

Energy Audit of Agricultural Enterprises: New Approaches and Assessment Criteria (Following the Russian-Finnish Project Interim Outcomes)

Hanne Soininen¹,
Dr.Sc.(Eng.);
Tuija Ranta-Korhonen¹,
MSc;

Evgeniy V. Timofeev²,
Ph.D.(Eng.), timofeev_ev84@mail.ru;
Andrey F. Erk²,
Ph.D.(Eng.);

¹South-Eastern Finland University of Applied Sciences (Xamk), Mikkeli, Finland;

²Institute for Engineering and Environmental Problems in Agricultural Production (IEEP) – branch of Federal Scientific Agroengineering Center VIM, Saint Petersburg, Russian Federation

Abstract. Currently implemented project “Russian-Finnish Bioeconomy Competence Centre – BioCom” within South-East Finland – Russia Cross-Border Cooperation Programme 2014-2020 aims to integrate the BioEconomy principles and approaches into the agricultural sector of the neighbouring border areas of Russia and Finland. The energy efficiency of farming and sustainable use of energy resources is one of the fundamentals of the bio-economy concept. The energy audit is the first step in identifying opportunities to reduce the energy inputs on the farms. (*Research purpose*) To discover the new approaches to the energy auditing of agricultural enterprises and new assessment indicators following the project experience. (*Materials and methods*) Four farms were selected for the energy inspection – two farms located in the Leningrad Region, Russia, and two farms located in the South Savo Region, Finland. In Russia the standard energy auditing, measurement, and calculation procedure was applied. The systems of electrical power supply, heat supply, water supply, sewage, and building envelopes on the farms were examined and estimated. (*Results and discussion*) Following the outcomes of the energy audits in the project framework and the previous relevant experience, the basic energy-saving and efficiency improvement measures were established. Three new approaches to the energy auditing of agricultural enterprises were suggested – energy and environmental assessment of applied technologies and equipment; consideration of the application of renewable energy-generating sources; consideration of the conversion of vehicles to biogas. (*Conclusions*) The study outcomes proved the energy audits to play an important role in improving the energy efficiency of agricultural production provided they are mandatory, take into account the energy environmental assessment criteria, consider the application of renewable energy-generating sources and the conversion of vehicles to biogas.

Keywords: energy survey, energy saving, energy efficiency, energy and environmental assessment, renewable energy sources.

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Критерии энергоаудита сельскохозяйственных предприятий: новые подходы и оценки (по промежуточным результатам российско-финляндского проекта)

Ханне Сойнинен¹,
доктор технических наук;
Туйя Ранта-Корхонен¹,
магистр;

Евгений Всеволодович Тимофеев²,
кандидат технических наук,
e-mail: timofeev_ev84@mail.ru;
Андрей Федорович Эрк²,
кандидат технических наук

¹Университет прикладных наук юго-восточной Финляндии, г. Миккели, Финляндия;

²Институт агроинженерных и экологических проблем сельскохозяйственного производства (ИАЭП) – филиал ФГБНУ ФНАЦ ВИМ, Санкт-Петербург, Российская Федерация

Реферат. Реализуемый в настоящее время проект «Российско-финляндский центр компетенции в области биоэкономики – BioCom» в рамках Программы приграничного сотрудничества Юго-Восточной Финляндии и России на 2014-2020 годы направлен на интеграцию принципов и подходов биоэкономики в сельскохозяйственный сектор соседних приграничных районов России и Финляндии. Подтвердили, что энергоэффективность сельского хозяйства и устойчивое использование энергоресурсов составляют одну из основ концепции биоэкономики. Показали необходимость проведения энергоаудита при



