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TECHNO-ECONOMIC OPTIMIZATION OF ENERGY SUPPLY OF A LIVESTOCK FARM

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Abstract. *Livestock farming is a significant part of agricultural market in Serbia. However, a descending trend of livestock species has been recorded recently, despite its potential for meat export. Application of new technologies could improve competitiveness of livestock farming. In this paper, energy efficient energy supply technologies and potentials for their application in livestock farms have been analyzed. A methodology for pinpointing profitable energy supply options which also provides significant energy and CO_2 savings has been proposed. A case study of a pig farm was used to perform an energy balance and allocation of energy supply costs. Potentials for application of energy supply technologies based on local resources have been estimated in the study. The effects of integration of proposed technologies were also estimated. The suggested methodology was used to analyze the feasibility of proposed energy supply options. Investment in a biogas cogeneration plant showed best profitability. An integrated option which envisages the application of heat pump for heat supply and photovoltaic solar collectors for production of electricity showed best energetic and environmental performance while managing to maintain financial feasibility.*

Key words: *livestock farming, efficient energy supply, cost benefit analysis, energy savings, CO_2 savings*

1. INTRODUCTION

Livestock farming is a significant part of the agriculture market in Serbia, with high potential for meat export predominantly [1]. The region of Central and South-east Serbia has a significant potential for livestock production, apart from fruit production and viniculture [2]. However, the number of livestock species has been decreasing recently.

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In the period from 2001 to 2007 the greatest decrease of 30.4% was registered for pig production, sows and pregnant gilts; the number of cows and pregnant heifers has decreased by 12.7%; and number of breeding sheep remained at the same level [1]. Pork production is considered as an important socio-economic factor in EU, where one fifth of the world's pork production takes place [4].

Introduction of new technologies to increase competitiveness of livestock production could improve prospects for domestic livestock production on the global market [1]. In this paper, possibilities for energy saving of a livestock farm are investigated. An intensive pig farm is used to generate and evaluate energy saving options. An energy audit is performed to gather data and perform an energy balance of the farm and its major energy processes. Energy demands for different types of final energy at the farm are determined, and potential for energy saving and cost reduction is further analyzed. A simple methodology relying on technical, environmental and economic criteria is used to generate and evaluate effectiveness of energy supply options.

Although the same methodology could be used for evaluation of other energy efficiency options, this paper focuses on more efficient energy supply at a pig farm, part of "Delta Agrar Ltd, Zaječar". The methodology envisages the use of spreadsheet software and may be used to address the problems of environmental and energy performance of similar energy systems as well. Energy performance data is collected, and consumption of different types of final energy at the premises is analyzed. Based on data collected and measured on-site, a steady state energy balance of a livestock farm as an energy system is performed. Energy balance data are used as a basis to generate economically feasible energy saving options and pinpoint options with most potential for detailed analysis and implementation.

1.1. Methodology

According to acquired and calculated energy performance data, cost of energy inputs and outputs is allocated and quantified. Energy production options are generated according to on-site energy demands and the following criteria: 1) utilization of available waste, 2) application of efficient conventional energy supply technologies, 3) utilization of on-site renewable energy sources, and 4) application of integrated options.

Performance of the generated options is estimated using the average annual performance data, and ranked based on simple pay-back period. Options with acceptable pay-back period are analyzed further using monthly performance data and cost benefit analysis (CBA). The ratio of on-site annual final energy demands met by the proposed systems are calculated, annual CO_2 reduction determined, and cost of annual estimated energy savings and profits are calculated.

Based on the obtained CBA results, non-feasible options are pinpointed. Since typical parameters calculated in CBA do not account for energetic and ecologic performance of any of the proposed investment options, an additional indicator is introduced to rank the analyzed energy supply options based on their financial, economic and ecologic performance, per unit investment cost. The option with the highest value of this indicator is chosen as financially feasible with best energetic and environmental performance.

2. Energy Balance of the Farm

According to research results in Flanders, the most energy efficient pig and dairy farms are intensive farms, where high production is combined with low energy consumption, resulting in a gross value added per production unit comparable to or higher than the average [3]. Research of energy consumption of Danish livestock farming indicated energy use of 20 MJ per kg of live weight pig produced, which varied more significantly between observed farms than between analyzed yearly data for each of the farms [5]. Analysis of the estimated potential for energy savings in EU showed possibilities for energy saving of up to 47% by using manure for energy production, up to 28% by reduction of feed use and, up to 25% by reducing manure in house storage [4]. Although manure utilization for energy production was found to have significant potential for both energy savings and greenhouse gas emissions (GHG), utilization of other energy supply technologies was omitted from the study. In this paper, utilization of renewable energy sources is analyzed as well as the use of waste generated at the farm.

A model for assessment of fossil energy use in agriculture showed that reduction of fossil energy use may be obtained with organic farming, but the production rate is also decreased this way [6]. This model may be used to calculate average production and fossil fuel consumption data, whereas the properties of specific energy processes are neglected. Production on biogas on livestock farms is recognized as a measure for improved waste management and energy supply improvement in the literature [7-14]. A recent research indicated that agricultural production is the hot spot of life cycle of food products, where impact of waste management systems in pig farming and environment impact are analyzed, but energy supply systems are omitted from the research [7]. Multiple environmental benefits in different sectors have been recognized from the Danish farm experience with centralized biogas plants from the 1970s until now: it generates renewable energy, it enables the recycling of organic waste, it can play a role in manure distribution and storage and improve the veterinary aspects of manure, it can reduce fertilizer use, and it contributes to the reduction of the greenhouse gas methane [8]. In this study, some problems of unstable plant operation, low biogas yields on small farms for reaching economic feasibility, are recognized for small systems, however energy generation is indicated as the dominant incentive, especially for centralized biogas systems [8]. The composition of input substrate affects methane and biogas yield, and can be further used to produced heat, steam and electricity [9]. In an economic analysis of available biogas production technologies in Sweden and utilization of biogas for production of heat, combined heat and electricity (CHP) and vehicle fuel, CHP option showed favorable economic feasibility, but also highest sensitivity to the tested parameters [10]. Non-technical barriers could also affect implementation of biogas and other energy efficiency and renewable energy options [11,12], but this isn’t within the scope of this paper. Comparison of eight waste to energy technologies in today’s energy systems showed that utilization of organic waste in manure based biogas production provides cheaper CO_2 reduction than incineration, and while utilization of produced biogas for transport provides the largest CO_2 reduction, utilization of biogas for CHP provides the lowest CO_2 reduction cost [13]. A study of economic feasibility of electricity generation from biogas in small pig farms showed that the payback period of the biogas production facility is significantly influenced by the equipment for H_2S removal, but the study assumed a 45% subsidy [14].

