Energy consumption in animal production

I. Veermäe, J. Frorip, E. Kokin, J. Praks, V. Poikalainen, A. Ruus, L.Lepasalu

Estonian University of Life Sciences

Agriculture 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.

Domesticated livestock can convert forages, crops and by-products into high nutritional value human foods. 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 if the sector is to satisfy this growth in ways that support society's goals for poverty reduction and food security, environmental sustainability and improved human health'.

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 the plants 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 (Heilig, 1993).

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 collection and treatment.

There are great differences in energy consumption between countries, livestock species and types of production system. In the developing world, fossil fuels are seldom used. For example, bullocks are used for transport, farmlands grazed cattle, goats and sheep do not require fuel. FAO (2009) defines livestock production systems into grazing, mixed farming and industrial (or 'landless systems'). Industrial systems include intensive beef cattle, pigs and poultry fed on feeds, purchased outside the farm. According to production intensity livestock enterprises can also categorise as follows ('Energy-smart food…', 2011)

Table 1. The scale of livestock enterprises

Scale of producer	Overall input intensity	Human labour units	Animal power use	Fossil fuel dependence	Capital availa-bility	Major food markets	Energy intensity
Subsis-tence level	Low	1-2	Common	Zero	Micro-finance	Own use	Low
Small family unit	Low	2-3	Possible	Low/medium	Limited	Local fresh/process/own use	Low to high?
	High	2-3	Rarely	Medium/high	Limited	Local fresh/regional process/own use	Low to high?
Small business	Low	3-10	Rarely	Medium/high	Medium	Local/regional/export	Low to high?
	High	3-10	Never	High	Medium	Local/regional/export	Low to high?
Large corporate	High	10-50	Never	High	Good	Regional process/export	Low to high?

Energy usage 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 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. Therefore it is important to choose in the beginning the appropriate conversion factors, system boundaries and production figures.

For input there can be several different choices in use (Ahokas et al, 2011):

- Lower heating value of the input material (LHV or gross energy, GE). This is the maximum energy value of the material itself.
- The metabolized energy of the material (ME).
- Energy needed for the material production (fossil energy, FE).
- 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.

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

$$E_R = E_o/E_i, \quad (1)$$

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**:

$$N_f = E_f/y, \quad (2)$$

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

To express the efficiency of the production procedure, the energy intensity is estimated as the ratio of the energy inputs per mass of product (Kraatz & Berg, 2009). Energy inputs can be characterized as direct or indirect (embedded) energy.

Direct energy inputs are fuel, lubricants and electrical energy. Fuel and lubricants used in feed processing and for energizing of delivery machinery. The electrical energy is used for managing extensive stock, space heating for young birds and piglets, ventilation for pigs and poultry. In dairy farm for milking, milk cooling, water heating and pumping, lighting, ventilation, heating, electrical fencing, manure handling, office and personnel working environment 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.

Feed is the dominant term in energy use whether as concentrates, conserved forage or grazed grass. The major fossil energy inputs required to produce grain and forage for animals includes fertilizers, farm machinery, fuel, irrigation, and pesticides. The energy inputs vary according to the particular grain or forage being grown and fed to livestock. Forage can be fed to ruminant animals because they can convert the forage cellulose into digestible nutrients through microbial fermentation. On average producing one kcal of plant protein for livestock feed requires about 10 kcal of fossil energy (Pimentel 2004). Grain and forage inputs per kilogram of animal product produced, and fossil energy inputs (kcals) required to produce 1 kcal of animal protein by Pimentel (2004) are presented in table 2.

Table 2. Grain and forage inputs per kilogram of animal product produced, and fossil energy inputs (kcals) required to produce 1 kcal of animal protein by Pimentel (2004).

