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Logarithmic Mean Divisia Index Decomposition Based on Kaya Identity of GHG Emissions from Agricultural Sector in Baltic States

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Abstract: Greenhouse gas (GHG) emissions from agriculture contribute to climate change. The consequences of unsustainable agricultural activity are polluted water, soil, air, and food. The agricultural sector has become one of the major contributors to global GHG emissions and is the world's second largest emitter after the energy sector, which includes emissions from power generation and transport. Latvian and Lithuanian agriculture generates about one fifth of GHG emissions, while Estonia generates only about one tenth of the country's GHG emissions. This paper investigates the GHG trends in agriculture from 1995 to 2019 and the driving forces of changes in GHG emissions from the agricultural sectors in the Baltic States (Lithuania, Latvia, and Estonia), which are helpful for formulating effective carbon reduction policies and strategies. The impact factors have on GHG emissions was analysed by using the Logarithmic Mean Divisia Index (LMDI) method based on Kaya identity. The aim of this study is to assess the dynamics of GHG emissions in agriculture and to identify the factors that have had the greatest impact on emissions. The analysis of the research data showed that in all three Baltic States GHG emissions from agriculture from 1995 to 2001–2002 decreased but later exceeded the level of 1995 (except for Lithuania). The analysis of the research data also revealed that the pollution caused by animal husbandry activities decreased. GHG intensity declined by 2–3% annually, but the structure of agriculture remained relatively stable. The decomposition of GHG emissions in agriculture showed very large temporary changes in the analysed factors and the agriculture of the Baltic States. GHG emissions are mainly increased by pollution due to the growing economy of the sector, and their decrease is mainly influenced by two factors—the decrease in the number of people employed in the agriculture sector and the decreasing intensity of GHGs in agriculture. The dependence of the result on the factors used for the decomposition analysis was investigated by the method of multivariate regression analysis. Regression analysis showed that the highest coefficient of determination ($R^2 = 0.93$) was obtained for Estonian data and the lowest ($R^2 = 0.54$) for Lithuanian data. In the case of Estonia, all factors were statistically significant; in the case of Latvia and Lithuania, one of the factors was statistically insignificant. The identified GHG emission factors allowed us to submit our insights for the reduction of emissions in the agriculture of the Baltic States.

Keywords: agricultural sector; sources of GHG emissions; factors of GHG emissions; decomposition analysis; LMDI; Kaya identity

1. Introduction

The rise in the average temperature of the Earth's surface and global warming are linked to greenhouse gases (GHGs), such as methane (CH_4), carbon dioxide (CO_2), nitrous oxide (N_2O), water vapor (H_2O), and hydrofluorocarbons (HFCs), through the greenhouse effect, which is a worldwide issue [1–3]. The main threat to the environment according to experts is climate change caused by anthropogenic atmospheric heating, due to increasing concentrations of greenhouse gases, mainly CO_2 [4]. Agriculture is inevitably linked to climate change. It should be noted that this sector is one of the largest emitters of greenhouse gases [5–8].

More than 80% of all agricultural greenhouse gas emissions come from CH_4 emissions from enteric fermentation and N_2O emissions from soil [9]. CH_4 is the third most important source of emissions from manure treatment, accounting for about 10%. The remaining sources make a relatively small contribution, accounting for less than 10% of total agricultural GHG emissions [10,11].

The analysis of the scientific literature on the research topic showed that the issues related to GHG emissions from the agricultural sector and energy-related GHG emissions in agriculture are discussed by various scientists. Research results are usually focused on greenhouse gas emission mitigation and reduction [6,12–14], analysis of the sources of greenhouse gas emissions [4,15], changes in greenhouse gas emissions [16–18], quantifying greenhouse gas emissions from global aquaculture [19], greenhouse gas emissions from supply chains of the livestock sector [20,21], etc.

The growing global greenhouse gas (GHG) emissions and their impact on climate change have increased the need for deeper research and assessments. Despite the diversity of research in this area, there is still a lack of comprehensive research related to GHG emissions in the agriculture sector and their dynamics and factors, as well by branches and sources, especially used in the LMDI model based on Kaya identity. The study conducted in this article will identify GHG emission factors and determine which of them reduce and which increase emissions and will provide insights for formulating effective carbon reduction policies and strategies for reducing emissions.

The aim of this study is to analyse GHG emissions in the agriculture sector and their dynamics, as well by branches and sources using the LMDI model based on Kaya identity to study the driving factors of agricultural GHG emissions.

This study consists of five main parts. In Section 2, we give a short analysis of the theoretical background. In this section we discuss the concepts of greenhouse gases and present reducing strategies of greenhouse gas emissions from the agricultural sector. In Section 3, the authors describe research methods and used data. Section 4 gives a data analysis of the empirical research. Section 4 also presents the results of a multivariate regression analysis, identifying the relationships between GHG emissions in agriculture and the factors used in the decomposition analysis. The final stage of this paper consists of a discussion and general conclusions based on the scientific literature and empirical research analysis.

2. Background

Greenhouse gases are all gases that can absorb infrared radiation (heat) due to their certain molecular structure. In the atmosphere, they play a very important role in trapping the heat that has reached the Earth and thus raising the temperature of the lower atmosphere [21]. Agricultural sustainability implies that high crop yields can be maintained under extreme natural conditions and that agricultural practices have acceptable environmental impacts [13]. Xiao et al. (2021) [12] have shown that quantity GHG emissions are driven by economic development and population size.

