Biogas on-farm: energy and material flow

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Introduction:

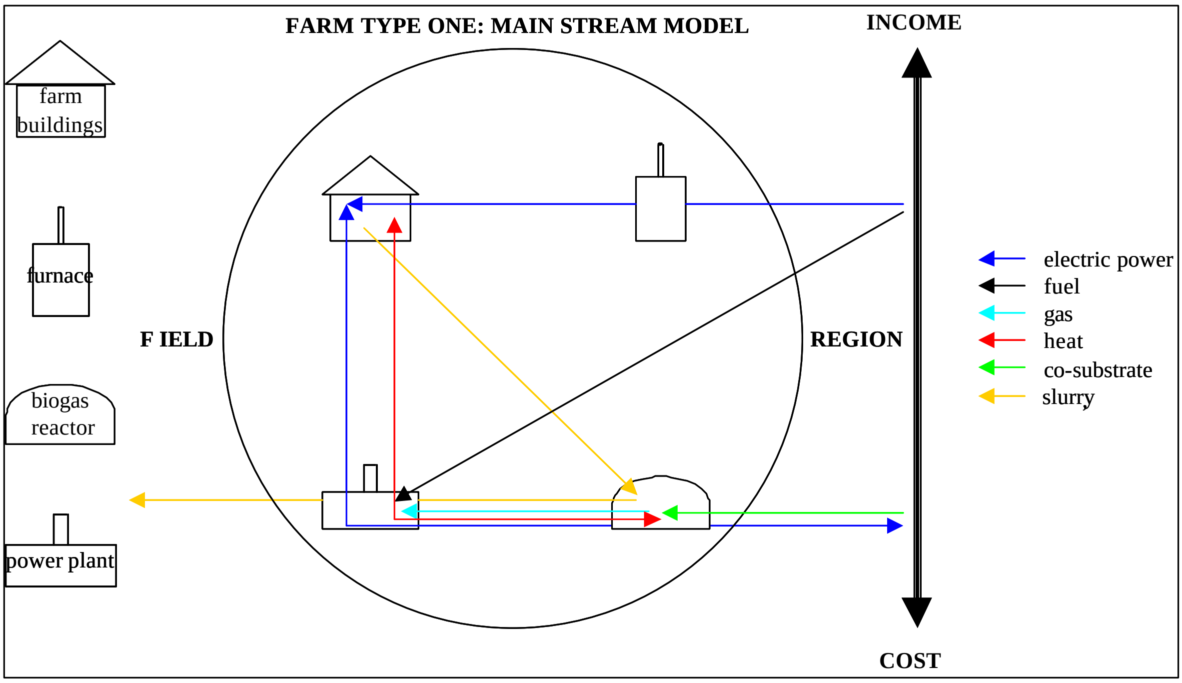
European countries are committed to reduce carbon dioxide emission originating from non-renewable energy sources. On-farm produced biogas may replace energy produced from fossil fuels and so contribute to achieve the target. Most on-farm biogas plants In Europe are operated in Germany. The data of these plants can be used to evaluate cost and benefit of on-farm biogas production.

Objective of my contribution is to answer the following question: How parameters of biogas plant construction and operation influence profit and sustainability of on-farm biogas production? My hypothesis is that a biogas plant integrated within a self-contained farm organism is economically more competitive and more sustainable than an industrial biogas production unit of a mainstream farm.

Methods:

- First, a model is established that describes energy and material flow of two farm types.
- Second, cost and benefit analysis of biogas production and application is done
- Third, parameter variation is employed to find out the sensibility of the most important variables in terms of marginal profit.

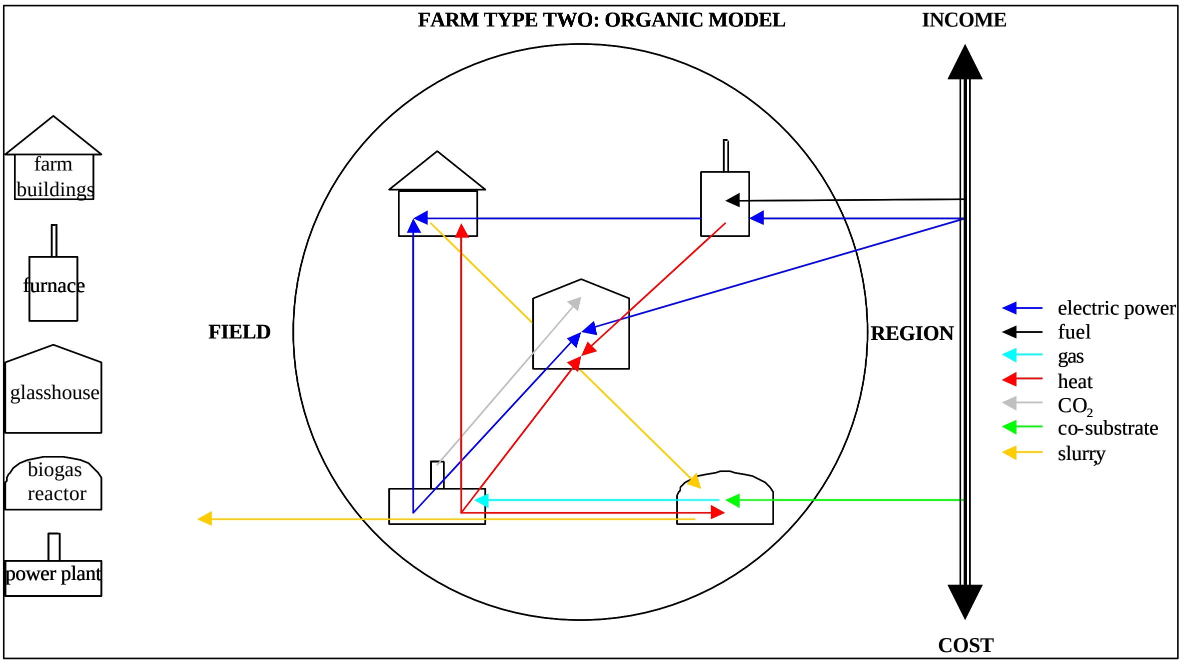
Farm type one uses electric power and light fuel oil as energy source. The biogas plant produces biogas from slurry of 100 adult bovine units (ABU) and 10% co-substrate. The



