

The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM), 2026

Volume 41, Pages 38-48

ICRETS 2026: International Conference on Research in Engineering, Technology and Science

Impact of Energy Savings Measures in Slaughterhouse for Premium Meat, Meat Preparations and Subproducts

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Abstract: The study shows an energy audit of a slaughterhouse for the production of premium meat, meat preparations and subproducts. The distribution of energy consumed at the site by individual consumers is shown - energy consumed for refrigeration, ventilation, heating, sanitary hot water and lighting. The distribution of energy consumed for the installed technological equipment at the site is also shown - refrigeration equipment and equipment for meat processing, including for cooking processes. Analysis of energy consumption in the enterprise was carried out, energy saving measures were proposed and a technical and economic analysis was carried out. The indicators energy savings ratio, the percentage of planned energy savings and saved carbon emissions to the environment were calculated. The results of the survey show that the energy savings due to the proposed energy saving measures amount to 37099 kWh per year, the energy savings ratio is 35.5%, the percentage of planned energy savings is 33.3%, and the saved carbon emissions are 30.38 tons of CO₂/year.

Keywords: Energy efficiency, Energy audit, Energy saving measures

Introduction

Subject to mandatory energy efficiency audit in accordance with regulation act in Bulgaria are: large enterprises for the production of goods, large service providers, industrial systems whose annual energy consumption is over 3000 MWh (Ordinance №E-RD-04-3, 2016), (Ordinance №E-RD-04-05, 2016). In addition, many small and medium-sized enterprises perform energy audits in order to obtain financing for new energy-efficient equipment and to optimize and automate their production processes (Ivanov et al., 2021; Kamburova et al., 2017; Iliev et al., 2026).

In food industry enterprises, the aim is to continuously optimize and reduce energy costs, which will lead to an increase in the competitiveness of the enterprise and obtaining a final food product with the lowest possible carbon footprint (Berk, 2009; Georgiev & Kadirova, 2025). In times of uncertain fuel supplies, the rational use of electricity consumed in the enterprise becomes especially important. The peculiarity of production processes in this type of enterprises is that very often in various technological processes we have waste heat flows, the potential of which must be used before they are discharged to the environment (Genné & Derden, 2008), (Wojdalski et al, 2020).

Reducing energy costs is necessarily carried out taking into account the possibilities for supplying energy carriers to the enterprise and complying with the requirements of the cold chain. It's definitely worth it for food products subject to cold processing and cold storage (Abou Elmagd et al, 2017, Fritzson & Berntsson, 2006) . This requires the use of methods for utilizing waste heat in enterprises and the use of heat pumps for heating and hot water for technological needs.

The implementation of the described activities will guarantee the receipt of a quality final product, increasing the competitiveness of the enterprise and increase in the company's profit. The increased level of automation and robotization in production gives the enterprise the opportunity to meet requirements for various quality and

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- Selection and peer-review under responsibility of the Organizing Committee of the Conference

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energy management standards, which subsequently enables it to offer its products to new markets (Baev et al., 2026; Kaloyanov et al, 2026).

Method

The object of the present study for energy efficiency of an industrial system is a slaughterhouse - manufacturer of meat products in Bulgaria. The investment proposal consists of an investment project for the reconstruction of an existing slaughterhouse and the construction of a new building for cutting premium meat, meat preparations and subproducts and the creation of a yard with a shed for pre-slaughter rest of large excess cattle and a circle for pushing the animals. The main production processes are: reception of live calves, meat production and meat processing with a capacity of up to 480 cattle per year and the cutting of the same into premium meats, meat preparations and subproducts.

The products that the company produces are:

- Large cuts of meat – 26880 kg/year
- Dry-aged cuts of meat and filleted meat – 26880 kg/year
- Head cheese – 13440 kg/year
- Subproducts – 14400 kg/year

In slaughterhouse the following technological processes are carried out:

- Heating equipment;
- Ventilation equipment;
- Hot water tanks;
- Lighting equipment;
- Technological equipment.

The choice of energy-saving measures, guaranteeing the highest value energy savings in the form of energy and low carbon emissions released into the environment, requires a detailed energy analysis of the enterprise's energy costs.