Greenhouse gas emissions from the EU's agricultural sector include national annual emissions indicators. Agricultural emissions between 2005 and 2019 remained stable. Following the implementation of the additional measures currently planned, a reduction of 55% is expected. This projected reduction would not be enough to meet the binding annual targets for most Member States, suggesting that further action is needed if the EU is to meet its 2050 climate neutralization target [22]. The 2018 report of the United Nations Intergovernmental Panel on Climate Change according to the Paris Agreement [23], to ensure that the global average temperature rises by no more than 1.5 degrees above pre-industrial levels by 2030, the world must reduce GHG emissions by 45% [24]. Data provided by countries to the United Nations Framework Convention on Climate Change show that GHG emissions in the European Union amounted to 4,065,462 million tonnes in 2019, excluding land use, land use change, and forestry of CO_2 equivalent. It should be noted that the EU is the third biggest emitter behind China and the United State and followed by India and Russia [25].

The livestock sector is an important agricultural sector in all Baltic countries. For example, GHG emissions from the Latvian and Lithuanian agricultural sector—methane (CH_4) and nitrous oxide (N_2O)—account for one fifth of total emissions (19.3% and 20.7% CO_2 equivalent in 2019, respectively), and this share is not decreasing from year to year [26]. Almost a fifth of Lithuania's GHG emissions come from the country's agriculture and 45% from the livestock sector (in 2019). CH_4 is mainly produced in the stomach during digestion. Another source of CH_4 is liquid manure as well as deep litter barns. The source of N_2O in the livestock sector is manure storage facilities. The share of GHG emissions in the total emissions from cattle manure in the last period was 18–20% [26].

According to the guidelines of the Common Agricultural Policy (CAP), countries must contribute to climate change mitigation and adaptation. To achieve this goal, the efficient management of natural resources—water, soil, and air—and the contribution to the protection of biodiversity, the improvement of ecosystem services, and the conservation of habitats and landscapes must be promoted [27].

For 2030, The National Climate Change Agenda has set a 15% target for reducing agricultural emissions by at least 11%, reducing the use of mineral fertilizers by up to 50%, using pig and cattle manure for biogas production, introducing pollution reduction technologies in animal husbandry, and managing at least 70% of the total amount of manure and slurry in a sustainable manner. The aim is also to double the area of organic farming (compared to 2020) by 2025 at the latest and develop and implement a GHG accounting system at the farm level and bring food supply chains closer to consumers [28].

It should be noted that the European Commission's impact assessment envisages further reductions in non-CO_2 greenhouse gas emissions from agriculture. Support for some effective measures, such as the use of fodder legumes, the improvement of manure treatment, and the use of sustainable fertilizers, has been isolated, and measures supported under the common agricultural policy have not been effective [29,30].

After discussing the theoretical background in the next chapter of this study, we will describe the methods of the research.

3. Methods and Used Data

The methodology for calculating GHG emissions is set out under the internationally agreed 2006 Guidelines for National Greenhouse Gas Inventories [31]. Meanwhile, researchers often analyse and assess the factors that influence GHG emissions and their evolution, including in agriculture [16,17,32–37]. However, there is no consensus among scholars on a universal method for an in-depth assessment of GNG emission changes in the agricultural sector. Despite that, decomposition analysis is one of the most used methods by scientists.

Index decomposition methodology was a technique first used in the late 1970s [38,39]. Index decomposition analysis (IDA) is an analytical tool that is used to measure different driving factors and their environmental side effects [40]. This method allows scientists to break down the aggregate indicator into a combination of several factors and to determine the influence of a single factor on the aggregate indicator [41]. In other words, the IDA method allows us to measure the impact of the main factors influencing changes over time in the GHG emissions produced by the agricultural sector. The method also makes it easy to explain and compare the results of the study. The IDA method can be divided into the Divisia IDA method and the Laspeyres IDA method [39]. Although both of these methods are used in research, the Divisia index method is superior to the Laspeyres index method because in the process of decomposition, there are no residual terms [41]; it considers the change in factors over time [42]. Ang and Liu (2001) [43] improved the Divisia index method and proposed a logarithmic mean Divisia index (LMDI) with good decomposition and aggregation.

To determine the impact of individual factors on total GHG emissions from agriculture in the countries analysed in this article, we used the LMDI method based on Kaya identity in this study. Kaya identity was first introduced in 1989 at the Intergovernmental Panel on Climate Change (IPCC) presented by Kaya [44]. Kaya identity is commonly used to determine total GHG (CO_2 equivalent) emissions from anthropogenic activities and is expressed as the product of four factors: human population, GDP per capita, energy intensity (per unit of GDP), and carbon intensity (emissions per unit of energy consumed) [18,45,46]. This is the case when it is necessary to determine how the interdependence of these four factors must change over time to reach a target level of GHG emissions in the future and to determine how these four factors have changed in the past.

The steps for decomposing GHG emissions from agriculture are based on the equations demonstrated in the studies by [44,47–50]. Each factor has a different effect on total GHG emissions over a different period of time [51]. GHG emissions (in CO_2 equivalent) from agriculture consist of four factors and are equal to their product.

$$C = \frac{C}{PGDP} \times \frac{PGDP}{AGDP} \times \frac{AGDP}{AL} \times AL \tag{1}$$

where C represents the GHG emissions from agriculture; PGDP represents the gross output value of crop–animal husbandry; AGDP represents gross output value of agriculture, and AL represents employment labour of the agriculture.

$$EI = \frac{C}{PGDP} \quad CI = \frac{PGDP}{AGDP} \quad SI = \frac{AGDP}{AL} \tag{2}$$

where EI, CI, and SI represent crop–animal husbandry GHG intensity, agricultural structure, and agricultural labour productivity, respectively.

In additive decomposition for the model in Equation (1), the effect of various driving factors from the baseline year 0 to the final year t were set as C_0 and C_t, respectively, can be expressed as follows:

$$\Delta C_{tot} = C_t - C_0 = \Delta EI + \Delta CI + \Delta SI + \Delta AL \tag{3}$$

where C_{tot} represents the total change of GHG emissions from agriculture.