biogas powers a diesel engine of 26 kW electric power capacity using 10% ignition diesel fuel. Electric power production covers 70% of farm consumption and a surplus that amounts to 84% of the production is supplied to the main grid. Heat energy is used as process energy of the biogas reactor and for heating the farm estate. The surplus amounting to 72% remains unused.

Farm type two uses electric power, light heating oil and additionally heavy fuel oil as energy source for heating a 1000 square meter glasshouse. Carbon dioxide is used for fertilising the glasshouse to produce perennial vegetables (e.g. cucumber). Farm type two produces the same amount of biogas from slurry of 100 adult bovine units (ABU) and 10% co-substrate. The biogas powers a 24 kW gas motor.

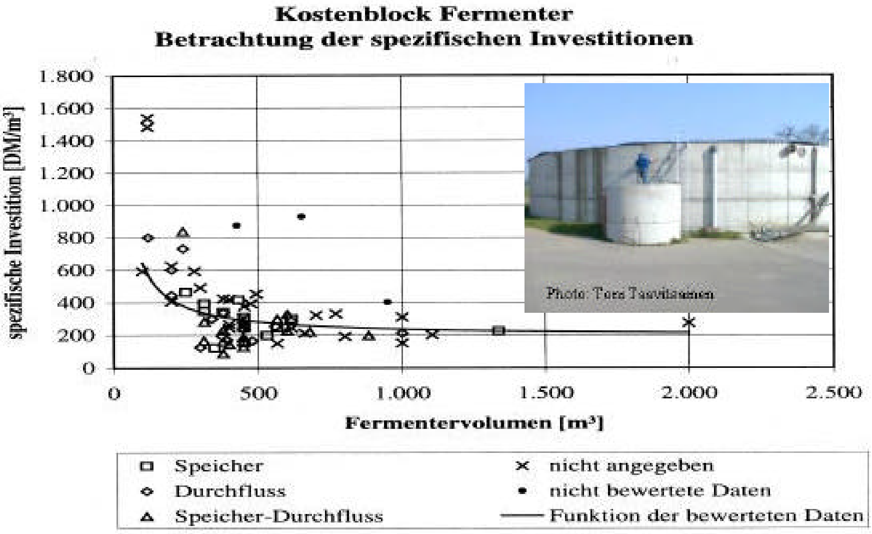
Electric power surplus and heat surplus is completely used by the glasshouse. Thus the gas motor covers 13% of the electric power and 22% of heat consumption. Further, the exhaust of the gas motor substitutes completely carbon dioxide fertiliser procurement to the glasshouse. Carbon dioxide surplus remains unused.



The cost and benefit analysis of biogas production and application is done using empirical data of the most recent biogas plant survey in Germany done by Oechsner and Knebelspiess. Oechsner and Knebelspiess grouped the investment costs of a biogas plant into three blocks:

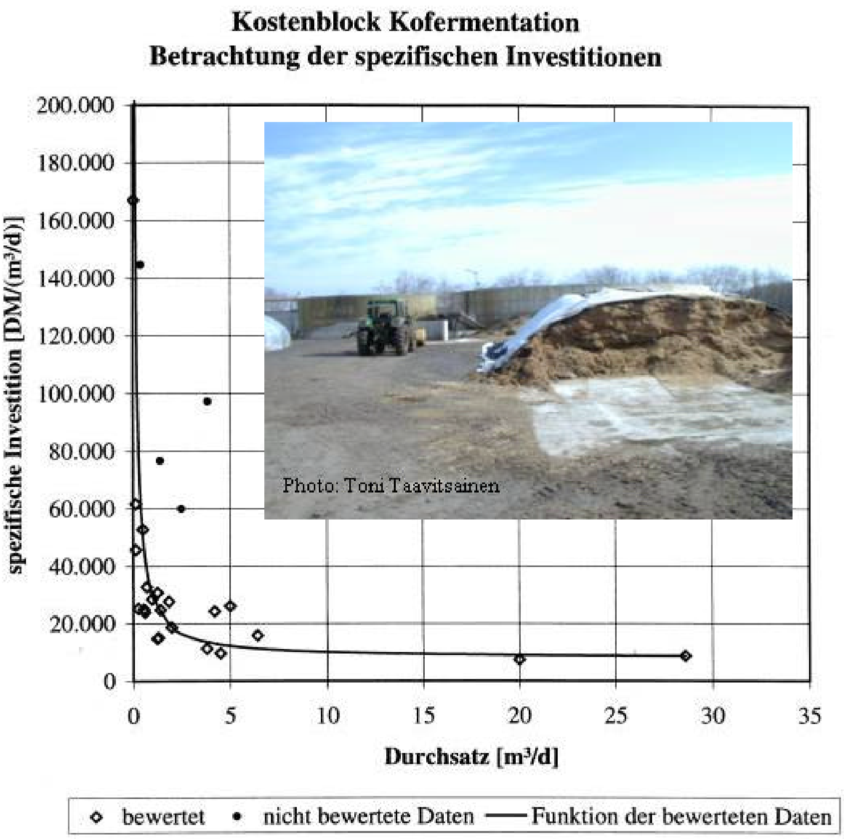
- Biogas reactor
- Co-substrate installation
- Electric power production equipment.

