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TECHNOLOGICAL AND MARKET ASPECTS OF MEAT PRODUCTION

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Purpose: The article presents a detailed analysis of the development of the European meat market. Based on statistical data for 2007-2023, a forecast of the sector's development until 2030 was prepared. The production of pork, poultry, beef, mutton and goat meat in all European Union countries was analyzed in detail. Based on statistical data, a forecast of carbon dioxide emissions and water consumption in the production process was prepared. The case study presents the characteristics of a selected meat plant from the point of view of the technological process implemented there and the impact of the meat plant on the environment. The main factors affecting the environment were also analyzed, i.e. the amount of air pollution emissions, the amount of waste generated and the amount of sewage discharged. The concentrations of pollutants released into the air were calculated for the installations operating in the plant.
Design/methodology/approach: The subject of observation and assessment were industry reports, technology block diagrams and calculations based on those provided by the examined business entity. The presentation and detailed analysis of available data took the form of tables and bar charts, which were justified descriptively. The source of information for this study was the literature on the subject, statistical data and numerous studies by the Central Statistical Office and Eurostat, reports in the industry section, an interview with the owner of the meat plant, analysis of source documents provided by the examined business entity as well as the authors' own observations. The characteristics and sales market of the company were examined. The machinery of the examined company and the level of investments made over the years were also analyzed.
Findings: The examined production plant produces goods for 12 months a year. It processes 2500 tons of raw material annually, or ca. 48 tons of livestock per week. The specific nature of the plant requires continuity of production. The article presents the characteristics of the production plant, the production process and the plant's technological and production facilities. The impact of the production process at the plant on the environment was analyzed in terms of applicable legal aspects and emission limits.
Research limitations/implications: The analysis of the meat production sector and development forecasts was carried out for all European Union countries. The impact of the meat production plant was analyzed for a selected entity located in Poland.
Keywords: production, technology, production plant, forecast.
Category of the paper: research paper.

1. Introduction

The market for animal products is one of the most important and fastest growing segments of the global economy. More and more meat products are produced every year (Pethick et al., 2021; Caputo et al., 2024). The reason is primarily the rapid growth of GDP (Gross Domestic Product) and the increase in the world population (Wanassi et al., 2023; Gilland, 2002).

The meat industry is constantly developing, which is associated with an increase in the amount of waste produced (Kaul et al., 2024; Flaibam, 2024). The production of processed meat generates ca. 18 million tons of waste annually (Sobczak, Błyszczek, 2009). The by-products pose a serious threat to the environment for both sanitary and odor-generating reasons. Chemical compounds such as hydrogen sulfide, aldehydes, organic acids and ammonia are produced (Wojdalski, Dróżdż, 2004). Another problem is inappropriate storage, which may lead to contamination of soil and groundwater through the penetration of leachates, grease and salts containing sulfates, nitrates and chlorides (Fathollahzadeh et al., 2024; Santos et al., 2023). The sewage is characterized by a high content of organic compounds, which range from 51-81% in relation to the dry matter. Meat processing plants generate mainly water that is used for technological and technical purposes. Domestic waste, or municipal waste, originates from mechanical workshops and other places of technical service of plants. Sewage in each department of the plant is characterized by different specificity of basic components as well as load - physical, microbiological or chemical (Wojdalski, Dróżdż, 2006). Gaseous pollutants include vapors, flue gases and fumes.

Entrepreneurs, under pressure from environmental organizations, are forced to carry out a disposal process that will allow to avoid contamination of air, land and water bodies (Manika et al., 2022; Vinci et al., 2024). Ignoring this problem has serious consequences that may affect human health and the surrounding environment. Such an undertaking is expensive, but it is the only effective way to produce environmentally safe meat. In recent years, the so-called concept of "clean production" has emerged, thanks to which all products began to be considered as potential substitutes for other valuable products. Some waste from the meat industry, e.g. meat and bone meal, can be used as a source of phosphorus.

Before waste is reused, it must first be neutralized and processed (Sigala et al., 2024; Mavai et al., 2025). Currently, only 37% of by-products are utilized, approximately 30% are discharged into sewage and 33% are landfilled. Animal waste, such as meat, meat-and-bone or carrion meals, is used as a fuel additive and for the production of feed. The process of utilization of by-products is a very important stage of the entire animal production chain. Inappropriate destruction or ignorance on this topic may lead to serious consequences for human health, life and the environment. The disposal of by-products depends on their type.

The objective of the manuscript is to present the impact of a meat processing plant on the environment. In the first step, an analysis was carried out and a forecast was prepared for the development of the meat market in the European Union. Then, using the example of a selected

food industry company located in Poland, the highest concentrations were calculated for the installations operating in the plant, and an analysis was made of the harmfulness of dust and gases introduced into the air by the plant.

2. Analysis of the meat market in the European Union

The European Union had a significant livestock population in 2018. There were almost 88 million cattle, 149 million pigs, 84.11 million sheep and 11.85 million goats (Augère-Granier, 2020; Vinci, 2022). However, the breeding of these animals has been dominated by a few large Member States. Almost a quarter (24%) of cattle farms belonged to France, and 25% to Germany and the United Kingdom. Spain is the leader in pig breeding - as much as 21% of the population originates from it. Germany has a slightly smaller share - 18%. One third comes from such countries as: France, Denmark, the Netherlands and Poland. The United Kingdom and Spain account for as much as 46% of all sheep in the European Union. Right behind them is Romania, which breeds 10 out of 84 million sheep. More than half, as much as 54% of goats in the European Union are owned by Greece and Spain. As in the case of sheep, Romania is in the third place (13% goats).

Populations of all livestock species have declined over the past decade. In 2023, 133 million pigs, 74 million cattle, 58 million sheep and 11 million goats were kept in the EU (Farmer, 2023). A detailed analysis of changes in animal production is presented below.

2.1. Pork production

Production in the European Union is based mainly on pork, which has held a dominant position in overall consumption for many years both in Poland and across Europe (Agri-Food Markets, 2024). It accounts for more than half of the entire meat production. Based on Eurostat data, 23.9 million tons of pork were produced in the EU in 2018. Although it is 0.9% less than in 2017, compared to 2012 and 2013, it increased by over 1 million tons.

Table 1 shows that in the European Union the dominant pork producing country in 2023 is Spain, which accounts for over 25% of European production - ca. 34 million pieces (Agricultural production - livestock and meat, 2022). With each passing year, production in this country increases. Second place is taken by Germany, which, contrary to the leader, produces less and less pork. Compared to 2019, in 2023 Germany produced 4.68 million pieces fewer. Poland is just behind France, producing over 9.62 million pieces in 2023, 2.65 million pieces fewer than the French, who are third in Europe. Despite this, the production of pork has been declining in European Union countries for years in favor of poultry. Profitability also has an impact - the production volume depends on grain prices (Szymańska, 2006). There is seasonality on the meat market, i.e. periods when supply is lower than demand.

Table 1.
Pork population in European Union countries in 2019-2022 (million units)

Area	Year			
	2019	2020	2021	2022
European Union - 27 countries (from 2020)	143.15	145.91	141.68	134.41
Belgium	6.09	6.22	6.04	5.75
Bulgaria	0.49	0.59	0.69	0.60
Czechia	1.51	1.55	1.49	1.33
Denmark	12.73	13.39	13.15	11.54
Germany	26.05	26.07	23.76	21.37
Estonia	0.30	0.32	0.31	0.27
Ireland	1.61	1.68	1.71	1.57
Greece	0.73	0.74	0.76	0.74
Spain	31.25	32.80	34.45	34.07
France	13.51	13.39	12.94	12.18
Croatia	1.02	1.03	0.97	0.95
Italy	8.51	8.54	8.41	8.74
Cyprus	0.35	0.36	0.36	0.33
Latvia	0.31	0.31	0.33	0.31
Lithuania	0.55	0.58	0.57	0.52
Luxembourg	0.08	0.08	0.08	0.07
Hungary	2.63	2.85	2.73	2.56
Malta	0.04	0.04	0.04	0.03
Netherlands	11.92	11.54	10.87	10.71
Austria	2.77	2.81	2.79	2.65
Poland	11.22	11.73	10.24	9.62
Portugal	2.26	2.25	2.22	2.18
Romania	3.83	3.78	3.62	3.33
Slovenia	0.24	0.23	0.22	0.20
Slovakia	0.59	0.54	0.45	0.38
Finland	1.06	1.10	1.09	1.00
Sweden	1.48	1.39	1.37	1.42
Iceland	0.04			0.02
Switzerland	1.35	1.32	1.37	1.35
Bosnia and Herzegovina	0.54	0.55	0.57	0.47
Montenegro	0.02	0.03	0.02	0.18
North Macedonia	0.14	0.16	0.19	0.18
Albania	0.18	0.16	0.16	0.14
Serbia	2.90	2.98	2.87	2.67
Kosovo (under United Nations Security Council Resolution 1244/99)	0.04	0.05	0.05	0.05

Source: Author's own study based on statistical data (Agricultural production - livestock and meat, 2022).