Energy efficiency audit of the industrial system is related to the implementation of the following activities:

- inspection of the industrial system;
- collection and processing of primary information on the functioning of the industrial system and energy costs;
- analysis of the existing state and energy consumption;
- determination of the baseline of energy consumption;
- analysis of energy use systems;
- development of energy-saving measures to increase energy efficiency;
- valuation of each of the measures;
- analysis and assessment of the annual amount of CO₂ emissions saved as a result of developing measures to increase energy efficiency.

The determination of specific electrical energy consumption (SEEC) is determined by the formula:

$$SEEC = \frac{EEC}{M}$$

where: EEC is electrical energy consumption, kWh/ year and M is manufactured output, kg/ year.

The net present value (NPV) of energy saving measure is calculated by the formula:

$$NPV = \sum_{i=1}^n \frac{B}{(1+r)^i} - I_0$$

$$NPV = B \cdot \frac{1 - (1 + r)^{-n}}{r} - I_0$$

where: n – technical/ economic life of the facility, years, r - real interest rate, % and I_0 – investment costs, €. Coefficient of net present value (NPVQ) is calculated according to the formula:

$$NPVQ = \frac{NPV}{I_0}$$

The pay back period (PB) of energy saving measure is determined by the formula:

$$PB = \frac{I_0}{B}$$

Energy savings ratio (ESR) is determined by the formula:

$$ESR = \frac{TES}{TC} \cdot 100, \%$$

where: TES = B – net annual energy savings, kWh/year, TC - energy consumption of equipment covered by energy saving measures, kWh/year.

Energy savings potential (ESP) is calculated by the formula:

$$ESP = \frac{TES}{TC^*} \cdot 100, \%$$

where: TES = B – net annual energy savings, kWh/year, TC^* - energy consumption of all equipment installed at the slaughterhouse, kWh/year. The parameters of the energy efficiency measures are calculated based on the following data:

- Carbon dioxide (CO₂) emissions of electricity are 0.819 kgCO₂/kWh;
- Price of electricity supply – 0.22 €/kWh;
- Duration of technical/economic life of the facility is n = 15 years;
- Real interest rate, r = 3.00 %.

The purpose of the study is to propose specific energy-saving measures for the slaughterhouse, and to assess the saving effect and the ecological impact of the energy-saving measures on the environment.

Results and Discussion

General Characteristics of the Slaughterhouse

General Information

The data from the energy audit will serve for the complete reconstruction and modernization of an existing slaughterhouse, the construction of new premises for cutting premium meat and the separation of a yard with a shed for pre-slaughter rest of large ruminants, a circle-type device for painlessly pushing the animals and a ramp with a scale.

For the proper functioning of the technological process, the project provides the following premises: main room, waste processing room and meat cutting room, rest room with toilet and shower system. The main working room is conditionally divided into two zones - dirty and clean, equipped with a pipeline with positions for sequential processing of the animal carcass. Sterilizers for knives and a contactless hand sink are provided, as well as a sink for washing internal packaging necessary for the production process.

1) The dirty area consists of:

- calf stunning position;
- bleeding position – bath;
- skinning position;
- skinning position – mechanical with a hoist up to 1.5 tons;
- head and leg separation position;
- gutting position with gut contents – trolley;

2) The clean area consist of:

- liver separation position;
- carcass halving position;
- liver veterinary inspection position;
- sample taking position for testing;
- calf carcass halving position;
- corner for washing inner packaging in a three-well sink;
- corner for washing hands with a contactless sink;

3) Room for processing of viscera with ventilation and corners used for:

- gut processing with a workbench and sink;
- corner for processing calf heads, legs with a workbench and sink;
- a corner for processing tripe – machine;
- a corner for washing trolleys with a water tap.

4) Warehouse used for packaging, trays, foil, labels, spices and edible intestines, equipped with racks – a rack for packaging, trays, labels, foil and a rack for spices;

5) A room for slicing and producing minced meat and meat preparations;

A pipe route is provided in it, which comes from cold room for cooling the carcass. A work table for slicing the carcass, a work table for packaging in trays, as well as a wolf machine, a mixer and a molding machine are provided.

6) Auxiliary premises:

A cold room for cooling and storing carcass meat, heads, legs and waste, equipped with a pipe path and racks for separate storage of packaged waste;

Dry agers for ripening carcass meat;

A cold room for storing cuts, minced meat and meat preparations;

A veterinarian's office;

A dispatch room where the pipe path ends.

A position is designated for manual foiling of carcass meat. The carcass meat is weighed on an electronic scale.

