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Sources of Greenhouse Gas Emissions in Agriculture, with Particular Emphasis on Emissions from Energy Used

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Abstract: The relationship between agriculture and climate change is two-sided. Agriculture is the branch of the economy most affected by the ongoing processes. It is also a large emitter of greenhouse gases and there are more and more voices about the need to reduce emissions. The purpose of the study was, based on FADN (Farm Accountancy Data Network) data, to determine the structure of greenhouse gas emissions in farms and to identify types of farms where it is possible to reduce GHG (greenhouse gas) emissions through better energy use. The emission volume was determined on the basis of the IPCC (Intergovernmental Panel on Climate Change) methodology modified for the FADN data. The emissions related to the production of energy were found to be of minor importance compared to other emission sources. Only in the horticultural crop type is the emission from the Energy section the dominant stream of GHG emission. The greatest emissions come from livestock production. Therefore, the emphasis on reducing emissions should not be placed on the Energy sector because, except for the type of horticultural farm, there is not much potential for reduction. The introduction of taxes for GHG emissions at the level of 27.31 EUR/t would reduce farm income from 21% for the type of field crops to 40% for the type of herbivorous animals. The exception is low-emission permanent crops, where the decrease in income would be only 3.85%.

Keywords: GHG; agriculture; energy consumption; farms; FADN

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1. Introduction

Over the past several hundred years, human activities have had a huge, mostly negative, impact on the environment. As a result, the area of forests was reduced, biodiversity was reduced, species died out, and many harmful substances were introduced into the environment. However, in the opinion of experts, the main threat to the environment is the climate change caused by anthropogenic heating of the atmosphere, as a result of the increasing concentration of greenhouse gases, mainly CO_2.

It is worth emphasizing that the concept of the greenhouse effect and climate change caused by GHG emissions is not new [1–3]. Pioneering scientific works appeared as early as the end of the 19th century [4]. After the Second World War, there was a breakthrough in climate research [5]. There is now an almost full scientific consensus that we are dealing with rapid climate change and that people are responsible for it [6,7]. In recognized scientific journals, one can find publications that indicate that many positive feedback loops were activated in the world, which resulted in the violation of the so-called tipping points. This could mean that climate change will be rapid, over decades, not linearly as previously thought, but abruptly [8–13]. The environmental, social, and economic impacts can be extremely severe in such unpredictable changes.

Agriculture is of particular importance in terms of climate change. The relationship between agriculture and climate change is two-sided. Agriculture is a major emitter of greenhouse gases. The conducted research shows that farms are responsible for approximately 16–27% of all anthropogenic emissions [14]. Emissions in agriculture take place at every stage of production, from seed preparation to harvesting and storage of finished products [15]. Agriculture is also the sector of the economy most affected by the ongoing processes, which requires large-scale adaptation measures [16]. For most areas of the world, climate change is a growing problem in ensuring an adequate level of food production for an ever-growing world population due to declining yields [17] and rising food prices [18–20]. This is evidenced by the value of the so-called transferable stocks of cereals (which are the main food product), determining the level of food security, which fell from 74 days in 2002 to 54 days in 2011 [21]. The amount of available food varies greatly between regions, and its shortages are particularly visible in the poorest regions of the world [22]. In terms of the energy value of food, 870 million people go hungry worldwide. The worst situation is in the sub-Saharan region, where almost 30% of the population does not have enough food, and, in South Asia, where this situation affects 300 million people [23]. The situation related to the climate crisis is exacerbated by the COVID-19 pandemic [24]. The reduction of agricultural production is directly caused by the fact that climate change causes:

- changing weather patterns, reducing rainfall in many regions of the world. Where rainfall is constant, its nature changes from long-term rainfall to long periods of drought, interrupted by storm rain,
- much more frequent occurrence of extreme phenomena, unfavourable for agriculture: storms, hail, frosts,
- the emergence of new species of pests, diseases that have not been encountered so far, do not have natural enemies [25],
- periods of extremely high temperatures, dangerous for crops and livestock. They also reduce the productivity of human labour, making it impossible at certain times.

Apart from these problems, activities to reduce GHG emissions turn out to be another risk factor for agriculture. The high emissivity of agriculture is becoming a subject of political and social discussion. This is related to a wider issue, such as achieving, by 2050, climate neutrality by the EU-zero net emissions [26].

Modern agriculture is dependent on external industrial energy sources. Fossil fuels and electricity have become an indispensable element of modern agricultural production. They are used directly to power machines and indirectly for their construction, extraction of mineral fertilizers, or the synthesis of nitrogen compounds.

The dominant role in this respect is played by non-renewable energy sources (fossil fuels), which contribute to the emission of greenhouse gases and, consequently, the degradation of the natural environment. Therefore, it becomes obvious to strive to improve the efficiency of energy use and to change the structure of its sources [27].

Taking into account the total dependence of agriculture on fossil fuels, which are a significant source of greenhouse gas emissions, research was undertaken on GHG emissions from energy inputs used in agricultural production. The main purpose of the study was therefore to assess the size and structure of greenhouse gas emissions from energy carriers used in farms of various production directions and then to indicate the possibility of reducing them.

2. Background

The main cause of climate change is the high consumption of energy produced by burning fossil fuels and the excessive development of transport. This sector is responsible for 75% of EU emissions. It is worth noting the evolution of views on the availability and use of fossil fuels. Fifty years ago, it was thought that the diminishing availability of fossil fuels would force a switch to renewable resources [28,29]. Currently, there is a clear trend in the development of renewable energy related to the fight against climate change. Thus, the availability of fossil fuels is less of a problem than predicted, while the question of their negative impact on the environment has turned out to be more serious.

Between 1950 and 1984, there was a "Green Revolution" which increased the grain yield by 250%. However, this increase required a multiple increase in energy inputs in agriculture, even 50 times [30]. Only rough calculations can be made to trace the increase in direct and indirect use of fossil fuels and electricity in modern agriculture. In the 20th century, when the world population increased 3.7 times and the inhabited area increased by about 40%, the energy input increased from 0.1 EJ to almost 13 EJ. As a result, in 2000, on average, about 90 times more energy was used per hectare of arable land than in 1900 [31]. This causes a decrease in the efficiency of energy use in farms [32]. The level of energy consumption and the efficiency of its use were the subject of research both in countries and in such sectors of agricultural production as beef production [33], milk [34] soy [35], or wheat [36,37]. The issues of energy consumption in agriculture are directly related to GHG emissions [38,39]. Some of the studies conducted indicate that the improvement of the energy efficiency of agriculture and the wider use of renewable energy sources is the best way to reduce GHG emissions [40,41].

Energy Consumption in Agriculture

Energy consumption in EU agriculture has had an upward trend since 2015, which is a clear change in the direction observed before 2015 (Figure 1).

Figure 1. Energy consumption by agriculture in EU in thousand tonnes of oil equivalent. Reproduced from [42], Eurostat: 2021.