2.2. Poultry production

Poultry are domesticated bird species such as chickens, geese, turkeys and ducks. Broilers are slaughtered most often due to their short time of gaining weight. The duration of breeding is only 2 months. Thanks to this, large-scale breeding is very profitable (Gardenlux, 2024).

It is estimated that the EU produced 13.0 million tons of poultry meat in 2022, corresponding to an estimated decline of 1.5% compared to the quantity recorded in 2021. This decline should be seen in the context of a strong upward trend in production until 2020. The level of poultry meat production in 2022 remained 3.2 million tons higher than in 2007 (Agricultural production…, 2022).

In 2022, the main producers of poultry meat in the EU were Poland (21.0% of production in the EU, 2.7 million tons), Spain (12.6% – 1.6 million tons), Germany (11.9% – 1.5 million tons), France (11.6% – 1.5 million tons) and Italy (9.3% – 1.2 million tons). Contrary to the general trend, poultry meat production in Poland increased rapidly (by 7.5%) to a new record in 2022, and in Spain it remained relatively stable (by +0.6%). In contrast, production levels were much lower in France (-8.7%) and Italy (-11.8%).

2.3. Beef production

Beef production in the European Union is almost half of pork production. It amounted to almost 74 million pieces in 2023. Table 2 shows that the dominant country is France, which accounts for one fifth of the total production (16.99 million pieces). Secondly, Germany produces 11 million pieces, and Poland produces less than 6.45 million pieces. Data provided by Statistics Poland show that the decrease in the total number of cattle herds compared to 2022 resulted from a decrease in the population of all herd age groups except cattle over 2 years old (excluding cows). One fourth of the beef produced in 2023 will belong to Ireland, Spain and Italy (ca. 6 million pieces each). In Germany alone, production has decreased by 6 million pieces of beef over the last four years. In other countries, production has increased or remains at a similar level (Topagrar, 2024).

Table 2.
Cattle population in European Union countries in 2019-2022 (million units)

Area	Year			
	2019	2020	2021	2022
European Union - 27 countries (from 2020)	77.16	76.55	75.71	74.81
Belgium	2.37	2.34	2.31	2.29
Bulgaria	0.53	0.59	0.61	0.58
Czechia	1.37	1.34	1.36	1.39
Denmark	1.50	1.50	1.48	1.47
Germany	11.64	11.30	11.04	11.00
Estonia	0.25	0.25	0.25	0.25
Ireland	6.56	6.53	6.65	6.55
Greece	0.53	0.63	0.61	0.58
Spain	6.60	6.64	6.58	6.46
France	18.17	17.82	17.33	16.99
Croatia	0.42	0.42	0.43	0.42
Italy	6.38	6.40	6.28	6.05
Cyprus	0.07	0.08	0.08	0.08
Latvia	0.40	0.40	0.39	0.39
Lithuania	0.63	0.63	0.63	0.64
Luxembourg	0.19	0.19	0.19	0.19
Hungary	0.91	0.93	0.91	0.89
Malta	0.01	0.01	0.01	0.01
Netherlands	3.72	3.69	3.71	3.75
Austria	1.88	1.86	1.87	1.86
Poland	6.26	6.28	6.38	6.45
Portugal	1.67	1.69	1.64	1.58
Romania	1.92	1.88	1.83	1.83
Slovenia	0.48	0.49	0.48	0.46
Slovakia	0.43	0.44	0.43	0.43

Cont. table 2.

Finland	0.84	0.84	0.83	0.82
Sweden	1.40	1.39	1.39	1.39
Iceland	0.08	0.08		0.08
Switzerland	1.53	1.52	1.53	1.54
Bosnia and Herzegovina	0.43	0.43	0.34	0.34
Montenegro	0.08	0.08	0.07	0.42
North Macedonia	0.22	0.22	0.18	0.17
Albania	0.42	0.36	0.34	0.30
Serbia	0.90	0.89	0.86	0.80
Türkiye	17.87	18.16	18.04	17.02
Kosovo (under United Nations Security Council Resolution 1244/99)	0.26	0.26	0.26	0.25

Source: Author's own study based on statistical data: (Agricultural production - livestock and meat, 2022).

2.4. Goat meat and mutton production

In 2023, 70 million pieces of goat meat (11.26 million pieces) and mutton (59.01 million pieces) were produced. It was almost 4 million pieces fewer than in 2019 (Eurostat, 2024). Tables 3 and 4 show that the vast majority of sheep and goat meat production in the European Union in 2023 came from five Member States. For mutton, these were Spain (24.4%), France (11.1%), Italy (11.1%), Romania (17.3%) and Greece (12.5%). Nearly 75% of the total mutton production in the EU originated from these countries. Greece also recorded a slight decrease over the last four years (12%).

Table 3.
Mutton population in European Union countries in 2019-2022 (million units)

Area	Year			
	2019	**2020**	**2021**	**2022**
European Union - 27 countries (from 2020)	62.47	61.46	60.45	59.01
Belgium	0.12			0.11
Bulgaria	1.28	1.31	1.20	1.10
Czechia	0.21			0.17
Denmark	0.14			0.13
Germany	1.56	1.48	1.51	1.52
Estonia	0.07			0.06
Ireland	3.81	3.88	3.99	4.02
Greece	8.43	7.72	7.69	7.38
Spain	15.48	15.44	15.08	14.45
France	7.11	7.00	6.99	6.60
Croatia	0.66	0.66	0.65	0.64
Italy	7.00	7.03	6.73	6.57
Cyprus	0.32	0.33	0.35	0.34
Latvia	0.10	0.09	0.09	0.09
Lithuania	0.15	0.14	0.14	0.14
Luxembourg	0.01			0.01
Hungary	1.06	0.94	0.89	0.87
Malta	0.01	0.01	0.01	0.01
Netherlands	0.76	0.71	0.73	0.72
Austria	0.40	0.39	0.40	0.40
Poland	0.27			0.27
Portugal	2.22	2.30	2.24	2.27
Romania	10.36	10.28	10.09	10.25
Slovenia	0.11			0.12

Cont. table 3.

Slovakia	0.32			0.30
Finland	0.14			0.13
Sweden	0.37	0.37	0.35	0.34
Iceland	0.42	0.40	0.39	0.37
Bosnia and Herzegovina	1.01	1.01	1.03	1.00
Montenegro	0.18	0.18	0.17	1.76
North Macedonia	0.68	0.63	0.63	0.65
Albania	1.76	1.56	1.48	1.37
Serbia	1.64	1.69	1.70	1.72
Türkiye	37.28	42.13	45.18	44.69
Kosovo (under United Nations Security Council Resolution 1244/99)	0.19	0.21	0.21	0.20

Source: Author's own study based on statistical data: (Eurostat, 2024).

In the case of goat production (Table 4), of which 11.26 million pieces were produced in the EU in 2023, which was a 7% decrease compared to 2019, most of it is produced in Greece (2.96 million pieces), Spain (2.46 million pieces) and in Romania (1.48 million pcs.). Most EU countries experience a decline in goat meat production.

Table 4.
Goat meat population in European Union countries in 2019-2022 (million units)

Area	**Year**			
	2019	**2020**	**2021**	**2022**
European Union - 27 countries (from 2020)	12.13	11.99	11.74	11.26
Belgium	0.04			0.08
Bulgaria	0.23	0.25	0.22	0.18
Czechia	0.03			0.02
Denmark	0.02			0.02
Germany	0.14	0.16	0.16	0.16
Estonia	0.01			0.00
Ireland	0.01			0.01
Greece	3.58	3.15	3.14	2.96
Spain	2.66	2.65	2.59	2.46
France	1.24	1.41	1.39	1.31
Croatia	0.08	0.09	0.09	0.08
Italy	1.06	1.07	1.06	1.01
Cyprus	0.25	0.26	0.26	0.25
Latvia	0.01	0.01	0.01	0.01
Lithuania	0.02	0.01	0.01	0.01
Luxembourg	0.01			0.01
Hungary	0.06	0.05	0.05	0.04
Malta	0.01	0.01	0.01	0.01
Netherlands	0.55	0.56	0.58	0.57
Austria	0.09	0.09	0.10	0.10
Poland	0.05			0.06
Portugal	0.32	0.37	0.35	0.35
Romania	1.59	1.61	1.49	1.48
Slovenia	0.02			0.03
Slovakia	0.04			0.02
Finland	0.01			0.01
Sweden	0.01			0.01
Iceland	0.00	0.00	0.00	0.00
Bosnia and Herzegovina	0.07	0.07	0.05	0.04
Montenegro	0.03	0.03	0.03	0.86
North Macedonia	0.09	0.10	0.08	0.08
Albania	0.86	0.77	0.78	0.72

Cont. table 4.

