Energy balance of different organic biogas farming systems

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Key words: biogas, energy balance, energy crop, farming system

Abstract

The ecological impact of biogas plants depends on their integration into a given farming system. Therefore only farm-specific and no general statements are possible. In this paper, two different concepts of biogas production for an organic cash crop farm have been energetically balanced using a model software. The analysis of input and efficient use of fossil energy carriers provides information on the environmental relevance of the farm operations. Apart from this, renewable energy production in the farming systems is compared to food production, and changes in the farm output are described. It turns out that organically run cash crop farms can benefit from a reasonable integration of a biogas plant, both in food crop and energy production. An increased orientation on the growing of energy crops, however, leads to worse utilization of fossil energy carriers and reduced food production.

Introduction

Striving for largely closed nutrient cycles and the conservation and improvement of soil fertility are intrinsic to organic farming systems. Reaching these aims, organic cash crop farms are faced with limits due to the absence of livestock. However, these limits can be overcome by integrating a biogas plant (BGP) into the farm system. The ecological consequences of integrating a biogas plant into a farm are complex and farm-specific. A model program for energy balancing on different technological levels (from crop cultivation to energy production) has been developed that not only allows one to analyse both existing and planned biogas systems, but also to estimate the effects prior to the erection of a plant. The paper describes the application of the model to an organic cash-crop farm, for which two management scenarios with different biogas intensity were elaborated. The input of fossil energy carriers is compared with the output in form of utilizable energy and food crops.

Materials and methods

Energy balancing includes the whole technological chain from the field (growing and harvest of food and energy plants) through storage (preservation) to the biogas plant (conversion) and the CHPP (combined heat and power plant). The energy input in the form of electricity and fuel (direct energy input) as well as the upstream energy input for the manufacturing of machines, equipment, and other expendables (indirect energy input) is considered. The energy output as well is described throughout the whole technological chain (yield of food crops / yield of energy plants – preserves – biogas – power and heat) with consideration of loss paths (storage and preservation losses, conversion losses, technical losses). To estimate the resource efficiency, the output/input ratio is computed. Energy balancing of crop production is performed

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according to Hülsbergen et al. (2001) on the basis of farm-related operational and yield data. The gas-forming potential of the substrates is calculated according to Keymer (2007), power and heat quantities correspond to those of a modern Otto gas engine with an efficiency up to 40 $\%_{el}$ and 53 $\%_{therm}$ (FNR 2005). To test its suitability for scenario calculations, the new energy balancing approach has been applied on the Experimental Farm Viehhausen. The results are taken into account in the current planning of an experimental biogas station in the investigated farm. The tested experimental farm (80 hectares) is located about 35 km north of Munich in the Bavarian Tertiary hills (480 m above see level, 780 mm, 7.8°C). In the farm, data records from field trials on yield potentials of cereals and energy crops and also on the development of grass/clover crops in biogas crop rotations were used to cover the computed model results. The five-field crop rotation of the stockless ecofarm (Sc REAL) is dominated by cereals (Table 1). The grass/clover gets mulched; cereals and grain legumes are sold. For the farm, two experimental management systems were designed representing different strategies of how to integrate a biogas plant into an organically run cash crop system. The extensive biogas system (Sc BGe) maintains the cash-crop-dominated crop rotation of Sc REAL, except grass/clover is used for energy production instead of being mulched (Table 1). The yield increase of grass/clover has been ascribed to cutting management, and that of cereals to increased N-supply and the high N use rate of the biogas slurry (about 60 % soluble N in the total N (FNR 2005)). The second scenario shows an intensive four-field rotation with mainly biogas crops (BGi). The acreage of cash crop growing declined from 80 % (Sc REAL and Sc BGe) to 25 %. Yield and quality levels of grass/clover and cereals correspond to those cutting in Sc BGe (Table 1).