Each effect is further expressed in Equations (4)–(7)

$$\Delta EI = \sum \frac{C_t - C_0}{\ln C_t - \ln C_0} \ln \frac{EI_t}{EI_0} \tag{4}$$

$$\Delta CI = \sum \frac{C_t - C_0}{\ln C_t - \ln C_0} \ln \frac{CI_t}{CI_0} \tag{5}$$

$$\Delta SI = \sum \frac{C_t - C_0}{\ln C_t - \ln C_0} \ln \frac{SI_t}{SI_0} \tag{6}$$

$$\Delta AL = \sum \frac{C_t - C_0}{\ln C_t - \ln C_0} \ln \frac{AL_t}{AL_0} \tag{7}$$

The variation in the individual factors (EI, CI, SI, and AL, see above) leading the change in total GHG emissions from agriculture, from the baseline year 0 to the final year *t*, is the sum of the annual changes in these factors.

If the value of the effect is positive, it means that the factor increases GHG emissions; if the value is negative, it reduces GHG emissions [51].

In the study, a multivariate regression analysis was performed to determine the relationship between independent (explanatory) and dependent (explained) variables. In the present study, the dependent variable is GHG emissions from agriculture, and the independent variables are crop–animal husbandry GHG intensity, agricultural structure, and agricultural labour productivity.

The main sources of GHG emissions in agriculture are:

1. GHG emissions from crop use, including land use, the addition of synthetic nitrogen and organic (manure, sewage sludge, and compost) fertilizers, pesticides and wastes to soils, and agricultural waste management, etc.;
2. Livestock emissions from cattle belching and manure management.

In this study we analysed and evaluated the sources and factors of GHG emissions in agriculture in the three Baltic States—Estonia, Latvia, and Lithuania—and their impact on total GHG emissions using the LMDI method based on Kaya identity. It is important to mention that these three Baltic countries were annexed by the USSR in 1940 and regained their independence in 1990–1991; in 2004, these countries became members of the EU, and they are also Member States of the Eurozone. They are classified as high-income economies by the World Bank [52]. Agriculture is one of the most traditional economic activities in Estonia, Latvia, and Lithuania. Agriculture continues to be important in the Baltic States, supplying food not only to Estonia, Latvia, and Lithuania but also to other countries and providing jobs for many people. It is therefore important to analyse, compare, and evaluate the environmental aspects of similar agricultural structures in countries with similar natural conditions in agriculture over a quarter of a century.

The research relied on the Eurostat Database [53]. The agricultural output was chosen as the economic activity indicator. The gross output value of agriculture and gross output value of crop–animal husbandry were taken from the economic accounts for agriculture provided by Eurostat. To ensure comparability over time and space, the gross output value of agriculture and the gross output value of crop–animal husbandry were measured in purchasing power standards (PPS) at the basic constant prices of 2010. The data on GHG emissions from agriculture in tonnes of CO_2 equivalent came from Eurostat greenhouse gas emissions by source sector statistics database. The number of employees (measured in 1000 annual work units) was obtained from the agricultural labour input statistics. The data cover years 1995–2019.

4. Results

4.1. GHG Emissions Trends from Agriculture

GHG emission trends in Estonian, Latvian, and Lithuanian agriculture in general and by branches were analysed for 1995–2019. The results are shown in Table 1. Agricultural activities directly contribute to GHG emissions and are second only to the energy sector in all three Baltic States. In Lithuania and Latvia, GHG emissions from agriculture (excluding land use, land use change, and forestry—LULUCF) accounted for an average of about one fifth during the period under review, and in Estonia for about 7% of their total quantity (Figure 1). In Estonia, compared to Lithuania, GHG emissions from agriculture were on average 3 times lower.

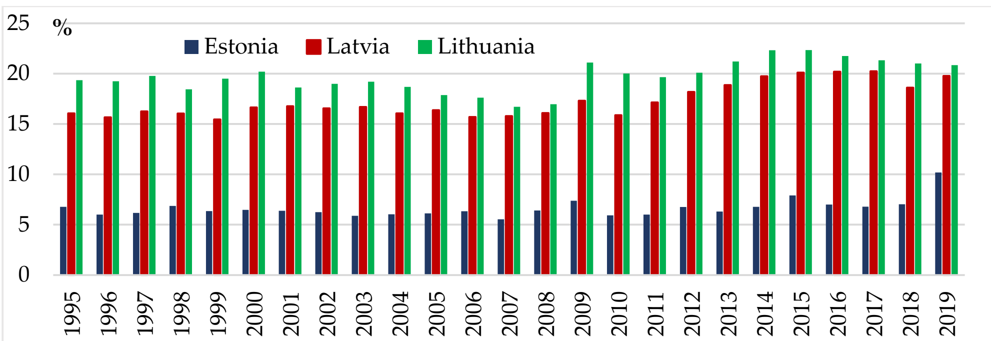


Figure 1. Share of GHG emissions from agriculture in the Baltic States, 1995–2019.

Table 1. GHG emissions from agriculture in the Baltic countries, 1995–2019, thousand tonnes, in CO_2 equivalent.