Serbia	0.19	0.20	0.20	0.19
Türkiye	11.21	11.99	12.34	11.58
Kosovo (under United Nations Security Council Resolution 1244/99)	0.03	0.03	0.03	0.03

Source: Author's own study based on statistical data: (Eurostat, 2024).

When assessing the situation of the meat sector in the EU over the years 2019-2023, a continuous increase in production was observed. Analyzing the European market, it can be observed that the largest producers are countries such as: Germany, Spain, France and Poland. Poultry meat enjoyed the greatest increase in production. In the case of Poland, in 2022 there was a percentage increase of as much as 7.52% compared to last year. The smallest increase (0.3%) was observed in the production of mutton and goat meat.

2.5. Meat production forecast for the European Union

Meat consumption per person in the European Union has so far been on an upward trend. The financial and economic crisis and the crisis in 2013 (due to the restructuring of the dairy sector, new regulations on the pork sector and tight meat supply) interrupted this trend. Consumption has increased significantly since 2014 (+4.4 kg per inhabitant by 2018). This is due to the improved economic situation and large stocks of meat, despite the growing export volume.

By 2030, the meat market will be influenced by changes in consumer preferences, export potential, profitability and, in the case of beef, changes in the dairy sector. Overall meat consumption in the EU will fall, from 69.3 kg per inhabitant in 2018 to 68.6 kg in 2030. This corresponds to a small reduction of 700 g per person. The decline will be driven by lower availability, despite higher imports. This will also change preferences, i.e. lower meat consumption and the selection of substitutes. Beef production in the Union is expected to decline, driven by smaller herds, low profitability and falling demand. As for mutton and goat meat, thanks to maintaining support related to production and maintaining domestic demand, production will increase in 2018-2030, reaching 950 thousand tons in 2030, compared to 903 000 tons in 2018 (Michna, 2012). Pork consumption in the EU will fall from 32.5 kg per capita in 2018 to 31.7 kg in 2030. This decline will be offset by higher exports, and global import demand will continue to grow at a rate of 0.7% per year in 2018-30. Poultry is the only meat that will see strong growth in production and consumption. By 2030, production should reach 15.5 million tons, up from 14 million tons in 2018.

The decline in meat consumption in Europe contrasts with other continents, which will further increase consumption. Mainly due to countries such as Canada, the United States, Japan and especially China. Meat consumption in Japan and China is gradually increasing due to the shift to more Western diets, which rely on more meat instead of fish. Reducing meat consumption is caused by: growing social and ethical concerns (e.g. animal welfare), environmental and climate problems, health problems (supported by WHO), aging European population, lower availability. Various emerging trends are expected to result in a decline in

fresh meat consumption. These trends include changing dietary patterns with a shift to plant-based diets and the growing number of vegetarians and vegans (especially among younger consumers), the growing importance that consumers attach to the origin of meat and the way it is produced (i.e. organic methods, compliance with animal welfare standards) and preferences in terms of quality versus quantity, the shift from fresh meat to more processed meat, and the use of meat in ready meals and other food products.

Based on Eurostat data on the production volume of individual types of meat from 2007-2018, a forecast was made in a spreadsheet. When creating a forecast, the program generates a new sheet that contains a table with historical and forecast values and a chart that presents these data. A confidence interval has also been added to the predicted values in the table, which shows how accurately the given statistic estimates the parameter. Such an interval requires the following components: the mean itself, the number of observations, and the standard deviation (Carlberg, 2010). Standard deviation is a basic measure that tells us about the average deviation from the arithmetic mean and we calculate it according to the formula (1):

$$SD = \sqrt{\frac{\sum_{i=1}^{n}\left(X - \bar{\bar{X}}\right)^2}{N-1}} \tag{1}$$

where:

SD – standard deviation,

$\overline{X}$ – mean,

X – subsequent value,

N – number of data.

From Figure 1 it can be concluded that by 2030 production will increase by over 4% compared to 2018. The increase is small considering the increasing human population.

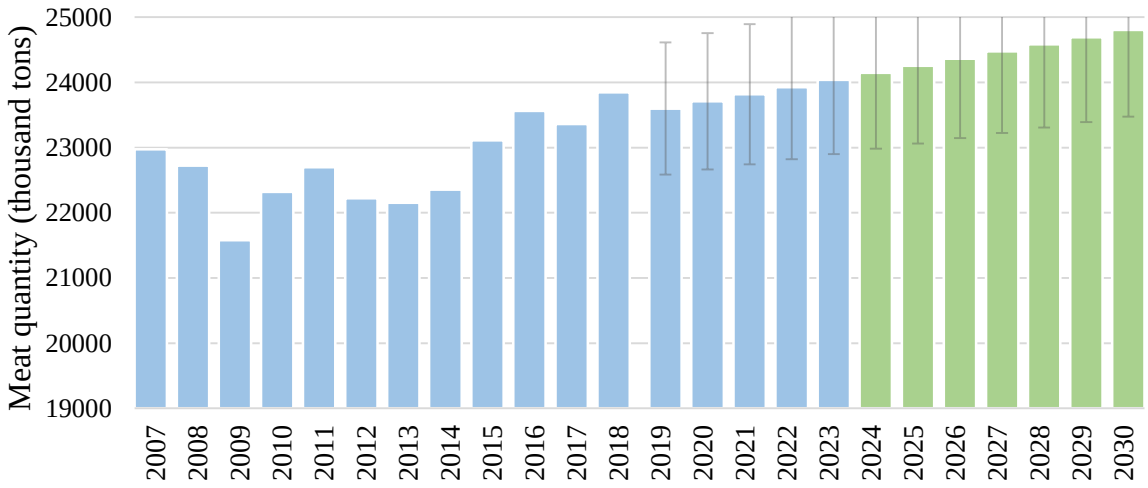

Figure 1. Forecasts of pork production in the EU in 2024-2030: blue color – statistical data; green color – forecast.

Source: Author's own study based on data obtained from (Eurostat, 2024).

Water consumption and carbon dioxide emissions are an integral part of meat production. The average CO2 emission intensity for pork is estimated to be 7.9 kg per kilogram of carcass weight (Opio, 2013). The forecast is presented in Figure 2. It can be seen that as pork production increases, carbon dioxide emissions and water consumption increase. By 2030, the values may reach up to 200,000 kg of CO_2 and 150,000 m^3 of water (The Guardian, 2024).

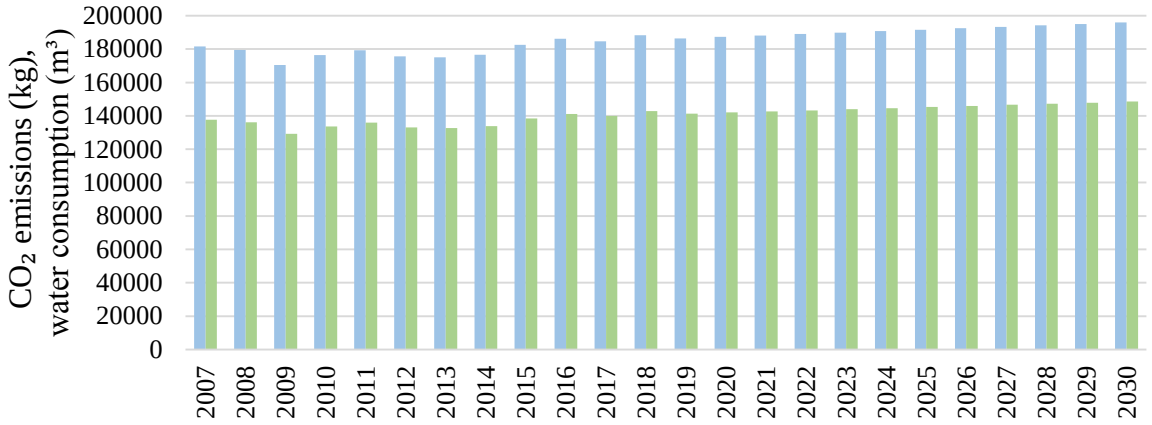

Figure 2. Forecast of carbon dioxide emissions and water consumption for pork: blue color – CO_2 emissions (kg); green color – water consumption in (m^3).

Source: Author's own study based on data obtained from (Eurostat, 2024).

It is projected that poultry meat will remain the most dynamically developing raw material. This can be said taking into account the low price, convenience and healthy image of the product in question. Production in 2030 may reach up to 22.3 million tons of poultry, as shown in Figure 3. This is almost 100% more than was observed in 2011.