Table 1: Crop rotation, yield and use of the products on the real farm (Sc REAL) and in the two experimental farming systems (Sc BGe and Sc BGi)

Sc REAL crop rotation	dt DM	use	**Sc BGe** crop rotation	dt DM	use	**Sc BGi** crop rotation	dt DM	use
grass clover 50*	80	mulch	grass clover 70*	120	biogas	grass clover 70*	120	biogas
winter wheat	34	sale	winter wheat	45	sale	winter wheat	45	sale
triticale + wcc	34	sale	triticale + wcc	45	sale	silage maize	154	biogas
pea + scc	23	sale	pea + scc	23	sale	+ rye for silage	27	biogas
winter wheat	34	sale	winter wheat	45	sale	cereal for silage	69	biogas

* proportion of clover 50 and 70 % respectively; wcc - winter catch crop; scc - summer catch crop

Results

A total farm analysis of the three systems and a comparison among the food crop and the energy production chains in each variant is given in Table 2.

In the biogas scenarios, energy input in cash crop production rises vis-à-vis Sc REAL due to the spreading of biogas slurry. The yield increase involves an enhanced energy output per hectare of cropping area of 28 % (BGe) and 37 % (BGi), respectively. The output/input ratio in food crop production differs little among the scenarios (Table 2). Although the area-related energy output of cash cropping increases in both biogas scenarios, only in Sc BGe does food production really increase (58 GJ ha^{-1}; 46 GJ ha^{-1} in Sc REAL) due to a constant cropping structure. In Sc BGi, food production decreases (20 GJ ha^{-1}) owing to the drastically reduced cropping area in favour of the cultivation of energy crops.

Power generation on the basis of biomass fermentation involves several conversion steps; each involving energy losses (Fig. 1). Correspondingly lower is the output/input ratio (6 to 7) compared with food cropping (15) (Table 2).

Table 2: Total farm and product related (food crops, power/heat) energy balance in the cash crop farm and under the two biogas scenarios

		Sc REAL		Sc BGe			Sc BGi		
		farm	food	farm	food	energy	farm	food	energy
	hectare	**80**	**64**	**40**	**32**	**8**	**40**	**10**	**30**
field	direct	2.5	2.2	3.7	2.8	6.5	5.3	3.,0	6.1
	indirect	1.7	1.8	2.3	1.9	3.5	3.4	2.,4	3.7
	Input fossil energy	**4.2**	**4.0**	**5.9**	**4.7**	**10.0**	**8.76**	**5.3**	**9.8**
	Output energy crops	-	-	43.8	-	219.1	169.7	-	226.3
	Output food	**46.4**	**58.0**	**58.0**	**72.5**	-	**20.1**	**80.4**	-
	Output/Input-ratio food production	**-**	**14.6**	**-**	**15.5**	**-**	**-**	**15.3**	**-**
store	**Output** preserved energy crops	-	-	36.8	-	184.2	141.0	-	188.0
BGP	**Input** fossil energy			**0.7**		**3.7**	**3.3**		**4.4**
	Output biogas			18.5		92.7	82.3		109.7
CHPP*	**Output**								
	power			7.4		37.1	32.9		43.9
	heat			9.8		49.1	43.6		58.1
	power + heat			**17.2**		**86.2**	**76.5**		**102.0**
	Output/Input-ratio energy production			-		**6.3**	**-**		**7.2**
	heat					3.6			4.1
	power					2.7			3.1
farm	**Input**	**4.2**		**6.7**			**12.0**		
	Output farm	**46.4**		**75.2**			**96.6**		
	food	**46.4**		**58.0**			**20.1**		
	energy	**-**		**17.2**			**76.5**		
	Output/Input-ratio farm production	**11.0**		**11.2**			**8.1**		