Livestock	Grain (kg)	Forage (kg)	Kcal input/kcal protein
Lamb	21	30	57:1
Beef cattle	13	30	40:1
Eggs	11	-	39:1
Grass-fed beef cattle	-	200	20:1
Swine	5.9	-	14:1
Dairy (milk)	0.7	1	14:1
Turkeys	3.8	-	10:1
Broilers	2.3	-	4:1

Depending on the animals' 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). Extensive pastoral systems for ruminants tend to have lower energy inputs than intensive livestock systems. Pasture requires the lowest energy demand (0.84 $MJ \cdot kg^{-1}$ of DM) because machines are used only for fertilization and cultivation operations (Kraatz & Berg, 2009). The process in livestock production requiring the most energy is the production and processing of concentrate feed. Embedded energy of some feed ingredients according to FAO framework for calculating fossil fuel (Sainz, 2003) use in livestock is given in Table 3.

Table 3. 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
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 meet presently used construction elements and materials. 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 via book keeping data. This is nearly impossible when the book keeping material of the erection phase is no more available or contains insufficient data. Average indirect energy input for farm buildings (80 years) by Gaillard *et al*. (1997) is 153 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, which has an energy cost associated with its use. These energy costs can be separated into three components: (1) the caloric value of the food the worker consumes; (2) the embodied energy of that food (i.e., the direct plus indirect fuel used to produce food); and (3) the fuel purchased with the wages and salaries of labour. Obviously, there are important differences between human labour and other factors, but this does not alter the fact that labour requires a continuous input of energy to sustain itself (Cleveland & Costanza, 2012). Low-inputs systems and organic agriculture require additional manpower compared to conventional systems (table 1). However, this input is hard to convert to energy figures (Refsgaard et al., 1998) and in case of intensive systems energy for human labour is considered to be outside of the system.

Energy output for livestock products comprises of food and non-food (manure) items.

Food energy content is calculated on the basis of product fat and protein content.
Dairy cattle milk energy content (Nutrient requirements…, 2001) is:

Milk energy (MJ kg^{-1}) = [0.0929xFat% + 0.0588xTrue Protein % + 0.192] x .18 (3)

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

E_{res} (Mcal kg^{-1}) = (proportion empty body fatx9.4 + proportion of empty body protein x5.55). (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} (MJ) = 0,817x[whole body weight (kg)x0.1884x9.4 + whole body weight (kg)x0.1675x5.55]x4.18 = 9.22xwhole body weight (kg). (5)

Dairy cows produce milk, calves and meat. Feed energy available for growth is lower than that available for milk production. The conversion of feed to milk is more efficient use of feed. To estimate the quantity of feed required to produce the observed milk and beef products default allocation of 14.4 per cent to meat and 85.6 per cent to milk can be used (Bulletin… 2010).

Chemical composition of the empty body of pigs (Ewan, 2001) is given in table 4.

Table 4. Chemical composition (%) of the empty body of pigs at various BW

Component	Birth	7 kg of BW	25 kg of BW	Market weight (approx.. 110 kg of BW, extremes)	
				Fat pigs	Lean pigs
Water	77	66	69	48	64
Protein	18	16	16	14	18
Lipid	2	15	12	35	15
Ash	3	3	3	3	3

By Ewan (2001) pigs' empty body GE content was estimated by calculation based on the protein and lipid content and using the factors 5.66 and 9.46 Mcal/kg for protein and lipid, respectively. When human edible feed is considered, dressing percentage (carcass weight/live weight) must take into account. Dressing percentages for beef range from 56 to 65 per cent, those for pork are in the 65 to 75 per cent range.

A large portion of non-food energy output is in the form of **manure**.
The general energy content of manure is calculated on the feed energy basis as follows:

$$GE_{man} = GE_{feed} - DE(\text{digestable energy})_{feed} + \text{urine energy}. \qquad (7)$$

In case of dairy cattle it is estimated as

$$GE_{man} = GE_{feed} \times (1 - \text{digestibility ratio for cows}) + 0.04 \times GE_{feed}. \qquad (8)$$

By Pimentel et al of the livestock systems evaluated, broiler-chicken production was the most energy efficient, with 1 kcal of broiler protein produced with an input of 4 kcal of fossil energy (Table 2). Turkey production is next in efficiency with a 1:10 ratio. Broilers and turkey are grain-only livestock system. Conventional milk production, based on a mixture of grain and forage feed, was also relatively efficient, with 1 kcal of milk protein requiring 14 kcal of fossil energy (Pimenetel et al, 2008)

Total on-farm energy inputs per unit of animal food product are presented in table 5 (Smil, 2008).