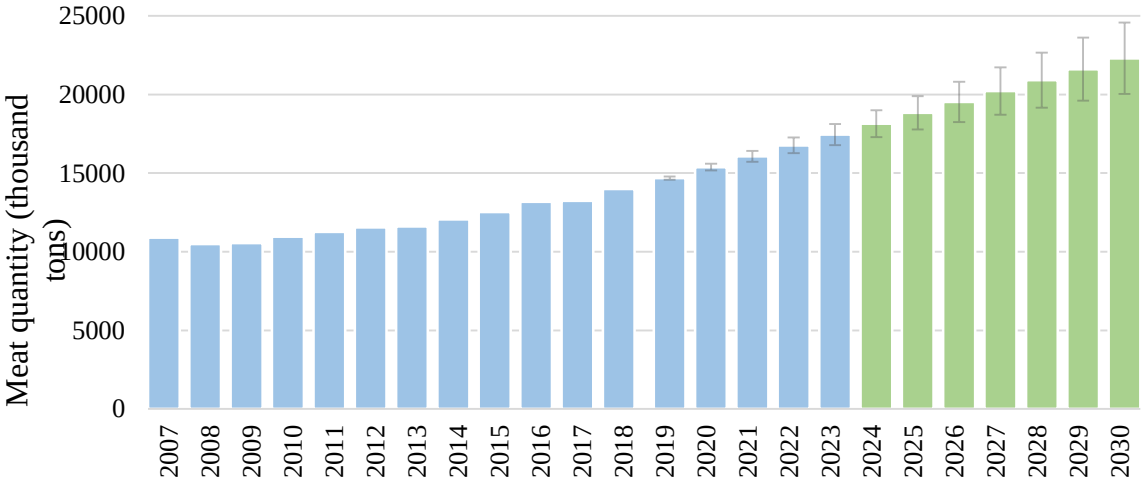

Figure 3. Forecasts of poultry production in the EU in 2023-2030: blue color - statistical data; green color – forecast.

Source: Author's own study based on data obtained from (Eurostat, 2024).

The rapid development of poultry production will contribute to a large increase in emissions and water consumption. In 2030, the values will be twice as high as they were in 2007, as shown in Figure 4. Despite this, emissions and water consumption will still be lower than they are

currently in pork production. This is also related to the fact that the average CO_2 emission intensity for poultry is 5.4 kg per kilogram of meat (Opio, 2013). However, the average water consumption is 4.3 m^3/kg, with almost 6 m^3 during pork production (The Guardian, 2024).

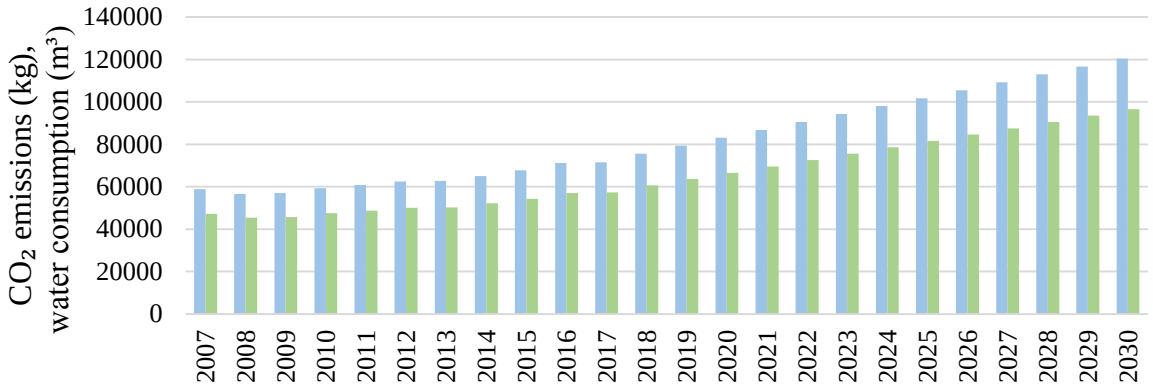

Figure 4. Forecast of carbon dioxide emissions and water consumption for poultry: blue color – CO_2 emissions (kg); green color – water consumption in (m^3).

Source: Author's own study based on data obtained from (Eurostat, 2024).

Figure 5 shows the forecast for beef production, which will decrease year by year. This impact will determine greater demand for white meat and the general public perception of the healthiness of this meat. An important factor will also be worse production profitability resulting from introduction of restrictions on annual greenhouse gas emissions in most EU Member States. The decrease between subsequent years will not be too large and will amount to an average of PLN 35,000 annually.

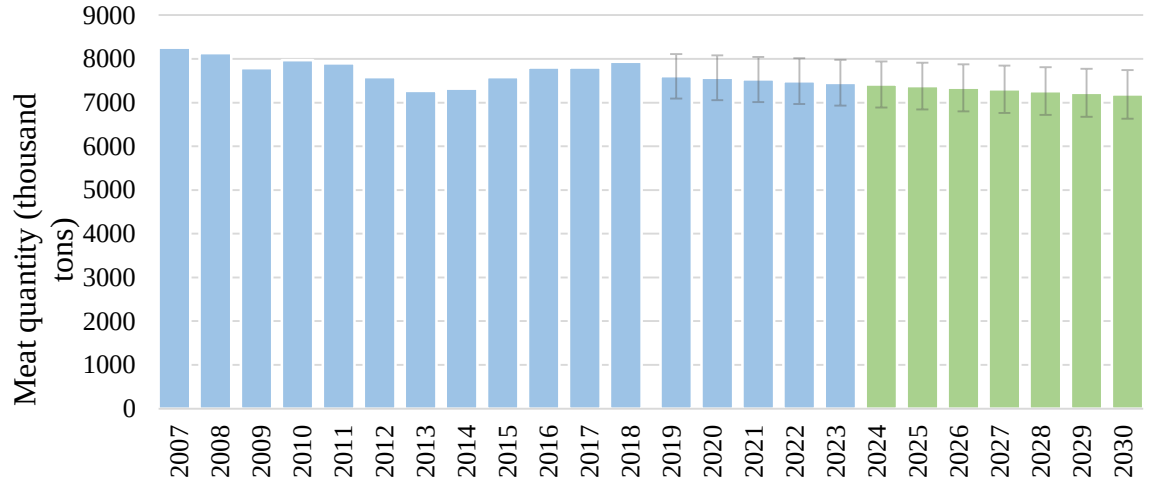

Figure 5. Forecasts of beef production in the EU in 2024-2030: blue color - statistical data; green color – forecast.

Source: Author's own study based on data obtained from (Eurostat, 2024).

Carbon dioxide emissions from beef production are the highest and account for as much as 65% of emissions in the entire animal production sector. The average emission intensity in the world is as much as 46.2 kg of CO_2 per kilogram of meat (Opio, 2013). However, since as much as 80% of beef in Europe is produced from dairy animals, this results in lower emission intensity

(26.6 kg of CO_2). Figure 6 shows that since 2018 there has been a decrease in emissions and water consumption, which amounts to 14.5 m3 per 1 kg of meat. It is estimated that after 2030, it may decrease by another thousand. During this time, water consumption may also drop below 10,000 m^3 (The Guardian, 2024).

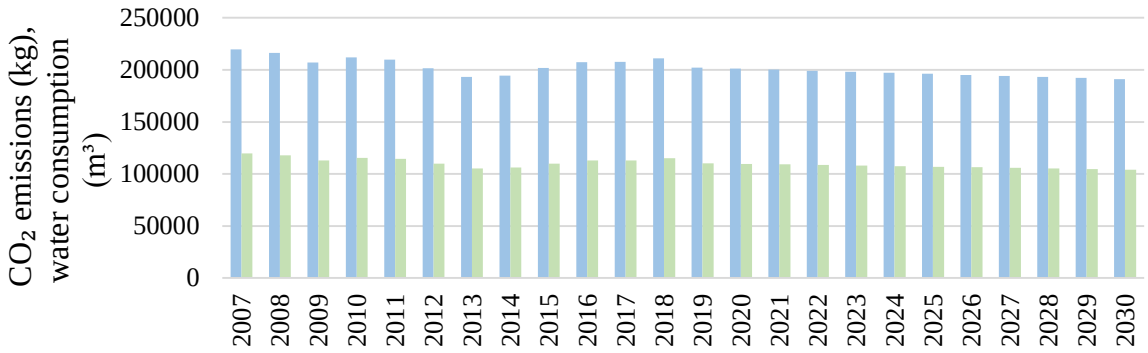

Figure 6. Forecast of carbon dioxide emissions and water consumption for beef: blue color – CO_2 emissions (kg); green color – water consumption in (m^3).

Source: Author's own study based on data obtained from (Eurostat, 2024).

The situation with goat meat and mutton on the market will be similar to beef. Figure 7 shows that the production of these raw materials will decrease and in 2030 it will amount to only 4.9 million tons.

