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Comparative Analysis of Agricultural Emissions Across European Countries

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Abstract **– Agriculture is one of the main sources of greenhouse gas (GHG) emissions and has great potential for mitigating climate change. For example, agriculture in Latvia was the second largest sector of GHG emissions after energy with a 22.2 % share of total GHG emissions in 2022. The study aims to compare and analyse the amount of GHG emissions generated by agriculture per domestic product (GDP) and population in different European countries. The ambitious goals set in Europe for 2030 envisage a 30 % reduction in the industry, however, in some countries, these indicators have not only decreased in recent years but also increased. The structure of GHG emissions in 2022 in Europe is as follows: intestinal fermentation (181.1 $MtCO_2e$), agricultural soils (112.9 $MtCO_2e$), and manure management (61.7 $MtCO_2e$). Agriculture is one of the main sources of GHG emissions and has great potential for mitigating climate change. This study aims to compare and analyze GHG emissions from agriculture in European countries against GDP, GDP against population, and population in 2022.**

Keywords **– Agriculture; carbon dioxide; Europe; Generated per domestic product (GDP); methane; nitrogen oxide.**

1. INTRODUCTION

Agriculture is a major contributor to anthropogenic global warming, and the agricultural sector is the main producer of methane and nitrogen emissions, which are converted into CO_2 equivalents [1]. The biggest emitters are the energy sector (66.5 % of GHG emissions), but the agricultural sector is also one of the biggest polluters (about 13.5 % of GHG emissions). It is interesting that of the total emissions, 20 % of carbon dioxide (CO_2); 70 % of methane (CH_4), and 90 % of (nitrous oxide) N_2O in the atmosphere were released as a result of various activities in the agricultural sector, and it is also reported that 35 % of CO_2; 47 % CH_4 and 53 % N_2O of total agricultural greenhouse gases originate in soil (e.g. manure management). Globally, a set of measures and many international agreements (i.e. Kyoto Protocol in 1997) were implemented to reduce GHG emissions worldwide, where developed countries have been required to reduce emissions by 25 % to 40 % by 2020. The United Kingdom introduced the concept of a low-carbon economy in 2003, followed by Germany, Japan, and the United States since then. In recent decades, many researchers around the world have studied the relationship between the agricultural sector and GHG emissions, and it has been argued that

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the interdependence of crop and livestock management could play an important role in GHG mitigation in the United States. It is also recommended to invest in crop production and crop improvement as a good strategy to reduce future GHG emissions. Also, GHG from the agricultural sector has been found to have increased annually by 1.1 % from 2000 to 2010 worldwide [2].

The rapid growth of the population and the increase due to anthropogenic activities create new problems associated with climate change and pose a great threat to the sustainability of natural resources and the stability of the Earth's biosphere. It should be noted that these problems are already causing an uncontrollable accumulation of gases in the atmosphere. Global GHG concentrations have been rapidly increasing since the beginning of the industrial age, for example, CO_2 concentrations in 1760 were 280 ppm and are expected to reach 590 ppm by the end of 2100. Global tracking of greenhouse gas emissions provides a basis for assessing individual countries' contributions to climate change. Climate change indicators define atmospheric concentrations of the most significant GHG emissions from human activities and how emissions and concentrations have changed over time. These indicators use the concept of 'global warming potential' to compare emissions of gases to convert amounts of other gases into CO_2 equivalents. Human-caused GHG emissions are increasing and exacerbating climate change. These rising levels of GHG lead to many more climate-related changes locally and globally [3].

European GHG emissions from the agricultural sector were reported to account for 10 % of total GHG emissions. The total amount of GHG emissions of European countries in 2021 was 3.6 $GtCO_2e$ and GHG emissions from agriculture were almost 500 million tons [4]. This shows that energy is one of the main inputs in the agricultural system, while the energy produced by the formation of fossil fuels is mainly used by agriculture and many other activities. For example, the Italy has the highest share of energy used in agriculture at 9.8 % (compared with 2020), followed by Slovakia at 9.3 % and France at 9.1 %. However, Portugal has the lowest percentage overall (+5.5 %) [5]. The increasing amount of energy is due to neoteric agricultural activities, which are partly responsible for the constant increase in GHG emissions. About half of the energy used in the agricultural sector comes from diesel and gas oil, which account for the largest share of energy used in the agricultural sector in Europe. Regardless of the size and contribution of the agricultural sector to the national GDP in each European Member State, Europe has achieved a 23 % reduction in GHG emissions over the past two decades [3].