Meat intended for canning is processed in a separate room, where dosing, mixing with spices and vegetables, heat treatment, filling into jars and sealing take place. An autoclave compartment is also provided, where sterilization of closed jars takes place, and there is also a separate area for blown jars. A packing room /stretching of jars/ and labeling is provided. For the finished canned products, a finished product warehouse, warehouses for jars, caps, labels, a room for inspection and rinsing of jars are provided. A protective sleeve is installed at the exit to protect the meat from contamination when loading into specialized transport. A storage area is formed, located under a canopy on a concrete platform with a channel grid and a water tap.

Two sanitary and household units of the sanitary filter type will be built with a changing room for outer clothing, showers, a changing room for work clothes, a rest room and toilets. The sanitary filter for workers in the dirty area of the slaughterhouse is separate from the one for the clean area and processing. In order to improve the personal hygiene of the staff, a foot disinfection bath and hand sanitizer are provided before entering the work premises. The sinks in the production premises will be contactless.

Water Supply and Sewage

The water supply of the enterprise will be carried out by an existing water supply system of the local water supply company, for which there is an open lot and an existing water supply system, and water suitable for drinking will be used. The necessary water will be for watering the animals, servicing the slaughterhouse, the cutting room for premium meat and sanitary and household needs. There is no need to build new water facilities. No treatment is planned for household waste. Waste from the production process will be stored in a refrigerator until it is handed over to a manure truck, and some of it, which is suitable for food for rare birds of prey, will be provided to environmental protection organizations caring for eagles, vultures, etc. Animal manure will be transported for storage and composting in an existing manure pit located within the farm. After composting, it will be used to fertilize fields and pastures, meadows and meadows managed by the client of the investment proposal.

Power Supply

The equipment of the enterprise envisaged in the project operates only with electricity. The electricity will be supplied from a substation located near the property.

Description of Production Process

The products produced by the enterprise are:

- Large local cuts;
- Meat cuts for dry aging and filleted meat in vacuum packaging;
- Meat preparations /minced meat, burgers, beef sausage, by-product sausage/;
- Canned meat in jars 0.700 kg. with twist-off caps.

The technological process in the enterprise is as follows:

Live cattle are brought by self-propelled and special truck to a pre-slaughter box from the farm owned by the investor or from partner farms, having previously been weighed on an animal scale. An isolation box is provided for cattle in case of doubts regarding the health condition of the animals. Large ruminants /in this case cattle/ are kept in a yard with a shed for pre-slaughter rest at the slaughterhouse 24 hours before slaughter, without feeding, but are watered regularly. Cattle from the pre-slaughter box enter a calf stunning box. Here, using a stunning gun with an unattached bolt, they are stunned, with the gun's stinger directed into the frontal skull bone. The bleeding of the cattle occurs immediately after stunning the animal and no later than 1-2 minutes after stunning. The following technological scheme of meat production is established:

- a/ Termination of life: stunning before slaughter, slaughter and bleeding;
- b/ Separation of the head and removal of the skin;
- c/ Removal of internal organs;
- d/ Cutting the carcass into quarters;
- e/ Dressing.

The receipt of products will be subject to systematic quality control. The full quality management system will ensure compliance with the norms regarding origin and production. The control system will cover the entire production chain, thus ensuring the traceability of the products. The enterprise will process premium meat, meat preparations and subproducts in a five-day working week. The production base is planned to operate in a single-shift mode with an 8-hour working day. The number of personnel employed in the enterprise is 10 people.

Energy Consumption Analysis

The enterprise will use one energy carrier – electricity.

Electricity

The power supply of the enterprise will be carried out from the transformer station located to the north in the former farmyard.

Heating

For the heating needs of the building, convector units operating on electricity have been proposed and selected, operating with a mechanical thermostat for temperature control in the rooms. Heating units are provided in the premises for meat production, sanitary and household premises and offices of the enterprise.