определении возможностей для снижения энергозатрат в сельском хозяйстве. (*Цель исследования*) Выявить новые подходы к энергоаудиту сельхозпредприятий и показатели оценки на основе опыта реализации проекта. (*Материалы и методы*) Для энергетического обследования выбрали четыре хозяйства – два в Ленинградской области, Россия, и два в регионе Южное Саво, Финляндия. В России применяли стандартную процедуру энергоаудита, измерений и расчетов. Обследовали и оценили системы электро-, тепло-, водоснабжения, канализации и ограждающих конструкций. (*Результаты и обсуждение*). По результатам энергетических аудитов в рамках проекта и предыдущего соответствующего опыта установили основные меры по энергосбережению и повышению энергоэффективности. Предложили три новых подхода к энергоаудиту сельскохозяйственных предприятий: энергоэкологическую оценку применяемых технологий и оборудования; рассмотрение вопроса об использовании возобновляемых источников энергии; изучение возможности перевода транспорта на биогаз. (*Выводы*) Подтвердили необходимость энергоаудита в целях повышения энергоэффективности сельскохозяйственного производства. Показали, что энергетические обследования должны учитывать критерии энергоэкологической оценки, возможность применения возобновляемых источников энергии и перевода транспортных средств на биогаз.

Ключевые слова: энергетическое обследование, энергосбережение, энергоэффективность, энергетическая и экологическая оценка, возобновляемые источники энергии.

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The current international project “Russian-Finnish Bioeconomy Competence Centre – BioCom” within South-East Finland – Russia Cross-Border Cooperation Programme 2014-2020 aims to integrate the BioEconomy principles and approaches into the agricultural sector of the neighbouring border areas of Russia and Finland. The energy efficiency of farming and sustainable use of energy resources is one of the fundamentals of the bio-economy concept.

The expected project outputs include:

- a sustainable educational platform (Competence Centre) in the field of bioeconomy [1];
- a set of educational programmes, training materials and demonstration equipment for promoting the agricultural application of renewable energy sources;
- a uniform system of indicators for the energy audit of agricultural enterprises in Russia and Finland;
- recommendations on the creation of Demo Zones of High Energy Efficiency in agricultural production in the pilot border areas based on results achieved [2];
- recommendations on agricultural application of renewable energy sources and energy-efficient practices based on results achieved [2, 3].

The energy audit is the first step in identifying opportunities to reduce the energy inputs on the farms. Its main objectives are to acquire the objective evidence on the energy volume consumed; to identify the energy efficiency indicators and to reveal the causes for irrational energy use; to determine the energy-saving potential; to suggest the measures to improve the farm energy efficiency with their costs and pay-back periods and to provide relevant recommendations [3].

RESEARCH PURPOSE is to identify the new approaches to the energy auditing of agricultural enterprises and assessment indicators with due account for the project implementation experience.

MATERIALS AND METHODS. According to the project Work Plan, four farms were selected for the energy

inspection – two farms located in the Leningrad Region, Russia, and two other located in the South Savo region, Finland.

The Russian farms specialized in dairy production and grain crops growing (a large-scale farm) and apiculture and poultry farming (small-scale private farm). The Finnish farms specialized in chicken egg and beef production.

The Finnish partner created preliminary energy calculation models for both farms and identified the basic data required for the calculations. A previously designed digital tool could be applied to examine the energy use on the farms in more detail and to reveal the most energy-consuming processes.

The Russian partner followed the standard energy auditing, measurement, and calculation procedure. The systems of electrical power supply, heat supply, water supply, sewage, and building envelopes were examined and estimated.

As far as the electrical power supply system was concerned, the energy inspection included the following actions [4-8]:

- survey and qualitative assessment of the structure of external electricity supply at the voltage level of 0.4 kV, the technical condition of distribution networks and metering systems, reliability level of external and internal electricity supply;
- recording of electrical current and voltage on the incoming and outgoing lines using stationary devices installed in the main switchboard (ammeters, voltmeters, full adders) [4, 5];
- measurement of actual power values (active and reactive) by phases for the most typical (or energy-intensive) electric drives with the use of portable measuring systems;
- technical evaluation of external and internal lighting system (lamp type, quantity, and wattage) and determination of the actual values of the natural illumination coefficient [5];
- cause identification of the inefficient use of electricity;

- thermal imaging control of electrical equipment.