Agriculture is actually very vulnerable to climate change, as its activities are directly dependent on climatic conditions. However, the impact of climate change on agricultural yields varies across countries and cultures. Some areas could benefit from the actions of some components of climate change (e.g. water scarcity, increased crop variability, reduced yields, etc.) [6]. In fact, in different countries, different combinations of these influences can exacerbate the overall situation. For example, increasing temperatures can have both positive and negative effects on agricultural yields. It should be pointed out that a strong rise in temperature means water shortages, which can significantly worsen agriculture in all countries, especially in semi-arid areas such as southern European countries. In this case, a negative relationship between rising temperatures and agricultural yields is hypothesized. Additionally, increased precipitation may benefit semi-arid areas by increasing soil moisture, but may exacerbate problems in areas with excess water. On the other hand, reducing the amount of precipitation could have the opposite effect. In irrigated areas, the negative effects of altered precipitation and increased temperature are reduced by the availability of irrigation water, making crops more resistant to climate change. In this last case, groundwater and rivers are mitigating factors of climate variability. In summary, each component of climate change has more than one effect, and the distribution of one type of biophysical effect depends on soil conditions, species, and plant type [7].

There is an opportunity to achieve climate-friendly agriculture by both sequestering carbon and reducing emissions. The main strategies are 1) enriching soil carbon (e.g. using perennial plants), 2) promoting climate-friendly livestock systems, 3) reducing the use of inorganic fertilizers and 4) restoring degraded lands and preventing deforestation, which is mainly for agricultural purposes [8], [9].

Agriculture is the second most important source of GHG emissions [10], for example, in Latvia they accounted for approximately 22 % of the total GHG emissions in the country in 2022. Emissions from agricultural soils accounted for the largest share of total emissions – 46.5 %, and intestinal fermentation emissions were the second largest source – 42 %. The proportion of emissions from manure management was estimated as 7.8 % of the total emissions in the sector, the remaining 3.7 % of emissions refer to liming and urea use. GHG emissions in 2022 increased by 0.04 % compared to 2021 [11].

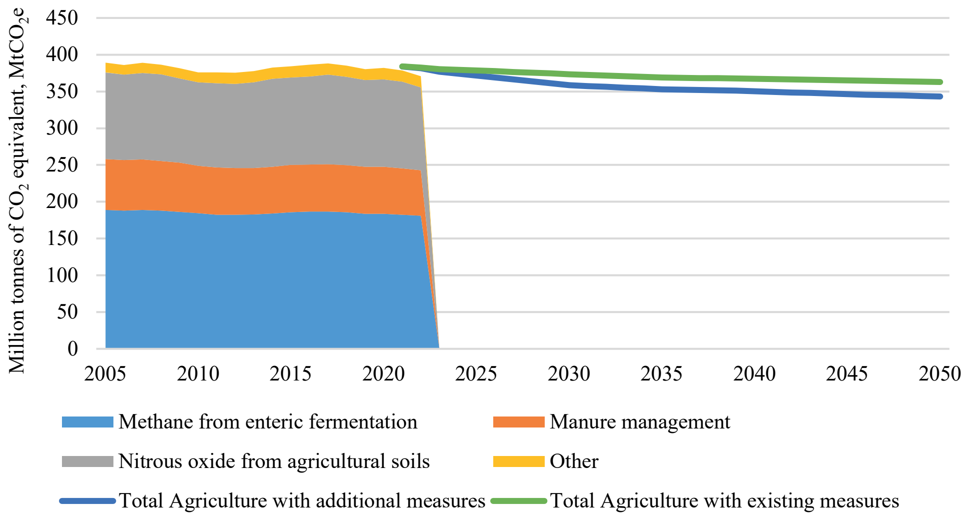

Fig. 1. EU agricultural emissions by source and projected emissions [12].

