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Energy consumption in animal production – case farm study

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Abstract. The objective of this study was to analyse the energy use by the dairy case-farm with un-insulated cowsheds in Estonia for the period of 2009-2010. The energy balance calculation includes the direct energy input of fuel, lubricants and electricity and the indirect input of forage, cereals, concentrates for young stock, dairy cattle and buildings. Energy outputs are milk, meat, and manure. The energy values were calculated multiplying the quantities of inputs and outputs by their energy conversion factors. The quantitative parameters of the inputs and outputs are based on book-keeping data, the energy conversion factors of feed were measured. The energy output-input ratio of the case-farm was 1.88 in 2009 and 1.85 in 2010. Energy input of milk was 5.4 and 5.3 per MJ kg^{-1}, respectively. Our study indicated that the case farm energy consumption is generally higher than that of comparable European dairy farms. The further research is needed to find the reason of mentioned differences.

Keywords: energy, consumption, dairy cattle, farm

Introduction

The publication of the Food and Agriculture Organisation (FAO): '*Livestock in the balance*' (FAO, 2009) points to continuing growth of the livestock sector, stating that: 'The sector has expanded rapidly in recent decades and demand for livestock products is expected to continue growing strongly through the middle of this century, driven by population growth, rising affluence and urbanization. Decisive action is required to satisfy this growth in ways that support society's goals for poverty reduction and food security, environmental sustainability and improved human health'.

Estonia is located at the northern border of profitable agricultural production area. For the cereal cultivation our climatic conditions are modest, the yield of grasslands is satisfactory. For this reason the breeding of dairy cows is favoured. Due to the low capital and reconstruction costs, cold un-insulated and semi-insulated cow housing structures have been of interest in recent years. Presently, Estonia already has over 100 semi-insulated structures housing between 300–1,000 animals each (altogether about a half of Estonian dairy cattle and one third of young stock).

The animal production is a poor converter of energy because it is based on a double energy transformation. First, solar energy and soil nutrients are converted into biomass by green plants. When crops are fed to animals, a major share of energy intake is spent on keeping up body metabolism and only a small portion is used to produce meat and milk.

Fossil energy is a major input of livestock production systems, used mainly for the production, transport, storage and processing of feed. Depending on location (climate), season of the year and building facilities, energy is also needed for control of the thermal environment (cooling, heating or ventilation) and for animal waste gathering and treatment. By Pimentel & Pimentel (2003) ratio of energy input to food-energy output was 57:1 for lamb, 40:1 for beef cattle, 39:1 for eggs, 14.1 for swine and dairy (milk), 10:1 for turkey, 4:1 for chicken and 1:4 for corn.

Energy use and specific energy consumption are analysed by system analysis methods, where the energy flows through the borders defined by the analyzer are examined (Ahokas et al., 2011). Energy inputs can be characterized as direct or indirect (embedded) energy.

Direct energy inputs are fuel and lubricants used in feed processing and for energizing of delivery machinery. The **electrical energy** is used for milking, milk cooling, water heating and pumping, lighting, ventilation, air heating, electrical fencing, manure handling, office and personnel working environment and etc. Conventional electricity consumption represents around 25% of the non-renewable energy use at the dairy farm; the diesel fuel corresponds to 15% of energy consumption (Bulletin of the International Dairy Federation, 2010).

Indirect energy is embedded in the products used on the farm. Indirect energy inputs are:

Feeds

Depending on the cow's diet the impact of the feed production can vary because the process to produce concentrates is more energy consuming than to produce fodder (Barnett & Russell, 2010). Pasture requires the lowest energy demand (0.84 MJ kg^{-1} of dry matter – DM) because machines are used only for fertilization and cultivation operations (Kraatz & Berg, 2009). Embedded energy of some feed ingredients according to FAO framework for calculating fossil fuel use in livestock is given in Table 1.

Table 1. Embodied energy ($MJ \cdot kg^{-1}$ of feed ingredients)

Ingredients	Production	Transport	Processing	Total
Alfalfa hay	-	-	-	1.59
Barley	3.74	0.07	-	3.81
Hay	-	-	-	2.77
Maize gluten meal	-	-	12.46	12.46
Maize grain	4.22	0.08	0.82	5.13
Maize silage	-	-	-	2.33
Oats	2.63	0.12	-	2.75
Salt + minerals	-	-	-	0.38
Soybean oil meal	4.41	0.09	1.11	5.61
Wheat	3.96	0.07	-	4.03

Building energy

There are three ways to calculate the indirect energy input of buildings:

1. Estimation of indirect energy input by use of published calculation results of similar building types (e.g. on square meter and life-span basis). The advantage is easy and fast calculation, the disadvantage – possible lack of precision if no publications for adequate buildings are available and/or calculations do not discriminate between construction and operating energy input.