In 2018, the amount of energy consumption in agriculture in the EU countries accounted for 3.2% of the final energy consumption in the EU (Table 1). In the years 2004–2018, the share of agriculture in the total final energy consumption did not change on average in the EU (it decreased to the greatest extent in Greece-by 3.9 pp). By far, the largest share of agriculture in total energy consumption among all EU countries was in the Netherlands (8.1%) and Poland (5.6%) [43].

Table 1. Share of energy consumption by agriculture in final energy consumption.

Countries	Energy Consumption by Agriculture in 2018	Change 2018/2004 (%)	Total Energy Consumption in 2018	Change 2018/2004 (%)	Share of Energy Consumption by Agriculture in Final Energy Consumption in 2018	Change 2018/2004 (pp.)
EU-28 *	25,166	−5.4	860,754	−5.4	3.2	0.0
Belgium	792	−3.0	33,111	−5.2	2.4	0.1
Bulgaria	185	−33.0	9750	6.5	1.9	−1.1
Czechia	619	11.2	24,180	−3.7	2.6	0.3
Denmark	596	−13.8	14,070	−3.9	4.2	−0.5
Estonia	124	18.4	2889	3.7	4.3	0.5
Ireland	223	−28.8	11,219	0.2	2.0	−0.8
Greece	264	−76.3	15,169	−23.0	1.7	−3.9
Spain	2458	−26.6	82,020	−9.4	3.0	−0.7
France	4089	−3.2	139,829	−7.7	2.9	0.1
Croatia	211	−0.7	6682	−3.6	3.2	0.1
Italy	2798	−5.5	114,422	−10.7	2.4	0.1
Cyprus	42	332.7	1581	3.8	2.7	2.0
Latvia	181	44.8	4025	4.3	4.5	1.3
Lithuania	108	2.3	5446	24.8	2.0	−0.4
Luxembourg	24	8.6	3737	−5.6	0.6	0.1
Hungary	641	9.3	17,865	4.8	3.6	0.1
Malta	5	–	515	50.5	0.9	0.9
Netherlands	3647	−3.3	44,933	−9.4	8.1	0.5
Austria	529	−3.5	26,036	3.7	2.0	−0.2
Poland	3918	−8.9	69,983	23.3	5.6	−2.0
Portugal	382	−28.6	16,201	−11.0	2.4	−0.6
Romania	566	144.0	23,445	−1.3	2.4	1.4
Slovenia	73	−1.3	4940	0.1	1.5	0.0
Slovakia	133	−18.0	9912	0.3	1.3	−0.3
Finland	688	−6.7	25,074	0.6	2.7	−0.2
Sweden	613	−19.7	31,777	−1.7	1.9	−0.4
United Kingdom	1257	46.2	121,944	−12.2	1.0	0.4

* Germany is not included as many data points are not available. Reproduced from [42], Eurostat: 2021.

In 2018, six EU countries with the highest energy consumption in agriculture accounted for almost 70% of energy consumption in agriculture in the entire EU, which proves a high level of concentration (Figure 2). The phenomenon meets the assumptions of the Pareto principle, and, in this case, 20% of the EU countries use 70% of energy in the agriculture of the Community.

In the EU, the greatest amount of energy used in agriculture came from gas oil and diesel oil, which in the analysed period accounted for over 50% of the structure of energy used (Figure 3). Electricity and natural gas were also important sources of energy. In the years 2004–2018, on average in the EU, the share of energy from renewable sources increased from 5 to 10%, although it seems that the pace of increasing the share of these sources is too slow. In the EU countries, the structure of energy consumption in agriculture varied considerably depending on the country. In almost all countries, gas oil and diesel oil were the most important, despite clear differences between countries (from about 90% in Slovenia to 9% in the Netherlands, which in this respect differed from other EU countries). In the Netherlands, like in no other country, more than 50% of the energy used in agriculture comes from natural gas. In Belgian agriculture, about 1/3 of the energy used came from natural gas. Natural gas was also important in Romania, Lithuania, and Hungary (20%, 19%, and 17%, respectively, in 2018). Poland, as the only country in the EU, to a large extent uses other bituminous coal (about 20%) as an energy source in agriculture. It is worth paying attention to Sweden and Austria, where over 30% of the energy used in agriculture came from renewable sources, which in the context of the current EU climate policy should be considered an example to be followed by other countries. Czechia, Slovakia, and Finland also stood out in this area, where renewable sources accounted for a quarter of the energy used for agriculture in 2018. For Germany, Malta and Cyprus, complete data for 2004 were not available. Therefore, data from the years 1998 (for Germany) and 2005 (Cyprus and Malta) were adopted for the study—these were the years closest to 2004 with complete data available.

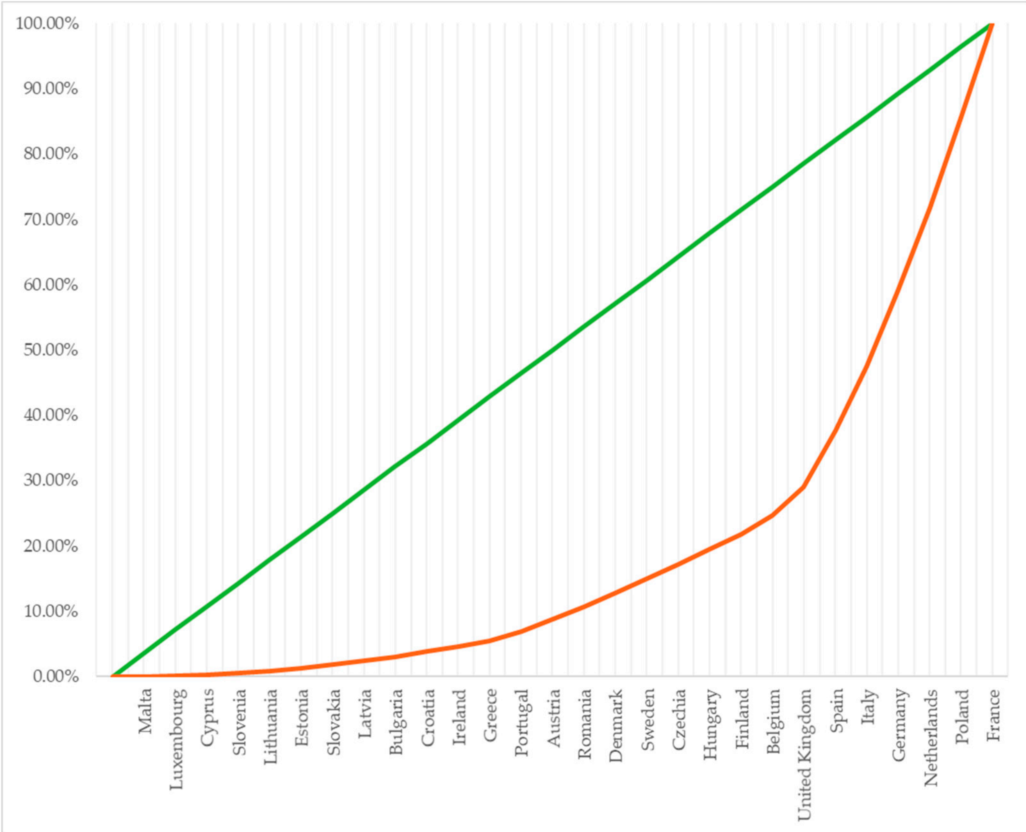

Figure 2. The concentration of energy consumption in agriculture in 2018. Reproduced from [42], Eurostat: 2021.