	Estonia						Latvia						Lithuania					
Year	**Crop Husbandry**	**Growth Rate %**	**Animal Husbandry**	**Growth Rate %**	**Total Emissions**	**Growth Rate %**	**Crop Husbandry**	**Growth Rate %**	**Animal Husbandry**	**Growth Rate %**	**Total Emissions**	**Growth Rate %**	**Crop Husbandry**	**Growth Rate %**	**Animal Husbandry**	**Growth Rate %**	**Total Emissions**	**Growth Rate %**
1995	567.89		805.91		1373.8		793.06		1210.79		2003.84		1479.98	-	2815.46	-	4295.44	-
1996	526.76	−7.24	745.07	−7.55	1271.84	−7.42	805.01	1.51	1158.39	−4.33	1963.40	−2.02	1743.46	17.80	2727.47	−3.13	4470.93	4.09
1997	540.05	2.52	741.35	−0.50	1281.39	0.75	815.80	1.34	1130.02	−2.45	1945.82	−0.90	1777.50	1.95	2730.70	0.12	4508.20	0.83
1998	586.49	8.60	717.62	−3.20	1304.12	1.77	790.06	−3.16	1051.55	−6.94	1841.61	−5.36	1764.21	−0.75	2620.86	−4.02	4385.06	−2.73
1999	510.39	−12.98	622.02	−13.32	1132.41	−13.17	743.25	−5.92	909.97	−13.46	1653.22	−10.23	1710.56	−3.04	2378.00	−9.27	4088.56	−6.76
2000	523.33	2.54	608.33	−2.20	1131.67	−0.07	762.90	2.64	915.53	0.61	1678.43	1.52	1716.85	0.37	2204.30	−7.30	3921.15	−4.09
2001	502.69	−3.94	640.84	5.34	1143.53	1.05	821.01	7.62	968.44	5.78	1789.45	6.61	1686.76	−1.75	2080.61	−5.61	3767.36	−3.92
2002	469.74	−6.55	613.63	−4.25	1083.37	−5.26	800.58	−2.49	960.71	−0.80	1761.29	−1.57	1773.93	5.17	2137.45	2.73	3911.38	3.82
2003	506.35	7.79	626.28	2.06	1132.63	4.55	846.25	5.70	958.65	−0.21	1804.90	2.48	1783.08	0.52	2205.96	3.21	3989.03	1.99
2004	534.97	5.65	639.47	2.11	1174.44	3.69	803.17	−5.09	927.44	−3.26	1730.62	−4.12	1802.06	1.06	2232.79	1.22	4034.85	1.15
2005	527.74	−1.35	650.96	1.80	1178.7	0.36	841.36	4.75	952.44	2.70	1793.80	3.65	1831.86	1.65	2224.58	−0.37	4056.44	0.54
2006	516.66	−2.10	660.86	1.52	1177.52	−0.10	833.22	−0.97	960.22	0.82	1793.43	−0.02	1779.93	−2.83	2268.76	1.99	4048.70	−0.19
2007	563.27	9.02	665.35	0.68	1228.63	4.34	873.68	4.86	1001.65	4.31	1875.32	4.57	1929.60	8.41	2273.56	0.21	4203.16	3.82
2008	620.82	10.22	666.43	0.16	1287.26	4.77	867.15	−0.75	971.18	−3.04	1838.34	−1.97	1888.99	−2.10	2212.13	−2.70	4101.12	−2.43
2009	561.87	−9.50	666.56	0.02	1228.43	−4.57	893.93	3.09	966.13	−0.52	1860.04	1.18	2027.14	7.31	2170.85	−1.87	4197.98	2.36
2010	569.32	1.33	686.45	2.98	1255.76	2.22	924.03	3.37	955.51	−1.10	1879.55	1.05	2006.90	−1.00	2142.98	−1.28	4149.89	−1.15
2011	581.66	2.17	694.76	1.21	1276.42	1.65	928.29	0.46	963.42	0.83	1891.71	0.65	2073.17	3.30	2118.81	−1.13	4191.98	1.01
2012	634.95	9.16	722.46	3.99	1357.41	6.35	995.22	7.21	979.70	1.69	1974.92	4.40	2170.16	4.68	2100.20	−0.88	4270.37	1.87
2013	629.55	−0.85	759.88	5.18	1389.43	2.36	1021.49	2.64	1012.25	3.32	2033.73	2.98	2174.32	0.19	2069.82	−1.45	4244.13	−0.61
2014	663.48	5.39	771.75	1.56	1435.23	3.30	1062.61	4.03	1048.05	3.54	2110.66	3.78	2346.72	7.93	2114.30	2.15	4461.02	5.11
2015	687.51	3.62	746.32	−3.30	1433.83	−0.10	1110.40	4.50	1048.61	0.05	2159.01	2.29	2402.66	2.38	2127.32	0.62	4529.99	1.55
2016	659.51	−4.07	727.44	−2.53	1386.94	−3.27	1117.15	0.61	1050.62	0.19	2167.76	0.41	2368.05	−1.44	2047.00	−3.78	4415.06	−2.54
2017	690.47	4.69	740.55	1.80	1431.02	3.18	1124.02	0.61	1056.57	0.57	2180.59	0.59	2389.63	0.91	1984.62	−3.05	4374.24	−0.92
2018	679.32	−1.61	741.16	0.08	1420.49	−0.74	1079.37	−3.97	1017.56	−3.69	2096.93	−3.84	2286.73	−4.31	1944.41	−2.03	4231.15	−3.27
2019	749.79	10.37	747.06	0.80	1496.87	5.38	1179.72	9.30	1022.65	0.50	2202.37	5.03	2347.23	2.65	1898.27	−2.37	4245.50	0.34

The growth rates of GHG emissions in agriculture in the Baltic States compared to 1995 are presented in Figure 2. These rates clearly show two periods, a reduction in GHG emissions and a subsequent increase in GHG emissions. The study revealed that GHG emissions in agriculture in all three Baltic States by 2002 had a sharp downward trend and reached 82.5% in Latvia (1999), 78.9% in Estonia (2002), and 87.7% in Lithuania (2001) comparing to 1995 level. Later, they grew quite fast, and in 2013 they reached the 1995 level and then started to increase. These changes were driven by the countries' integration into the EU and increased opportunities for greater investment in and public support for agricultural production, in other words, the modernization and mechanization of the countries' agricultural sector through the implementation of the CAP and other support measures.