Table 5. Total on-farm energy inputs (including indirect energy for feed, buildings and equipment) per unit of animal food product (Smil, 2008)

Food product	Animal feed conversion	Direct and indirect energy inputs
Chicken	4.2 kg/edible meat	25-35 MJ/kg meat
Pork	10.7 kg/edible meat	25-70 MJ/kg meat
Beef (feedlots)	31.7 kg/edible meat	80-100 MJ/kg meat
Laying hens	4.2 kg/kg eggs	450-500 MJ/year
Dairy milk	0.7 kg/litre milk	5-7 MJ/litre of fresh milk

Southwell & Rothwell (1977) investigated energy inputs for on-farm production of pork, broilers and eggs in Ontario (Canada). In their analysis, they traced all energy inputs back to the original energy resource. For example, the energy cost of the feed is taken as the total energy required for producing and processing the ingredients. Thus, the energy cost included the energy needed to cultivate, seed and harvest, and the energy required to produce the chemicals, fertilizers and equipment involved in crop production (Barber at al, 1989). The energy output includes nutritional and non-nutritional outputs. The nutritional energy output was calculated as the metabolizable energy content of products, intended for human consumption. The energy output/input rations, as calculated by Southwell & Rothwell, are given in table 6.

Table 6. Energy output/input ratios of plant and animal products for human nutrition (Southwell & Rothwell, 1997)

Product	Energy ratio for nutritional output only	Additional non-nutritional outputs	Energy ratio for total energy output
Pork	0.38	Manure	0.70
Eggs	0.32	Manure	0.46
Broiler chickens	0.11	Manure	0.30
Milk	0.50	Manure	0.94
Lamb	0.27	Manure	1.15
Beef	0.21	Manure	1.65
Soybeans	5.4		5.4
Wheat	3.77	Straw	7.3

Energy used in animal production in England and Wales and input energy structure by Woods et al, 2010 are given in table 7.

Table 7. Energy used in animal production at the commodity level in England and Wales (ecw = edible carcass weight)

Commodity	Poltry	Pig meat	Beef	Lamb meat	Milk	Eggs
Unit	1 t ecw	1 t ecw	1 t ecw	1 t ecw	M^3	1t
Primary energy, GJ	17	23	30	22	2.7	12
Feed (%)	71	69	88	88	71	89
Manure & litter (%)	2	1	1	1	0	-4
Housing (%)	1	4	0	0	3	3
Direct energy (%)	25	26	11	11	26	12

Of total energy inputs feed (concentrates, forage or grass) is the dominant term in energy use (average of about 75%). Direct energy includes space heating for young birds and piglets, managing extensive stock and ventilation. Hosing makes up relatively small fraction. For egg production, the energy demand of manure management is more than offset by the value of chicken manure as fertilizer, hence the negative value (Woods et al, 2010).

The following table shows farm input energy ratio to produced milk from different articles.

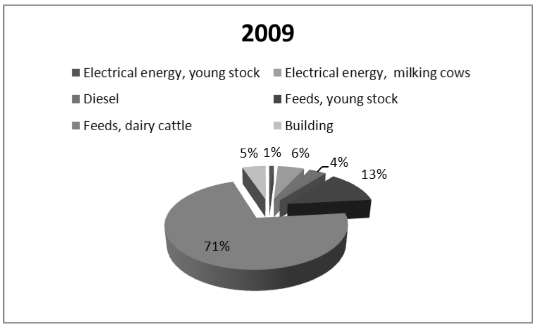
Table 8. On-farm energy inputs per kg of milk from different sources.