The Netherlands was characterized by the highest energy consumption in agriculture per hectare of arable land. In 2018, the Netherlands used nearly four times more energy per hectare of UAA (2052.93 kgoe) than in Belgium, second in the ranking, and over 15 times more than the average in all EU countries (Figure 4). This was due to very intensive agriculture and a high share of energy-intensive greenhouse production. The lowest final energy consumption per hectare of UAA was observed in Romania (33.5 kgoe/ha), Lithuania (35.3 kgoe/ha), and Bulgaria (36.8 kgoe/ha). In the case of Germany, the data for 2010 was used, as the data for 2008 were incomplete.

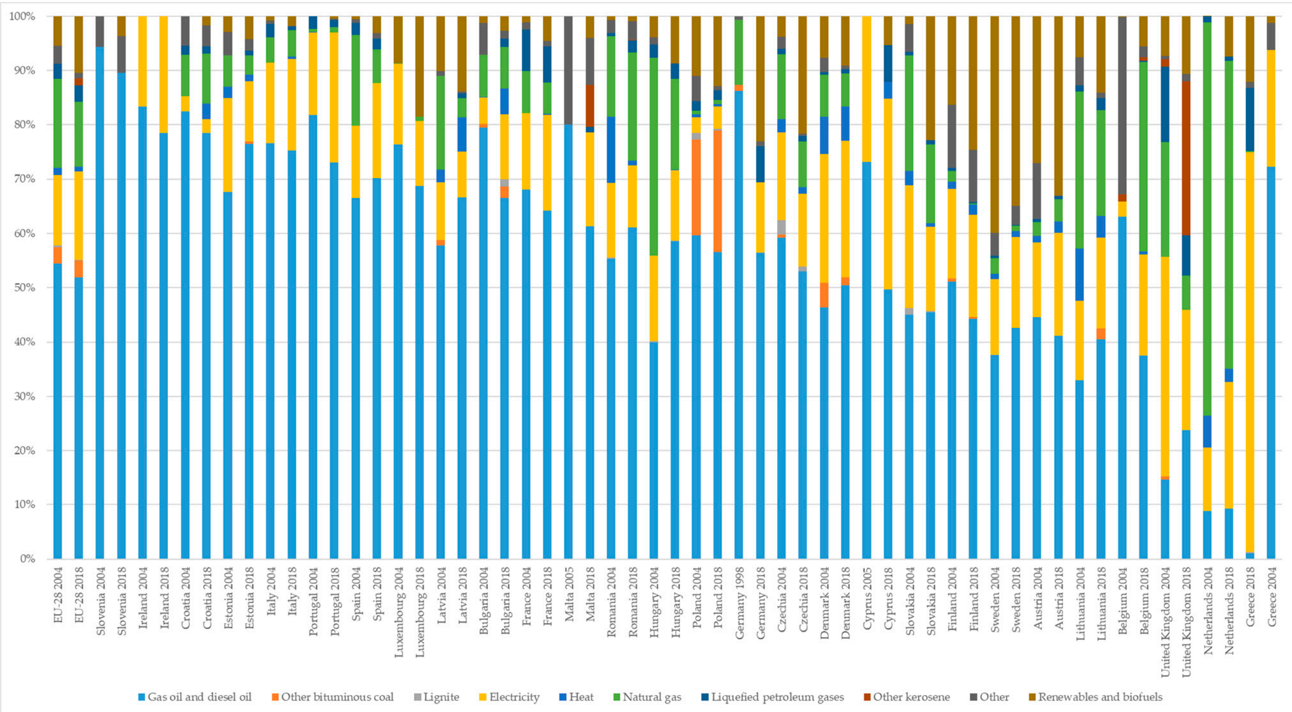

Figure 3. The structure of energy consumption in agriculture in the EU countries in 2004–2018. Reproduced from [44], Eurostat: 2021.

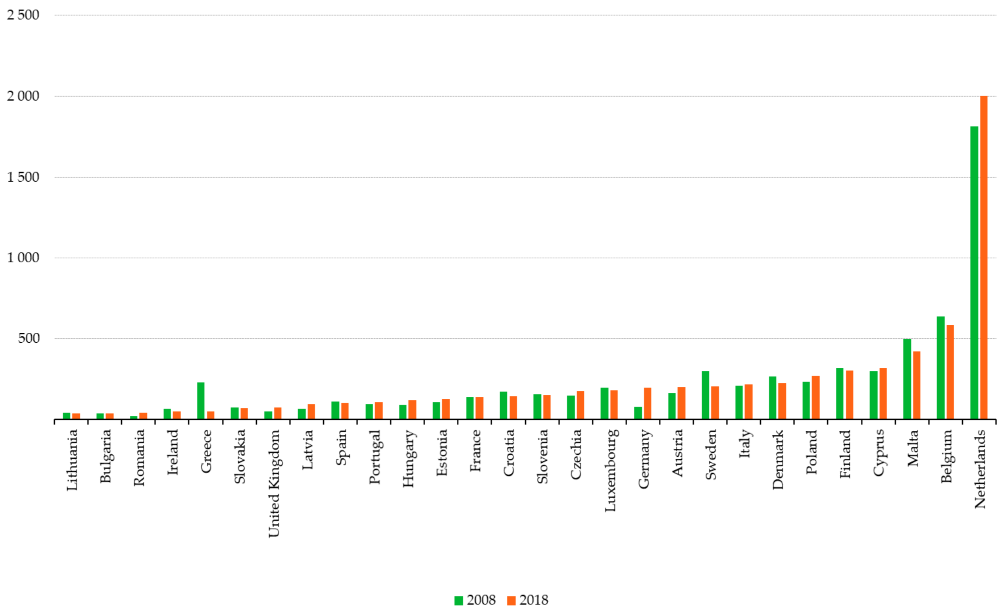

Figure 4. Energy consumption in agriculture per hectare of arable land in kgoe. Reproduced from [45], Eurostat: 2021.

3. Materials and Methods

3.1. Overview

In the research on the level and structure of emissions from Polish farms, data from the FADN (Farm Accountancy Data Network) from 2017 were used. The FADN operating in Poland is part of the European system, operating since 1965, based on Regulation of the Council of 15 June 1965 setting up a network for the collection of accountancy data on the incomes and business operation of agricultural holdings in the European Economic Community [46]. Data in FADN are collected in the management accounting convention. The FADN database is economic and organizational. It is now the most complete source of information on the situation of agricultural holdings. The identical principles of operation of the FADN system throughout the EU make the results comparable for all EU countries. The obtained data are used both for decision-making by EU bodies, monitoring the effects of these activities, and scientists dealing with the economics and organization of agriculture. Participation in the FADN system is voluntary. Farmers participating in the research write down every economic event that took place on their farm, in a special book, then agricultural advisors transfer them to the system.

