Energy and emergy evaluation of Danish organic dairy farms: potentials for energy self-sufficiency by production of biogas, bioethanol or biodiesel

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Background

❖Contemporary agricultural and food production systems depend on massive use of fossil fuel and other limited resources.

❖ *Climate change* and *global peak oil production* necessitates out-phasing of fossil fuels and up-scaling of bio energy production.

❖ We propose farm level *self-sufficiency* of energy intensive inputs including fuel, fertilizer and fodder as an ideal for *decoupling food supply security* from *supply of fossil fuel*.

❖ Self-sufficiency provides a theoretical framework for assessing the *actual productivity in agricultural systems* (in contrast to indirect production upstream, e.g. input of commercial fertilizers).

Aim of the study

❖To find out whether 10 Danish organic farms in cooperation can benefit from investing in a shared facility for biobased energy production.

❖To demonstrate the concept of self-sufficiency as a framework for assessing *productivity* of agricultural systems.

❖To evaluate agricultural systems in emergy-terms.

Approach

❖Construct a theoretical farming model based on key data from the literature and national statistics (see figure for details and assumptions).

❖Design four scenarios with different bio-energy processes to demonstrate opportunities and weaknesses (see table for definition of scenarios).

❖Account for input/output of energy of three different forms; liquid fuels, electricity and food/feed.

❖Account for resource use in a scale of Solar Energy Joules (SEJ; also known as emergy evaluation). This means considering both the *direct and indirect solar energy* used to provide material and energy flows in a system.

Overall assumptions of the model

Ten identical organic dairy farms of each 100 ha share a facility for producing biobased energy. In scenario 1-3, 90% of the fields are producing fodder and 10% are producing energy crops. In scenario 4, 20% of the land is producing energy crops.

Farms are assumed to be self-sufficient with fodder, fertilizer, seeds, water and livestock.

Crop production
The mix and yield of crops are based on national statistics for organic dairy farms on fertile loamy soils in Denmark.

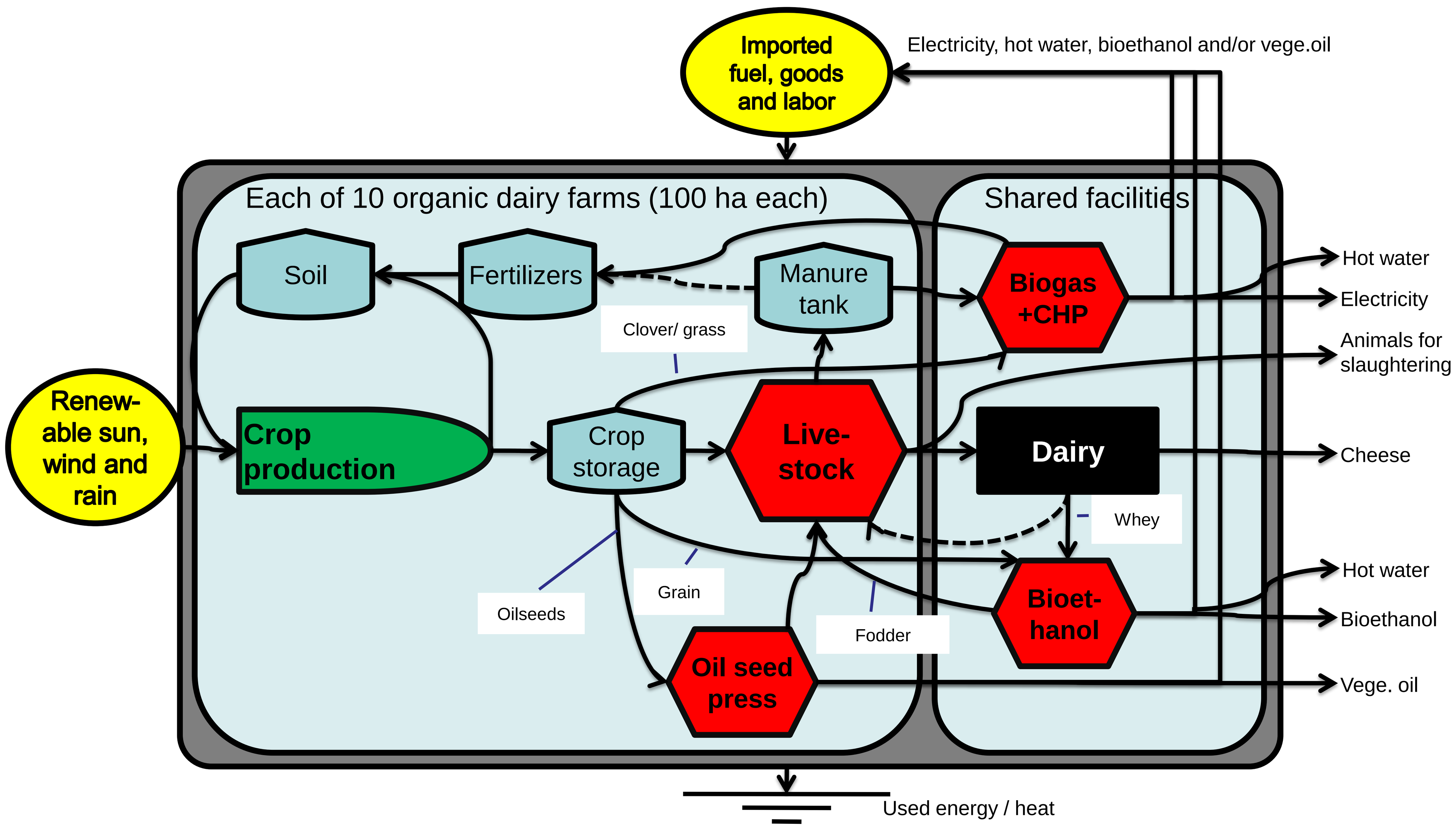
Livestock *intake of fodder* and *yield of milk and manure* are based on national statistics. The diet consists of ca 77% whole crop, 17% grains and 6% of whey that is fed back from the cheese-production. In scenarios with oilseed production oilcakes are fed to livestock.