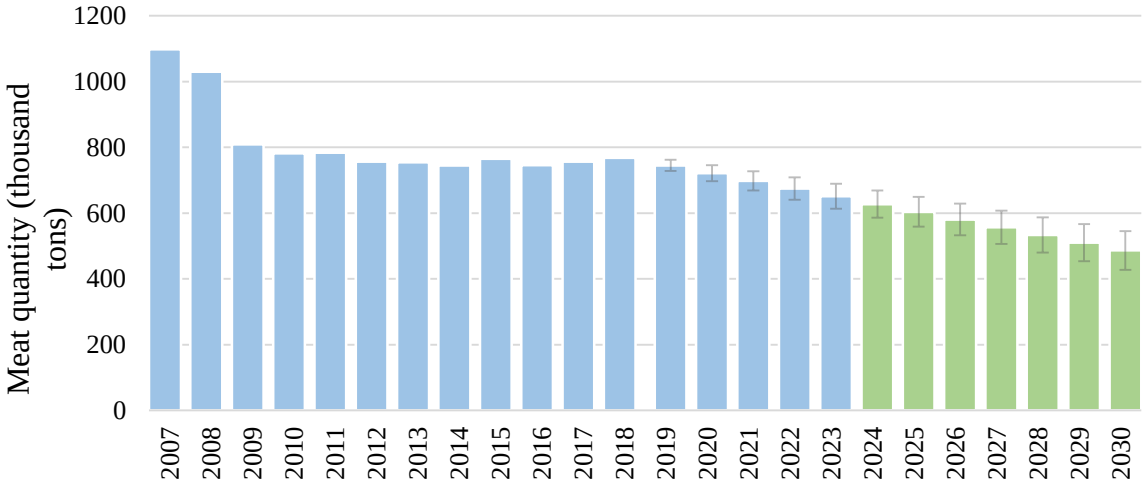

Figure 7. Forecasts of sheep and goat meat production in the EU in 2024-2030: blue color – statistical data; green color – forecast.

Source: Author's own study based on data obtained from (Eurostat, 2024).

Although the amount of carbon dioxide emissions is as high as in the case of beef (almost 24 kg of CO_2 per kg of meat), taking into account the amount of goat and sheep meat produced, the harmfulness is much lower. Since 2009, the amount of carbon dioxide emitted has been below 20,000 kg, and taking into account the rapid decline in the production of this type of meat, it is predicted that emissions in 2030 may amount to only 11.5 thousand kg (Opio, 2013). The average water consumption during production is 10.42 m^3 and currently, when producing 745 thousand tons of meat, it is ca. 7800 m^3 (The Guardian, 2024).

By 2030, the amount of water used may amount to approximately 5000 m³ (Fig. 8).

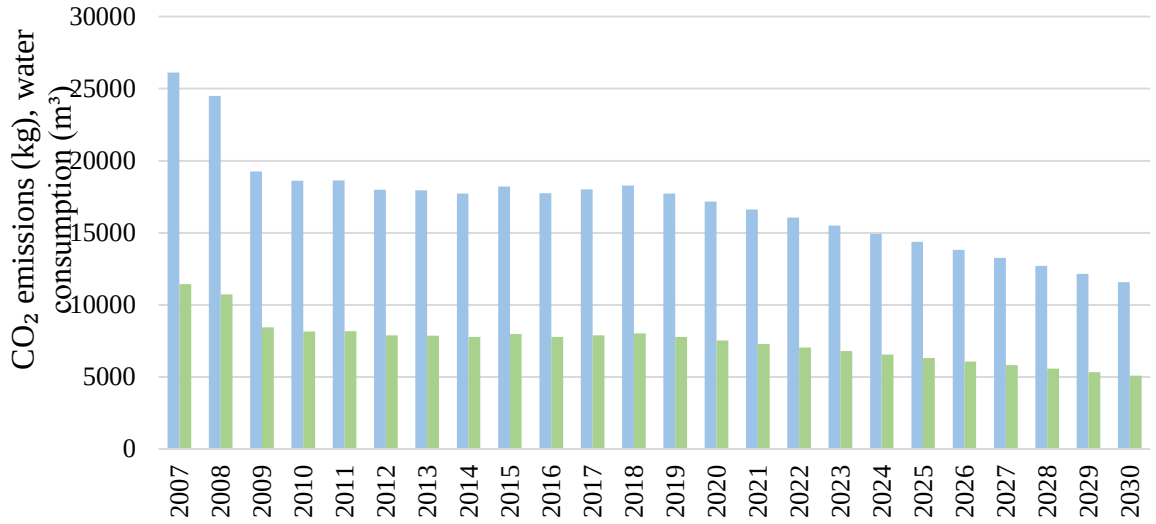

Figure 8. Forecast of carbon dioxide emissions and water consumption for goat and sheep meat: blue color – CO_2 emissions (kg); green color – water consumption in (m^3).

Source: Author's own study based on data obtained from (Eurostat, 2024).

3. Case study

The selected food industry plant was established in 1993 and conducts meat processing as well as wholesale and retail trade. Over the course of several years, the company has expanded its offer from a few to over 200 types of products, implementing dynamic growth in product improvement, including by investing in human capital, modernizing machinery and technology as well as strengthening the brand image on the local market, and then nationwide. The plant carries out production in the following departments: meat cutting, production of finished products. The company also houses warehouses for finished products and shipments. Production relies on meat products based on beef and pork raw materials, intended for human consumption in ready form or after heat treatment. Animal products, which are the main raw material in the plant, can be divided into: pork half-carcasses, chilled beef and pork offal, beef quarters, chilled cuts of pork and beef (bone-in and boneless). The above parts are used to produce: beef and pork cuts, smoked meats, sausages, and offal products. It processes 2500 tons of raw material annually, or ca. 48 tons of livestock per week.

The technological process of the meat processing plant includes: cutting of pork and beef, production of smoked meats, production of sausages, and production of offal products. Meat processing production is a multi-stage process. The general diagram presented in Figure 9 shows the operation of the company from the receipt of raw material, through its processing, to the placement of the product on the market. Production ends with the stage of washing and disinfecting the premises and production equipment. At the same time, it is a preparatory phase for receiving the next batch of meat.

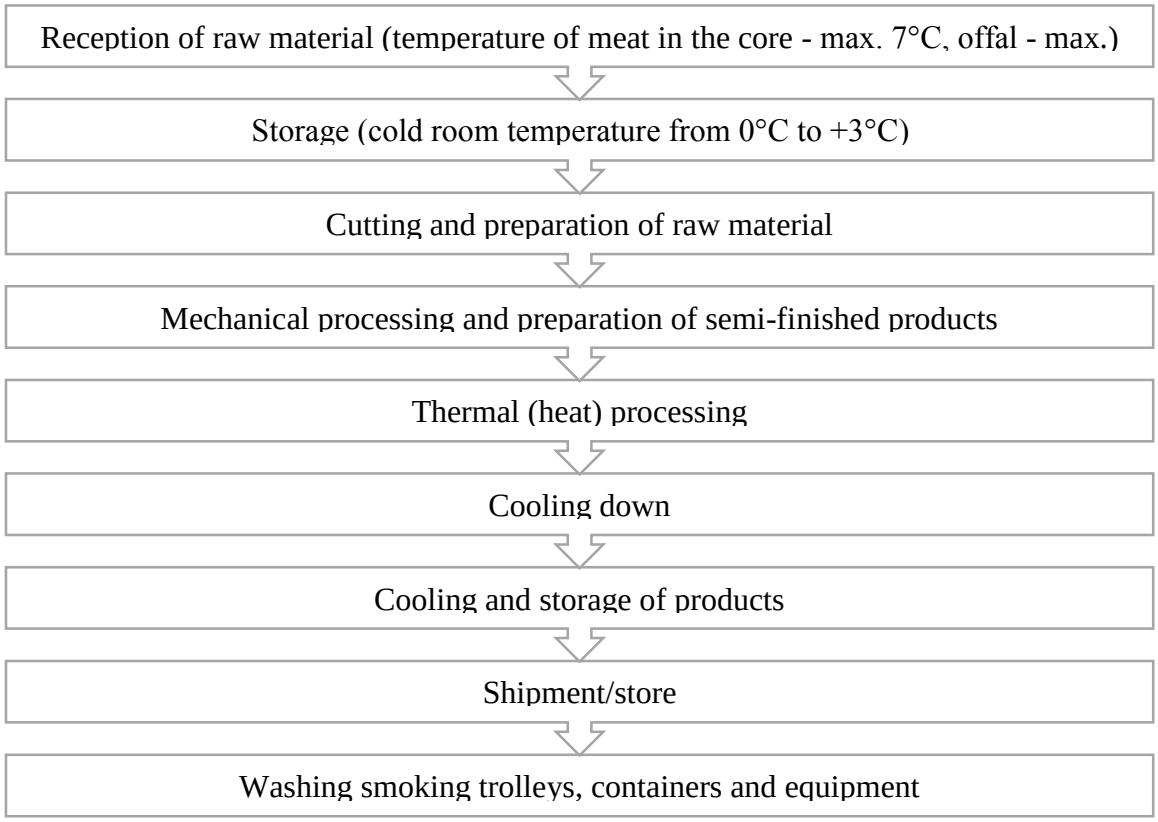

Figure 9. Production process diagram

Source: Author's own study.