2.1. Brief description of the farm's processes

The farm exclusively produces fattened pigs and sows. It has a capacity for production of 1,350 sows, and 32,000 fatlings. Breeding is a batch process, carried out in specific stages, which is repeated throughout the year in cycles. First stage in the breeding process and start of the cycle is mating followed by farrowing, growing and finishing. Animals are housed in sections according to the stage of breeding process they are in. So, as time goes by, piglets and sows are moved from one section to the other in precise time intervals so that production dynamics and capacity are sustained. As they are moved from one place to the other, rooms they were in are prepared, cleaned and disinfected, for the next batch. After cleaning, slurry is drained through the slatted building floor, and collected in a storage reservoir. Solid phase is separated from the slurry so the liquid phase could be reused for building flushing. In the latter finishing stage pigs are kept in boxes and fed to gain weight. When they reach target age and mass they are sold to other companies. Temperature in the buildings for animal housing is maintained throughout the breeding process according to the breeding stage. There are 6 buildings for animal housing, but only 3 of them, where farrowing and growing takes place, consume heating energy supplied from a nearby boiler house. A functional scheme of the farms processes is presented in Fig. 1.

2.2. Energy balance and energy consumption indicators

Energy consumption at the farm is represented by heating and electricity demands (Fig.2). Electricity provided by the national supply grid is used to power animal feeding equipment, fans and pumps used for heating and ventilation of the buildings, water supply pumps and lighting. Electricity consumption data was collected for a period of 3 years, and average monthly values are presented in Fig. 2. Heat is supplied by two identical 750kW coal fired boilers, distributed for heating of animal housing buildings, an office building and heating sanitary hot water.

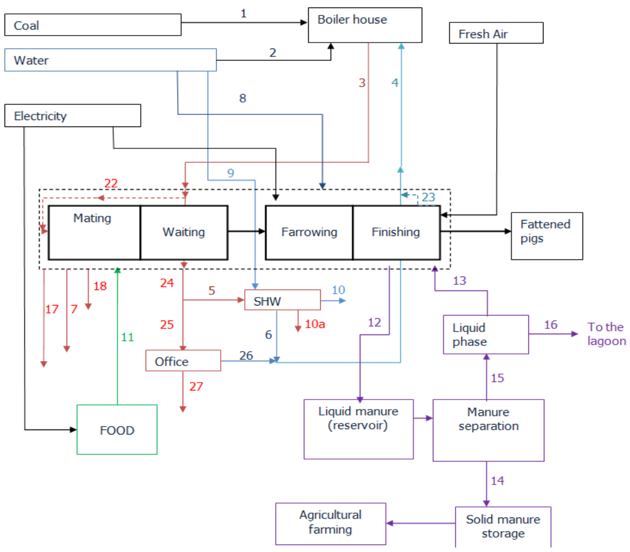

Fig. 1 Functional scheme of the farms processes

Sanitary hot water (SHW) is used every day by the farms staff, for showering before and after entering the animal housing facilities. Sanitary hot water system is equipped with a 3000l tank, which is heated to 60°C by heat supplied from the boilers in the heating season and by electric heaters in the summer. Degree day method was used for preliminary assessment of energy demands for heating, while SHW demands are calculated based on the number of showers per day per employee [15].

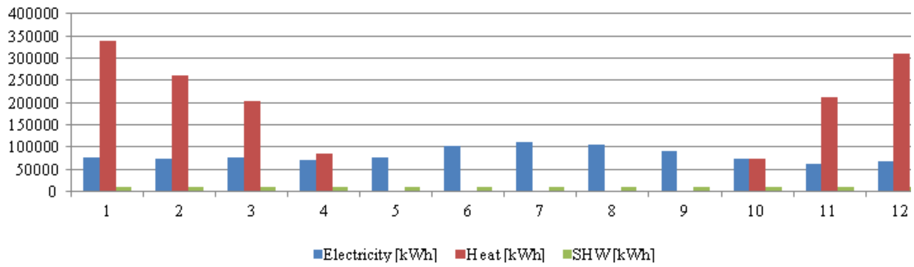

Fig. 2 Annual energy demands at the farm

According to data acquired on-site, an energy balance of the farm as en energy system was performed (Fig 3). The boilers are fired using “Lubnica” coal produced in the area, with the following composition [16]: 25.51% Carbon (C), 11% Oxygen (O), 2.8% of Hydrogen (H), 1% Nitrogen (N), 1.15% Sulfur, 23.49% ash and a water content of 35.05%.

The boilers and the heat distribution system are manually operated, with the intention of continuous 24h a day heating. Energy efficiency of the boiler is calculated according to coal composition data and available boiler exhaust annual measurement data [16]. Calculated theoretic and real specific volumes of combustion air and properties of exhaust gas are presented in Table 1. Coefficient of excess air of 1.9 and volumetric flow of exhaust gas is determined according to annual exhaust quality measurement data for the boilers, performed by a subcontractor for the farm.