2. Calculation of the indirect energy input of a whole building based on construction elements ready-calculated on square meter or running meter basis. The advantage is that during the planning phase of a new building alternative construction solutions can be compared relatively fast. This approach is not very suitable for existing agricultural buildings, if the construction elements can only be identified by destructive investigations and/or if the building is too old to fit the construction elements and materials presently used. Because there are many ways to assemble a construction parts from different materials a profound data base of construction elements is a precondition.

3. Calculation of a whole building based on construction materials and real input used. This can easily be done on buildings under construction following up the material or book-keeping data. This is nearly impossible when the book-keeping material of the erection phase is not available anymore or contains insufficient data. Average indirect energy input for farm buildings (80 years) by Gaillard *et al*. (1997) is 153 MJ/m^2/year. In our case the figure is 150 MJ/m^2/year.

Energy of machinery

Indirect energy input for machinery depends on the intensity of use, the date and location of manufacture and the useful life of machinery. Machines are normally at the end of their life time recycled and only the manufacturing and maintenance energy is used for agricultural production (Ahokas et al., 2011).

Human labour

The substitute for fossil energy is human labour. Low-inputs systems such as organic agriculture require additional manpower compared to conventional systems. However, this input is hard to convert to energy figures (Refsgaard et al., 1998) and is not included into analysis.

Energy output for livestock products comprises of food and non-food (manure) items. The nutritional energy outputs for animal production systems as the metabolizable energy content of all products, intended for human consumption was calculated by Southwell & Rothwell (1977). Output/input ratios for pork, poultry meat and eggs amounted to 0.38, 0.11 and 0.32 respectively, while this ratio was 0.50 for milk production.

Energy ratio describes the relationship between the energy output of a system and energy inputs needed to operate the system. Energy ratio can be expressed as

$$E_R = E_o/E_i, \tag{1}$$

where E_o is energy output and E_i is energy input (Mikkola & Ahokas, 2009).

In cases where the fossil energy consumption is analysed its share in the production can be calculated with **fossil energy ratio**:

$$N_f = E_f / y, \tag{2}$$

where E_f is fossil energy input of production and y is yield or production (Ahokas et al., 2011).

The problem in farm energy analysis is that the energy parameters and units used in input and output may differ (Ahokas et al., 2011). For input there can be several different choices in use:

- Lower heating value of the input material. This is the maximum energy value of the material itself;
- The metabolized energy of the material (ME);
- Energy needed for the material production;
- Lower heating value plus the energy needed for production.

The output is usually calculated with lower heating value (LHV) because this is the only practical unit. Depending on how the input is chosen the energy balance gets different figures.

The aim of the paper was to analyse the energy efficiency regarding the milk production in case-farm with un-insulated loose-housing cowsheds in Estonia. Electricity consumption in insulated tied-housing cowsheds was analysed by Annuk et al in 2004. After this investigation new technologies have been introduced for milk production and detailed analyses of energy consumption have not been done yet.

Materials and methods

The investigation was carried out in 2009–2010 in un-insulated cowshed for 974 dairy cows and young stock. The annual production was 9,215 and 9,558 kg in 2009 and 2010 respectively. Calculations are based on farm book-keeping and feedstuff analysis data. The energy balance is estimated starting from the feed energy and ending with the meat and milk that is sold from the farm (input-output boundaries).

Direct energy inputs

Electric energy consumption (kW h). Conversion factor is 3.6 MJ (kW h)$^{-1}$. More detailed electric energy measurements are in progress, analysis follows.

The conversion factors of diesel fuel and lubricants are estimated as 35.7 MJ litre^{-1} and 40 MJ litre^{-1} respectively.

Indirect energy inputs

Cattle feeds. The feedstuffs were produced mainly on-farm, only a minor amount of commercial feed was used. Feed analyses were performed for ME. Gross energy was calculated as metabolizable energy divided by energy metabolizability ratio and energy digestibility ratio (Söötade…, 1997). Dry matter (DM), metabolizable energy (ME), gross energy (GE) and fossil energy (FE) data are presented in Table 2.

Table 2. Input of fossil energy (FE) during production and gross energy (GE) in animal feeds (DM). GE and DM energy are analysis results, FE – assumptive results.

Feedstuff	**DM**	**ME MJ kg $^{-1}$**	**GE MJ kg $^{-1}$**	**FE MJ kg $^{-1}$**
Starter	0.86	12.0	17.0	5
Pasture	0.20	11.3	18.7	1.2
Field hay	0.83	8.5	18.4	7.2
Silage	0.29	9.3	18.4	3
Maize silage	0.25	10.5	18.8	3
Straw	0.83	7.0	18.3	9
Oats	0.67	13.6	19.6	4
Concentrates	0.86	13.3	18.8	5
Rape oil meal	0.89	13.7	22.0	11

Machine manufacturing and maintenance energy is not taken into account. Energy for human labour was considered to be outside of the system.