1. Biogas reactor: Cost = f (capacity)



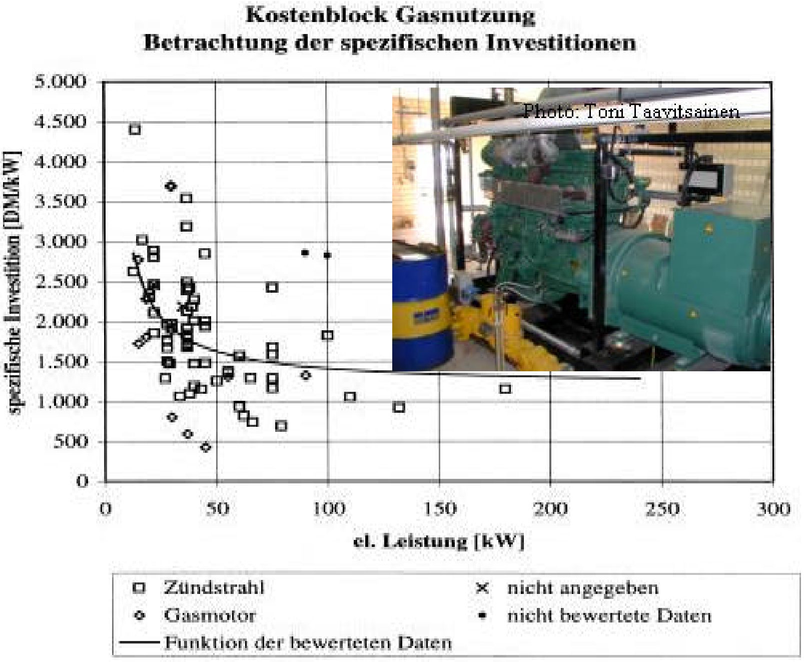
Oechsner, H., Knebelspiess, M. 1999. Ermittlung des Investitionsbedarfs und der Verfahrenskosten von landwirtschaftlichen Biogasanlagen. Hrsg. Kuratorium für Technik und Bauen in der Landwirtschaft e.V. (KTBL), Darmstadt, 172p.

2. Co-substrate installation: cost = f (flow rate)



Oechsner, H., Knebelspiess, M. 1999. Ermittlung des Investitionsbedarfs und der Verfahrenskosten von landwirtschaftlichen Biogasanlagen. Hrsg. Kuratorium für Technik und Bauen in der Landwirtschaft e.V. (KTBL), Darmstadt, 172p

3. Electric power production equipment: cost=f (installed el. power)



Oechsner, H., Knebelspiess, M. 1999. Ermittlung des Investitionsbedarfs und der Verfahrenskosten von landwirtschaftlichen Bio-gasanlagen. Hrsg. Kuratorium für Technik und Bauen in der Landwirtschaft e.v. (KTBL), Darmstadt, 172p

Based on this data they developed a model to calculate fixed and running cost of a biogas plant depending on about 60 different variables. I grouped the cost variables into three blocks for the parameter variation.

First cost block: gas production

Variable	Concerns
Number of adult bovine units (ABU)	Farm size, Quantity of slurry Capacity of biogas reactor
Organic dry matter (oDM) of slurry	Capacity of biogas reactor Gas production rate
Quality and quantity of co-substrate	Gas production rate Gas quality
Fermentation period	Capacity of biogas reactor Gas production rate

Second cost block: investment and running costs

Variable	Concerns
Cost of biogas reactor construction	Portability to other countries, e.g. insulation
Cost of technical installation	Heat and electric power production, Co-substrate
Share of maintenance costs for buildings / technical installation	Portability to other countries, e.g. use of local technology or import
Labour costs	Income

Third cost block: power and heat production

Variable	Concerns
El. Power production hours per day	Maintenance, reliability
Power efficiency	Type of engine and generator Fuel cell
Process energy and heat energy consumption on-farm	Insulation and construction costs
Energy prices	Costs, income

For energy prices the following figures were used and the figures for other variables differing between the farm types are:

	Unit	Germany[4]	Finland
Light fuel oil	€ l^{-1}	0,40[5]	0,40[1]
Electric power buy	€ kWh^{-1}	0,115	0,05[2]
Electric power sale	€ kWh^{-1}	0,0735	0,025[2]
Glass house			
Electric power buy	€ kWh^{-1}	-	0,05[3]
Heavy fuel oil	€ kg^{-1}	-	0,24[3]