Fuel, goods and labor are imported to system: diesel and electricity, goods such as machinery and buildings, and labor (two full-time employees per farm and two full-time employees in shared facilities).

Biogas + Combined Heat and Power (in scenario 1 and 4). Feedstock are **manure and clover grass.** Efficiency of power generation is set to 40% of heating value of biogas.

Figure legend

- External resource
- Production
- Consumer
- Storage
- Flow of material
- In scenario without biogas (2 and 3) or bioethanol (1,3 and 4) this indicates the alternative route



Bioethanol (scenario 2) is produced from whey and grain. Dried distillers grain is feed back to livestock

Oil seed press (scenario 3 and 4) produces biodiesel based on oilseed rape. Oilcakes is feed to livestock

Dairy produce "raw-cheese" from the milk. Energy and labor for production of actual cheese is not accounted for in evaluation. Whey are used as fodder or for bioethanol production (scenario 3)

Definition of scenarios			Energy evaluation						Emergy evaluation			
			Food (milk and cheese)		Liquid fuels (l diesel equivalents)		Electricity (j)					
Scenarios (1000 ha)	% of land used for energy crops	Number of cows	Year rations of food (with 2500 kcal prs.$^{-1}$ day^{-1})	produced: consumed	Produced	Produced: used	Produced (j)	Produced: used	Use of local recources (SEJ)	Use of imported resources (SEJ)	Emergy yield ratio (1)	Environ-mental load ratio(2)
1 Biogas Clover grass	**10%**	67	3078	**140:1**	0	**n.a.**	4,07E+12	**0,81:1**	1,05E+18	3,70E+17	3,84	0,35
2 Bioethanol from rye	**10%**	67	3078	**140:1**	123.256	**1,89:1**	0	**n.a.**	1,05E+18	1,11E+18	1,95	1,06
3 Oilseed rape	**10%**	69	3172	**159:1**	63.201	**1,01:1**	0	**n.a.**	1,05E+18	9,46E+17	2,11	0,90
4 Oilseed rape and biogas	**20%**	62	2847	**129:1**	63.201	**0,96:1**	4,07E+12	**0,87:1**	1,05E+18	1,35E+17	8,79	0,13

(1) The ratio of the emergy yield to that required for processing. Describing actual production in system (2) A ratio of all non-renewable emergy flows (inside and outside the system) to the renewable emergy flows

Results and discussion

❖ Production of bioethanol (scenario 2) gives a surplus of liquid fuel corresponding to 89% of diesel used in the system. *But in practice bioethanol can not substitute diesel, so the system would still be importing diesel.*

❖ The produced heat (hot water) from either the bioethanol process or CHP (from biogas) can in principle be a valuable resource for nearby buildings. But in practice transport of hot water is to expensive to be feasible for many organic famers.

❖ Based on our assumptions, organic dairy farms can become self-sufficient with energy, fodder and fertilizer by devoting ca 10% of arable land to clover grass for biogas and 10% for oilseed rape.

❖ Self-sufficiency as a theoretical framework is very useful for evaluating the actual production of agricultural systems.

❖ The emergy evaluation shows that being self-sufficient with energy yields more emergy to surrounding economy, and that it uses the least non-renewable resources.

Conclusion

❖ Even though the dairy farms dedicate 20% of arable land to energy crops, they can barely achieve *farm gate energy self-sufficiency.*

❖ Processing and distribution of the produced food is not included in our system, meaning that the *food supply system* as a whole would still need fuel and electricity from other sources.

In practice this means that these farms of a total 1000 ha can produce (but not process or distribute) food in form of cheese and meat corresponding to the total food that 2847 people eat in on year. But they cannot provide any of these people with other energy products. E.g. doctors, teachers, politicians, scientists etc can be fed, but not supplied with energy for powering transportation, homes, computers, working places etc.

If organic dairy agriculture is to *power the food supply system* and *yield biobased energy to the surrounding economy,* a revolution in efficiency is needed - alternatively a fundamentally different production system.

Key references: Dalgaard, T., N. Halberg, and J. R. Porter. 2001. A model for fossil energy use in danish agriculture used to compare organic and conventional farming. *Agriculture Ecosystems & Environment* 87, (1): 51-65.
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