Table 1. Installed electrical power of the facilities in the slaughterhouse

Name	Value	Power, kW	Total kW	power, power,	Operating hours, hours/year	Annual consumption, kWh/ year
Technological equipment						
Refrigeration unit 1 Qo=1.45 kW	1	0.93	0.93		2925	2720
Refrigeration unit 2 Qo=1.8kW	1	1.40	1.40		2925	4095
Refrigeration unit 3 Qo=2.6kW	1	2.00	2.00		2925	5850
Trip cleaning machine	1	0.85	0.85		1040	884
Bone chest freezer	1	0.35	0.35		1040	364
Salmon chest freezer	1	0.35	0.35		1040	364
Blood refrigerator	1	0.18	0.18		1039	187
Knife sterilizer	3	0.75	2.25		1040	2340
Half-cutting saw	1	1.20	1.20		520	624
Electric hoist	1	2.50	2.50		1040	2600
Stun gun	1	0.50	0.50		520	260
Chilled carcass meat scale	1	0.15	0.15		393	59
Warm carcass meat scale	1	0.15	0.15		393	59
Undercounter refrigerator	1	0.33	0.33		1039	343
Spice grinder	1	0.50	0.50		390	195
Filler	1	1.50	1.50		1040	1560
Shaping machine for meat blanks	1	1.00	1.00		1040	1040
Mixer	1	0.75	0.75		1040	780
Wolf machine	1	0.36	0.36		1039	374
Bone chest freezer	1	0.68	0.68		1040	707
Cooking pot	1	24.00	24.00		1300	31200
Bone saw	1	1.50	1.50		1300	1950
Total usable power			43.43			58555
Heating equipment						
Electric convector 2000W	10	2.00	20.00		1300	26000
Total usable power			20.00			26000
Ventilation equipment						
Fans for sanitary premises	4	0.06	0.24		521	125
General exchange ventilation fans	2	0.15	0.30		2600	910
Exhaust ventilation fans	1	0.35	0.35		2600	780
Total usable power			0.89			1815
Hot water						
Hot water boiler V= 150 l, Nel=2.5kW/220V	2	2.50	5.00		4000	20000
Total usable power						20000
Lighting equipment						
LED lighting fixtures 2x36W for open ceiling mounting, IP44	28	0.072	2.02		1000	2020
Evacuation lighting fixtures - illuminated arrows with power LL 2x8W	8	0.016	0.13		1000	130
Lighting fixture type spotlight with MHL 100W, IP65, wall mounting	10	0.100	1.00		3000	3000
Total usable power			3.15			5150
Total power			72.47			111520

Ventilation

For the ventilation needs of the premises in the building, general exchange ventilation is provided. The released harmful substances – vapors, odors, etc. are removed from the premises by local exhaust ventilation. For the sanitary units, independent exhaust ventilation with a check valve, wall or ceiling mounting is provided. The exhaust air is taken to the roof of the building through ventilation verticals made of round PVC pipes.

Hot Water

For the preparation of hot water for technological and sanitary needs, two volumetric hot water tanks with a single capacity of 150 liters (total volume 300 liters), equipped with an electric heater, are planned.

Technological Processes

The equipment used to carry out all technological processes consumes electrical energy. According to the technology of the processes taking place in the enterprise, the corresponding number of working hours has been determined for the different groups of equipment, with 249 working days per year (5 days/ week). In Table 1 installed electrical power and annual consumption of the facilities in the slaughterhouse are shown. According to the data from Table 1, the annual electricity consumption of the enterprise is determined to be 111520 kWh/year. On Figure 1 a percentage distribution of electrical energy consumed in slaughterhouse is shown in Figure 1..