Table 1 Theoretic and real combustion air volume and composition of exhaust gas

Specific volume of combustion air	Theoretic (m^3/kg)	Real (m^3/kg)
	2.69	5.14
Specific volume of exhaust gas	Theoretic (m^3/kg)	Real (m^3/kg)
	3.36	5.87
Exhaust gas	Specific volume (m^3/kg)	Volume (%)
CO2	0.477	12.329
SO2	0.008	0.208
N2	2.121	54.826
O2	0.513	13.262
H2O	0.749	19.372

Values of volumetric flows and enthalpy of combustion air and stack gas are used to perform energy balance of the farms energy distribution system. Enthalpy of exhaust gas together with other losses resulted in total boiler loss of 30% [16], where most of the loss can be addressed to: exhaust gas loss 18%, loss due to fuel drop through the furnace grate 3.21%, unburned fuel 1.7%, incomplete combustion loss 0.17%, and the rest to unused heat of the ash. These results are obtained for exhaust gas temperatures of 150°C, and average ambient air temperature of 5°C.

In order to perform the energy balance, calculated mass flow rates of air, coal and exhaust air were used. Mass flow rates and temperatures of water supply and return, and water supply to the animal housing and office buildings were measured using Greyline PT400 mass flow rate sensor and TESTO 831 temperature sensor. It was assumed that the temperature at the surface of hot water supply pipe (without insulation) was approximately the same as temperature of water in the pipe. Coal is transferred to heat, which is distributed further by the main distribution pipeline to the block of 3 animal housing buildings, an office building and to the SHW boiler. Temperature of the main supply pipeline was read from an existing thermometer in the boiler house. The following temperatures were read at the time of the measurement (Fig 1): main supply pipeline temperature 90°C (3), temperature at inlet for heating buildings 81.2°C (22), temperature at office building inlet and SHW heating 74.5°C (25), temperature at main return pipeline 71.6°C (4). Measured fluid flows were 4.98kg/s for the mains, 0.32kg/h for the office pipeline and 0.15kg/s for SHW heating.

Energy balance for a steady state with assumed average ambient temperature of 5°C was performed, and the allocated annual energy streams are given as a Sankey diagram Fig 3.

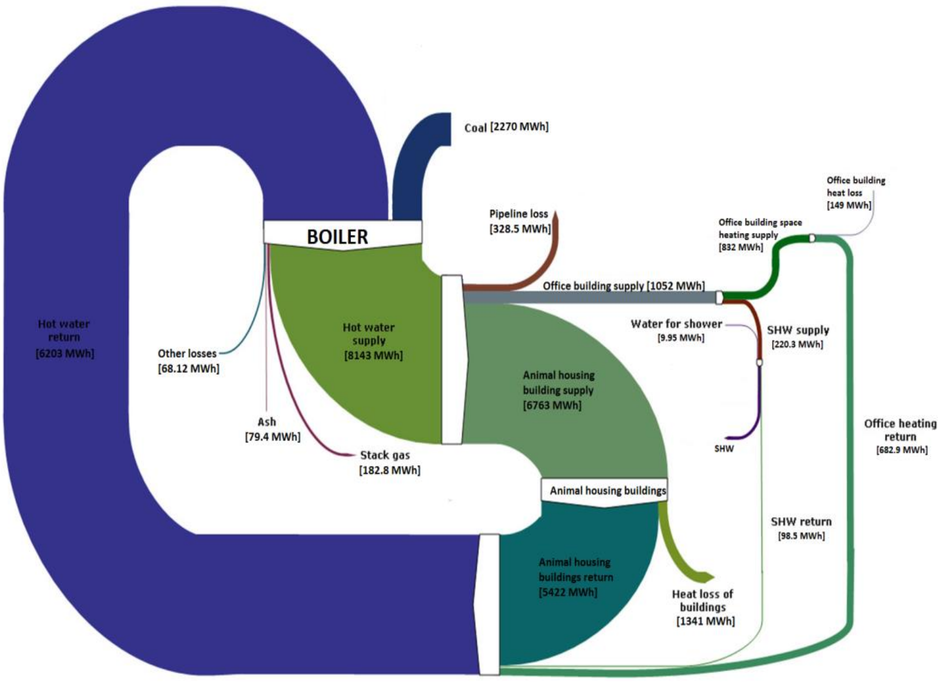

Fig. 3 Sankey diagram based on annual energy balance

According to the balance, it can be observed that most of the energy consumption can be allocated to the energy housing buildings. Total heat consumption of the system, together with the distribution losses was found equivalent to 2270MWh. Specific energy consumption per animal head was calculated and compared to the benchmark values [17]. Results are presented in Table 2.

Table 2 Calculated energy indicators compared to benchmark values

Indicator	Unit	Value	Benchmark value
Water consumption	m^3/head/year	1.19	1.825 (partly slated floor) 0.07-0.3 (Breeding and finishing farms)
Electricity consumption	kWh/head/year	43.43	42.7 (Integrated farms)
Thermal energy consumption	kWh/head/year	49.28	43.74 (Integrated farms for 180 day heating season)
Total energy consumption	kWh/head/year	92.72	83-124 (over 450 sows/year) 41-147 (over 2100 piglets/year)

Compared to the benchmarks, calculated energy indicator values tend to have just slightly higher values. The presented benchmark values represent average values, instead of best practice values.

2.3. Allocation of costs

Energy consumption data and results of the energy balance are used to allocate costs of the energy supply and allocate costs of identified energy streams. Breakdown of the farms energy supply costs is presented with respect to the following assumptions: (1) Cost of kWh of supplied heating is calculated based on annual coal consumption for 4320 hours of the heating season, and supply cost of “Lubnica“ coal [18] in €; and (2) Cost of electricity is taken from the available data, as average cost per kWh. With these assumptions, the cost of heat supply is 10.125€/MWh and the average cost of electricity is 61.97€/MWh. Breakdown of the costs of heating at the farm is presented in Fig 4.

