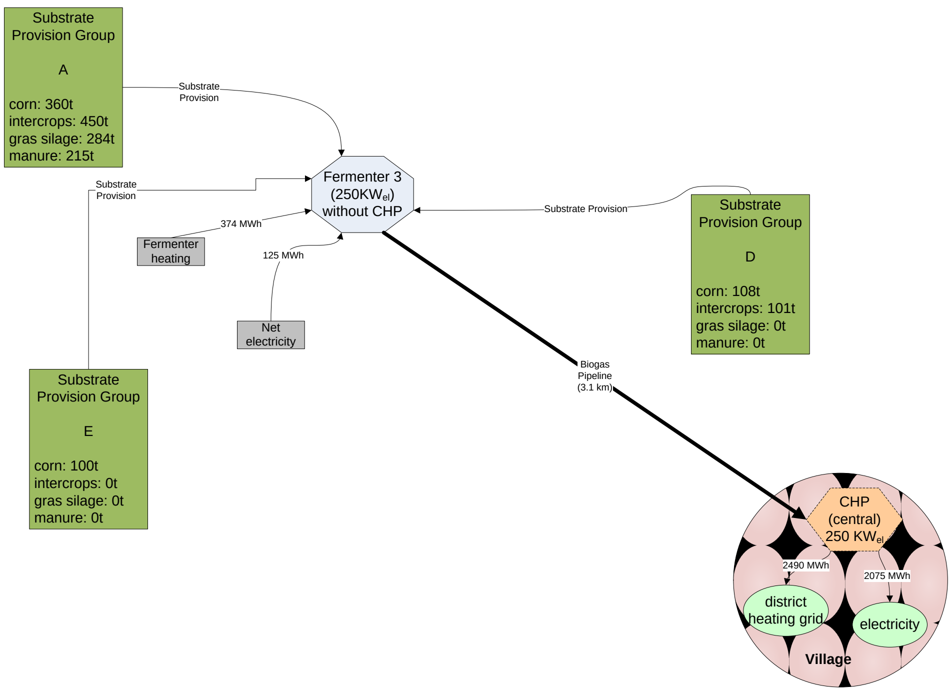

Figure 2: PNS - Optimum Structure

4.2 Ecological evaluation - SPI

Chapter 4.1 figured out how a biogas production can look like with the emphasis of highest revenue for the overall system. To rate the environmental effects of the optimal solution an ecological footprint was calculated. Due to lack of data environmental impact for biogas pipeline infrastructure is not taken into account.
Figure 3 illustrates the Process Chain for the production of electricity and heat from biogas feedstock.

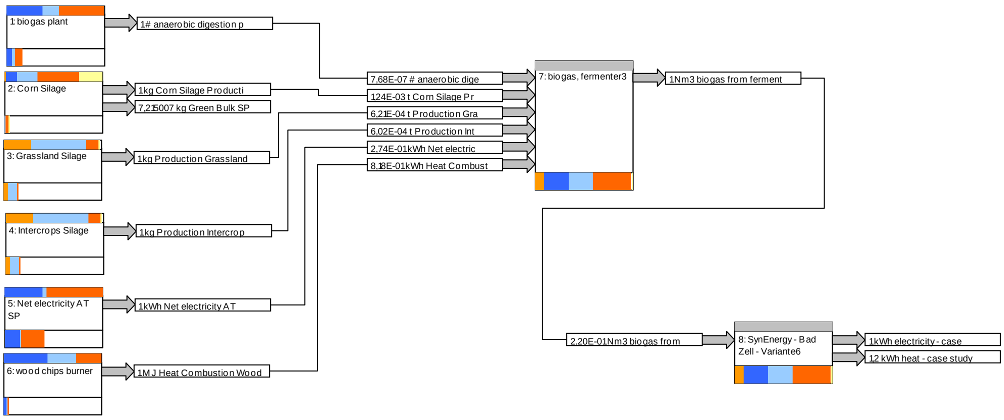

Figure 3: SPI – Process Chain

This results in a footprint of **14.35 m²a / kWh** per year. According to this result **40.7 g** of CO_2 is emitted to atmosphere per kWh of electricity or heat.

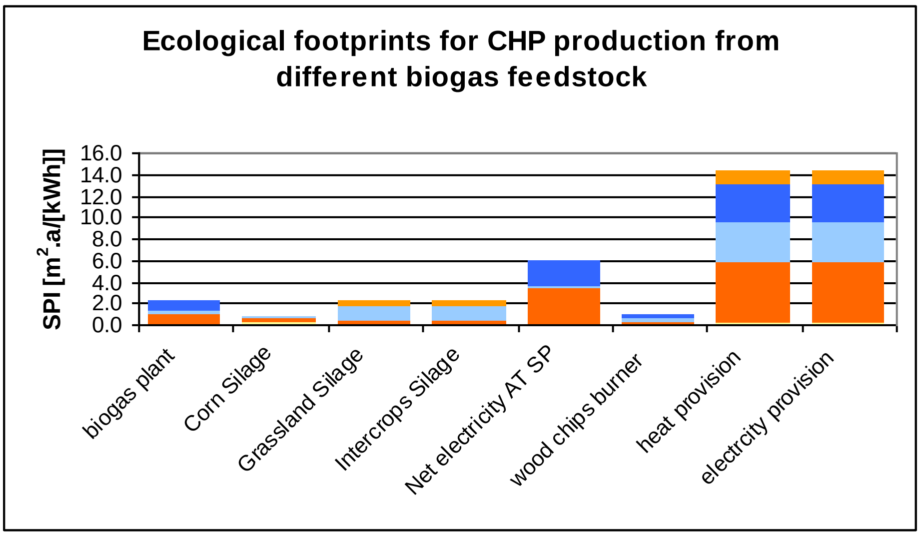

Figure 4: SPI – Process Chain Report

Figure 4 illustrates the specific footprints for different substrates, infrastructure, fermenter heating and net electricity. It is obvious that the usage of net electricity increases the footprint dramatically. From the economic point of view it makes more sense to sell electricity from biogas to the grid than using it internally.
Each footprint is shared into different SPI categories which are the different colours (orange = area for emissions to soil, dark blue = area for emissions to water, light blue = area for emissions to air, red = area for usage of fossil carbon and yellow = area for infrastructure).

5. Conclusions

Focus of the optimisation is not to identify a pathway through a huge set of different technologies which are producing heat or electricity. PNS was used in this case study to proof if the usage of intercrops is economic feasible. Main crops like corn are still used because of a high biogas yield but also intercrops are part of the optimal structure. Planting of intercrops requires a rethinking of farmers and needs subsidies for a wide introduction.
SPI evaluation gives a view on the ecological footprint and carbon dioxide emission through the whole process chain.

Outlook

Transport distances are a key factor for PNS optimisation. Because of this importance future work is to include transport based on time consumption and not distances. Loading and unloading to biogas plants are time intensive which results in higher costs than a kilometre of road transport. Manure transportation with flexible tubes will be part of future maximum structure for PNS.
Ecological footprint evaluation will be stressed until a more detailed PNS optimisation is available.

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