The FADN observation field covers only commercial farms, i.e., farms supplying the market. In 2017, the results in Poland were calculated for 12,100 farms with an economic size greater than or equal to EUR 4000.

3.2. Types of Farms

The type of farm is defined based on the share of individual agricultural activities in the creation of the entire Standard Output of a farm. In the conducted research, grouping was made according to eight basic types. In practice, there were seven types because type 3-Vineyards does not occur in Poland (Table 2). Farms classified to a particular type are specialized in this type of agricultural production.

Table 2. Grouping of farms by type.

Symbol	Name	Description of the Type of Farm
1	Field crops	Specializing in the cultivation of cereals (including rice), oilseeds, and protein crops for seeds
2	Horticultural crops	Specializing in outdoor horticulture, under high cover, (vegetables, strawberries, flowers, and ornamental plants) and the cultivation of mushrooms and in nursery and horticulture
3	Vineyards	Specializing in viticulture
4	Permanent crops	Specializing in the cultivation of fruit trees and shrubs
5	Dairy cows	Specializing in dairy cattle farming
6	Herbivorous animals	Specializing in rearing cattle for slaughter (including breeding), sheep, goats, and other animals fed on roughage
7	Granivorous animals	Specializing in rearing pigs, poultry, and other animals fed with concentrated fodder
8	Mixed	Mixed-different crops, different animals

While there are some doubts about the use of the FADN for environmental issues [47], it is the most comprehensive source of information on farms in the EU. Basic organizational and economic information on the researched farms, grouped by type of farm, is presented in Table 3.

Table 3. Characteristics of the researched farms.

Description	Unit	Type of Farm							Average
		Field Crops	Horticultural Crops	Permanent Crops	Dairy Cows	Herbivorous Animals	Granivorous Animals	Mixed	
Sample size	pcs.	3922	304	445	2665	735	729	3313	–
Economic size	EUR	38,380	80,157	24,251	50,189	27,662	120,671	37,008	45,432
Labor inputs	AWU	1.73	3.48	2.28	1.99	1.59	2.08	1.74	1.87
Agricultural land area	ha	47.89	7.21	13.14	31.99	27.76	33.77	29.68	35.04
Total production value	EUR	47,111	79,738	35,891	65,427	23,821	144,360	40,855	54,272
The value of livestock production	EUR	1790	292	126	57,532	17,321	118,932	22,073	27,470

Table 3. *Cont.*

Description	Unit	Type of Farm							Average
		Field Crops	Horticultural Crops	Permanent Crops	Dairy Cows	Herbivorous Animals	Granivorous Animals	Mixed	
The value of plant production	EUR	44,931	79,257	35,311	7642	5973	24,974	18,519	26,462
Income from the farm	EUR	20,263	17,744	14,747	31,918	11,551	38,177	15,458	21,794
Income per full-time employee	EUR	13,844	10,033	9612	16,699	7393	22,036	9239	13,197

3.3. Methodology of Estimating Emissions in Farms

The problem of estimating the amount of greenhouse gas emissions in farms is difficult. GHG emission depends on numerous variables such as soil type, species, cultivation technology, breeding, the weather pattern in a given year, etc. Research carried out in one country does not have to be useful in other countries, and the obtained results are often very divergent [48].

The work attempts to link the internationally recognized methodology used by The National Centre for Emissions Management (KOBiZE) with data from the FADN database. The first attempts to calculate GHG emissions based on these data took place in Italy [49]. The authors of this study focused on a group of 695 farms in the Veneto region. They identified six emission sources, which were then calculated based on FADN data and national emission factors. Later, the research was extended to cover the entire FADN population [50]. In Poland, research combining FADN and greenhouse gas emissions is carried out at the Institute of Agricultural and Food Economics-National Research Institute [48,51,52]. Similar works are also carried out in other EU countries [53,54].

This study adopts its methodology for calculating GHG emissions, taking into account the latest Intergovernmental Panel on Climate Change (IPCC) guidelines. Contrary to Polish studies, GHG emissions at farms, emissions from fuel combustion (liquid, solid and gaseous), and electricity consumption were also taken into account. The main sources of emissions in agriculture, together with the data and indicators necessary for their estimation (in an IPCC-compliant format), are divided into three main categories: Energy (Sector 1), Agriculture (Sector 3), Land use (Sector 5) [55,56].

Within individual sectors, a total of 15 emission streams were identified (Table 4), each of which required a separate approach and determination of the GHG emission level based on the available FADN data and based on the guidelines contained in Guidelines for National Greenhouse Gas Inventories [56–58], modified in a way that allows the use of data collected in the FADN system. The amount of emissions in farms was calculated according to the formula:

$$Y = X_1 + X_2 + \ldots + X_{15} \quad (1)$$

Table 4. Calculation of GHG emissions in farms.

Emission Source	Emission Factor	Reference
X_1—Energy production for agriculture	Energy consumption [MWh] × Factors of the produced electricity for the end-user [1 MWh = 781 kg CO_2]	[59]
X_2—Combustion of fuels in agriculture	Fuel consumption x Emission factor for fuels [Diesel: 1 GJ = 74.1 t CO_2; Petrol: 1 GJ = 69.3 t CO_2]	
X_3—Intestinal fermentation	Number of animals of a certain species and age × Emission factor for species and age × 28 (Global Warming Potential-GWP) [Emission factor: from 5 kg CH_4/year for goats to 75.59 kg CH_4/year for bulls over 2 years of age]	[56,60]