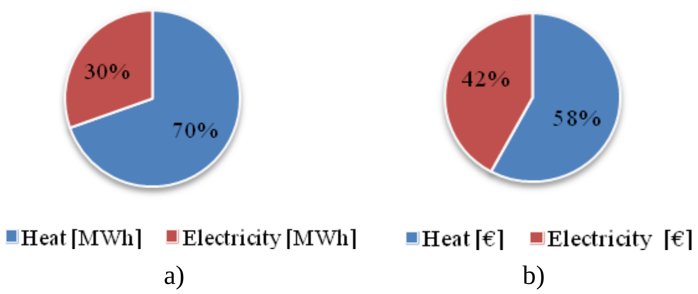

Fig. 4 Breakdown of total energy consumption and costs of consumed final energies

Energy demand of the farm consists of: heating demand 69.63% and, electricity demand 30.37%. Breakdown of costs for consumed energy show that 72.75% of costs are related to electricity consumption and 27.25% to production and distribution of heat. An average price of 25.87€/MWh can be calculated for the farms energy supply based on total annual energy consumption and total annual cost of supplied energy.

3. EFFICIENT ENERGY SUPPLY OPTIONS

Available energy demand data was used as a basis to generate and evaluate possible options for more efficient energy supply. A preliminary estimation of techno-economic performance of the generated options was conducted: energetic performance of each option was estimated and energy savings quantified, initial investment and operation costs are estimated, static payback period is calculated for initial evaluation. Options are arranged according to the obtained payback period and the value of initial investment. Based on these results, economically feasible options are pinpointed, and the rest of the generated options are discarded from further analysis. Feasibility of combined performance of application of selected options has also been analyzed.

Economic analysis is then performed with more detail for pinpointed energy supply options. Net present value (NPV), Financial Rate of Return (FRR), and net cash flow for the project lifecycle are then calculated.

3.1. Potentials for application of heat-pump technology

Since most of the energy consumption at the farm can be related to space heating, application of compression heat pumps is analyzed as a cost effective energy supply solution [19]. The farm already uses water from three on-site wells for washing and animal feeding. The temperature of this water pumped to the ground surface was 10^{o}C on the day of the measurement. The quantity of the underground water is considered sufficient to be used as a source for a compression heat pump, since it meets annual water demands of the farm. Typically, coefficient of performance (COP) for heating of heat pumps can vary significantly during operation, and the average values with source temperature of 10^{o}C drops significantly from maximum rated values for output temperatures of 55^{o}C [19,20]. Better COP could be achieved with lower output temperatures, but this requires additional investment on the consumer side. Performance of heat pump application is performed with the assumptions: average COP of the heat pump is 3.3 [20,21]; the heat pump would distribute heat through the existing distribution network; the heat pump will take advantage of the existing water-well system; cost of the electricity used to power the heat pump is equal to the average calculated electricity supply cost from the grid; CO_2 emission is calculated based on estimated electricity consumption from the grid, with a conversion factor of 1tCO_2/MWh$_e$. Estimated performance of application of heat pump is presented in Table 2. A heat pump typically provides lower temperature heat supply, which may lead to additional expenses for ensuring the same quality of space heating. A binary setup is analyzed in the study, where a heat pump is used to cover base loads coupled with a boiler for peak loads [19]. In binary supply scenario, the use of the existing manually operated coal fired boilers would be difficult for automatic operation. Based on the heat pump market in Serbia, initial investment of large scale heat pump I_{hp}[€] can be approximated as a linear function of installed heat pump power P_{hp} [kW]:

$$I_{hp} = -0.116P_{hp} + 218.325 \quad (1)$$

According to the initial estimation, the heat pump heat supply option could provide energy savings up to 69% and CO_2 savings up to 35% (Tab 5). However, with the current ratio of costs of coal produced heat coal and electricity, this option is not competitive.

3.2. Potentials for utilization of solar thermal energy

The farm and its buildings have an open position, i.e. other objects do not block solar radiation to the farm. All the buildings at the farm are one story buildings set apart so there are no shadows on the rooftops. This represents a substantial area suitable for mounting solar collectors. According to the annual energy demand profile (Fig 2), solar thermal energy could be used to meet SHW demands by reducing electricity consumption in the summer. Performance of the solar SHW system is estimated based on average annual data [22], i.e. production of heat of a square meter of solar thermal collector is estimated to 460kWh/m^2, based on average annual efficiency and average annual radiation on collector surface. The proposed flat plate solar thermal collector system of 36 solar thermal collectors with collector area of 86.40m^2 is sized to avoid system stagnation in the summer. Annual solar heat production is estimated to 39.74MWh, which corresponds to 45.35% of the summer SHW heat demand and 2% of total net annual heat demand. Hence, annual energy saving for SHW heating by application of solar thermal collectors is estimated based on saved electricity for SHW production at 2462.94€. Initial investment of the solar thermal system I_{st} is estimated at 30240€ based on specific cost of a square meter of solar thermal collector of 350 €/m^2.

3.3. Potentials for on-site biogas production and utilization

Generally, quantities of manure, sludge and urine generation are difficult to measure, and therefore they were estimated according to BREF daily values [17] per animal and average livestock count for the farm. In addition to fattened pigs and calves production, the company is in charge of agricultural crop production, where usually corn, wheat, barley and alfalfa are produced. The total area of arable land near the farm is 390ha, out of which 250ha is in the property of the company, and the rest is taken in lease. Possible methane production was calculated using average values for methane yield from the literature [3].