For the heat supply system, the energy inspection included checking the availability and condition of metering devices and automation systems, control valves and instrumentation (pressure gauges, thermometers, temperature, and pressure sensors); and determining the actual heat loss through thermal insulation of pipelines.

The technical condition of the water supply and sewage system was examined and estimated; the water and wastewater management system was assessed.

The building envelopes survey included the infrared thermography and the results processing.

RESULTS AND DISCUSSION. Following the outcomes of energy audits in the project framework and previous relevant experience, the basic energy-saving and efficiency improvement measures were established. Conventionally, they may be classified as managerial, economic, technical, and special energy-related ones.

Managerial measures include the relevant training of personnel; regular buildings and equipment inspections, infrared thermography and energy audits, testing of energy metering instruments, and maintenance activities in compliance with the energy efficiency requirements. The important economic measure is motivation and incentives and related managerial decision-making. These measures require minimal human, financial, technical and other resources. The energy conservation and payback period are difficult to define by the direct method. However, they are important in improving the energy efficiency of agricultural production.

Technical measures aim to replace the operating, outdated equipment with an energy-saving one, belonging to a higher energy efficiency class, resulting in lower energy intensity of agricultural production. The most required technical measures were found to be the lighting system upgrading; the automated control of electric drives; the economical water heaters, and local electric heaters.

The use of LEDs instead of the present incandescent lamps is the most promising way to save energy. The lighting system upgrading includes the introduction of automated control systems inside the cattle houses, street lighting, etc. Their payback period ranges from 1.1 to 2.0 years. The frequency-controlled electric drive is found to be the most effective energy- and resource-saving and environmentally friendly technology. It is installed in water supply systems, ventilation and inside climate systems, in vacuum pumps of milking units, and various conveyors. The payback period of such drive is from 0.5 to 2.0 years [9].

Examples of energy-efficient equipment are well and vacuum pumps with control systems; energy-saving water heaters for the technological needs of livestock farms; water treatment systems; local infrared heating of young animals and auxiliary facilities; heating of rooms for drying clothes and shoes of farmworkers with a water and solid-state off-peak electrical energy storage device. The payback period of such equipment ranges from 1.4 to 5.5 years [10].

The measures aimed at thermal energy-saving are also

required, especially in winter, though the thermal energy consumption in agricultural production is only 3% of the total fuel and energy inputs. The payback period of such measures ranges from 0.8 to 4.0 years [9, 10].

Satellite monitoring of vehicles (tractors and cars) comes into common use in agriculture. The estimated payback period for the implementation of this equipment due to the saving of motor fuel is 0.8-3.9 years [9, 11].

Special energy-related measures provide for involving the secondary energy resources and local and renewable energy sources in the energy balance of agricultural enterprises. To optimize the structure of energy flows in an agricultural enterprise means to find such a combination of energy sources when the specific energy consumption reaches its minimum.

Many livestock farms use heat exchangers in milking parlours by utilizing the heat released by animals. Air-to-air and water-to-air heat pumps are increasingly frequently used in livestock houses. However, the payback of such systems is rather long – from 7 to 9 years.

Wood and plant waste, other local fuels, gas-driven and wind-driven generators are used instead of traditional energy resources. The payback period of wind turbines when used for water lifting and heating is 4.7 years.

Solar energy is used mainly in two ways – as thermal energy by applying various thermal systems or through photochemical reactions. The widest solar energy application is to heat the water or premises. The low-temperature energy is sufficient for these purposes. Solar collectors can be used in agriculture to heat the water for technological needs in animal husbandry, to heat the soil and water in greenhouses, to heat the water in workshops, garages, etc. The payback period of such systems is 6.5 years. Photovoltaic systems (solar panels) are a durable and environmentally friendly practice of solar energy converting.

A new approach to the energy auditing of agricultural enterprises is the use of energy and environmental assessment of applied technologies and equipment.