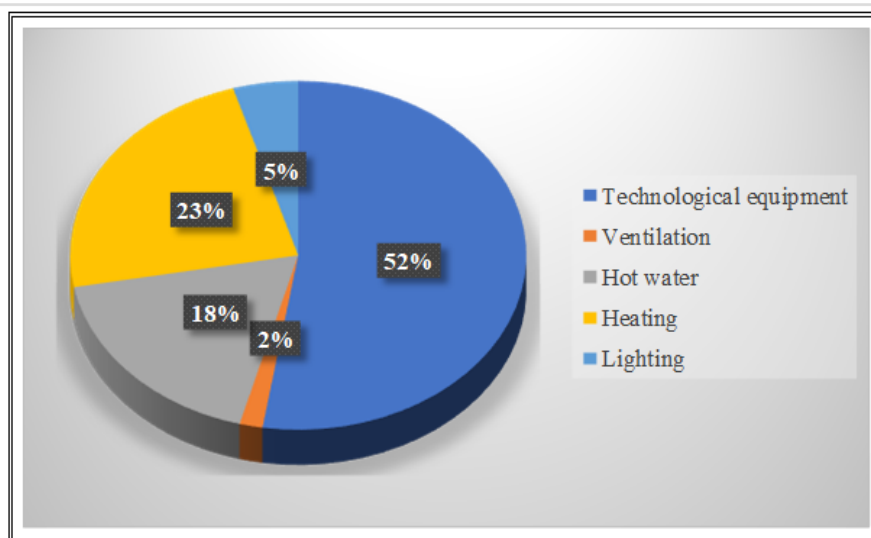


Figure 1. Distribution of electrical energy consumed in slaughterhouse

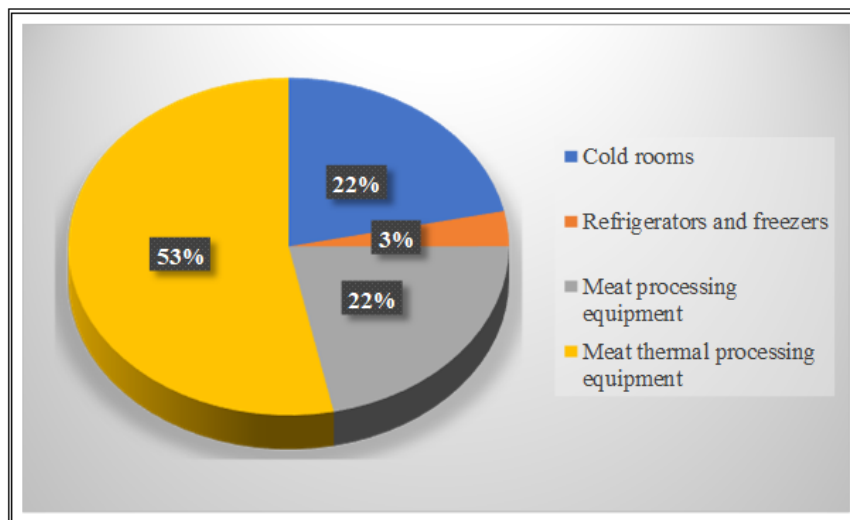


Figure 2. Distribution of electrical energy consumed by technological equipment

The data shows that 52 % of electrical energy in slaughterhouse are consumed by technological equipment - refrigeration equipment, cooking pot, etc. On Figure 2 a percentage distribution of electrical energy consumed by technological equipment is shown in Figure 2. The data shows most of electrical energy for technological equipment is consumed by meat thermal processing equipment (cooking pot) and refrigeration installation for cold rooms.

Proposed Energy Saving Measures

After analyzing the energy consumption of the slaughterhouse, we must focus our attention on taking energy-saving measures in the following areas:

- implementation of measures reducing the consumption of electrical energy of the technological equipment - equipment for cooking processes (cooking pot for head cheese);
- implementation of measures reducing the consumption of electrical energy for heating the premises;
- implementation of measures reducing the consumption of electrical energy for heating hot water for sanitary and technological needs;

The following conclusions can be made:

- For heating the premises of the meat production premises, sanitary and household premises and offices, electric convectors are used, which generate high energy costs;
- To provide hot water for sanitary and technological needs, a conventional system operating with electrical energy has been selected, which generates high energy costs for water heating;
- There is a possibility of using waste heat from the refrigeration machines, serving cold rooms.

The following energy saving measures (ESM) are proposed:

ESM 1: Installation of inverter air conditioning installations (split systems) of high energy class, operating on principle of a refrigeration cycle with direct evaporation of the refrigerant in the meat production premises, sanitary and household premises and offices. According to expert assessment and manufacturers' data, air conditioning installations of this type can achieve 60% electricity savings compared to electric convectors;

ESM 2: Installation of a heat pump hot water tank with a capacity of 300 l., operating on the principle of a refrigeration cycle with direct evaporation of refrigerant. The heat pump tank is a volumetric tank with a capacity of 300 l. with a built-in coil, which is a condenser of the integrated heat pump system. The refrigerant transfers heat to the water in the tank at the cost of low energy costs. According to expert assessment and manufacturer data, air conditioning systems of this type can achieve 60% electricity savings compared to the electricity consumed by a standard volumetric tank with an electric heater of the same capacity;