For the possible biogas production two waste streams, stream 14 and stream 16 were considered (Fig 1). Since no precise data for chemical composition was available, the

Table 3 Estimated organic waste for biogas production

		Heads No.	Slurry (kg/head/day)	Solid manure (kg/head/day)	Urine (kg/head/day)
Finishers		7870	5.35	3	1.5
Weeners		5221	1.85	1	0.5
Finishers (160 kg)		2	11.5	6	10
Farrowing sows		1080	13.4	5.7	10.2
Gestating sows		258	7.1	2.4	4.7
Suckers		3104	1.85	1	0.5
Gilts		258	3.6	2	1.6
Total	(kg/day)		17535	39238.2	28628.9
	(m3/day)		16.86	37.729	28.628

following assumptions and estimations were made: biogas potential was calculated based on the theoretical amount of biogas produced per unit of fresh pig slurry and theoretical amount of produced slurry calculated for the average type and number of animals on the farm, according to literature data [1,3].

Available slurry for methane production is estimated to 74.6 t per day (Table 3), and a biogas yield of 27.5 m^3 of biogas per *t* of fresh slurry [22], annual methane yield is estimated to 450242.1 m^3. For this estimation, a ratio of methane in produced biogas of 60% is assumed [23].

Although biogas could be used in gas fired boilers to meet local heat demands, in an economic analysis of available biogas production and utilization technologies in Sweden utilization of biogas for combined production of heat and electricity (CHP) was among the top rated solutions [10]. According to estimated annual methane production capacity, a CHP unit could be used to cover base heating loads and produce electricity.

A comparison of possible prime movers for small scale cogeneration installations including Solid Oxide Fuel Cell (SOFC), Polymer Electrolyte Membrane Fuel Cell (PEMFC) Engine and Internal Combustion Engine (ICE) [24] and gas-turbine [24, 29, 30] was conducted, showing the comparison of their efficiencies and investment costs. According to the simulations and evaluations [24] Stirling engine is most efficient, closely followed by the Reciprocating IC engine. Gas turbine based trigeneration configurations with absorption chillers with and without heat storage, are optimized and confronted to conventional systems in [25,26]. Greenhouse gas emission indicators and estimations relevant for CHP plants and comparison to conventional plants [27] show that emission reduction greatly depends on the technology adopted for system integration. CHP technologies fuelled by gas can provide quite good GHG emission reduction, in the range from about 20% (for small scale gas turbines) up to about 35% (for ICEs and CCs). Also ICEs prove to exhibit good potential emission reduction performance [28]. Based on the literature performance review, SOFC and PEMFC seem better suited for smaller system integration, hence ICE is chosen for further analysis.

In order to obtain a valid permit for selling electricity, average annual efficiency of 85% for the cogeneration unit has to be insured [31]. Waste heat can be used for building heating in the heating season (Biogas cogeneration with space heating load priority - CHP-BHP) or for drying digestate throughout a year (Biogas cogeneration with digestate drying priority - BCHP-DDP). Project profitability is obtained if the CHP module is operated throughout a year with utilization/sale of both heat and electricity produced. For solid fertilizer production, heat is applied to dry the digestate, a byproduct of the biogas production process used for fertilizer production. In this case study, with the manually operated coal fired options, use of CHP for digestate drying and fertilizer production throughout a year seems more practical.

For estimating performance of CHP in both scenarios, the following assumptions were made: 1) CHP ICE engine runs with constant efficiency transferring 35% of input fuel energy to electricity and 52% to heat; 2) due to substantial estimated amounts of organic waste for biogas production, all of the rejected heat from the CHP module can be utilized for digestate drying; 3) all of the produced electricity is exported to the grid, 4) electricity export price is 123.1€/MWh_e [32] for electricity produced using gas of animal origin. According to literature review [33,34], investment cost for the biogas CHP plant I_{BCHP}[€] is estimated according to installed power for electricity production of the CHP $P_{CHPe}[kW_e]$ module as:

$$I_{BCHP} = -1.09P_{CHPe} + 3602 \tag{2}$$

In the CHP-BHP scenario, up to 69.5% of heating demands could be met by the CHP module. In the periods with no heat demands for space heating, heat can be utilized to produce 906.64 t of fertilizer. Achieved profit in CHP-BHP scenario is estimated at 205,669€/year, which is obtained by electricity export to the grid and sale of fertilizer produced in the summer. Achieved profit of CHP-DDP scenario is estimated at 213,829€/year, which is obtained by electricity export to the grid sale of fertilizer produced throughout a year. CHP-DDP option enables 2 times higher fertilizer production, and it is used for further comparison in the study, marked as BCHP only.

3.4. Potential for application of photovoltaics

The farm has significant roof top and land area to mount photovoltaic solar panels (PV). Available rooftop surface with south-east orientation on all of the farms buildings is estimated at 9190m^2. Estimation of effects of using such a system, with an assumption of possibility to export electricity to the grid with feed-in tariffs is presented. The feed-in tariff for electricity produced using PV [32] decreases with installed power of PV. Effects of mounting a PV array at a single rooftop and 6 rooftops, of the 12 available rooftops are presented below. The feed-in tariff used in the estimation for rooftop mounted solar collectors is a linear function of total installed (peak) PV array power [31]. The estimation of the investment included the costs of DC/AC inverters and the costs of roof mounting support system for the PV array over the existing old rooftop construction. Investment cost of a PV system is estimated based on specific cost per kW of installed power of 1.5 €/kW$_e$ which includes AC/DC inverters. Performance of the PV system is estimated based on an average annual performance per of 105kWh/m^2 of PV.

Number of PV modules which could be mounted on a single rooftop is 370, with a peak power of 99.90kW. A single rooftop system could produce an annual energy yield of 115.37MWh creating an annual profit of electricity export of 23,077.11 €/year.