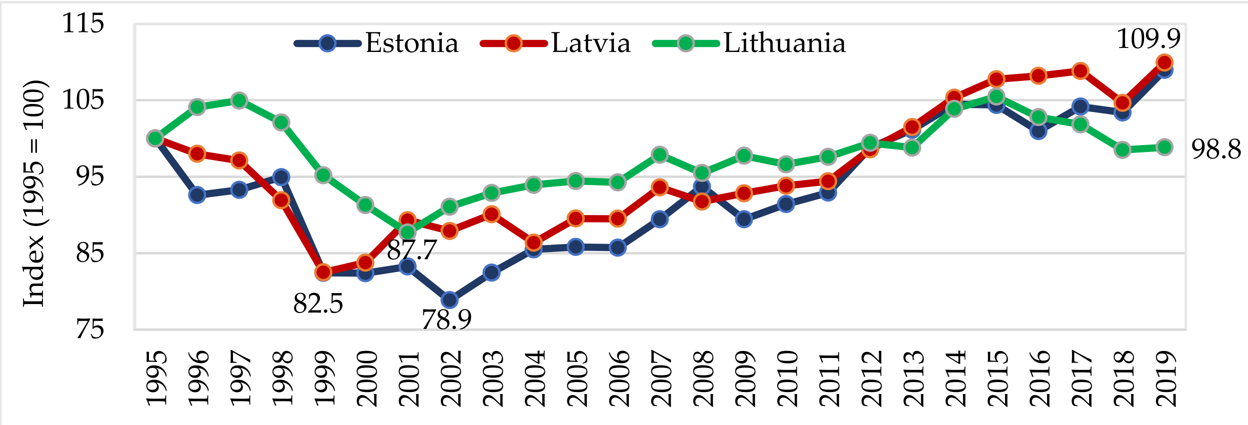


Figure 2. GHG emissions indices from agriculture in the Baltic States, 1995–2019.

The growth rate of GHG emissions in Latvia in 2019, compared to 1995, was the highest among the Baltic States. GHG emissions increased from 2.00 million t to 2.20 million t (in CO_2 equivalent) or 9.9% (an average of 0.39% per year). Emissions from Estonian agriculture also increased significantly from 1.37 million to 1.50 million t or 9.0% (average 0.36% per year). In Lithuania, these changes were negative during the period under review—GHG emissions decreased from 4.30 million t to 4.25 million t or 1.2% (an average of 0.05% per year). Estonia and Latvia had the highest GHG emissions from agriculture (measured by the coefficient of variation (CV)); Lithuania had the lowest (Table 2).

Table 2. Dynamics of GHG emissions in agriculture in the Baltic States, 1995–2019.

Country	GHG Emissions, Thousand Tonnes, in CO_2 Equivalent		Rate of Growth, % 2019/1995	Average Annual Growth Rate, %	Standard Deviation, Thousand Tonnes	Mean, Thousand Tonnes	CV
	1995	2019					
Estonia	1373.80	1496.87	9.0	0.36	118.5	1280.53	0.09
Latvia	2003.84	2202.37	9.9	0.39	162.4	1921.23	0.08
Lithuania	4295.44	4245.50	−1.2	−0.05	200.3	4203.71	0.05

4.2. GHG Emissions Trends from Animal Husbandry

4.2.1. From Enteric Fermentation

As already mentioned, GHG emissions in the agricultural sector are generated in livestock from animal gut fermentation and manure handling systems and from crop production, such as liming, use of nitrogen fertilizers (urea), and agricultural soils. GHG emissions from intestinal fermentation in the Baltic States from 1995 to 2019 had a declining trend. It declined sharply until 2002, and compared to the 1995 level, it was down by almost a quarter. This was due to a sharp decline in livestock numbers. For example, in the Baltic

States the number of cattle decreased by about a third, the number of pigs in Latvia and Lithuania by almost a fifth and in Estonia by almost a quarter, and the number of sheep by about 55–70%. This was due to very low livestock and milk purchase prices and high livestock costs, insufficient government financial support for the livestock sector, stable or even declining consumption of meat and meat products due to slow growth in purchasing power, insufficient long-term relations and support and cooperation between livestock farmers and meat processors, and an undeveloped international market. It is important to note that before the accession to the EU, the Baltic livestock market was largely closed. After the restoration of independence, the Baltic States lost their former export markets to the east, and exports to the west were not developed. Meat imports were very low due to low prices in the Baltic States, and exports were also low due to insufficient meat quality and existing customs duties and other restrictions. In addition, livestock production had been uncompetitive on the world market due to excessive costs. These factors were determined by the fact that in the Baltic States after the restoration of independence in 1990–1991 land reform was still under way; a new system of price and income support was being developed, and the search was on for new markets. The structure of agriculture also changed: With the establishment of agricultural companies instead of collective farms and Soviet farms, most large farms collapsed, and private property developed, but small farms were underfunded materially and financially. With the accession of countries to the EU and the increase in direct payments and investment support for livestock farmers, the number of animals, especially butcher, started to rise, as did emissions. Since 2009, emissions from animal gut fermentation increased in Latvia and Estonia, although at the end of the period under review, they did not reach the 1995 level. In Lithuania, meanwhile, the volume of this type of pollutant grew, and since 2007, there was a marked downward trend (Figure 3). Strict animal husbandry regulations from an environmental point of view, increasing international competition, rising breeding costs and low increases in animal purchase prices, and unstable or even declining milk purchase prices were some of the main reasons why Baltic farms were abandoning livestock farming.