*CHPP - combined heat and power plant

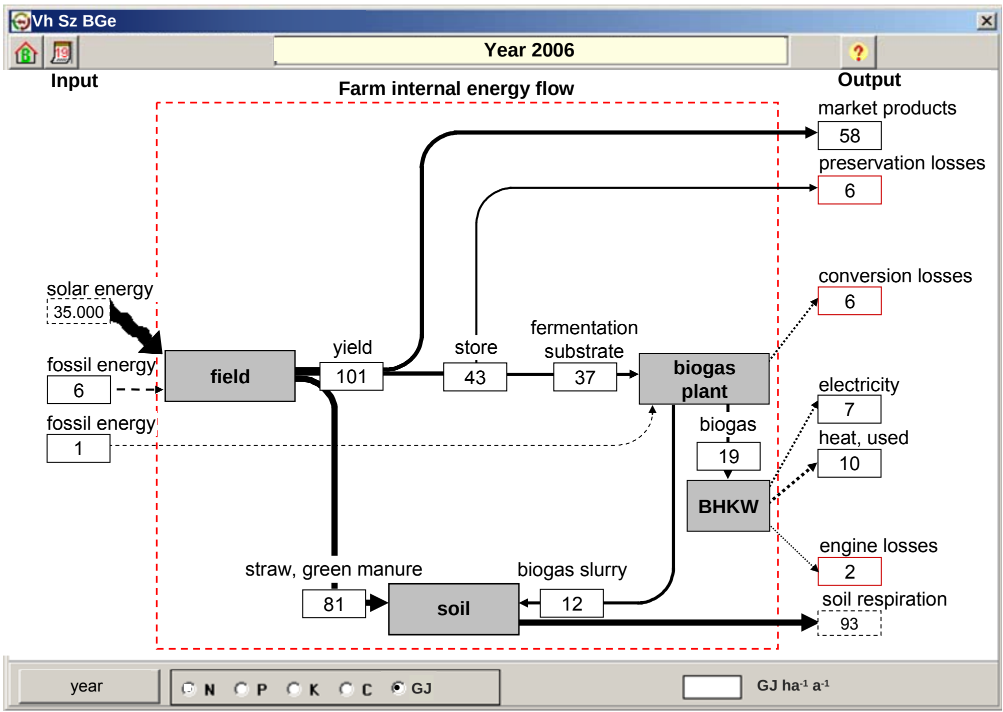

Fig. 1: Energy flow in an organic cash crop farm with biogas plant: fossil energy input, energy fixation in the biomass, energy output (food products, electricity, heat) and energy loss paths in Sc BGe. Screenshot from the REPRO model (Hülsbergen 2003).

In the biogas scenarios, apart from cash crops, utilizable renewable energy in the form of electricity and heat is generated by fermentation of by-products (BGe) or energy crops (BGi). This entails an increase in the total energy output of the farm in both biogas scenarios (75 and 97 GJ ha^{-1} in BGe and BGi; 46 GJ ha^{-1} in Sc REAL) (Table 2). In Sc BGi the output/input ratio deteriorates markedly: more fossil energy carriers are consumed (12 GJ ha^{-1}; 4 and 7 GJ ha^{-1} in Sc REAL and Sc BGe) with reduced use efficiency.

Discussion

The main argument for an expansion of renewable energy sources is the CO_2-neutral energy provision. Energy balances allow one to draw conclusions on the utilization efficiency of fossil energy carriers (Mead & Pimentel 2006) and the resulting CO_2-emissions. Reliable information, however, can only be obtained from farm-specific analyses over the entire farm production chain. Such an approach has also been called for by Berglund & Börjesson (2006). Producing bioenergy may also entail changes in cropping structure and yields. Rising yields of cash crops increase food production only when the cropping area is kept constant; a decline in the cash crop area in favour of energy plants may reduce food production despite enhanced yields per hectare.

Conclusions

Apart from biogas generation, there are further possibilities for providing energy by using agricultural biomass, which may turn a farm enterprise into a net energy producer already at a low proportion of energetically converted biomass. However, not only is the highest possible energy gain required for complying with the principle of sustainability; the objective must also be maximum utilization of the input of fossil resources. In this connection, power generation on the basis of biogas turns out to be more energy efficient than, for example, RME or bioethanol production (output/input ratio 1 to 6) (Venendaal et al. 1997).

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