References	Energy input, MJ kg^{-1} of milk	Remarks
Refsgaard et al., 1998	3.3	conventional farming
Refsgaard et al., 1998	2.1	organic farming
Ceberberg & Mattsson, 2000	3.5	conventional farming
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	conventional farming
Grönroos, 2006	4.4	organic farming
Smil, 2008	5 – 7	
Kraatz & Berg, 2009	3.5	
Mikkola & Ahokas, 2009	1.6	feed production energy consumption
Mikkola & Ahokas, 2009	3.2	feed production and housing energy consumption

In comprehensive survey of 150 dairy farms throughout New Zeland the energy usage ranged between 0.9 and 5.6 MJ kg^{-1} per litre of milk, indicating great variability in dairy farm energy consumption. An average dairy farm consumed 1.84 MJ kg^{-1} (Wells, 2001). In 2006 Hartman

& Sims found 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 consumption per 1 kg of milk tends to be higher. In all cases the use of energy is lower in organic systems than in conventional systems due to feeding strategies and cultivation practices in plant production.

Fossil energy input according to measuring and bookkeeping results in Estonian case farm are shown in the Figure 1, energy figures in table 9 (on the basis of GE and FE).



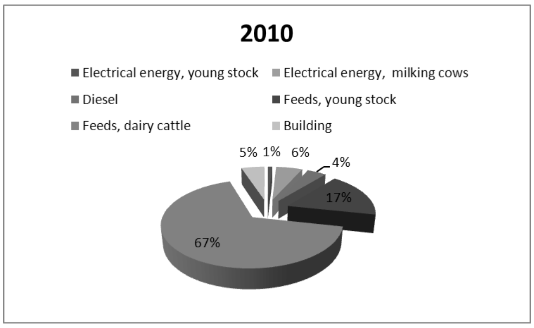


Figure 1. Fossil energy inputs in 2009 and 2010.

Table 9. 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	62939	62351	62939	62351
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 input 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 ration (E_R) of 0.5; using fossil energy input the ratio was 1.85.

Several methods and models have been used for the purpose of analyzing the energy costs of agricultural systems. FAO provides a framework for calculation of the fossil energy use in various animal production systems, using the widest definition of the term. That is, a production system here is regarded as the sum total of the inputs (including the cropping systems used to provide feed) all the way to a product that has been prepared and is ready for consumption. Default values for all parameters, obtained from the literature, are included.

Models for evaluating fossil energy input into the production of food energy and protein by intensive livestock enterprises are presented by Keener et al (2008). Models include energy in feed and conversion efficiency of animals, the impact of housing, equipment, labour, supplies, energy inputs, resource recovery and reproductive efficiency of breeding stock. Five U.S. livestock systems were analyzed. Results indicated 54-59% of fossil energy input is associated with feeding program. Order of fossil energy efficiency of species was poultry, swine, beef II (grazing) and beef I without recycling manure.

References

Ahokas, J., Mikkola, H., Schäfer, W. 2011. Energy analysis in ENPOS project. ENPOS, Energy Positive Farm. Interreg IV A Programme 28 pp

Barber, E.M., Classen, H.L., Thacker, P.A. 1989. Energy use in the production and housing of poltry and swine – an overview. Can. J. Anim. Sci. 69, 7-21.

Barnett J. & Russell J. 2010. Energy Use on Dairy Farms. Environmental issues at dairy farm level. Bulletin of the International Dairy Federation**. 443**, 23-32.

Bulletin of the International Dairy Federation. 2010. A common carbon footprint approach for dairy. The IDF quide to standard lifecycle assessment methodology for dairy sector. 445/2010. 42 pp.

Cederberg, C. & Mattson B. 200. Life cycle assessment of milk production – a comparision of conventional and organic farming. Jourbal of Cleaner Production, **8**, 49-60.

Cleveland C., Costanza R. 2012. Net energy analysis. In: Encyclopedia of Earth. Eds. Cutler J Cleveland Washington D.C.: Environmental Information Coalition, National council for Science and the Environment). http://www.eoearth.org/article/Net_energy_analysis

‚Energy-smart' food for people and climate. 2011. FAO Issue paper. https://www.google.com/search?q=Energy-smart%E2%80%98+food+for+people+and+climate&rls=com.microsoft:et:IE-SearchBox&ie=UTF-8&oe=UTF-8&sourceid=ie7

Ewan, R. C. 2001. Energy utilization in swine nutrition. Pages 85-94 in Swine Nutrition. 2nd

ed. A. J. Lewis and L. L. Southern, ed. CRC Press. Boca Raton, FL.