3.1. Sewage

The meat processing plant discharges technological sewage along with municipal and domestic sewage in an amount of up to 100 m^3/d. The amount of wastewater generated in a meat processing plant is directly related to the amount of water used by the plant.

Municipal and domestic sewage is discharged directly to the MZGK sewage treatment plant, while technological pollutants go first to the pre-treatment plant, and from there they are discharged to the sewage treatment plant. Water consumption in 2018 amounted to 29,053 m^3. Water is taken from the municipal water supply - the plant does not have water supplies or its own well. Process water is used as an addition to meat, e.g. for preparing brines. On the other hand, municipal and domestic water is used, *inter alia*, for cleaning production rooms, smoking and cooking chambers and industrial machinery. The company had sewage pre-treatment installations located at four points around the plant - these are open catchers and sieves used to retain fibers, paper, hair, etc. The efficiency of sewage refreshment was very low and the level of odor nuisance was very high. In 2003, a project was undertaken to build a sewage pre-treatment plant in a closed room with typical gravity ventilation. After the investment, pre-treated sewage is still discharged to the municipal sewage treatment plant, and not to the receiving body (stream). Due to the European Union requirements regarding the separation of parts of the plant into "dirty and clean parts", the pre-treatment plant was located in a place

away from the production premises. Technical data of the technological sewage pre-treatment plant building: building area – 115.95 m^2, usable area – 103.96 m^2, cubic capacity – 732.00 m^2.

In order to guarantee the proper conduct of the planned process of initial sewage treatment and management of released waste, it was necessary to separate technological sewage from the plant's municipal and domestic sewage. This task was accomplished by separating the technological and sanitary sewage systems. Industrial sewage flows by gravity to the P1 pumping station where a mixer and a pump forcing the sewage to the I1 arc sieve are installed.

From there, the sewage flows to the P2 pumping station. It is equipped with a mixer and a submersible pump that pumps sewage to the I2 arc sieve. Pumping stations P1 and P2 are located under the floor of the pre-treatment plant building. The following devices were installed in the pre-treatment building: arc sieve I1, arc sieve I2, vertical flow grease trap with a surface scraper, flocculator (reaction chamber) with a reagent preparation and dosing line, flotation unit with a system supporting the flotation process with the saturation process, and a sewage neutralization line.

3.2. Animal by-products

There are various types of waste in the meat processing plant. After slaughter, we receive main and secondary raw materials, which can be divided into edible and inedible. In meat plants, there is a classification of animal by-products, which can be divided into three categories. Category 1 – it includes, without limitation: animals that are infected or suspected of being infected with TSE (Transmissible Spongiform Encephalopathies), laboratory or zoo animals as well as animal products that contain prohibited substances. Category 2 - these are products containing veterinary medicines above the permissible standard, containing foreign bodies as well as by-elements from animals imported from third countries or European countries that do not meet EU requirements. Category 3 - this category includes all by-products intended for human consumption, i.e. blood, greaves, carcasses. It also includes products such as feathers, wool, hair, horns and hair from healthy or dead animals, if no contraindications have been demonstrated (Olszewski, 2018). Waste from categories 2 and 3 is stored in containers in a waste warehouse and then transferred to a company licensed to dispose of it.

Table 5 shows the amount of waste in the meat processing plant in 2022, divided into months and categories. Most by-products belong to the third category. Only in May 2022, the amount of second category waste exceeds the quantity of products from the last category by over 3,185 kg. There are large fluctuations throughout the year. The biggest leap occurred between the months of January and February. The difference between category three waste was almost 46,307 kg, or 90%. For the next three months, until May, the amount of Category 3 waste decreased. There were fluctuations until the end of the year. The most kilograms of by-products were registered in August - 78,795, and the least in November - 71,039 kg. On average, ca. 12,000 kg of category one products were produced throughout the year.

At the beginning of 2022, as many as 19,460 kg of by-products were produced, while at the end of the year, in December, over 10,000 less of them were obtained, i.e. 9250 kg. Until the middle of the year and from October to the end of the year, leaps occurred also in the second category.

From June to September there was a sustainable period where the average amount of waste was 40,550.

Table 5.
Specification of waste by category for individual months in 2022

Month	Category 1 (kg)	Category 2 (kg)	Category 3 (kg)
January	19460.00	38240.00	51361.50
February	9281.00	34970.00	97668.30
March	11805.00	57800.00	65726.20
April	13100.00	39150.00	53690.80
May	13745.00	56310.00	53124.62
June	10255.00	40310.00	69623.00
July	9420.00	40700.00	65414.00
August	10900.00	40760.00	78795.00
September	11864.00	40430.00	63759.75
October	11350.00	52280.00	77573.93
November	15580.00	49250.00	71039.03
December	9250.00	53050.00	73720.65

Source: Author's own study.

In the case of category 3 waste, the largest group accounting for 29% is blood. In 2022, as many as 295 tons of this product were disposed of. The next production waste, accounting for 18% - i.e. 146.3 tons, is animal hide, which can be divided into several layers. The third by-product, the amount of which differs from that of hides by 21.7 tons, is tallow, which is part of the slaughter fat. In 2022, the meat plant obtained 16,430 kg of bristles, which are removed after scalding the carcasses using rollers or scrapers. They take up only 2% compared to the other elements. This is due to the fact that the bristles are very light.

3.3. Emission and filters

The company's boiler room is equipped with one steam boiler with a nominal capacity of 2.4 Mg of steam/h. Air protection devices are installed behind the boiler - a battery of cyclones type CE 4X500 OKZ 2x2 and a battery cyclone dust collector type CE/S-2X800 with total efficiency of 90.0%. Pollutants generated during the combustion process in the steam boiler are released into the air after being cleaned in air protection devices with an emitter with a flue gas outlet diameter of 0.8 m. The liquid fuel filling station is equipped with one diesel oil tank with a capacity of 5 m3 and one distributor. Diesel oil is used only to refuel trucks and construction machinery owned by the company. The annual turnover of diesel oil is ca. 300 m^3.

The on-site smokehouse has four Fessmann Turbomat T 3000 smoking chambers. The machinery is equipped with a smoke generator type RZ 550 Ratio. Two chambers are used only for drying and steaming cold meats, the smoking process is not carried out there. The chambers are electrically heated, only during the smoking process the beech chips placed

in a special container of the smoke generator burn slowly. Each smoking chamber has a separate emitter. The installations operate all year round, 6 days a week, 8 to 16 hours a day.

Maximum emission of dust and gases in the plant boiler room: sulfur dioxide 1.580 kg/h, nitrogen dioxide 0.632 kg/h, carbon dioxide 10.84 kg/h, total dust 0.300 kg/h (including suspended dust 0.144 kg/h), benzo(a)pyrene 2.52x10- 4kg/h.

Maximum annual emission of pollutants into the atmosphere - assuming 6 days of operation per week for 16 hours: total dust 1502 Mg/year (including suspended dust 0.721 Mg/year), sulfur dioxide 7912 Mg/year, nitrogen dioxide 3165 Mg/year, carbon monoxide 54,286 Mg/year.

Emission factors (depending on the amount of smoked meat) for Fressmann Turbomat smoking chambers: acetaldehyde 0.040 g/kg of input, acetic acid 0.100 g/kg of input, hydrocarbons 0.035 g/kg of input.

Maximum dust and gas emissions for the meat smoking process: total dust 0.0135 kg/h = 0.0038 g/s (including suspended dust 0.3 x 0.025 kg/h = 0.0041 kg/h = 0.0012 g/s), sulfur dioxide 2.2 x 10-4 kg/h, nitrogen dioxide 0.002 kg/h = 0.0005 g/s, carbon monoxide 0.114 kg/h = 0.0317 g/s, acetaldehyde 0.002 kg/h, acetic acid 0.005 kg/h, hydrocarbons 0.00175 kg/h.

Values for air pollutants were adopted in based on the Regulation of the Minister of the Environment of 26 January 2010 (Journal of Laws No. 16, item 87). Outside the premises of the meat processing plant, appropriate concentrations must be maintained, as presented in Table 6.