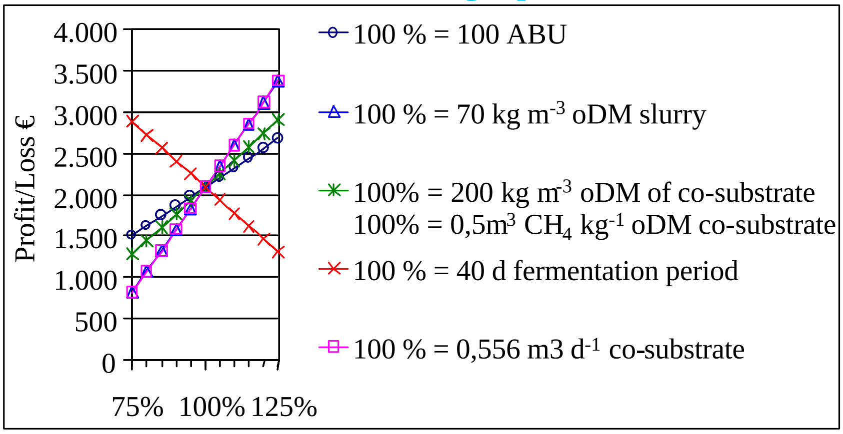
[1]Kauppa- ja teollisuusministeriö: http://domino.poutapilvi.com/ek/ek.nsf/displayStatistics?
[2]Tiusanen, Pekka 2002. Sähkö ja kaukolämpö 2001, p. 41, p. 43, http://lehdisto.energia.fi/sener/#600775.1/Sähkövuosi 2001.ppt
[3] Östermann, Peter 2001. Valokurkun tuotantokustannus ja kannattavuus. Maa- ja elintarviketalouden tutkimuskeskus, Taloustutkimus (MTTL), Selvityksiä 21/2001, p42.
[4]Oechsner, H., Knebelspiess, M. 1999. Ermittlung des Investitionsbedarfs und der Verfahrenskosten von landwirtschaftlichen Biogasanlagen. Hrsg. Kuratorim für Technik und Bauen in der Landwirtschaft e.V. (KTBL), Darmstadt, 172p.
[5]Oechsner & Knebelspiess used 0,20€ l^{-1} 1999

Results:
The mainstream model delivers a surplus of 2092€ under German conditions. Under Finnish conditions there is no profit possible. The surplus of the organic model is 6770€ under Finnish conditions.

Investments €	**Main stream**	**Organic**
Reactor	46 252	46 252
Power station	26 200	24 874
Co-substrate equipment	12 945	12 945
Sum	85 397	84 071
Costs and income € a^{-1}		
Maintenance buildings and technique	-16 743	-14 529
Fuel savings heating estate	1 855	1 855
Fuel savings heating glass house		2 164
Electric power income/savings	13 429	7 638
Co-ferment compensation	3 551	3 551
CO_2 savings		6 090
Difference	**2 092**	**6 770**

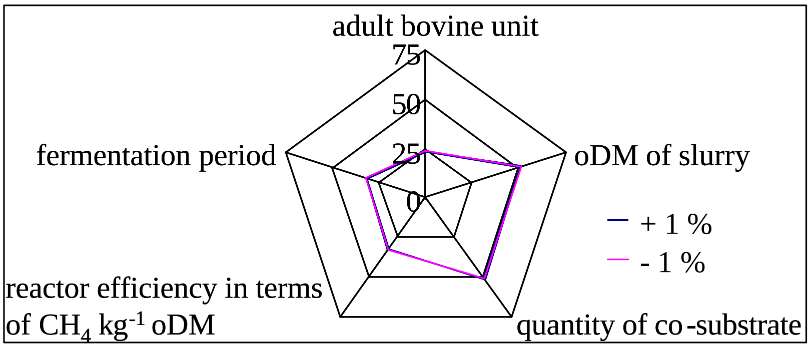
The sustainability of this results is investigated by parameter variation: The following chart shows the change of the surplus of the mainstream model ranging from 809 to 3369€ under application of +/- 25% gas production parameter variation:

Parameter variation gas production

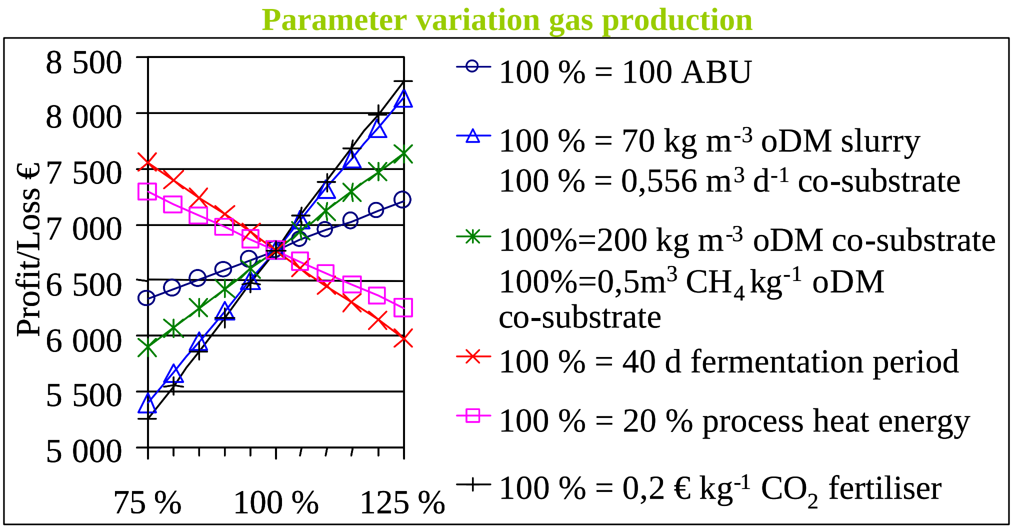


Concerning gas production the marginal profit sensibility decreases in the following order: dry matter of slurry > quantity of co-substrate (both indicating importance of oDM content) > reactor efficiency > fermentation period > number of ABU (indicating low importance of farm size):