GHG emissions from agriculture, including crop and livestock farming, forestry, and associated land-use change, account for a significant share of anthropogenic emissions, up to 30 % according to the Intergovernmental Panel on Climate Change (IPCC) [13]. The European Climate Law [14] stipulates that Europe will transition to a climate-neutral economy by 2050 with an intermediate goal of reducing GHG emissions by at least 55 % by 2030. Also, targets have been set that determine the annual reduction for each member state in the period from 2021 to 2030, respectively [15], [12]. CH_4 emissions from gut fermentation and N_2O emissions from soil account for 48 % and 31 % of total agricultural GHG emissions, respectively. CH4 from manure management is the third most important source of emissions, accounting for about 17 %. The remaining sources produce relatively small amounts of emissions, accounting for less than 5 % of agricultural GHG emissions. Between 2005 and 2021, Europe agricultural GHG emissions show a slight decrease of 3 %, with a decrease of only 2 % in 2022. Projections of the member states show that GHG emissions will remain at approximately this level until 2030. If additional measures are taken into account, GHG emissions could rise to 8 % [16].

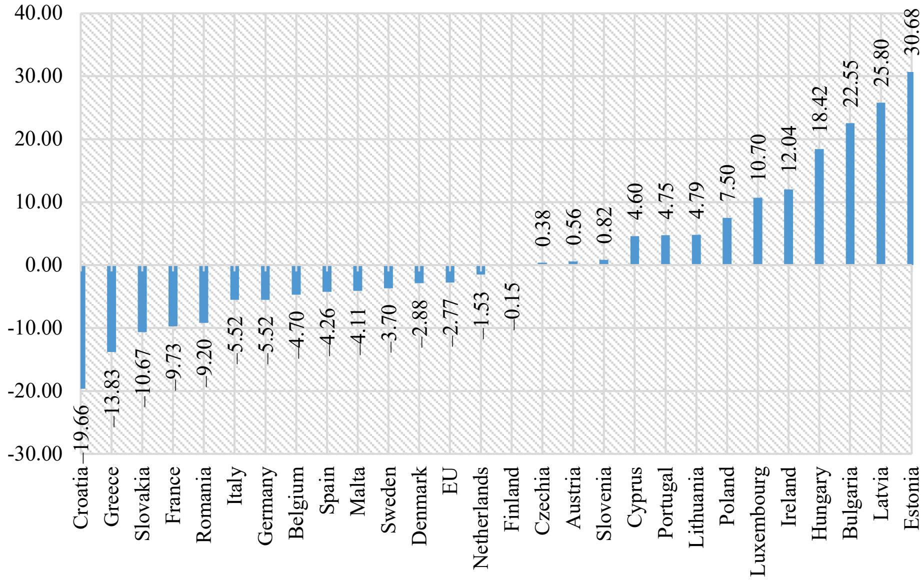

Fig. 2. Agricultural emissions and projected emissions by EU Member State in percentage change 2005–2021.

During the period from 2005 to 2021, the amount of GHG emissions from agriculture in Europe changed very little, but the trends of each country were very different, for example, they increased in 13 countries and decreased in 14 countries. For example, emissions fell by more than 10 % in Greece, Croatia, and Slovakia, while they increased by more than 10 % in Estonia, Hungary, Bulgaria, Latvia, Ireland, and Luxembourg. Taking into account the forecasts, an increase in emission trends is expected in most European countries if the current situation continues and no measures are taken to mitigate them. Twelve Member States have not reported planned additional measures that could reduce emissions more than existing measures [12]. The study aims to compare the emissions generated in the agricultural sector of the European Union countries against GDP, population, and GDP against population. The studies carried out so far have shown a comparison of the relationship with GHG emissions in agriculture, but no emphasis has been placed on their comparison with GDP and population [17], [18].

2. Methodology

The amounts of GHG emissions in the agricultural sector for all countries of the European Union [19], the total population [20], and the country's GDP per capita [21] were analysed. The calculation of GHG emissions per GDP and population often uses methodological approaches of normalization and comparison. In this process, GHG emissions are expressed as emissions per capita or per unit of GDP. This allows an objective comparison to be made between countries or regions, regardless of their population or economic size. Such an approach enables the identification and analysis of trends and differences in the intensity of GHG emissions in relation to population and economic activity. In the European Union, agriculture is an important source of emissions, especially for GHG emissions such as methane and nitrogen oxides, as well as ammonia and sulfur dioxide.