Table 4. *Cont.*

Emission Source	Emission Factor	Reference
X_4—Methane emissions from livestock manure	Number of animals per species × Emission factor for species × 28 (GWP) [Emission factor for species: from 0.02 kg CH_4/year for broilers to 11.87 kg CH_4/year for dairy cows]	[56]
X_5—Direct emission of nitrous oxide from livestock manure	Number of animals of a certain species and age × Emission factor for species and age (Nex) × N_2O-N to N_2O conversion factor × 265 (GWP) [Nex: from 1 kg N_2O/year for turkeys to 83 kg N_2O/year for dairy cows; N_2O-N to N_2O conversion factor = 44/28]	[56]
X_6—Indirect emission of nitrous oxide from livestock manure	Composed of two processes: Indirect N_2O emissions due to volatilization of N from manure management and Indirect N_2O emissions due to leaching from manure management	[58] Equations: 10.27 and 10.29
X_7—Use of mineral fertilizers	Amount of mineral fertilizers applied × Fertilizer emission factor × 44/28 × 265 (GWP) [Fertilizer emission factor = 0.01 kg N_2O out of 1 kg of N]	[56,58]
X_8—Use of organic fertilizers	Amount of organic fertilizers applied × Fertilizer emission factor × 44/28 × 265 (GWP) [Fertilizer emission factor = 0.01 kg N_2O out of 1 kg of N]	[56,58]
X_9—Animal manure on pastures and grasslands	Number of animals of a certain species and age × Emission factor for species and age (Nex) × Pasture maintenance factor × Emission factor for manure from grazing animals × 265 (GWP) [Pasture maintenance factor-from 0.103 (dairy cows) to 0.44 (sheep); Emission factor for manure from grazing animals–0.2 for cattle and pigs and 0.01 for sheep, goats, and horses]	[56,58]
X_{10}—Plant residues	Annual harvest of a given crop × Dry matter share × Nitrogen content in biomass × (1—Share of burnt biomass−Share of biomass removed from the field)	[56,58]
X_{11}—Nitrogen deposition from the atmosphere (indirect emissions)	Annual amount of mineral fertilizers × Factor of nitrogen participation in fertilizers emitted in the form of NH_3 and NO_x + Annual amount of organic fertilizers + Annual amount of animal manure on pastures x Factor of the share of nitrogen from the manure emitted in the form of NH_3 and NO_x × 44/28 × 265 (GWP) [Factor of nitrogen participation in fertilizers emitted in the form of NH_3 and NO_x = 0.01; Factor of the share of nitrogen from the manure emitted in the form of NH_3 and NO_x = 0.2]	[56,58]
X_{12}—Leaching and oxidation of nitrogen from the ground (indirect emissions)	(Annual amount of mineral fertilizers + Annual amount of organic fertilizers + Annual amount of plant residues) × Factor of the share of nitrogen leached from the ground into the waters × Emission factor of leached nitrogen × 44/28 × 265 (GWP) [Factor of the share of nitrogen leached from the ground into the waters = 0.3; Emission factor of leached nitrogen = 0.0075]	[56,58,60]
X_{13}—Liming	Annual amount of calcium fertilizers $CaCO_3$ × $CaCO_3$ emission factor + Annual amount of calcium fertilizers $CaMg(CaCO_3)_2$ × $CaMg(CaCO_3)_2$ emission factor [$CaCO_3$ emission factor = 0.12; $CaMg(CaCO_3)_2$ emission factor = 0.13]	[56,58]
X_{14}—Burning crop residues	(Annual harvest of a given crop × Dry matter share × Nitrogen content in biomass × Share of burnt biomass × Combustion efficiency) × Carbon content in biomass = Total amount of carbon released	[56,58]
X_{15}—Urea fertilization	Amount of urea used during the year × Emission factor × Conversion factor [Emission factor = 0.2 kg C/kg N; Conversion factor of C in CO_2 = 44/12]	[56,58]

The Global Warming Potential (GWP) was used to calculate the emissions of individual GHGs, i.e., a conversion factor enabling the determination of individual GHG emissions as a CO_2 equivalent. GWP is a measure of how much energy the emissions of 1 kg of a gas will absorb over a given period of time, relative to the emissions of 1 kg of CO_2. The individual factors are presented in Table 5.

Table 5. Global warming potential of greenhouse gases.

Greenhouse Gas	Global Warming Potential (GWP)
CO_2	1
CH_4	28
N_2O	265
SF_6	23,500
NF_3	16,100

For example, the emission of 1 kg of methane for the climate equates to the emission of 28 kg of CO_2 [60]. This allows the emissions of all GHGs to be reduced to one value.

The amount of taxes/fees for GHG emissions was calculated based on the price of emission allowances, which was achieved at the auction on the European Energy Exchange (EEX) on 23 September 2020—27.31 EUR/t [61]. This method was used in other studies [62]; it is also similar to the calculations made by Richard Tol on the social costs of GHG emissions [63].

4. Results and Discussion

4.1. Total GHG Emissions from Agriculture

In 2018, the total EU GHG emissions amounted to 4.4 billion tonnes. In the years 1990–2018, the share of individual GHG emission sources in the EU did not change. In the case of Agriculture, the share fluctuated in the range of 1–14%, which is comparable to the Industry (Figure 5) [64–66]. In absolute terms, agriculture emitted an annual average of 436 million tonnes of greenhouse gases. In the context of the GHG emission reduction process, it should be noted that, since 1990, emissions in agriculture have been reduced by 23%. This was due to several factors. First of all, the livestock stock decreased and the consumption of nitrogen compounds was limited [67]. Except for Spain, each EU Member State has reduced GHG emissions between 1990 and 2018. The largest decreases were recorded in Germany, Romania, and Poland [66]. However, globally, the agricultural sector has increased GHG emissions by 1.1% [64].

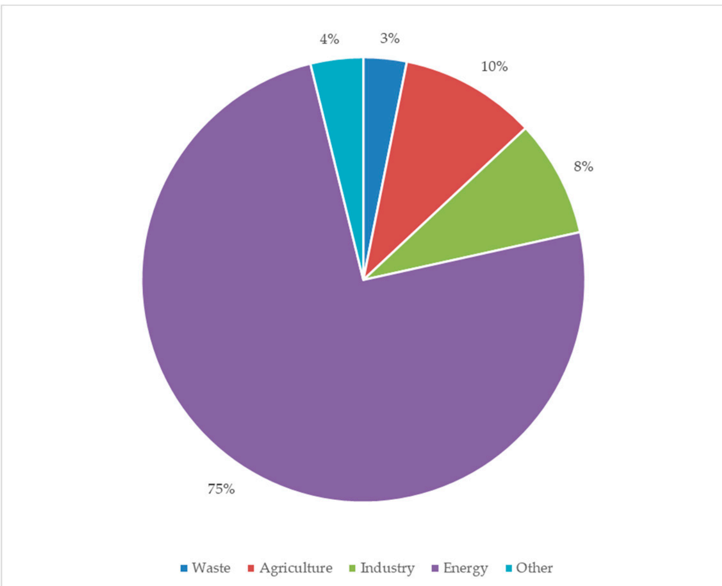

Figure 5. Structure of GHG emissions in the EU in 2018 by sector. Reproduced from [68], Eurostat: 2021.

Poland, with GHG emissions at the level of 416 million tons per year, ranks 5th in the EU. The sectoral structure of GHG emissions in Poland is slightly different than the EU average. The dominant sector is energy with a share of over 80% of the total emissions, while agriculture is responsible for 8% of the emissions in the country, recording a decrease in emissions by almost 1/3 in the years 1990–2018. This was due to a reduction in the number of livestock, the collapse of inefficient State Agricultural Farms, and more rational use of fertilizers based on the principles of a market economy or shaping the production structure [69,70].

4.2. GHG Emission from Energy Inputs in Agriculture

Energy consumption in EU agriculture increased in the years 2004–2018 by 3%, while the emissions accompanying this consumption increased by almost 6%, which proves that, on average, in the entire Community structure of energy sources, there were more sources with a higher greenhouse gas emission index (Table 6). Agricultural energy consumption was reduced most in Greece, Bulgaria, and Ireland by 76%, 33%, and 29%, respectively. However, Slovakia deserves special attention, as it has reduced energy consumption by 1/5 while reducing emissions from this energy consumption by almost 40%, which shows the replacement of high-emission energy carriers, e.g., with renewable energy. Slovakia, along with Czechia and Slovenia, had the lowest emissivity of energy inputs in agriculture, far below the average for the entire EU [71].