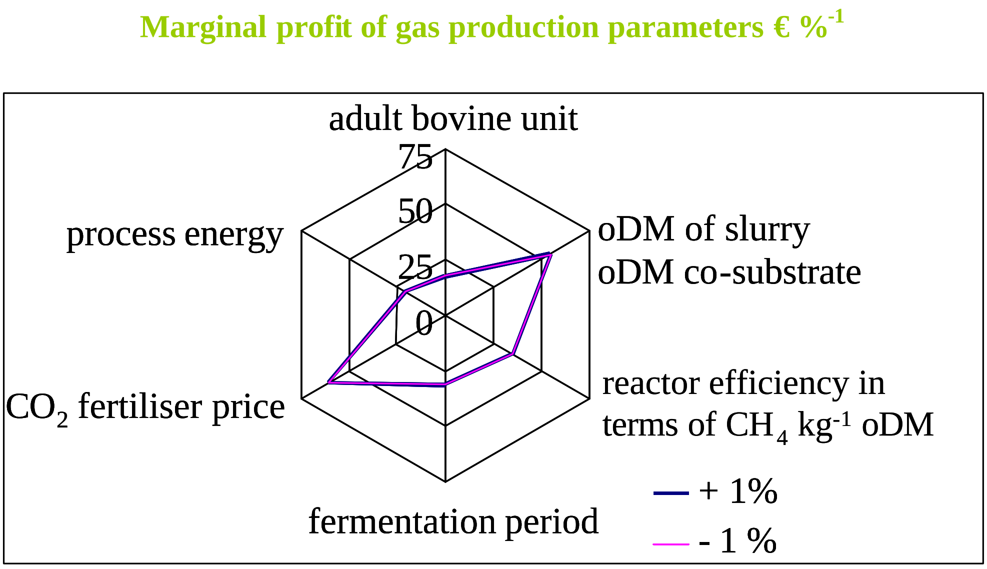
Marginal profit/loss of gas production parameters € $\%^{-1}$



The following chart shows the change of the surplus of the organic model ranging from 5248 to 8293€ under application of +/- 25% gas production parameter variation:



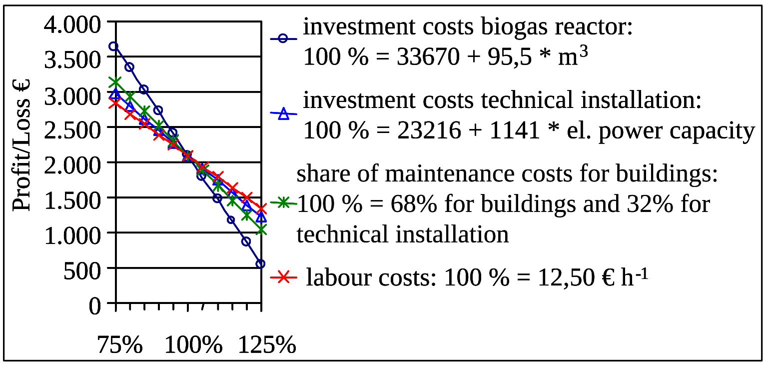
Concerning gas production the marginal profit sensibility decreases in the following order: Carbon dioxide price (indicating dependency on market price) > dry matter of slurry > quantity of co-substrate > reactor efficiency > fermentation period > process energy > number of ABU:



Because in the organic model there is no heat surplus, the process energy has to be taken in consideration, but its influence is small.

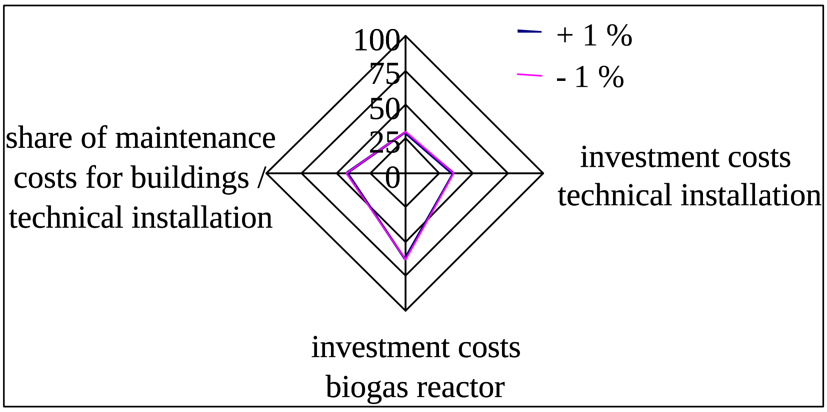
The following chart shows the change of the surplus of the main stream model ranging from 542 to 3643€ applying +/- 25% of investment and running costs parameter variation:

Parameter variation investment and running costs



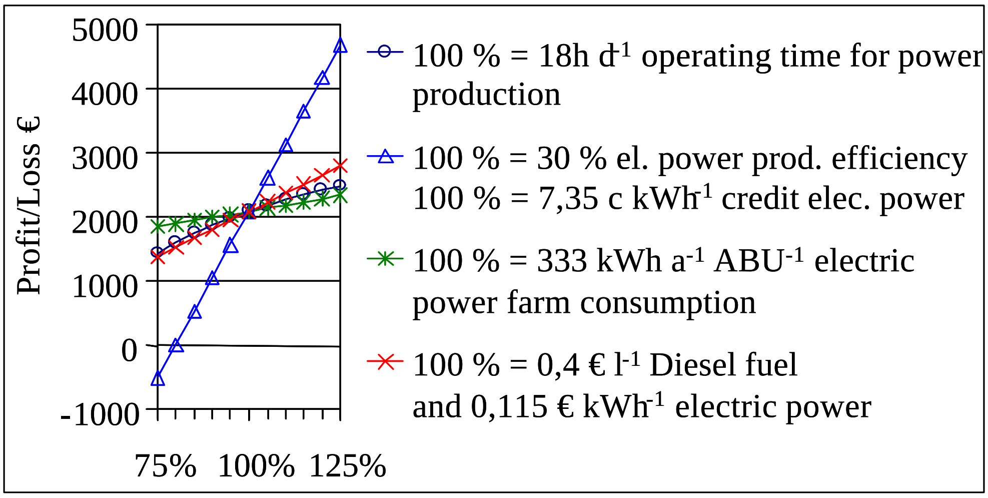
Concerning investment and running costs the marginal profit sensibility decreases in the following order: Investment costs biogas reactor (indicating dependency from construction costs) > share of maintenance costs for buildings and technical installation respectively > investment costs technical installation and labour costs. In the organic model the ranking is the same:

Marginal profit/loss investment and running cost parameters € $\%^{-1}$



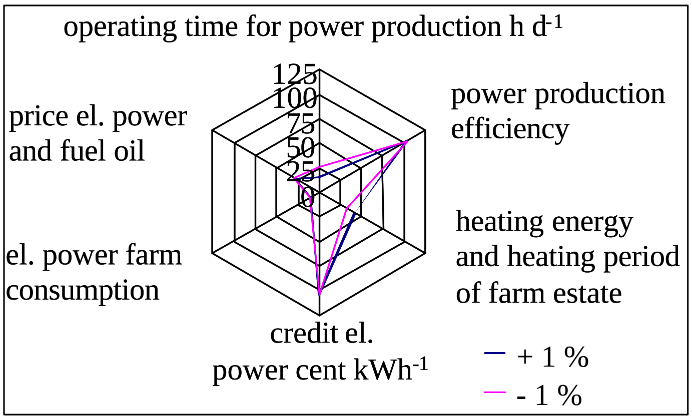
The following chart shows the change of the surplus or loss of the main stream model ranging from –505 to 4689€ under application of +/- 25% power and heat production parameter variation:

Parameter variation power and heat production



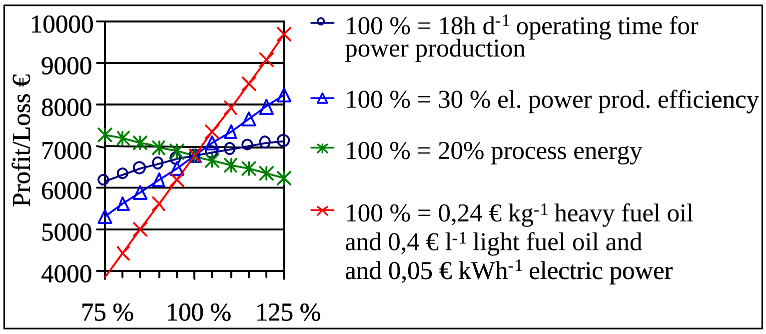
Concerning energy production the marginal profit sensibility decreases in the following order: credit electric power (indicating high dependency on energy politics) > power production efficiency (indicating a bright future for fuel cell technology) > heating energy and heating period of farm estate (indicating rather independence from climate conditions) > price electric power and fuel oil (indicating low dependence from non renewable energy sources).

Marginal profit/loss of electric power and heat production parameters € $\%^{-1}$



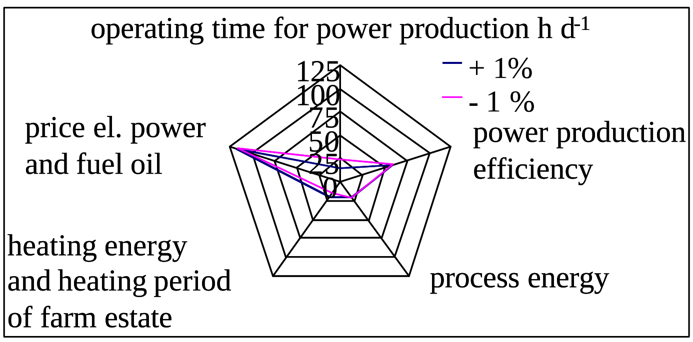
The following chart shows the change of the surplus of the organic model ranging from 3856 to 9685€ under application of +/- 25% power and heat production parameter variation:

Parameter variation electric power and heat production



Concerning power and heat production the marginal profit sensibility decreases in the following order: price electric power and fuel oil (indicating long term sustainability because profitability will increase with raising prices for non renewable energy sources) > power production efficiency > process energy > heating energy and heating period of farm estate > operating time for power production.