3.5. Integrated energy supply options

According to the previously estimated performance of analyzed energy supply technologies, integrated options were generated and performance of integrated options was estimated.

It is assumed that: (1) All of the on-site produced electricity can be exported to the grid according to the current feed-in tariff system; (2) Heat produced using a biogas cogeneration plant (BCHP) is used for digestate drying and fertilizer production, instead of space heating thus increasing the existing heating demand; (3) Proposed heat-pump system is used to meet average heating loads, contributing with 70% in heat production; (4) One rooftop PV system is used for integration except for integration with heat pump. Results are presented in Table 4. Methane emission reduction was not considered for BCHP.

Table 4 Estimated performances of integrated energy supply options

Option	HP+ PV6	HP+ PV1	HP+ BCHP	BCH P+ST	PV1 +ST	PV1+ BCHP	HP+BCHP +ST	PV1+BCHP +ST	HP+PV1+ BCHP+ST
Integration level	2	2	2	2	2	2	3	3	4
Heat prod. (MWh)	1358	1358	4107	2793	43	2365	4151	2793	4151
Ele.prod. (MWh)	692	115	2365	2365	115	2480	2480	2480	2480
El. export (MWh)	692	0	1777	2365	115	2480	1777	2480	1892
Fertilizer prod. (t)	0	0	1823	1823	0	1823	1823	1823	1823
Heat saved (MWh)	1358	1358	1358	43	43	1401	1401	43	1358
CO_2 saved (t)	692	435	320	20	136	115	656	771	771
Invest. (1000 €)	1025	275	1251	1126	180	1149.5	1281	1179.6	1304.6
Profit (1000 €)	925.5	9.6	175.9	191.8	25.5	235.4	178.4	236.6	223.2
SimplePay-back	11.1	28.5	7.1	5.9	7.1	4.9	7.2	5.0	5.8
H. demand (MWh)	1940	1940	1940	4305	1940	4305	4305	4305	4305
El. demand (MWh)	1578	1578	1578	990	990	990	1578	990	1578
Heat ratio (%)	0.70	0.70	0.70	0.01	0.02	0.33	0.33	0.01	0.32
Electricity ratio (%)	0.44	0.07	1.50	2.39	0.12	2.50	1.57	2.50	1.57

4. EVALUATION OF ENERGY SUPPLY OPTIONS

To estimate economic feasibility of the presented energy supply options, a cost benefit analysis (CBA) was performed [35].

The economic life of defined projets could be estimated for each of the projects individually. For the purpose of this study, a unified ecomic life of 12 years was used to provide comparability of the options. This coresponds to the period of viability of electricity export contracts according to the active feed-in tarif system [31,32]. For the evaluated future revenues and expences, i.e. inflation impact, constant price model was used, corrected by a real price growth of 0.6%. Since the end of the project lifecycle does not predict revenues originating from sale of the assets, no residual value is assumed. Project revenues originate from exported electricity and energy saved compared to the base case, as well as for sales of fertilizer, for the BCHP options.

The following parameters were calculated to investigate financial and economic feasibility of the project [35]:

Net annual savings: $$B = \sum B_t P_e - \Delta C_e \quad (3)$$

Where: B-total annual savings; B_t – energy savings for one year (t=1…n); ΔC_e - exploitation cost change.

Net present value NPV:

$$NPV = \sum_0^n B_t/(1 + d^t) \quad (4)$$

Where: d – discount rate; n – estimated project lifetime, B – annual net cash flow (revenue).

Since the revenueas are persumed constant during the project lifetime, NPV is calculated as:

$$\text{NPVQ=NPV/PVI} \quad (5)$$

Table 5 Results of the CBA

Option	Investment (€)	Profit (€)	Pay-back	NPV (12 year)	FRR (12 year)	NPVQ (12 year)	Feasible Yes/No
HP	125000.00	N/A	N/A	N/A	N/A	N/A	N/A
ST	30240.00	2462.94	11.9	-4,660.22	0.25%	-0.15	No
PV1	147000.00	23077.11	6.6	88,705.28	12.07%	0.60	Yes
PV6	882000.00	105987.19	8.7	206,558.30	6.77%	0.23	Yes
BCHP	1126282.18	212335.13	5.6	1,035,877.87	16.21%	0.92	Yes
HP+PV6	1007000.00	103476.81	10.2	60,024.31	4.00%	0.06	Yes
HP+PV1	272000.00	20566.74	13.7	-57,828.72	-0.87%	-0.21	No
HP+BCHP	1251282.18	209824.75	6.3	889,343.88	13.51%	0.71	Yes
HP+ST	155240	N/A	N/A	N/A	N/A	N/A	N/A
BCHP+ST	1156522	214798	5.7	1,031,217.65	15.85%	0.89	Yes
PV1+ST	177240	25540	7.2	84,045.06	10.29%	0.47	Yes
PV6+ST	912240.0	108450.1	8.8	201,898.08	6.58%	0.22	Yes
PV1+BCHP	1273282	235412	5.7	1,124,583.14	15.74%	0.88	Yes
HP+BCHP+ST	1281522	212288	6.3	884,683.66	13.24%	0.69	Yes
PV1+BCHP+ST	1303522	237875	5.8	1,119,922.92	15.43%	0.86	Yes
HP+PV1+BCHP+ST	1428522	235365	6.4	973,388.93	13.12%	0.68	Yes

Financial rate of return FRR is calculated for a scenario of investment without a loan from comercial banks for the discount rate of 3% using the Microsoft Excell built in iterative solver. Cost benefit analysis of options with simple pay back period higher than 12 years was ommited from further analysis.

Results of the analysis with the discount rate of 3% for each of the projects are shown in Table 5, and Fig. 4 and 5.