Outputs

Dairy cattle milk energy content (Nutrient requirements…, 2001) is:

$$\text{Milk energy (MJ kg}^{-1}) = \\ = (0.0929 \times \text{Fat \%} + 0.0588 \times \text{True Protein \%} + 0.192) \times 4.18 \qquad (3)$$

Meat output energy was calculated as dairy cows' whole body energy (Nutrient requirements …, 2001). Total reserves energy is suggested to be

$$E_{res} \text{ (Mcal kg}^{-1}) = (\text{proportion empty body fat} \times 9.4 + \\ + \text{proportion of empty body protein} \times 5.55). \qquad (4)$$

Empty body weight is 0.817 of whole body weight. For average body condition (score 3) the proportion of empty body fat is 18.84% and proportion of empty body protein is 16.75%. (Nutrient requirements …, 2001). The whole body energy of cow is

$$E_{res} \text{ (MJ)} = 0{,}817 \times [\text{whole body weight (kg)} \times 0.1884 \times 9.4 + \\ + \text{whole body weight (kg)} \times 0.1675 \times 5.55] \times 4.18 = \\ = 9.22 \times \text{whole body weight (kg)}. \qquad (5)$$

By Gill et al., 1993, the proportion of empty body fat is 9.3% and proportion of empty body protein is 18.7% for young stock. For young stock the whole body energy is

$$E_{res} \text{ (MJ)} = 0.817 \times [\text{whole body weight (kg)} \times 0.093 \times 9.4 + \\ + \text{whole body weight (kg)} \times 0.187 \times 5.5] \times 4.18 = \\ = 6.5 \times \text{whole body weight (kg)}. \qquad (6)$$

The general energy content of manure is

$$\text{GE} - \text{digestible energy} + \text{urine energy}. \tag{7}$$

In case of dairy cattle it is estimated as

$$\text{GE} \times (1 - \text{digestibility ratio for cows}) + 0.04 \times \text{GE}. \tag{8}$$

On the basis of production output/input energy ratio and fossil energy input the energy ratio E_R (1) and fossil energy ratio N_f (2) were estimated. Relationship between the feed energy input and milk and beef production was used as default allocation of 14.4 per cent to meat and 85.6 per cent to milk for input energy (Bulletin…2010). Dressing percentage of slaughter cattle is 60%.

Results and discussion

Our study shows that the indirect energy input for buildings is 150 MJ $(m^2)^{-1}$ per year. To validate this figure the indirect energy input based on construction materials and elements was calculated for a cowshed as a building with light structures. Total energy input for cowshed of 33 × 115 m was estimated as 2859,210 MJ and for life span of 50 years 15.1 MJ $(m^2)^{-1}$ per year.

For milking centre (34 × 26 m) as insulated building with concrete and sandwich structures the indirect energy was estimated to be 8906,715 MJ and 10,250 MJ $(m^2)^{-1}$. For lifespan of 50 years it makes 205 MJ $(m^2)^{-1}$ per year. As there are a lot of extra elements in the farm complex (service facilities and places and roads) 150 MJ $(m^2)^{-1}$ per year is considered to be suitable for indirect energy calculations of farm buildings. The following case-farm buildings are included into our calculations: cowshed (3,795 m^2), milking centre (869 m^2), personnel rooms and corridors (367 m^2), calving department (1 144 m^2), shed (609 m^2), storage (1,008 m^2), cowshed for young cattle (2,280 m^2). On the basis of energy input as 150 MJ $(m^2)^{-1}$ per year the total energy input for buildings is 1510,800 MJ.

Fossil energy input according to measuring and book-keeping results are shown in the Fig. 1, energy figures in Table 3 (on the basis of GE and FE).

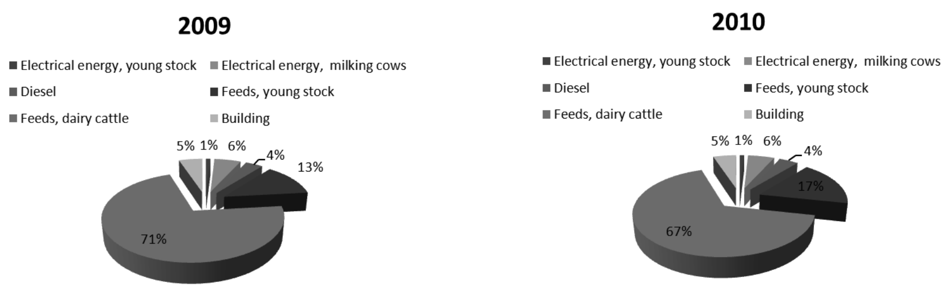

Fig. 1. Fossil energy inputs in 2009 and 2010.