Table 6. GHG emission from energy inputs in agriculture in the EU countries in 2004–2018.

Countries	Energy Inputs 2018 (TJ)	Change 2018/2004 (%)	GHG Emissions 2018 (t)	Change 2018/2004 (%)	Emissivity of Energy Inputs 2004 (t GHG/TJ)	Emissivity of Energy Inputs 2018 (t GHG/TJ)	Change 2018/2004 (%)
EU-28	1,193,555	3.1	103,671,715	5.6	84.80	86.86	2.4
Slovenia	3059	−1.3	219,729	−4.9	74.54	71.82	−3.6
Ireland	9355	−28.8	972,756	−24.0	97.37	103.98	6.8
Croatia	8821	2.1	658,303	0.5	75.79	74.63	−1.5
Estonia	5199	18.4	447,061	7.2	95.00	85.98	−9.5
Italy	117,157	−5.5	11,117,330	−3.2	92.64	94.89	2.4
Portugal	15,992	−28.6	1,704,399	−19.7	94.83	106.58	12.4
Spain	102,896	−26.6	9,691,288	−20.7	87.24	94.19	8.0
Luxembourg	990	8.6	75,993	−5.6	88.35	76.76	−13.1
Latvia	7565	44.8	576,977	42.5	77.48	76.27	−1.6
Bulgaria	7757	−33.0	690,938	−23.7	78.26	89.07	13.8
France	171,192	−3.2	15,890,349	0.1	89.77	92.82	3.4
Malta	203	–	19,327	–	–	95.14	–
Romania	23,690	144.0	1,979,516	122.5	91.61	83.56	−8.8
Hungary	26,834	9.3	2,167,087	7.3	82.19	80.76	−1.7
Poland	164,050	−8.9	13,125,832	−6.6	78.07	80.01	2.5
Germany	139,904	1573.4	10,392,644	7231.5	16.96	74.28	338.1
Czechia	25,933	11.2	1,937,408	−9.7	91.98	74.71	−18.8
Denmark	24,938	−13.8	2,555,070	−13.9	102.56	102.46	−0.1
Cyprus	1776	332.7	210,908	142.8	211.65	118.76	−43.9
Slovakia	5555	−18.0	415,070	−38.2	99.20	74.72	−24.7
Finland	28,822	−6.7	2,379,596	−9.4	84.96	82.56	−2.8
Sweded	25,656	−19.7	1,831,157	−9.5	63.37	71.37	12.6
Austria	22,156	−3.5	1,664,652	−0.5	72.83	75.13	3.2
Lithuania	4507	2.3	373,509	2.5	82.66	82.87	0.2
Belgium	33,148	−3.0	2,841,637	6.3	78.23	85.73	9.6
United Kingdom	52,631	46.2	4,961,670	17.8	116.98	94.27	−19.4
Netherlands	152,697	−3.3	12,942,532	16.5	70.36	84.76	20.5
Greece	11,069	−76.3	1,828,980	−62.0	103.07	165.24	60.3

Reproduced from [44], Eurostat: 2021; Reproduced from [58], IPCC: 2006.

The amount of emissions from consumed energy directly depends on the amount of energy consumed and on the structure of energy carriers with different greenhouse gas emissivity. In the years 2004–2018, emissions in Poland, similarly to energy consumption, reached a minimum level of 11.18 million tonnes in 2015. It was followed by an increase, also visible in the rest of the Polish economy.

The emissions from energy sources in agriculture are dominated by diesel oil, which is constantly growing, accounting for half of the emissions in 2018. Two more energy carriers play an important role in the emission structure-bituminous coal 34% and electricity 11%. Searching for opportunities to reduce energy consumption and, at the same time, to reduce greenhouse gas emissions, in-depth research was carried out to find the answers to which farms emit greenhouse gases from energy carriers the most and where to look for opportunities to reduce energy consumption and thus greenhouse gas emissions in the first place. [31,72–74].

4.3. GHG Emissions from Energy Carriers Depending on the Type of Farm

As part of the research, the GHG emissions were calculated in individual production types of farms in the Polish FADN system. Calculations were made for all 15 emission streams. For the sake of legibility, they have been aggregated into categories related to Plant production, Animal production, and Fertilization. The Energy category has been presented broken down into Electricity and Fuels. Figure 6 shows the emission volumes for the subsequent emission categories.

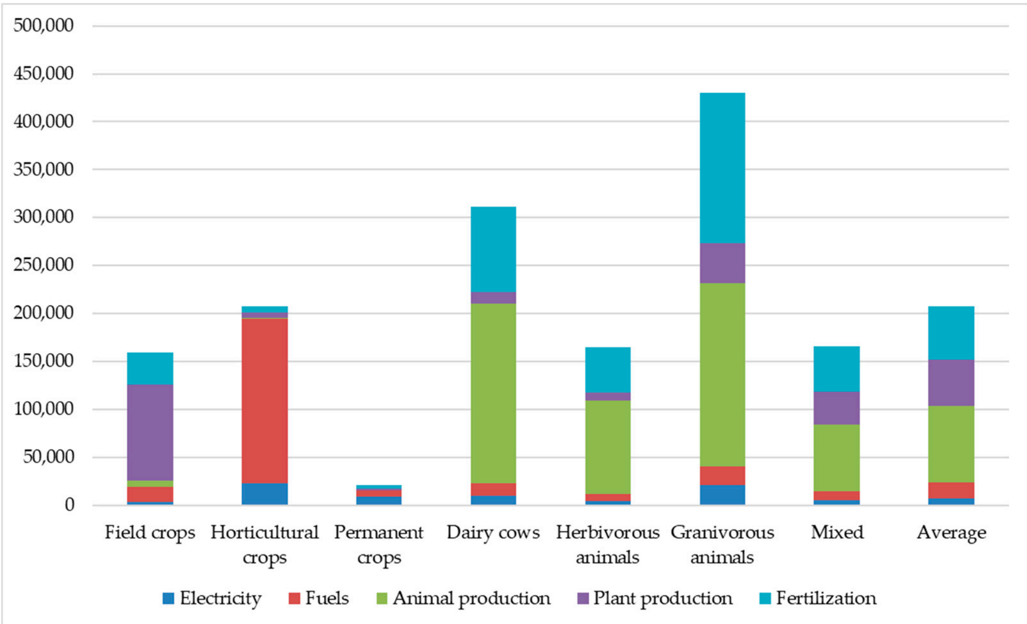

Figure 6. GHG emission in particular types of farms in kg. Source: own study.

The average level of all GHG emissions in Polish farms covered by the FADN system was over 207,000 kg per farm, including 24,000 kg from energy inputs, which accounted for 12% of all emissions. The highest total emission level was observed for two types of farms involved in livestock production: dairy cows and granivorous animals, respectively 311,000 kg and 430,000 kg of GHG per farm (Figure 6). This is confirmed by studies [75–77], that animal production is the main source of emissions. The lowest emission level was found on farms of the type of permanent crops, which in the Polish FADN system include fruit-growing farms. As already mentioned, one of the important sources of emissions in the surveyed farms were fuels and electricity, which together accounted for the average emission on the farm from 11,700 kg of GHG in the type of herbivorous animals to 194,500 kg of GHG in horticultural crops.