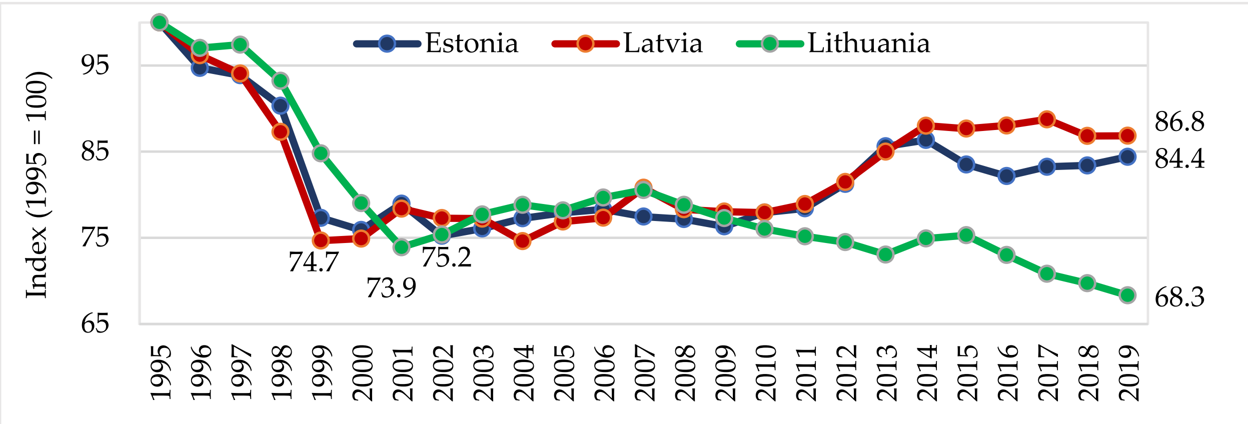


Figure 3. GHG emissions indices from enteric fermentation in the Baltic States, 1995–2019.

During the period under review, GHG emissions from animal intestinal fermentation decreased the fastest in Lithuania. Although its volume was the highest, in 2019, compared to 1995, the amount of this pollution decreased from 2.17 million t to 1.48 million t (in CO_2 equivalent) or almost a third (an average of 1.57% per year). Emissions from animal gut fermentation decreased the slowest in Latvia from 0.98 million t to 0.85 million t or 13.2% (an average of 0.59% per year). The largest fluctuations in this type of emissions were in Lithuania (coefficient of variation of 10.9%), where the rate of change was the highest (Table 3).

Table 3. Dynamics of GHG emissions from enteric fermentation in the Baltic States, 1995–2019.

Country	GHG Emissions, Thousand Tonnes, in CO_2 Equivalent		Rate of Growth, % 2019/1995	Average Annual Growth Rate, %	Standard Deviation, Thousand Tonnes	Mean, Thousand Tonnes	CV
	1995	2019					
Estonia	647.16	546.22	−15.6	−0.70	42.8	531.5	0.08
Latvia	978.97	850.12	−13.2	−0.59	69.3	812.7	0.09
Lithuania	2170.51	1483.12	−31.7	−1.57	187.9	1721.3	0.11

The study revealed that about 95% of these gases in all Baltic countries were generated by cattle; 1.1–2.5% by sheep; 1.6–1.8% by pigs; and 0.6–1.6% by intestinal fermentation of other species. However, while the amount of GHG emissions from the fermentation of cattle and pig intestines decreased in all Baltic countries in 2019 compared to 1995 (especially from pigs), it increased from sheep in Latvia and Estonia by about 1.5 times and in Lithuania by as much as 4 times (Figure 4). The reduction in GHG emissions from pig intestine fermentation was due to a decrease in the number of pigs due to African swine fever and competition between local pork producers and importers. Another reason is that due to high grain prices, farmers with arable land refused to raise pigs. In the last ten years alone, the number of pigs in Estonia and Latvia fell by about 17%, and in Lithuania by more than a third. In 2019, compared to 2009, the number of sheep in Latvia increased by more than 40% and in Lithuania by as much as 3.5 times. The increase in their number was due to the emergence of sheep export opportunities. As their numbers grew, so did their pollution.