Table 6.
Emission factors for individual substances

No.	Substance name	Reference values in µg/m³ for the period		Numerical designation of the substance (CAS number)
		one hour	calendar year	
1.	Aliphatic hydrocarbons	3000	1000	-
2.	Suspended dust	280	40	-
3.	Nitrogen dioxide	200	40	10102-44-0
4.	Sulfur dioxide	350	30	7446-09-05
5.	Carbon oxide	30000	-	630-08-0
6.	Acetaldehyde	20	2.5	75-07-0
7.	Acetic acid	200	17	64-19-7
8.	Benzo(a)pyrene	0.012	0.001	50-32-8

Source: Author's own study.

Table 7 presents reference values for substances in the air in the country.

Table 7.
Permissible fall of air pollutants

No.	Type of pollution	Reference value of dust fall in g/m³ x year
1.	Cadmium (as the sum of the metal and its compounds in dust)	0.01 g/m² x year
2.	Lead (as the sum of the metal and its compounds in dust)	0.1 g/m² x year
3.	Total dust	200 g/m² x year

Source: Author's own study.

Reference values of substances in the air or permissible levels of substances in the air are considered to be met if the frequency of exceeding the D1 value averaged over 1 hour is not more than 0.274% of the time per year in the case of sulfur dioxide, and 0.2% of the time per year for other substances.

3.4. Calculations of maximum concentrations

Table 8 presents data received from the meat processing plant regarding the highest maximum concentrations obtained for the emitter installed in the boiler room. Taking into account the requirements specified in the regulation of the Minister of the Environment, it is checked whether the condition has been met.

Table 8.
Emission factors for individual substances

No.	Substance name	Reference values in µg/m³ for the period		Highest of the maximum concentrations of substances in the air (S_{mm})	Percentage share (%S_{mm})
		one hour (D_1)	calendar year (D_a)		
1.	Nitrogen oxides	200	20	26.409	13.2
2.	Sulfur dioxide	350	30	66.029	18.9
3.	Suspended dust	280	40	3.011	1.1
4.	Carbon oxide	30000	-	82.529	0.3
5.	Benzo(a)pyrene	0.012	0.001	0.00526	43.8

Source: Author's own study.

The condition is met when $S_{mm} \leq 0.1 \times D_1$.

Table 9 shows the permissible substance standards for a smoking emitter.

Table 9.
Permissible substance standards for smoke emitters

Substance name	Value	Criterion met?
Nitrogen oxides	26.409 > 0.1 x 200 = 20 µg/m³	Condition not met
Sulfur dioxide	66.029 > 0.1 x 350 = 35 µg/m³	Condition not met
Suspended dust	3.011 < 0.1 x 280 = 28 µg/m³	Condition met
Carbon oxide	82.529 < 0.1 x 30000 = 3000 µg/m³	Condition met
Benzo(a)pyrene	0.00526 < 0.1 x 0.012 = 0.0012 µg/m³	Condition not met

Source: Author's own study.

The specification of the highest maximum concentrations obtained for the emitter is presented in Table 10. On the other hand, table 11 shows that all conditions in the meat processing plant were met.

Table 10.
Emission factors for individual substances

No.	Substance name	Reference values in µg/m³ for the period		Highest of the maximum concentrations of substances in the air (S_{mm})	Percentage share (%S_{mm})
		one hour (D_1)	calendar year (D_a)		
1.	Nitrogen oxides	200	20	1.458	0.7
2.	Sulfur dioxide	350	30	0.175	0.1
3.	Suspended dust	280	40	1.750	0.6
4.	Carbon oxide	30000	-	92.455	0.3
5.	Aliphatic hydrocarbons	3000	1000	1.458	0.0
6.	Acetaldehyde	20	2.5	1.633	8.2
7.	Acetic acid	200	17	4.083	2.0

Source: Author's own study.

The condition $S_{mm} \leq 0.1 \times D_1$ must be verified (reference value of substances in the air averaged for one hour).

Table 11.
Permissible substance standards for the smoking chamber

Substance name	Value	Criterion met?
Nitrogen oxides	1.458 < 0.1 x 200 = 20 µg/m³	Condition met
Sulfur dioxide	0.175 < 0.1 x 350 = 35 µg/m³	Condition met
Suspended dust	1.750 < 0.1 x 280 = 28 µg/m³	Condition met
Carbon oxide	92.455 < 0.1 x 30000 = 3000 µg/m³	Condition met
Aliphatic hydrocarbons	1.458 < 0.1 x 3000 = 300 µg/m³	Condition met
Acetaldehyde	1.633 < 0.1 x 20 = 2 µg/m³	Condition met
Acetic acid	4.083 < 0.1 x 200 = 20 µg/m³	Condition met

Source: Author's own study.

Residential buildings are located in the impact area. Most of them are single-story buildings. The nearest residential buildings higher than one-story are located ca. 120 m from the plant plot border. Calculations were made at a height of z = 4 m. The following concentration values were obtained at the height of the windows: nitrogen oxide 26,001 µg/m³, sulfur dioxide 65,010 µg/m³, carbon monoxide 81,255 µg/m³, suspended dust 3582 µg/m³, aliphatic hydrocarbons 49,472 µg/m³, acetaldehyde 0.948 µg/m³, acetic acid 2.369 µg/m³, benzo(a)pyrene 0.00626 µg/m³.

Then, it must be verified whether the condition $S_{mm} \leq D_1 - R_a$ is met (Table 12).

Table 12.
Permissible substance standards at the height of residential buildings

Substance name	Value	Criterion met?
Nitrogen oxides	26.001 > 200-20 = 180 µg/m³	Condition met
Sulfur dioxide	65.010 > 350-35 = 315 µg/m³	Condition met
Carbon oxide	81.255 < 30000-3000 = 27000 µg/m³	Condition met
Suspended dust	3.582 < 280-28 = 252 µg/m³	Condition met
Aliphatic hydrocarbons	49.472 < 3000-300 = 2700 µg/m³	Condition met
Acetaldehyde	0.948 < 20-2 = 18 µg/m³	Condition met
Acetic acid	2.369 < 200-20 = 180 µg/m³	Condition met
Benzo(a)pyrene	0.00626 < 0.012-0.0012 = 0.0108 µg/m³	Condition met

Source: Author's own study.

The maximum concentrations of pollutants from all sources operating simultaneously at the height of residential buildings also do not exceed 0.1 x D_1.

3.5. Analysis of the on-site liquid fuel filling station

Emissions of liquid fuel storage vapors are divided into organized and fugitive emissions. Fugitive emission of hydrocarbon vapors may be caused by fuel condensing when the guns are removed from or hung up on the stand, and by product overflowing through the filler hole when the filler pipe is too narrow. However, these situations are eliminated when operation is correct.

The liquid fuel filling station is equipped with a tank with a capacity of 5 m^3. Diesel oil is stored in the tank. The tank is equipped with a vent emitter with a height of h = 4 m. The station has one pump for refueling cars and machinery. The station supports its own equipment only and does not conduct retail sales.

The filling station was secured by placing the diesel tank in a tight metal tub. It must be stated that the filling station meets all the requirements specified in the Regulation of the Minister of Economy of 21 November 2005 on the technical conditions to be met by liquid fuel bases and filling stations, long-distance transmission pipelines for the transport of crude oil and petroleum products and their location, and an additional security measure not included in the regulation is the placement of fuel tanks in a tight metal tank, which provides a full guarantee of protection of the surface of the earth, soil, surface and groundwater against possible leakage of petroleum products.

Taking into account that the calculated hydrocarbon emissions are very low, it must be concluded that the emission of pollutants emitted from the filling station is negligible and its impact on the air condition in the impact area is negligible.

The specification of the highest maximum concentrations obtained for the emitter is presented in Table 13. The maximum values do not exceed 300 µg/m³, as shown in table 14.

Table 13.
Emission factors for aliphatic hydrocarbons

Substance name	Reference values in µg/m³ for the period		Highest of the maximum concentrations of substances in the air (S_{mm})	Percentage share (%S_{mm})
	one hour (D_1)	calendar year (D_a)		
Aliphatic hydrocarbons	3000	1000	58.751	2.0

Source: Author's own study.

The condition $S_{mm} \leq 0.1 \times D_1$ must be verified.

Table 14.
Permissible substance standards for liquid fuel filling stations

Substance name	Value	Criterion met?	Substance name
Aliphatic hydrocarbons		58.751 < 0.1 x 3000 = 300 µg/m³	Condition met

Source: Author's own study.

4. Summary and discussion

The meat market is one of the most important markets in the agri-food sector. The production of meat products fluctuates frequently. It depends, *inter alia*, on the structure and volume of raw material consumption, purchase prices and retail prices of meat and meat products. The European Union is dominated by the pork and poultry markets, the latter having gained importance in recent years. Due to changes in dietary habits as well as attention to the origin and health of meat, a decline in production is expected, primarily of beef, goat and sheep meat. In the case of poultry, it is estimated that production will develop dynamically. This is due to the fact that poultry, as white meat, is much healthier than red meat, i.e. pork and beef. Meat processing results primarily in carbon dioxide emissions and high water consumption. Currently, most CO_2 is produced during the production of beef, and most water is produced during the production of pork.