Marginal profit/loss of electric power and heat production parameters € $\%^{-1}$



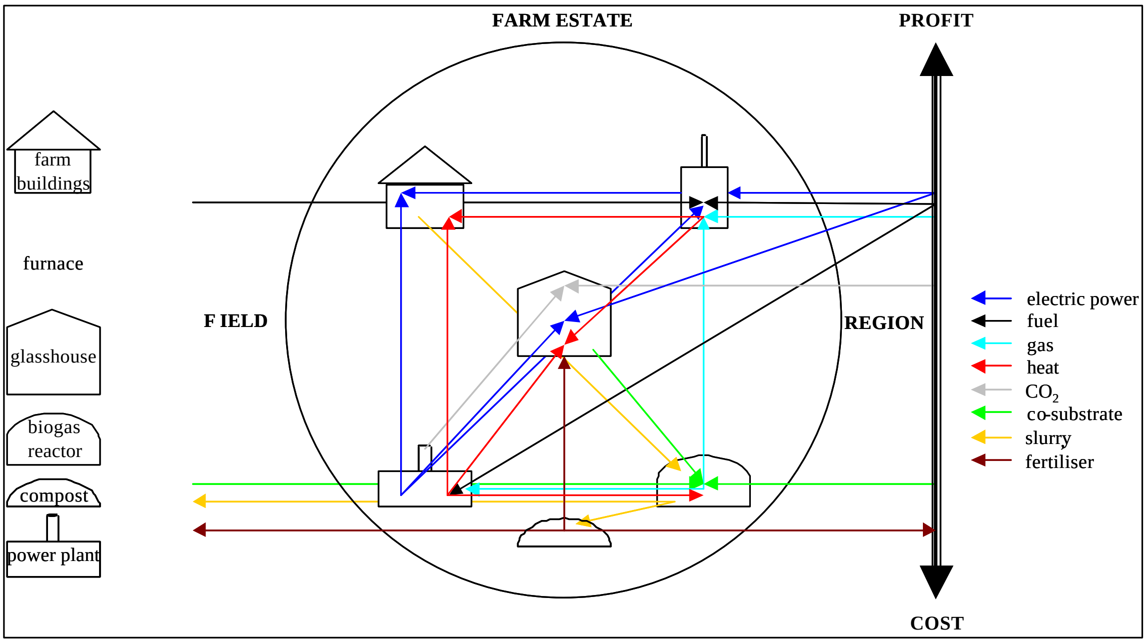
Discussion:

To increase the surplus for both models the following conclusions can be applied:

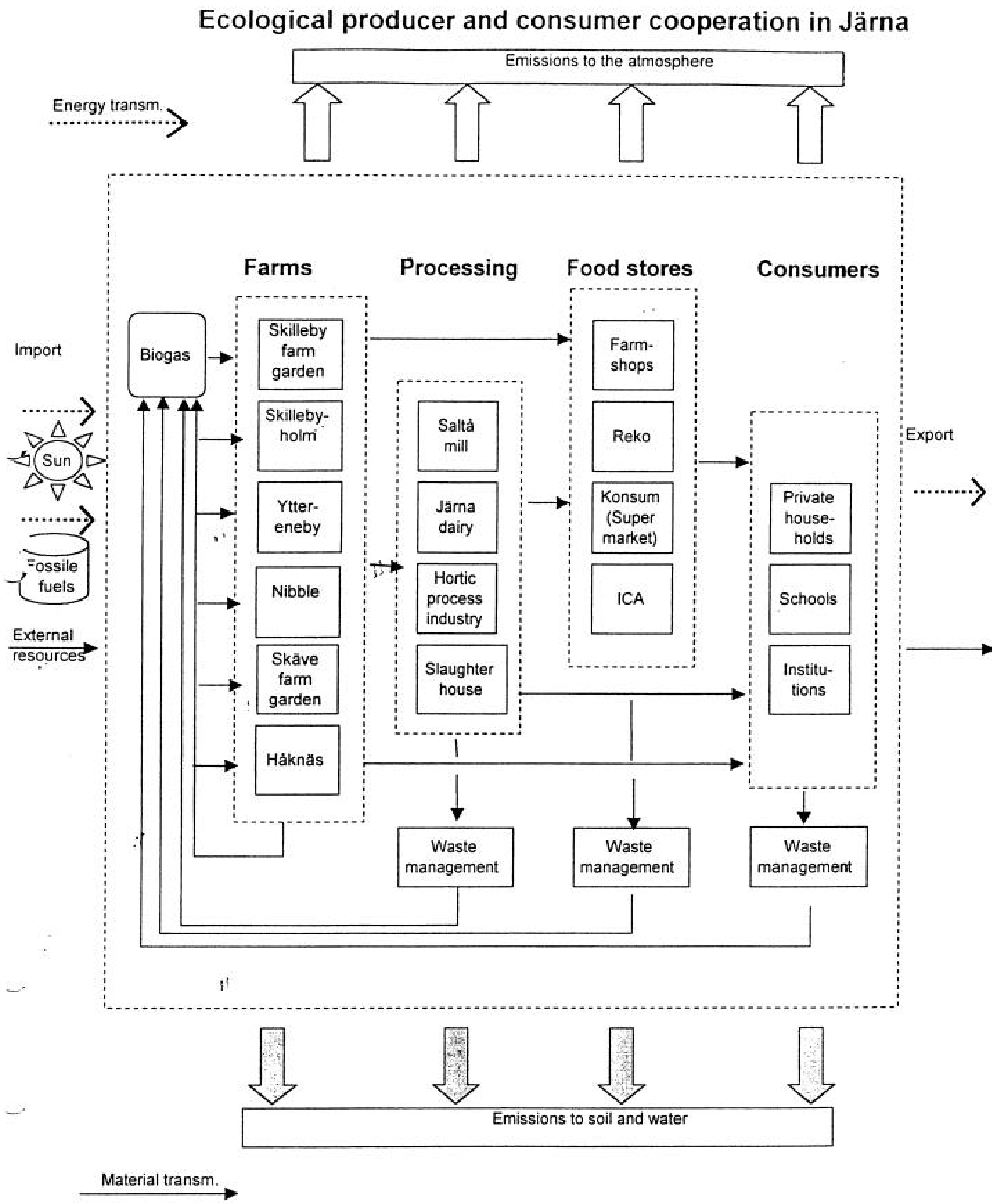
- Decrease construction costs of reactor
- Use co-substrates
- Develop fuel cell technology for use with biogas
- Enlarge production diversity