Gaillard G., Crettaz, P., Hausheer. J. 1997: Umweltinventar der landwirtschaftlichen Inputs im Panzenbau. FAT 46 Schriftenreihe der Eidg. Forschungsanstalt für Agrarwirtschaft und Landtechnik CH-8356 Tänikon TG.

Grönroos J., Seppäla, J., Voutilainen P., Seuri P., Koikkalainen K. 2006. Energy usage in conventional and organic milk and rye bread production in Finland. Agriculture, Ecosystems and Environment **177**, 109-118.

Hartman, K. & Sims, R.E.H. 2006. Saving energy on the dairy farm makes good sense. Proceedings of the 4th Dairy3 Conference held in Hamilton New Zeland. Centre for Professional Development and Conferences, Massey University, Palmerston North, New Zeland, pp 11-22.

Heilig, G.K. 1993. Lifestyles and Energy Use in Human Food Chains. Working paper WP-93-14. IlASA International Institute for Applied Systems Analysis. A-2361 27 p.

Keener, H. M., Wicks, M. H., Roller, W. L. 2008. Fossil Energy Cost of Food Energy and Protein Production From Intensive Livestock Production. Providence, Rhode Island, June, 29 – July, 2. 2008. An ASABE Meeting Presentation. Paper Number: 085233

Kraatz S., & Berg W.E. 2009. Energy Efficiency in Raising Livestock at the Example of Dairy Farming. ASABE Annual International Meeting Grand Sierra Resort and Casino Reno, Nevada June 21 – June 24, An ASABE Meeting Presentation Paper Number: 096715 19 p.

Livestock in the balance (2009). The state of food and agriculture FAO.

http://www.fao.org/docrep/012/i0680e/i0680e00.htm

Mikkola H.J. & Ahokas J. 2009. Energy ratios in Finnish agricultural production Agricultural and food science **18**, 332-346.

Nutrient requirements of dairy cattle. 2001. Seventh Revised Edition, Eds. J. Clark, D.K. Beede, R.A.Ersman, J.P. Goff, R.R.Grummer, J.H.Linn et al National Academy Press, Washington, D.C., 381 pp.

Pimentel D. & Pimentel M. 2003. Sustainability of meat-based and plant –based diets and the environment. Americal Journal of Clinical Nutrition, **78** (suppl) 660S-3S.

Pimentel, D. 2004. Livestock production and energy use. In, Encyclopedia of Energy,

Matsumura, R. (ed.), Elsevier, San Diego, CA. pages 671-676.

Pimentel D., Williamson S., Alexander C.E., Gonzalez-Pagan O., Kontak C., Mulkey S.E. 2008. Reducing Energy Inputs in the US Food System. Hum Ecol **36**, 459–471

Refsgaard, K., Halberg, N., Kristensen E.S. 1998. Energy Utilization in Crop and Dairy Production in Organic and Conventional Libestock Production Systems. Agricultural Systems**. 57** No 4, 599-630.

Sainz R.D. 2003. Fossil fuel component. Framework for calculating fossil fuel use in livestock systems. http://www.fao.org/WAIRDOCS/LEAD/X6100E/x6100e00.htm#Contents

Smil V, 2008. Energy in nature and society- general energetic of complex systems. MIT Press, Cambridge, Massachusetts. 512 pp.

Southwell, P. & Rothwell, T. M. (1977). Analysis of output/input energy ratios of food production in Ontario. School of Engineering, University of Guelph, Canada.

Söötade keemilise koostise ja toiteväärtuse tabelid. 2004. Eesti Põllumajandusülikool, loomakasvatusinstituut. Tartu 122 pp.

Wells, C. 2001. Total Energy Indicators of Agricultural Sustainability: Dairy Farming Case. Study, Wellington: Ministry of Agriculture and Forestry

Woods, J., Williams, A., Hughes, J.K., Black, M., Murphy, R. Energy and food system. 2010. Phil. Trans. R. Soc. B 365, 2991-3006.