Table 3. Energy figures

Item	Input energy as GE		Input energy as FE	
	2009	2010	2009	2010
Energy input, TJ	114.59	110.47	29.39	29.89
Energy output, TJ	54.95	55.26	54.95	55,260
Feed input, TJ	109.93	105.68	24.73	25.10
Milk and meat output, TJ	15.93	16.45	15.93	16.45
Meat output for human consumption, kg	62,939	62,351	62,939	62,351
Meat energy for human consumption, TJ	0.51	0.51	0.51	0.51
Energy output/energy input	0.48	0.50	1.88	1.85
Milk and meat energy/feed energy	0.14	0.16	0.64	0.66
Input energy per 1 kg of milk, MJ	21	20	5.40	5.31
Input energy per kg of meat for human consumption, MJ	262	255	67	69
Input energy/animal per year, TJ	0.12	0.11	0.03	0.03

The consumption of fossil energy is quite stable. Dairy cattle feed is the biggest input (67–71%) which means that it has also the highest influence on the energy ratio E_R. Electrical energy and diesel fuel consumption is almost the same. By Kraatz & Berg (2009) the energy intensity of dairy farming is significantly influenced by feed supply at about 50%.

It appeared that the animals can convert only 14–16% of the feed input energy (GE) to usable product (milk and meat energy). Using GE values in calculations the year 2010 gave us a whole farm input-output energy ratio (E_R) of 0.5; using fossil energy input the ratio was 1.85.

The following table shows farm input energy ratio to produced milk defined by different authors.

In New Zeland the energy use on an average dairy farm was 1.84 MJ kg^{-1}, ranging between 0.9 and 5.6 MJ kg^{-1} (Wells, 2001). Hartman & Sims, 2006 found that the average total energy input was 3.9 MJ kg^{-1} (range 3.0–5.4), whereby irrigated farms inputs were higher. In the regions where the use of concentrates is higher than that used in NZ, the energy use per 1 kg of milk is also higher. Organic farming needs less energy than conventional farming. Our calculations have shown that the fossil on-farm energy inputs per one kg of milk are 5.35 MJ.

Feedstuff energy conversion factors need to be studied more comprehensively to get reliable results. At the moment conversion factors were taken from different literature sources, but production figures can vary a lot between different countries. Calculating exact conversion factors for feedstuff production in Estonia is a crucial matter to get reliable results in energy analysis.

The case-farm energy consumption is higher than suggested by different authors (Table 4). That leads to a conclusion that the case-farm in local conditions consumes more energy than comparable European dairy farms. To find the reason for that further research is needed.

Table 4. On-farm energy inputs per kg of milk from different sources

References	Energy input, MJ kg^{-1} of milk	Remarks
Refsgaard et al., 1998	3.3	
Refsgaard et al., 1998	2.1	organic farming
Ceberberg & Mattsson, 2000	3.5	
Ceberberg & Mattsson, 2000	2.5	organic farming
Wells, 2001	1.84	range 0.9–5.6
Hartman & Sims, 2006	3.9	range 3.0–5.4
Grönroos, 2006	6.4	
Grönroos, 2006	4.4	organic farming
Smil, 2008	5–7	
Thomassen et al., 2008	5.0	
Thomassen et al., 2008	3.1	organic farming
Kraatz & Berg, 2009	3.5	
Mikkola & Ahokas, 2009	1.6	Feed production energy consumption
Mikkola & Ahokas	3.2	Feed production and housing energy consumption

Conclusions

Agricultural production has had a constant growth of raw materials and fossil energy consumption due to the intensification and mechanization of production technologies. Energy efficiency is one of the key indicators for developing more sustainable agricultural practices.

Any farm type energy balance can be calculated using this kind of methodology. It is important to choose in the beginning the appropriate conversion factors, system boundaries and production figures. Energy balance calculations can help to understand the energy flows in the farm also helping to find ways of saving energy. In milk and meat production energy consumption varies widely due to the choice of analytical methods, the included and excluded parameters and also the allocation of production. Also the results can be very different if the system boundaries are not set correctly.

There are several methods of calculating an energy balance for a farm. Our aim is to develop a suitable calculation model for Estonian farms, which could take into consideration climate, soil, buildings, feed stuff and other conditions.

Our calculations have shown that the fossil energy output-input ratio in case-farm was 1.88 in 2009 and 1.85 in 2010. Energy input per MJ kg^{-1} of milk was 5.4 and 5.3, respectively.

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