Waste from the meat industry, such as bones, hide and blood of animals, is also a threat to the environment. If stored improperly, it may contribute to soil and groundwater contamination. Fortunately, nowadays there are many possibilities of using waste, including: for the production of brushes, gelatin and fertilizers.

The production plant in question processes 2500 tons of raw material annually. The company has a multi-stage production line that allows for meat cutting, preliminary processing and production of the finished product. The production process ends with the products being transported to the warehouse where they are packed for sale. In the company, waste is classified into three categories. Most waste belongs to the third category, including 36% of blood, 18% of hide and 15% of animal tallow.

The company's dynamic development and expansion of its product range contribute to the production of an increasing amount of waste, gas and dust emissions as well as water consumption which affect the environment negatively. The plant is equipped with a sewage pre-treatment plant whose task is to remove carbon, nitrogen and phosphorus compounds from contaminated sewage. In addition, the plant has filters installed that purify the air from harmful substances, such as sulfur dioxide and carbon monoxide. The company transfers production waste to third-party entities for disposal. Among them, animal blood and hide accounts for the biggest part of it. The parameters of the emitters of installations located on the premises of the multi-industry enterprise meet the currently applicable requirements for air protection against pollution.

References

1. Agri-Food Markets (2024). *Browse by Topic. European Commission*. Available online: https://agridata.ec.europa.eu/extensions/DataPortal/agricultural_markets.html, 19 September 2024.
2. Augère-Granier, M.L. (2020). *The EU pig meat sector*. Available online: https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/652044/EPRS_BRI(2020)652044_EN.pdf, 19 September 2024.
3. Caputo, V., Sun, J., Staples, A.J., Taylor, H. (2024). Market outlook for meat alternatives: Challenges, opportunities, and new developments. *Trends in Food Science & Technology, 148,* p. 104474. https://doi.org/10.1016/j.tifs.2024.104474.
4. Carlberg, C. (2010). *Statistical analysis. Microsoft Excel*. Gliwice: Helion, pp. 193-377.
5. Eurostat (2022). *Agricultural production - livestock and meat.* Available online: https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agricultural_production_-_livestock_and_meat, 19 September 2024.
6. Eurostat (2024). *Decline in EU livestock population in 2023*. Available online: https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20240521-2, 19 September 2024.
7. Farmer. *Eurostat: EU livestock population to decline in 2023*. Available online: https://www.farmer.pl/produkcja-zwierzeca/eurostat-spadek-poglowia-zwierzat-gospodarskich-w-ue-w-2023-r,146639.html, 19 September 2024.
8. Fathollahzadeh, K., Saeedi, M., Khalili-Fard, A., Rabbani, M., Aghsami, A. (2024). Multi-objective optimization for a green forward-reverse meat supply chain network design under uncertainty: Utilizing waste and by-products. *Computers & Industrial Engineering*, pp. 110578. https://doi.org/10.1016/j.cie.2024.110578.
9. Flaibam, B., Silva, M.F., Mélo, A.H.F., Carvalho, P.C., Galland, F., Pacheco, M.T.B., Goldbeck, R. (2024). Non-animal protein hydrolysates from agro-industrial wastes: A prospect of alternative inputs for cultured meat. *Food Chemistry, 443,* pp. 138515. https://doi.org/10.1016/j.foodchem.2024.138515.
10. Gardenlux (2024). *Broiler chicken breeds with photos and descriptions*. Available online: https://gardenlux-en.decorexpro.com/hozyajstvo/ptitsevodstvo/porody-brojlernyh-kur-s-foto-i-opisaniem.html, 19 September 2024.
11. Gilland, B. (2002). World population and food supply: can food production keep pace with population growth in the next half-century? *Food Policy, 27*, pp. 47-63. https://doi.org/10.1016/S0306-9192(02)00002-7.
12. Kaul, K., Rajauria, G., Singh, R. (2024). Valorization of agro-industrial waste for pectinase production and its influence on circular economy. *Food and Bioproducts Processing, 148*, pp. 141-153. https://doi.org/10.1016/j.fbp.2024.09.008.

13. Manika, D., Iacovidou, E., Canhoto, A., Pei, E., Mach, K. (2022). Capabilities, opportunities and motivations that drive food waste disposal practices: A case study of young adults in England. *Journal of Cleaner Production, 370*, pp. 133449. https://doi.org/10.1016/j.jclepro.2022.133449.
14. Mavai, S., Bains, A., Sridhar, K., Chawla, P., Sharma, M. (2025). Emerging deep eutectic solvents for food waste valorization to achieve sustainable development goals: Bioactive extractions and food applications. *Food Chemistry, 462*, pp. 141000. https://doi.org/10.1016/j.foodchem.2024.141000.
15. Michna, W. (2012). Development Forecasts for Global Agricultural Production and its Consumption as Well as Use for Non-Food Purposes in 2011-2020. *Zagadnienia Ekonomiki Rolnej, 3*, pp. 104-113.
16. Olszewski, A. (2018). *Meat processing technology*. Warszawa: WNT, pp. 46-313.
17. Opio, C., Gerber, P., Mottet, A., Falcucci, A., Tempio, G., MacLeod, M., Vellinga, T., Henderson, B., Steinfeld, H. (2013). *Greenhouse gas emissions from ruminant supply chains – A global life cycle assessment.* Rome: Food and Agriculture Organization of the United Nations (FAO). Available online: https://www.fao.org/4/i3461e/i3461e.pdf, 19 September 2024.
18. Pethick, D.W., Hocquette, J.F., Scollan, N.D., Dunshea, F.R. (2021). Review: Improving the nutritional, sensory and market value of meat products from sheep and cattle. *Animal, 15*, pp. 100356. https://doi.org/10.1016/j.animal.2021.100356.
19. Santos, R.A., Costa, J.S., Maranduba, H.L., Neto, J.A., Rodrigues, L.B. (2023). Reducing the environmental impacts of Brazilian chicken meat production using different waste recovery strategies. *Journal of Environmental Management, 341*, p. 118021. https://doi.org/10.1016/j.jenvman.2023.118021.
20. Sigala, E.G., Chroni, C., Boikou, K., Abeliotis, K., Panagiotakos, D., Lasaridi, K. (2024). Quantification of household food waste in Greece to establish the 2021 national baseline and methodological implications. *Waste Management, 190*, pp. 102-112. https://doi.org/10.1016/j.wasman.2024.09.012.
21. Sobczak, A., Błyszczek, E. (2009). Ways of management of by-products from meat industry. *Czasopismo Techniczne. Chemia, 106*, pp. 141-151.
22. Szymańska, E. (2006). Influence of the EU enlargement on the pork market in Poland. *Zeszyty Naukowe SGGW w Warszawie - Problemy Rolnictwa Światowego, 15*, pp. 377-386.
23. The Guardian (2024). *How much water is needed to produce food and how much do we waste?* Available online: https://www.theguardian.com/news/datablog/2013/jan/10/how-much-water-food-production-waste, 19 September 2024.
24. Topagrar (2024). *Beef Market 2023 - Decrease in headcount, production and exports. Who is pushing elbows in the EU and wants to take our place?* Available online: https://www.topagrar.pl/articles/bydlo-miesne/rynek-wolowiny-2023-spadek-poglowia-

produkcji-i-eksportu-kto-rozpycha-sie-lokciami-w-ue-i-chce-zajac-nasze-miejsce-2496994, 19 September 2024.

25. Vinci, C. (2022). *European Union beef sector. Main features, challenges and prospects.* Available online: https://www.europarl.europa.eu/RegData/etudes/BRIE/2022/733676/EPRS_BRI(2022)733676_EN.pdf, 19 September 2024.
26. Vinci, G., Prencipe, S.A., Ruggieri, R., Ruggeri, M. (2024). How much does overnutrition weigh? The environmental and social impacts of Metabolic Food Waste in Italy. *Science of The Total Environment, 947*, p. 174420. https://doi.org/10.1016/j.scitotenv.2024.174420.
27. Wanassi, O.K., Torres, D.F.M. (2023). An integral boundary fractional model to the world population growth. *Chaos, Solitons & Fractals, 168,* pp. 113151. https://doi.org/10.1016/j.chaos.2023.113151.
28. Wojdalski, J., Dróżdż, B. (2004). Podstawy analizy oddziaływania zakładów przetwórstwa rolno-spożywczego na środowisko. *Inżynieria Rolnicza, 5,* pp. 363-371.
29. Wojdalski, J., Dróżdż, B. (2006). Podstawy analizy energochłonności produkcji zakładów przemysłu rolno-spożywczego. *MOTROL, Motoryzacja i Energetyka Rolnictwa, 8A,* pp. 294-304.