Normalization and Comparative Analysis: The approach used for the analysis involves normalizing emissions by population size and economic output to facilitate meaningful comparisons between European Union countries. This method accounts for varying population sizes and economic capacities across countries, ensuring that emissions data is not disproportionately influenced by these factors.

Emissions per population: This metric was calculated by dividing the total GHG emissions from agriculture by the total population of each country. By normalizing emissions in this way, the analysis accounts for the population size, making it easier to compare how agricultural emissions relate to each country's population size. Countries with higher emissions per capita indicate a higher intensity of agricultural emissions relative to their population.

$$\text{Emissions per population, kt } CO_2 \text{ eq} = \text{emissions / population} \quad (1)$$

Emissions per GDP: This value was derived by dividing total agricultural emissions by the GDP per country, allowing for a clearer view of emissions intensity in relation to economic output. This calculation highlights which countries have higher or lower emissions in comparison to their economic size, providing insight into the efficiency of their agricultural sectors in managing emissions relative to their economic productivity.

$$\text{Emissions per GDP, kt } CO_2 \text{ eq/million EUR} = \text{emissions / GDP} \quad (2)$$

Emissions per GDP per Capita: By dividing the GHG emissions by both GDP and population, this indicator gives a more detailed look at emissions relative to both economic output and individual contribution to the economy. This method captures both the environmental and economic efficiency of agricultural sectors in different countries, allowing for a nuanced comparison across the EU.

$$\text{Emissions per GDP per Capita, kt } CO_2 \text{ eq/EUR} = \text{emissions / population} \quad (3)$$

Overall, agriculture accounts for around 10–12 % of the EU's total GHG emissions, and this can vary by country, agricultural practices, and policies. For example, more intensive agriculture, such as livestock and industrial farming, can lead to higher levels of emissions [25].

The EU has introduced various policy initiatives to reduce emissions from agriculture and promote more sustainable practices. Examples are the Common Agricultural Policy [26] and the Green Deal [27], which aim to promote environmental and climate goals in agriculture. In addition, research and technological development, such as more efficient fertilization methods or technologies to reduce methane emissions, can be important factors in reducing emissions in the agricultural sector in the EU. 27 European Union countries were compared, as well as each country's agricultural emissions in 2022; calculation data are given in Table A1, see the Annex.

3. RESULTS

Fig. 3 shows data on the amount of greenhouse gas emissions (expressed as kilotons of carbon dioxide equivalent) per million euros of GDP in different European countries. This indicator provides an insight into the environmental efficiency of each country's economy, showing how much greenhouse gas is emitted to produce one million euros worth of GDP:

– Austria and Belgium stand out with relatively low emissions per million euros of GDP, which indicates efficient use of resources in the economy.

- Countries such as Bulgaria, Croatia, Greece, Latvia, Lithuania, Poland and Romania demonstrate higher emissions per million euros of GDP, indicating a less environmentally friendly mode of economic production.
- Ireland stands out with high emissions, possibly due to specific economic activities such as agriculture.
- Malta shows the lowest emissions per million euro of GDP, which indicates a relatively environmentally friendly economic development, in terms of greenhouse gas emissions per unit of economic output.

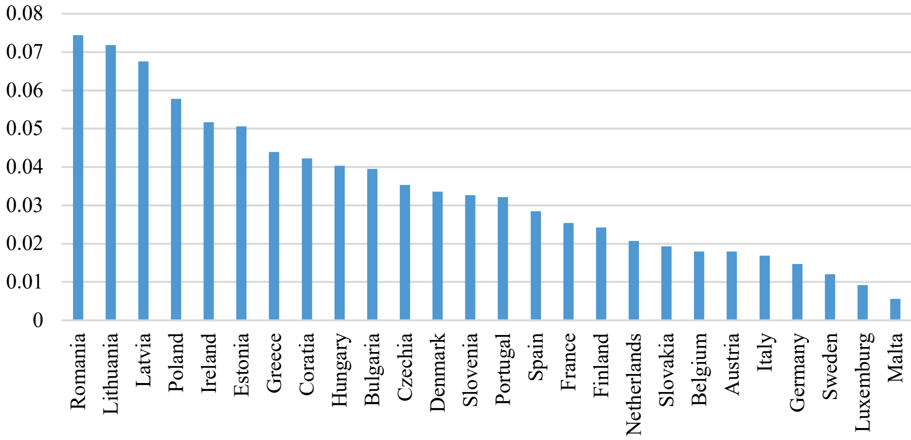

Fig. 3. Emissions in agriculture per GDP.