The energy assessment includes the analysis of energy supply and energy consumption systems. The electricity and heat generation by the autonomous local sources involves the atmospheric emissions of pollutants in rural areas. These emissions can be minimized by selecting a proper generation source.

When considering the energy supply systems the energy-ecological criterion K_{EE} is calculated, which takes into account both economic and environmental indicators:

$$K_{EE} = (C_{inv} + C_{gen}) \cdot \sum \{M_{pol} \cdot K_{HE}\} \cdot Q, \quad (1)$$

where C_{inv} – unit cost of construction investments, thousand roubles/kW.h;

C_{gen} – energy generation cost, thousand roubles/kW.h;

M_{pol} – the mass of pollutants emitted during the energy generation; g/kW.h;

K_{HE} – harmful effect factor;

Q – the generated energy, kW.h.



When considering the energy consumption systems the energy efficiency criterion KEF is calculated to estimate the energy efficiency of technologies and equipment. It is determined as a ratio of the total fuel and energy consumed to the production volume:

$$K_{EF} = (\Sigma S \cdot K_{util} \cdot CF_1 + \Sigma Q \cdot K_{utilHE} \cdot CF_2 + \Sigma P_{fuel} \cdot CF_3) / V, \quad (2)$$

where S – electrical energy consumption, kW·h;
 K_{util} – annual equipment utilisation rate, h;
 CF_1 – conversion factor of kW·h to tons of reference fuel;
 Q – heat energy consumed, kcal;
 K_{utilHE} – annual heating equipment utilisation rate, h;
 CF_2 – conversion factor of kcal to tons of reference fuel;
 P_{fuel} – motor fuel consumption, t;
 CF_3 – conversion factor of tons to tons of reference fuel;
 V – production volume, t.

When examining the energy supply systems both traditional and renewable energy sources were considered. When examining the energy consumption systems both external generation sources (e.g. boiler houses of various types designed for heating) and internal generation sources (e.g. a drying unit can be equipped with a generator working of liquid fuel or alternative fuel) were considered.

One more new part suggested in the energy audits of agricultural enterprises is associated with recommendations on the selection of energy generation sources.

Modern agricultural enterprises have many small power consumers: livestock houses, offices, post-harvest crop treatment facilities, warehouses, storages, etc. They are located at different distances from power supply sources. Low-power transformers provide the centralized power supply via long-distance overhead power lines. Electrical energy demand is irregular throughout the day; the quality of electricity is low; there are big energy losses in the networks (Fig. 1, 2).

Recently, the issue of decentralized (autonomous) energy supply for some consuming objects in rural areas has been considered with ever-increasing frequency. Various low-power generators can provide the decentralized energy supply using local and renewable energy sources.

The use of renewable energy sources, including solar radiation, makes it possible to solve energy problems of remote power consumers such as poultry and sheep houses, buildings for small-scale production, premises for fishing cooperatives, and others. There are many such consumers in the agricultural sector in the Leningrad region.

Generating facilities can be both traditional (diesel generators, gas-piston power plants) and using renewable energy sources (wind turbines, solar stations, micro-hydroelectric power stations). The main reason for using renewable energy sources may be lower inputs of primary fuel, i.e. the economic effect. However, replacing the traditional energy with renewable energy will have a

positive effect on the environmental indicators as well.

The generating sources may be selected by both economic and environmental criteria. The economic criterion is the cost of one kW·h of both electric and thermal energy. The environmental criterion is the total specific emissions of pollutants in the process of energy generation at local generating sources (grams of pollutant per kW·h).