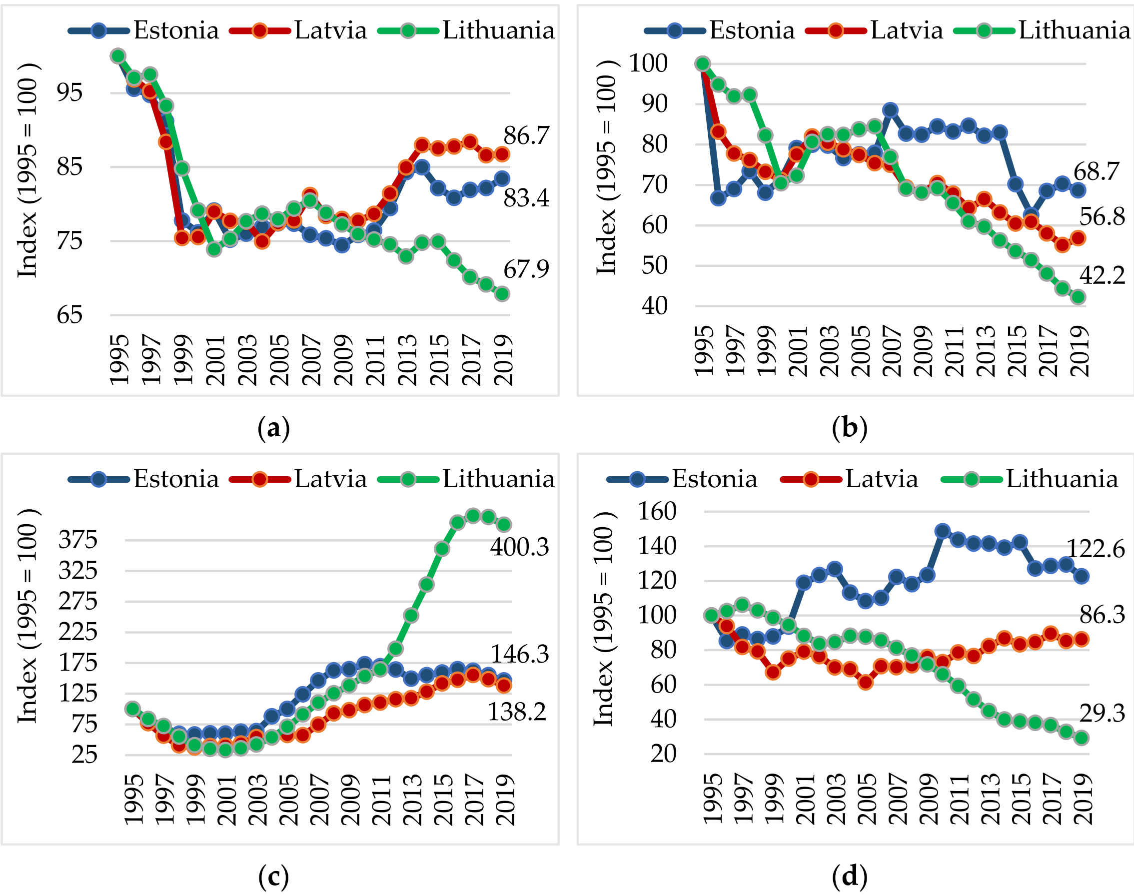


Figure 4. GHG emissions indices from kind of animal enteric fermentation in the Baltic States, 1995–2019. (**a**) Cattle. (**b**) Pigs. (**c**) Sheep. (**d**) Other livestock.

Thus, the reduction in GHG emissions from animal gut fermentation was caused not only by international agreements on the reduction of pollutants and animal welfare requirements, but also by changes in the number of individual species, herd structure, affected by public financial support, developed export markets, full and balanced feeding ration, use of appropriate preparations, improvement of animal productivity, and application of new farm management systems.

4.2.2. From Manure Management

The study revealed that the dynamics of GHG emissions from manure management systems were similar in Latvia and Lithuania and had a declining trend in the long run, but in Estonia, on the contrary, these emissions increased. Up until 1999–2001 in all the Baltic States, emissions fell to three quarters of the previous level in 1995, but then they increased in Latvia and Estonia until 2006–2007, and after that they showed a clear downward trend. In Estonia, meanwhile, emissions from manure management systems rose since 2000 and increased only slightly from 2015 onwards (Figure 5). This may have been influenced by the fact that in 2000 Estonia switched from litter to liquid manure management systems on dairy farms. Using this method opens the possibility of anaerobic conditions, which can result in the release of up to 80% of methane, while very little methane is released from solid manure [54].

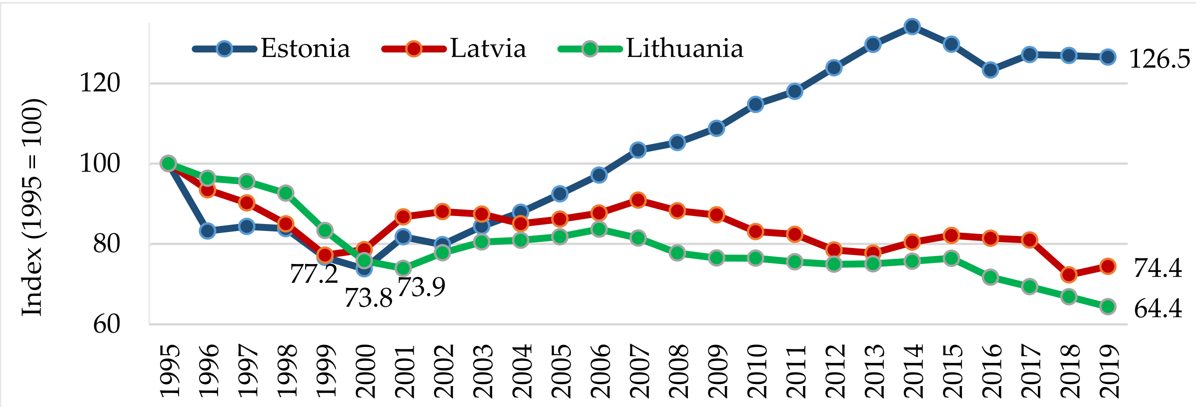


Figure 5. GHG emissions indices from manure management in the Baltic States, 1995–2019.

In the period under review, GHG emissions from manure management decreased the most in Lithuania and Latvia in 2019; compared to 1995, the amount of these emissions decreased by almost 36% and 26%, respectively or by 1.82% and 1.22% annually on average. In Estonia, meanwhile, emissions from manure management rose from 0.16 million t to 0.20 million t over the long term, or more than a quarter (0.98% annually on average). This type of emission also had the largest fluctuations (coefficient of variation of 19.4%) (Table 4).

Table 4. Dynamics of GHG emissions from manure management in the Baltic States, 1995–2019.

Country	GHG Emissions, Thousand Tonnes, in CO_2 Equivalent		Rate of Growth, % 2019/1995	Average Annual Growth Rate, %	Standard Deviation, Thousand Tonnes	Mean, Thousand Tonnes	CV
	1995	2019					
Estonia	158.75	200.84	26.5	0.98	31.9	164.9	0.19
Latvia	231.82	172.53	−25.6	−1.22	14.4	195.2	0.07
Lithuania	644.95	415.15	−35.6	−1.82	57.1	511.9	0.11

The dynamics of GHG emissions from manure management by animal species is shown in Figure 6. In Latvia and Estonia, more than half of this type of emission comes from the processing of cattle manure (average 55%); in Lithuania this share is about 44%.