Fig. 4 shows data on the amount of GHG in the agricultural sector in relation to GDP per capita in different countries, expressed as kilotons of carbon dioxide equivalent per euro of GDP per capita.

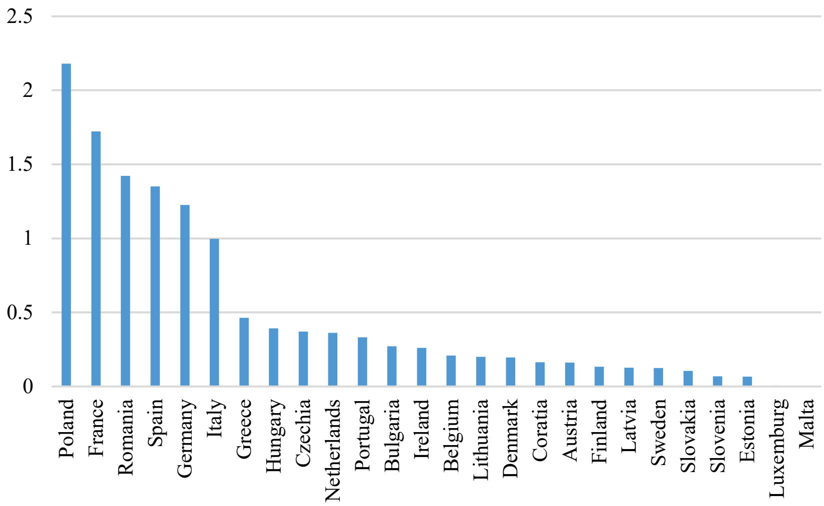

Fig. 4. Emissions in agriculture per GDP per capita.

This indicator helps to assess the environmental impact of the agricultural sector in each country, taking into account the amount of emissions, economic activity, and population:

- Countries such as Poland, France, Romania, Spain, and Germany have relatively high emissions in the agricultural sector in relation to GDP per capita, which may indicate a large environmental impact of the agricultural sector in these countries.
- On the other hand, in countries such as Malta and Luxembourg, emissions in the agricultural sector in terms of GDP per capita are very low, possibly due to the small importance of the agricultural sector or environmentally friendly agricultural practices.

Fig. 5 shows data on the amount of GHG in the agricultural sector per capita in different countries, expressed as kt CO_2eq per capita. This indicator indicates how much greenhouse gases are emitted per capita in the country's agricultural sector:

- Countries such as Ireland and Denmark have relatively high per capita emissions from the agricultural sector, which may indicate that the agricultural sector in these countries produces a larger amount of greenhouse gas emissions relative to the population.
- On the other hand, in countries such as Malta and Slovakia, emissions in the agricultural sector per capita are relatively low, possibly due to the small importance of the agricultural sector or effective environmental protection practices in these countries.