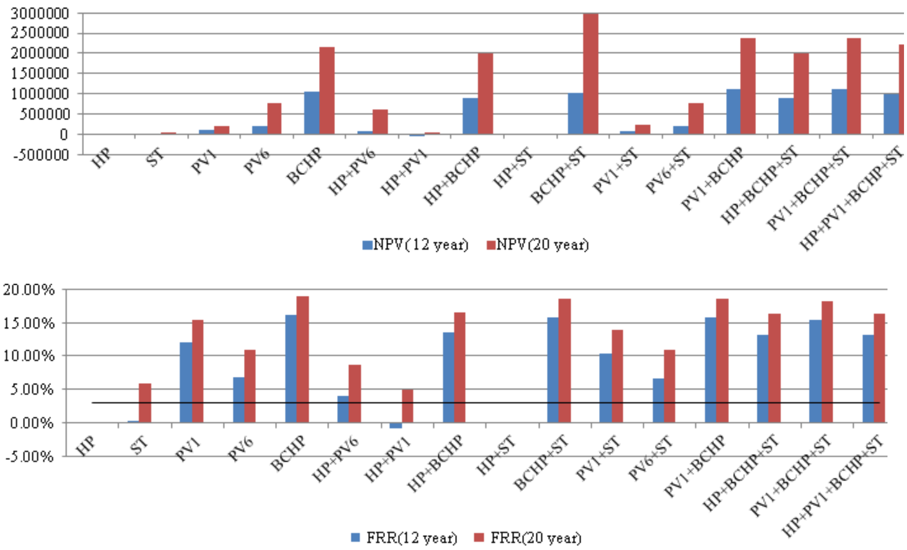

Fig. 4 Results of the cost-benefit analysis (CBA)

According to the results of the CBA, feasibility of the projects was determined. Projects with either negative NPV value at the end of project economic life, negative NPVQ and FRR<d are rated as not feasible.

Cash flow diagrams for each of the analyzed projects with the net cash flow at the end of economic life for each of the project options are given in Fig. 5. The analysis indicated best financial performance of the options including BCHP and PV options.

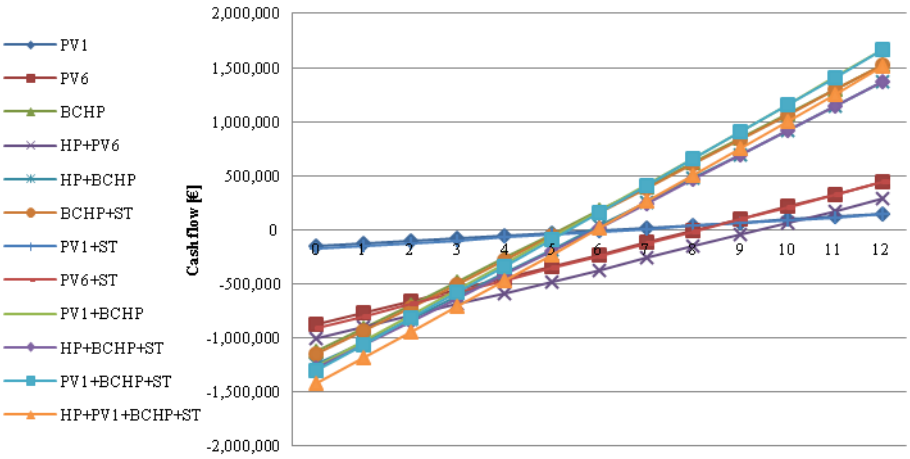

Fig. 5 Cash flow diagrams of the analyzed options

To better present the financial and environmental and energetic background of each of the options, the following profit factors were introduced:

$$P_{NPV,i}=NPV_i/I_i \tag{6}$$

Where: $P_{NPV,I}$ is the NPV performance coefficient, indicating obtained NPV per 1000€ of investment of the *i-th* option; NPV_i is the obtained NPV of the *i-th* investment option, I_i is the investment of the *i-th* option in 10^3€.

$$P_{CO2,i}=S_{CO2,i}/I_i \tag{7}$$

Where: $P_{CO2,I}$ is the CO_2 reduction performance coefficient of the *i-th* option; $S_{CO2,i}$ is the obtained CO_2 saving of the *i-th* investment option in (t), I_i is the investment of the *i-th* option in 10^3€.

$$P_{E,i}=S_{E,i}/I_i \tag{8}$$

Where $P_{E,i}$ is the energy production and saving performance coefficient of the *i-th* option; $S_{E,i}$ is the obtained CO_2 saving of the *i-th* investment option in MWh, I_i is the investment of the *i-th* option in 10^3€.

To determine combined financial, energetic and environmental performance of each of the investment options, a combined investment performance coefficient is introduced as:

$$P_{inv,i}= (P_{CO2,i}+ P_{E,i})/ P_{NPV,i} \tag{9}$$

According to the $P_{inv,I}$ coefficient, investment options are evaluated, and the option with the highest score is pinpointed as an optimal investment option (Fig. 6).