ESM 3: Installation of hydraulic modules for utilizing waste heat from the condensers of the refrigeration machines for cold rooms. The hydraulic modules are a plate heat exchanger refrigerant - water with a pump and automation. The module is connected to the refrigeration system of the respective cold room, by being connected between the refrigeration compressor and the air-cooled condenser of the refrigeration system. The hot vapors from the refrigeration compressor enter the plate heat exchanger, where they are cooled by water, which is heated to a temperature of about 60 °C and can be used as hot water for the cooking processes (for a cooking pot for head cheese). When hot water is needed, the refrigeration installation works with the water-cooled plate heat exchanger, and when there is no need for it, the air-cooled condenser fan of the refrigeration installation is turned on and the heat is released to the environment. According to expert assessment and manufacturers' data, 50% of the waste heat from the refrigeration condensers can be utilized through hydro modules for waste heat utilization. Utilization of waste heat leads to savings of the same amount of electrical energy consumed by the refrigeration machines for cold rooms. This is equivalent to 16% savings of electrical energy consumed by the refrigeration machines.

Technical and Economic Analysis of Energy Saving Measures

A comparison of specific energy consumption before and after energy saving measures is shown in Table 2.

Table 2. Comparison of specific costs before and after energy saving measures

	Before ESM			After ESM			
	Energy consumption for related with measures activities	Produced output	Specific energy consumption	Corrected energy consumption for related with measures activities	Energy consumption for related with measures activities	Produced output	Specific energy consumption
	kWh/year	kg/year	kWh/kg	kWh/year	kWh/year	kg/year	kWh/kg
ESM 1	26000	81600	0.32	26000	10400	81600	0.13
ESM 2	20000	81600	0.25	20000	8000	81600	0.10
ESM 3	58555	81600	0.72	58555	49056	81600	0.60
Total:	104555	81600	1.28	104555	67456	81600	0.83

Calculation whether the measures are cost-effective (values of NPV, NPVQ) and their payback period (PB) are presented in Table 3.

Table 3. Assessment of the economic effectiveness of energy saving measures

	B, kWh/year	B, €/year	I ₀ , €	PB, years	NPV, €	NPVQ, -
ESM 1	15600	3432.00	6300.00	1.83	+ 34 670.99	5.50
ESM 2	12000	2640.00	3800.00	1.44	+ 27 716.15	7.29
ESM 3	9499	2089.78	6250.00	2.99	+ 18 697.66	2.99
Total:	37099	8161.78	16350.00	2.00	-	-

The values of energy saving ratio (ESR), energy saving potential (ESP) and ecological equivalent (t CO₂/ year) of energy saving measures are shown in Table 4.

Table 4. ESR, ESP and ecological equivalent of energy saving measures

Energy saving measures	Energy carrier	Energy savings			Ecological equivalent t CO ₂ / year
		TES, kWh/year	ESR, %	ESP, %	
ESM 1	electricity	15600	60.0	-	12.77
ESM 2	electricity	12000	60.0	-	9.83
ESM 3	electricity	9499	16.0	-	7.78
Total:	-	37099	35.5	33.3	30.38

Conclusion

The energy audit of the slaughterhouse showed the following results:

- After implementing the described measures, annual savings of 37099 kWh of electricity are expected, with an ecological equivalent of 30.38 tons of CO₂ emissions saved. The total annual savings from the reduced consumption of electricity are in the amount of 8161.78 €;
- Energy savings ratio ESR is 35.5%, the percentage of planned energy savings PES is 33.3%;
- The payback periods of the measures PB vary from 1.44 to 2.99 years, and for the entire package of energy-saving measures the payback period is 2.00 years;
- The net present value NPV of each of the measures is a positive value, this means that all energy-saving measures are economically profitable;
- The sequence for implementing the measures according to the values of the net present value coefficient NPVQ should be: first implemented measure is ESM 2 (NPVQ = 7.29), followed by ESM 1 (NPVQ = 5.50) and ESM 3 (NPVQ = 2.99);

Scientific Ethics Declaration

* The author declares that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the author.

Conflict of Interest

* The author declares that there is no conflict of interest

Funding

*This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Acknowledgements or Notes

* This article was presented as an oral presentation at the International Conference on Research in Engineering, Technology and Science (www.icrets.net) held in Batumi/Georgia on July 09-12, 2026.

* The author thanks the reviewers who evaluated the paper, the conference organizing committee, and the conference scientific committee.

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To cite this article:

Valchev, S. (2026). Impact of energy savings measures in slaughterhouse for premium meat, meat preparations and subproducts. *The Eurasia Proceedings of Science, Technology, Engineering and Mathematics (EPSTEM)*, 41, 38-48.