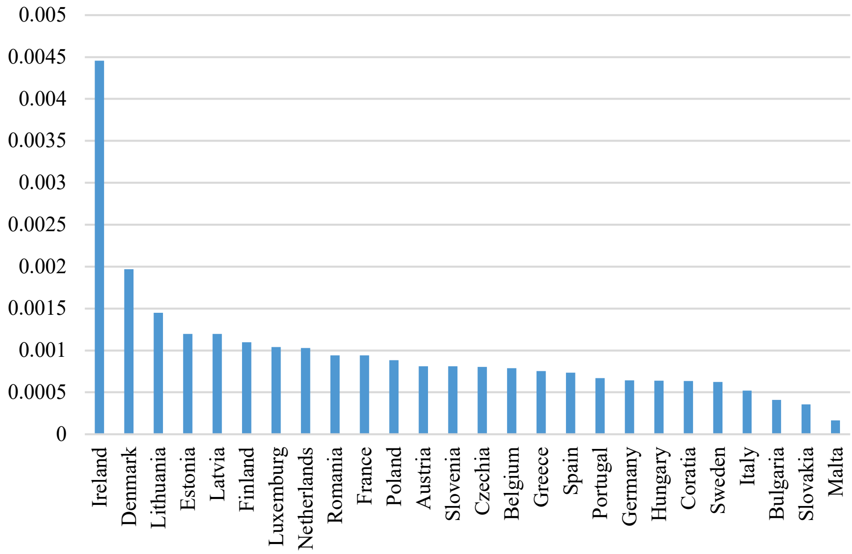

Fig. 5. Emissions in agriculture per population.

Despite the EU's ambitious targets to reduce GHG emissions from agriculture by 2030, current trends show a mixed picture of progress towards achieving these targets. While some Member States have made significant progress in curbing emissions, others still face challenges in meeting reduction targets.

Several Member States, including Croatia, Greece, and Slovakia, have achieved significant reductions in agricultural emissions since 2005. These countries are examples of successful emission reduction measures, demonstrating that effective mitigation measures are possible. In Europe, total agricultural GHG emissions have decreased slightly between 2005 and 2021, indicating some progress towards the 2030 reduction targets. This trend shows that current measures have had some impact on reducing emissions in the agricultural sector [28]. Despite overall reductions, agricultural emissions have increased in some Member States, such as Bulgaria, Estonia, Hungary, Ireland, Latvia and Luxembourg. These countries face challenges in implementing sufficient mitigation measures or may have structural barriers that hinder emissions reduction efforts. Projections show that, without further intervention, some Member States foresee a reversal of emission reduction trends. Greece and Romania, for example, expect emissions to rise if existing measures continue, underscoring the need to step up efforts to meet targets [29]. There are large differences between Member States in terms of emission levels and progress towards targets. Factors such as agricultural practices, land use patterns, and policy structures contribute to these differences. The European Commission's impact assessment highlights the challenges of further reducing non-CO_2 GHG emissions from agriculture, pointing to the need for innovative strategies and targeted measures [30]. To accelerate progress towards agricultural emission reduction targets, Member States should prioritize the implementation of effective mitigation measures tailored to their specific contexts and challenges. Promoting sustainable agricultural practices, investing in research and innovation, and providing adequate support and incentives to farmers are critical to achieving emission reduction targets. Cooperative efforts at the European level, including the exchange of best practices, knowledge sharing, and coherent policy frameworks, can foster collective action and drive progress toward common goals [31].

In conclusion, although some progress has been made in Europe in reducing agricultural emissions, there are still challenges to achieve the ambitious goals set for 2030. Tackling these challenges requires concerted efforts, innovative approaches, and continued commitment by Member States to a more sustainable transition. and a climate-resilient agricultural sector.

4. CONCLUSIONS AND DISCUSSION

The results of the comparative analysis reveal differences in emission intensity between European countries, providing valuable insight into the factors that influence these differences. A number of factors contribute to differences in emission intensity, including agricultural practices, economic structure, policy guidelines, and environmental considerations. Differences in agricultural practices, including livestock management, cropping methods and land use patterns, have a significant impact on emissions intensity. Countries with intensive livestock farming or extensive fertilizer use may have higher emissions compared to countries with more sustainable and environmentally friendly agricultural practices. The economic structure of a country, including the composition of its GDP and the relative importance of the agricultural sector, affects the intensity of emissions. Countries with a larger agricultural sector may have a higher emission intensity relative to their GDP because they are more dependent on emission-intensive agricultural activities [32]. The presence of strong environmental policies, regulations, and incentives can play a crucial role in shaping emission intensity levels. Countries with strong regulations and supportive policy systems that promote sustainable agriculture and emission reduction measures tend to show lower emission intensities compared to countries with less comprehensive policies. Emissions intensity is also influenced by environmental factors such as climate, soil conditions, and geographical features. In countries with favorable environmental conditions, agriculture may have a lower emission intensity due to higher productivity and efficiency of resource use. Improved technologies and practices such as precision agriculture, renewable energy, and methane capture systems can help reduce emission intensity by improving resource efficiency and reducing emissions from agricultural activities. Socio-economic factors, including population density, income levels, and cultural preferences, can affect the intensity of emissions. Countries with higher population density or higher demand for agricultural products may have higher emissions intensity due to increased pressure on land and resources. Historical factors, including past land-use practices, industrialization trajectories, and agricultural development policies, can also affect emissions intensity. Countries with legacy effects from historical land management practices or industrial activities may face challenges in reducing emission intensity. In summary, differences in emission intensity between European countries are multifaceted and are influenced by agricultural practices, economic structures, policy frameworks, environmental considerations, technological developments, socio-economic factors, and historical context. Understanding these factors is essential to develop tailored strategies and measures to effectively reduce agricultural emissions and promote sustainable agriculture across Europe. To limit and reduce the emissions caused by the agricultural sector, significant improvements must be made not only in the reduction of animals but also in the improvement of feed, because improving the quality of feed improves the reduction of emissions caused by animals (livestock). Also, more emphasis should be placed on the transition to organic agriculture.