The share of Energy in the emission structure in the researched farms was very diversified and ranged from 7% for dairy cows and herbivorous animals to 84% for horticultural crops (Figure 7). The high share of energy is related to production technology. In general, vegetable growing is a type of production associated with extremely intensive use of production factors such as land, water, energy [78]. In the case of the horticultural crops type, especially for cultivation in greenhouses, high costs are incurred to ensure the appropriate temperature. This requires the combustion of fossil fuels, gas, coal, or the use of electricity. The situation is slightly different for permanent crops. These are fruit-growing farms, with the dominant role of apples. The high emissions in the Energy category are related to two issues. The production of fruit requires intensive protection and many operations performed by machines, which causes high consumption of fuels, especially diesel oil. During the season, even a dozen or so agrotechnical treatments are performed, such as sprinkled fertilization, foliar fertilization, disease and pest control, and weed control. Each of these treatments requires the use of agricultural tractors. After harvest, the apples are placed in various types of storage (with a normal, modified, or controlled atmosphere) [79]. Maintaining the assumed conditions, temperature, and atmosphere composition require the consumption of electricity, which directly translates into the structure of emissions in these farms [80]. The next stage is also important—packing and often distributing the fruit on the farm's own. It is worth noting that within the energy section, fuels were dominant, accounting for an average of 69% of emissions from energy inputs in the researched farms. The highest share of fuels was recorded in horticultural crops, 88%, while the lowest share of fuels among the researched farms was in the case of permanent crops and amounted to 41% of GHG emissions in the total emission from energy sources [81].

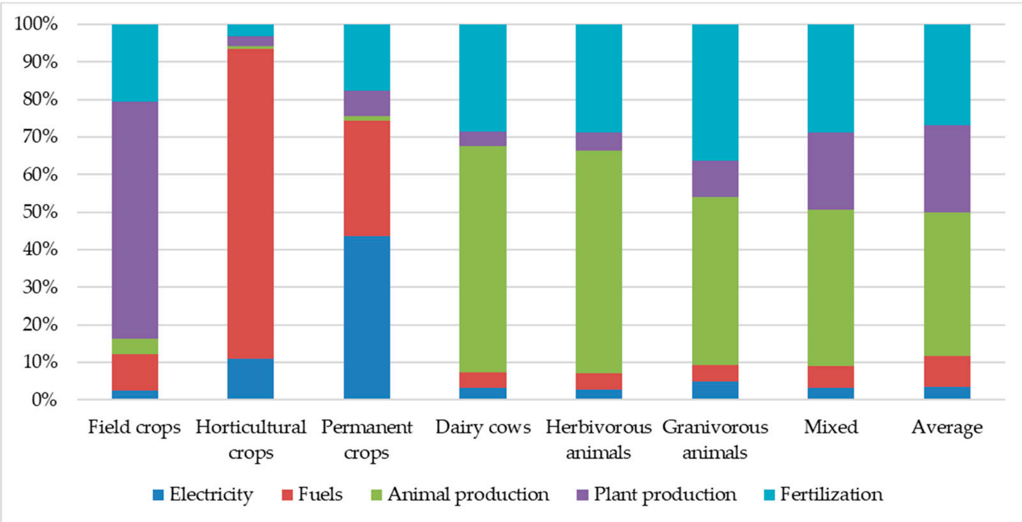

Figure 7. Structure of GHG emissions in types of farms. Source: own study.

Subsequently, the intensity of emissions from energy inputs in the researched farm types was determined by relating the emission level to the area of agricultural land (Table 7).

Table 7. Emission from energy inputs per 1 ha of agricultural land and production value per 1 kg of GHG from energy inputs.

Index	Field Crops	Horticultural Crops	Permanent Crops	Dairy Cows	Herbivorous Animals	Granivorous Animals	Mixed	Average
GHG from energy inputs (kg/ha)	407.42	26,976.23	1178.09	724.65	422.35	1196.15	511.28	689.40
Production value per kg GHG from energy inputs (EUR)	2.41	0.41	2.32	2.82	2.03	3.57	2.69	2.25

Source: own study.

The highest ratio was achieved by horticultural crops type-26,976.2 kg of GHG emissions/1 ha of UAA, and the lowest-field crops type, only 407.4 kg of GHG/1 ha of UAA. The issue of environmental efficiency is also important, as shown in Table 7 as the production value per 1 kg of GHG emissions from the energy used in the production process. Except for horticultural crops, 1 kg of GHG emissions from the Energy category allowed to generate production worth EUR 2–3, in the case of horticultural crops it was only EUR 0.41. By far the highest environmental efficiency in this respect was presented by farms of the granivorous type, where 1 kg of GHG from the energy used allowed to generate over EUR 3.5 of the production value.

4.4. Farm Income and GHG Emission Costs from Energy Inputs

Taking into account the economic aspect and social costs of GHG emissions, the impact of introducing charges/taxes on emissions on farm income was determined (Figure 8). Two variants were presented: introducing taxes/fees related only to energy inputs as well as to all GHG emissions in the farm.

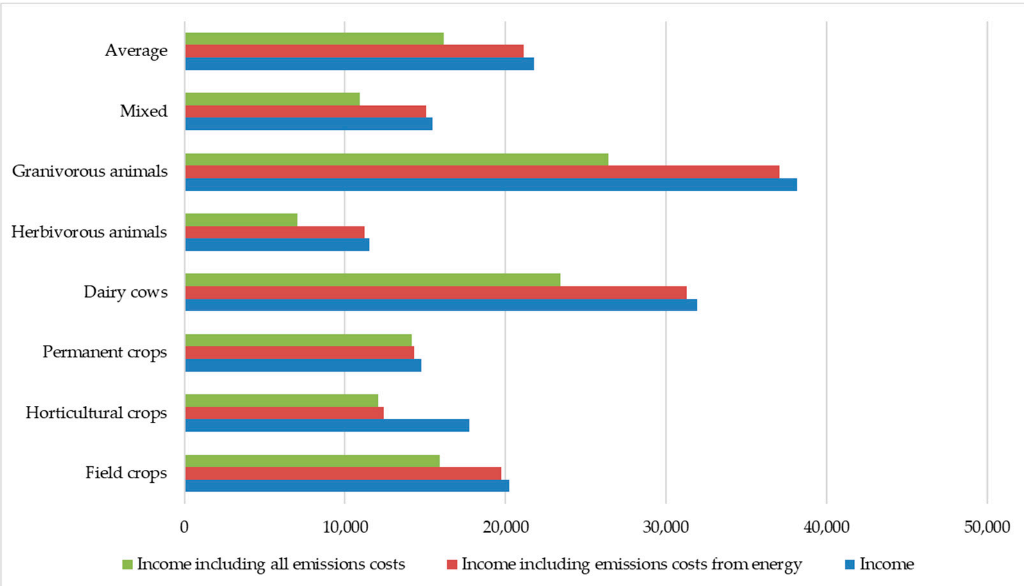

Figure 8. Farm income before and after taking into account GHG emission costs in EUR. Source: own study.