The better economic performance of the organic model under Finnish conditions mainly bases on substitution of CO_2 fertiliser by the gas motor exhaust gas. Because heavy fuel oil is cheaper than electric power and biogas production does not cover the heat energy demand of the organic model the use of the biogas for heat production **only** would raise the surplus. However, dependence from grid would increase.

The marginal profit of the organic model is very sensitive on energy input prices; the marginal profit of the mainstream model is more sensitive on the credit for electric power. Further use of reactor digestion residues as organic fertiliser may improve sustainability of the organic model



Using bio mass fuel from the farm enhances sustainability; use of biomass from farm residues increases gas production, composting the fermentation residues will decrease nutrient losses and results in a tradable organic fertiliser. Extending the organic model by adding more organs/production units will increase synergy effects, profitability, and sustainability as demonstrated by the local food system of Järna/Sweden, which includes farms, food processing, food stores and consumers waste management for biogas production.

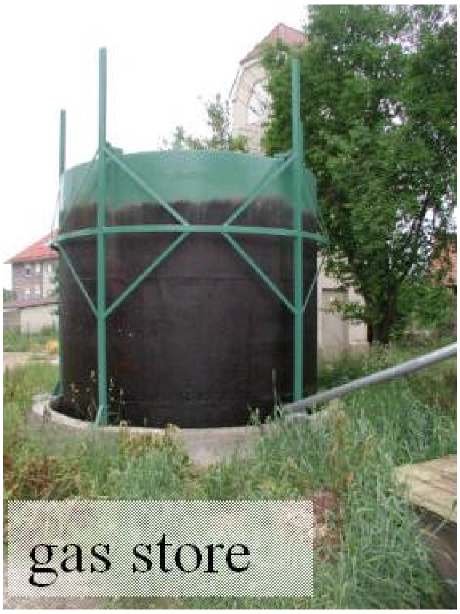


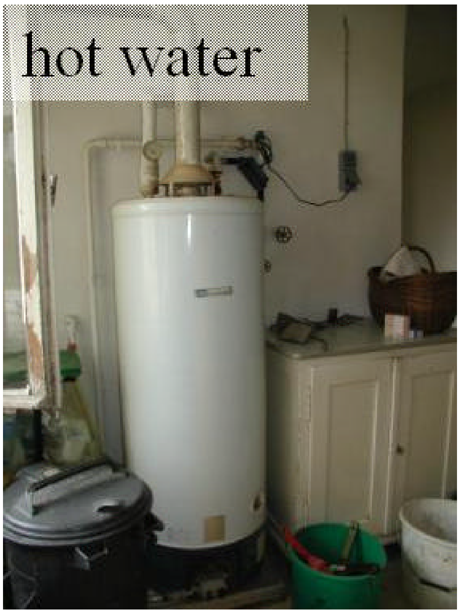
Artur Granstedt
Figure 1. Energy, material and plant nutrient flows in cooperation between local ecological producers, processors, retailers and consumers in Järna. The goal is, by promoting a high degree of recycling, reduced use of non-renewable energy, and use of the best known ecological techniques in each part of the system, to reduce consumption of limited resources and minimize harmful emissions to the atmosphere, soil and water(Granstedt 2002).

Baltic Ecological Recycling Agriculture and Society (BERAS)

I presented models and figures; the biogas plant in Järna presents facts. So let me close with this appeal to research funding agencies and decision makers: Please support in future organic demonstration farms and pilot biogas plants to green and animate dry figures.

Organic farmers showed already decades ago that biogas on-farm supports sustainability, economy, and environmental friendly farming.





43 years biogas on-farm from 15-20 ABU
in Bernloch/Germany

Photos: Sonja Neumann