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ANNEX

TABLE A1. INPUT DATA

Country	Population [22]	Emissions, kt CO_2 eq [23]	GDP, million EUR [24]	Emissions per population, kt CO_2 eq	Emissions per GDP (kt CO_2 eq/million EUR)	Emissions per GDP per capita, kt CO_2 eq/EUR
Austria	895 6000	7276.88	405 397.2033	0 .000813	0.01795	0.16076
Belgium	11 590 000	9149.05	508 280.2418	0.000789	0.018	0.20862
Bulgaria	6 878 000	2808.4	71 084.94004	0.000408	0.039508	0.271734
Coratia	3 879 000	2467.91	58 428.90211	0.000636	0.042238	0.163841
Czechia	10 510 000	8422.28	23 8434.8938	0.000801	0.035323	0.371247
Denmark	5 857 000	11 522.98	343 146.5434	0.001967	0.03358	0.19668
Estonia	1 331 000	1593.02	31 457.89412	0.001197	0.05064	0.067402
Finland	5 541 000	6074.92	251 013.0132	0.001096	0.024202	0.134101
France	67 760 000	63 645.38	2 502 864.265	0.000939	0.025429	1.72307
Germany	83 200 000	53 348.73	3 618 929.196	0.000641	0.014742	1.226499
Greece	10 570 000	7980.46	181 579.6321	0.000755	0.04395	0.464554
Hungary	9 710 000	6212.06	154 013.5113	0.00064	0.040335	0.391648
Iceland	372 520	595.98	21 649.04487	0.0016	0.027529	0.010255
Ireland	5 033 000	22 436.76	434 212.6252	0.004458	0.051672	0.260067
Italy	59 130 000	30 763.81	1 822 906.004	0.00052	0.016876	0.997892
Latvia	1 884 000	2253.83	33 352.32449	0.001196	0.067576	0.127314
Lithuania	2 801 000	4058.76	56 501.79608	0.001449	0.071834	0.201208
Luxemburg	640 064	665.57	72 387.03445	0.00104	0.009195	0.005885
Malta	518 536	86.09	15 298.15764	0.000166	0.005627	0.002918
Netherlands	17 530 000	18 039.53	870 750.7288	0.001029	0.020717	0.363173
Norway	5 408 000	4642.65	414 665.5865	0.000858	0.011196	0.060549
Poland	37 750 000	33 296.98	576 326.4876	0.000882	0.057775	2.180988
Portugal	10 360 000	6941.3	216 093.2062	0.00067	0.032122	0.332782
Romania	19 120 000	17 987.73	241 712.1949	0.000941	0.074418	1.422872
Slovakia	5 447 000	1934.43	100 287.4474	0.000355	0.019289	0.105066
Slovenia	2 108 000	1706.32	52 295.70784	0.000809	0.032628	0.06878
Spain	47 420 000	34 863.24	1 222 840.592	0.000735	0.02851	1.351946
Sweden	10 420 000	6513.09	541 288.5084	0.000625	0.012033	0.125379
Switzerland	8 705 000	5887.6	688 017.0023	0.000676	0.008557	0.074492