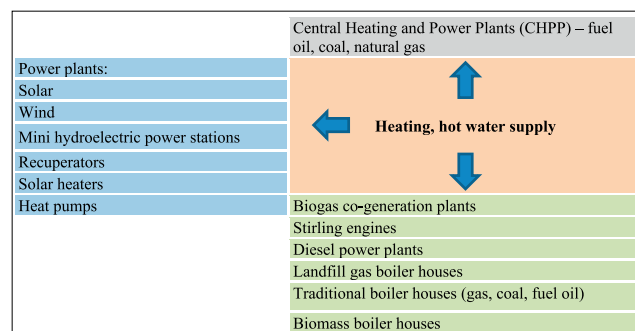


Fig. 1. Energy supply pattern for heating and hot water supply

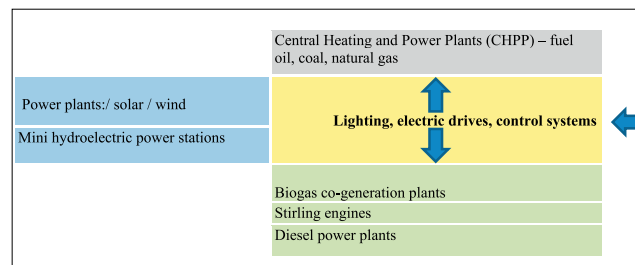


Fig. 2. Energy supply pattern for lighting, electric drives and control systems

A single criterion for the selection of energy-generating sources is defined as the product of the kW·h cost of energy generated and the specific pollutant emissions. This criterion may be called the “factor of energy and environmental friendliness (compliance)”. The desired value of this factor when choosing a power-generating source is the smallest (Table).

The third new issue suggested for the energy audits is the evaluation of the feasibility of conversion of vehicles to biogas.

Currently, this issue is becoming relevant for both economic and environmental reasons. Therefore, during the energy surveys, it is reasonable:

- to examine the machine and tractor fleet: vehicle type, mileage, fuel consumption, etc.;
- to estimate the overall fuel inputs on the farm;
- to calculate the feasibility of converting vehicles to gas by the energy and economic evaluation criteria;
- to estimate the quantity and quality of organic waste on the farm, which could be processed to generate the biogas;
- to justify the use of biogas as a motor fuel;
- to justify the introduction of a closed cycle on the farm: animals and plants – organic waste – biogas – vehicles – animals and plants.

Таблица							Table
SPECIFIC EMISSIONS OF POLLUTANTS IN THE PROCESS OF ELECTRIC AND THERMAL ENERGY GENERATION AT LOCAL GENERATING ENERGY SOURCES, g/kW.h							
Emission source: boiler-houses	Carbon dioxide CO ₂	Carbon monoxide CO	Dust	Sulfur oxides SO ₂	Nitrogen oxides NO ₂	Hydrogen sulfide H ₂ S	Total
Diesel	6.8	0.3-0.6	0.04	8.0-10.5	1.8-3.2	0.05	19.1
Coal	9-10	0.3-1.0	0.4-1.4	6.0-12.5	3.0-7.5	6.0-9.0	37.4
Fuel oil	5.4	0.1-0.5	0.2-0.7	4.2-7.5	2.4-3.0	2.5-5.4	20.2
Wood	2.3	0.2-0.8	0.3-0.8	–	0.07	–	2.9
Pellets	1.9	0.1-0.6	0.2-0.6	–	0.5	–	3.2
Wood chips	1.3	0.1-0.5	0.5-1.3	–	0.2-1.3	–	3.4
Biogas	3.2	–	–	–	2.0-2.7	0.06	5.6
Natural gas	1.29	–	0.05	0.02	1.9-2.4	–	3.6

- to forecast the use of biogas as a motor fuel and the construction of a biogas plant both on the farm and for the joint use of several farms.

CONCLUSIONS. The interim results of the current international project “Russian-Finnish Bioeconomy Competence Centre – BioCom” within South-East Finland – Russia Cross-Border Cooperation Programme 2014-2020 and the previous experience in energy auditing of agricultural enterprises proved the energy audits to be an important step in improving the energy efficiency of agricultural production. However, to fulfil their mission they have to be mandatory and result in the elaboration of energy-

saving measures and recommendations. Three new approaches to the energy auditing of agricultural enterprises were suggested: energy and environmental assessment of applied technologies and equipment; consideration of the application of renewable energy-generating sources; consideration of the conversion of vehicles to biogas.

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