In the first case, if emission charges were introduced only from energy inputs, the impact of these solutions on farm income would not be large, except for horticultural crops, where the income would be reduced by about 30%. The decline in income for the remaining types is only 2–3%. The situation is completely different in the variant of taxation of all emissions on the farm. The income of the surveyed farms would drop from 21% for field crops to 40% for herbivorous animals. The low-emission farms in the type of permanent crops are a phenomenon here, where the decrease in income would amount to only 3.85%.

4.5. Outlook

The conducted research shows the types of production and the main types of emissions. For many years, research has been conducted on the possibility of reducing these emissions. The methods of reducing emissions can be divided into two groups: economic, influencing eating habits and related to production technology.

Various administrative and economic instruments are considered to encourage farmers to reduce emissions and the society to reduce the consumption of goods that require high emissions. This problem is particularly relevant to livestock production [82]. There are more and more calculations of the hidden environmental costs of this production, combined with the calculation of the benefits that can be achieved by switching to a vegan or vegetarian diet [24]. Research confirms that maintaining current eating habits will lead to high GHG emissions [83]. The European Parliament discussed the taxation of meat so that its price fully corresponds to environmental costs. A tax at a rate of 60 EUR/t CO_2 equivalent emissions would reduce total GHG emissions in the EU by 5% [84]. The research conducted in Denmark determined that the introduction of the burden at the level of 150–1730 DKK per 1 ton of CO_2 equivalent emissions results in a reduction of the emis−sion footprint from food production by 2.3–8.8% [85].

In addition to changes in food consumption, it is also postulated to introduce various technological changes aimed at reducing the level of GHG emissions. They relate to different emission areas [86]:

1. Reduction of emissions from nitrogen fertilizers:
    - limiting the consumption of mineral fertilizers,
    - selection of appropriate forms of nitrogen fertilizers,
    - use of inhibitors,
    - maintaining an appropriate soil pH [87].
2. Carbon retention in soil and biomass.
3. Breeding progress:
    - increasing the area of legume crops,
    - introducing more fats into the diet of ruminants [88],
4. Genetic improvement of animals.
5. The use of animal excrements for the production of biogas, which prevents the escape of nitrogen compounds into the atmosphere [89,90].
6. Increasing energy efficiency, the use of renewable energy and improved sources of nuclear energy [91].

Taking into account the research carried out (Figure 6), it seems that the application of GHG emission reduction methods should cover two directions. First, there is a need to change food habits, move away from ruminant animal products. The main role should be played by economic tools, taxes and fees. At the same time, production methods limiting GHG emissions, especially related to livestock production, should be introduced.

In the case of reducing emissions from energy carriers, the problem is extremely complex. Research shows that the intensification of energy consumption in agriculture has made it possible to feed a rapidly growing world population [27]. With the current level of production intensity and a large number of agricultural operations, the possibilities of reducing these emissions are small. However, a decrease in GHG emissions can be achieved in two ways:

1. Fossil fuel consumption reduction

In research and studies carried out all over the world, there are various examples of how to reduce fuel consumption. They are mainly related to changes in production technology:

- Cultivation without plowing (simplified cultivation)—although it is difficult to convince farmers to this type of cultivation, it causes even a threefold decrease in GHG levels [92].
- Precision agriculture and precision agriculture technologies (PAT) [93]. One of the main tasks of precision agriculture is to optimize the use of agricultural inputs, fertilisers, fuel. From the point of view of GHG emissions, techniques that reduce the consumption of nitrogen fertilizers and the number of activities seem to be crucial. This allows a reduction in fuel consumption [94].
- Electrically powered agricultural tractors. Despite the serious obstacle of low battery capacity, agricultural tractor manufacturers are trying to placing them on the market. Two versions of the machines are tested: with batteries and with a cable connection to the power source [94,95]. There are also ideas for introducing agricultural tractors with modern combustion engines, powering electric motors.

- Technical progress in the construction of traditional combustion engines. 2020 is a transition period for engines below 75hp and above 175hp due to the introduction of the Stage V standard. Until 30 June 2020, manufacturers could install transition engines on their machines and market them until 31 December 2020. For machines with a capacity of 75–175 hp, the transition year is 2021 [96].
- Appropriate use of existing agricultural tractors. Appropriate management of tires and weights, use of start-stop systems, longer work sequence, eco-driving, replacing agricultural tractors with more energy-efficient machines [97].

2. Renewable energy

The development of renewable energy in rural areas will be a key element in reducing GHG emissions from energy carriers. Different types of RES are possible: biomass, solar energy, wind farms. Agricultural biogas plants are particularly promising. In addition to solving the problem of CH_4 emissions from animal manure, they provide electricity and heat necessary for agricultural production. It is interesting to combine different types of technologies, where the farmer is both a producer and consumer of energy (prosumer). This makes it possible to combine renewable energy sources with electric vehicles charged from own sources. Another solution may be to combine livestock farming that supplies input to a biogas plant, which supplies electricity and provides heating for the farm.

5. Conclusions

The implementation of the ambitious vision of Europe by 2050 as a climate-neutral continent set out in the European Green Deal requires the intensification of efforts to reduce GHG emissions in all sectors. Such actions must also be taken in agriculture, which is responsible for about 10–14% of their emissions. From simulations by The National Centre for Emission Management (KOBiZE) [98] it results that in Poland if the current production technologies are continued to be used, achieving the ambitious targets for reducing emissions from the agricultural sector will be very difficult. Attempts to implement more ambitious reduction targets may lead not only to a decrease in farm income but also to a relatively high reduction in the level of production, which may increase food prices. This study does not take into account GHG emissions related to the consumption of energy carriers, as well as in the materials and databases of FAO, EPA, and other organizations. It is not included in the agriculture section but belongs to the general category of energy. This is the reason for difficulties in comprehensive assessments of the effectiveness of activities aimed at reducing GHG gas emissions in agriculture.

Looking for ways to reduce energy consumption, and at the same time to emit greenhouse gases, in-depth research was carried out to find out which farms emit greenhouse gases from energy carriers the most, and where to look for ways to reduce energy consumption and thus greenhouse gas emissions in the first place. The average GHG emission level in Polish farms covered by the FADN system was over 207 Mg per farm, of which 24 Mg came from energy inputs, which accounted for 12% of the total GHG emission. The lowest share, amounting to 7%, was characteristic for farms keeping dairy cows and herbivorous animals, and the highest (84%) for horticultural crops farms. The amount of GHG emission from the consumed energy was directly dependent on the amount of its consumption and the structure of the energy carriers used. Emission from diesel oil consumption (50%) dominated, followed by bituminous coal (34%) and electricity (11%).

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