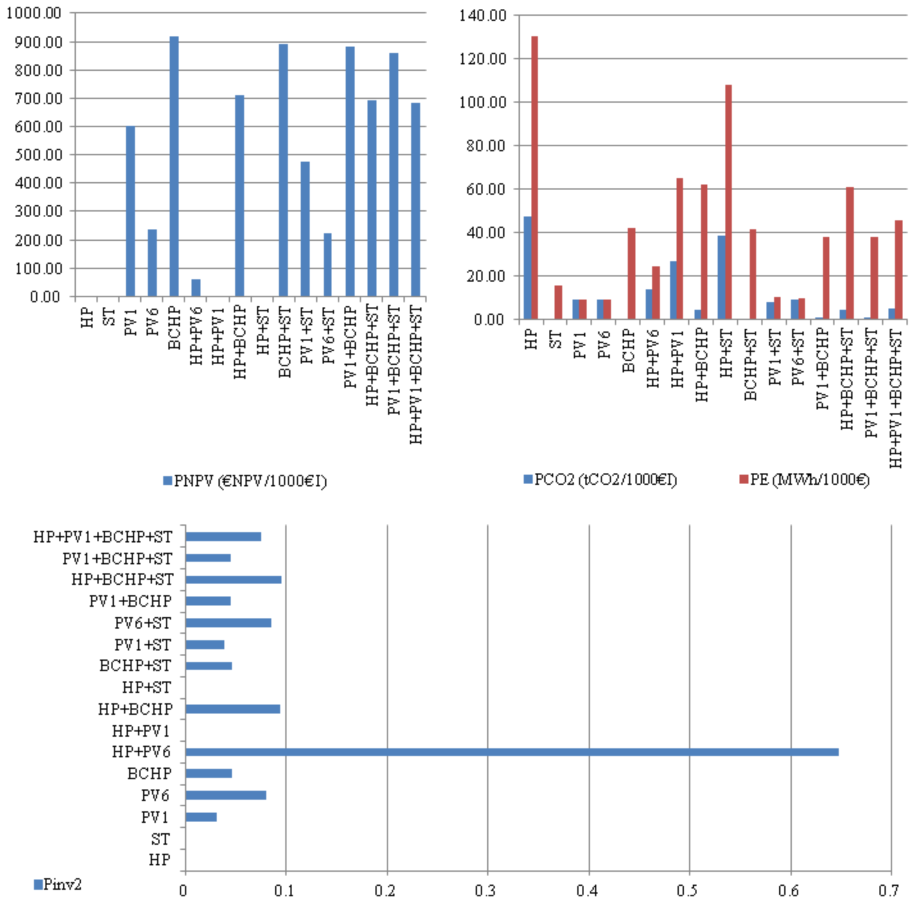

Fig. 6 Combined financial, energetic and environmental evaluation of analyzed energy supply options

According to the typical CBA criteria, investment in energy supply options based on BHCP showed highest cumulative net cash flows at the end of the economic life of the project, greatest NPV and greatest FRR values.

With the introduced coefficient of combined financial, energetic and ecologic performance of analyzed energy supply options, investment option with the highest value of this indicator is chosen as optimal solution based on the introduced criteria. In the analyzed case-study, based on the given criteria, integration of a heat pump for heating in combination with 6 rooftop PV system showed the highest score. This option is considered financially feasible, with the most significant specific energetic and environmental performance per unit of investment.

5. CONCLUSION

This paper addresses the problems of efficient energy supply on live-stock farms. A simple methodology based on average annual performance data is proposed as a tool pinpointing profitable energy supply options with improved energetic and environmental performance.

A case study of an integrated pig farm was analyzed. Energy performance data were collected at a chosen farm, and an energy balance was made. Analysis of costs of energy supply at the farm has shown that 70% of the farms final energy demands can be attributed to heat and 30% to electricity, whereas the electricity consumption is responsible for 70% of the energy related costs. Energy and cost balance data were further used to investigate the potentials for application of more efficient energy supply technologies. The following options were analyzed: 1) application of heat pump for space and sanitary hot water heating; 2) application of flat plate solar collectors for sanitary hot water heating; 3) application of photovoltaic solar collators for electricity production; 4) utilization of organic waste generated at the pig farm to produce biogas, heat, electricity and fertilizer; and 5) integrated options with combined performance of previous energy supply options.

For each of the options, investment cost and annual energy production and savings were estimated and used in the CBA. Based on the results of the CBA, non-feasible options were pinpointed. Options which include biogas cogeneration plant can be considered most profitable, with the greatest NPV and FRR values for the chosen economic project life of 12 years. Since these values represent only financial feasibility of the project, and indicator of energetic and environmental performance of unit of estimated investment was introduced and calculated for options which resulted in positive CBA feasibility. The highest value of this indicator was found for the integrated option where water-water heat pump is used for heat supply and a 6 rooftop PV system is used for electricity production. This option was chosen the best, since it provides greatest energy and CO_2 savings for achieved NPV per unit of investment.

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TEHNO-EKONOMSKA OPTIMIZACIJA SNABDEVANJA ENERGIJOM FARMI STOKE

Stočarstvo predstavlja značajan deo poljoprivrednog sektora Srbije. Ipak, stočni fond na farmama u Srbiji beleži stalni pad u poslednje vreme. Upotreba savremenih tehnologija bi mogla da doprinese konkurentnosti farmi stoke. U ovom radu su analizirane savremene energetski efikasne opcije snabdevanja energijom. Predložena je metodologija za ocenu profitabilnosti opcija snabdevanja energijom, pri čemu se uzimju u obzir i energetsko i ekološko ponašanje razmatranih opcija. Rezultati predložene metodologije prikazani su za primer farme svinja, pri čemu je urađen energetski bilans i izvršena alokacija troškova snabdevanja energijom na farmi. Na osnovu lokalnih resursa, napravljena je procena efekata primene efikasnih tehnologija snabdevanja energijom. Sagledani su i efekti primene integrisanih tehnoloških rešenja.Upotrebom predložene metodologije, izvršena je analiza finansijske izvodljivosti predloženih opcija snabdevanja energijom. Investicija u biogasno kogeneraciono postrojenje je pokazala najveće parametre profitabilnosti. Integrisano rešenje gde se za snabdevanje toplotom koristi toplotna pumpa, a za proizvodnju električne energije sistem fotonaponskih solarnih prijemnika, je pokazalo najbolje energetske i ekološke efekte i finansijsku rentabilnost.

Ključne reči: *farma stoke, efikasno snabdevanje energijom, cost benefit analiza, ušteda energije, smanjenje emisija* CO_2