In Estonia and Lithuania, almost a quarter of these pollutants during the period under review were related to the management of pig manure; in Latvia it accounted for about 18%. Up to one fifth of this group of pollutants accounted for indirect nitrous oxide emissions associated with manure management.

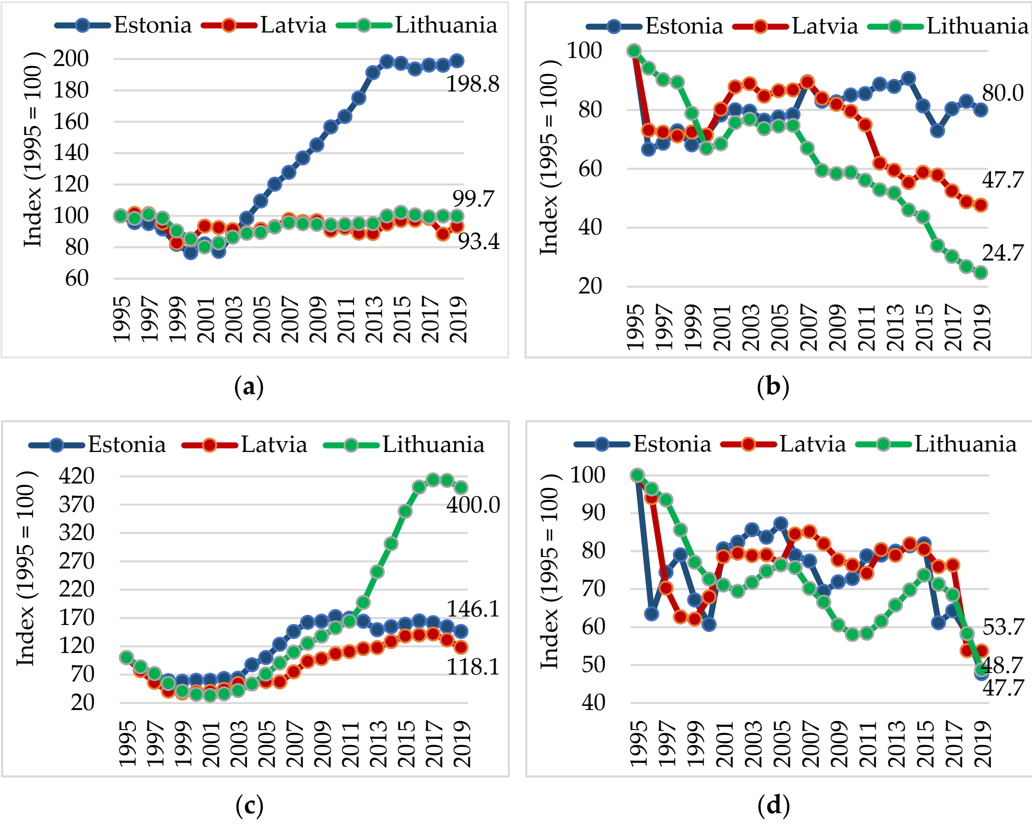


Figure 6. GHG emissions indices from kind of manure management in the Baltic States, 1995–2019. (**a**) Cattle. (**b**) Pigs. (**c**) Sheep. (**d**) Other livestock.

It is important to note that emissions from pig manure management also decreased as the number of pigs kept decreased (80% in Estonia in 2019, 48% in Latvia, and only 25% in Lithuania in 1995). In the long run, indirect nitrogen oxide emissions from manure management had also been declining in all Baltic countries. In 2019, they accounted for about 61% in Latvia and Estonia and in Lithuania for about 72% of these emissions comparing to 1995. Conversely, emissions related to the handling of sheep manure increased 1.2 times in Latvia, 1.5 times in Estonia, and as much as 4.0 times in Lithuania during the period under review as the number of sheep kept increasing. The increase in the number of cattle kept in Estonia also led to a rapid increase in emissions from cattle manure management, which doubled during the period under review, while in Latvia it decreased by almost a tenth, and in Lithuania it remained at the same level as in 1995.

Garnett (2009) [55] identified four ways to mitigate GHG emissions from the livestock sector, focusing on improving productivity, changing management systems, managing production, and reducing livestock numbers. The first three methods may involve technical measures, and the fourth method may require structural changes. Thus, by applying existing knowledge, innovation, and raising the awareness of agricultural actors, GHG emissions can be reduced in all areas of agricultural production [55].

4.3. GHG Emissions Trends from Crop Husbandry

4.3.1. From Managed Agricultural Soils

In the crops sector, one of the sources of GHG emissions is agricultural soils. Emissions from this source account for the largest share of pollution from agricultural activities. Its share in the structure during the period under review had an upward trend in all Baltic countries. It grew the fastest in Lithuania from 34.2% in 1995 to 54.6% in 2019 and increased by as much as 20.4 percentage points. Meanwhile, the share of pollution from this source in the structure of Latvia increased by almost half (11.6 percentage points, from 39.5% to 51.1%), and in Estonia it was 2.5 times less than in Lithuania (8.0 percentage points, from 41.0% to 49.0%).

Up until 2011 (except 2008) in Estonia and up until 2005 in Latvia, emissions from this source did not exceed (or did so only slightly) their former 1995 levels, but later their growth rates began to increase rapidly. In Lithuania, emissions from agricultural soils tended to increase throughout the period under review (Figure 7). Such negative changes in emissions may have been caused by the rapid growth of crop areas. It can be assumed that the increase in the area under crops, especially cereals, was influenced by the 2004 accession of the Baltic States to the EU when new opportunities for international trade opened up. For example, in Lithuania the area of crops increased 1.5 times and that of cereals 1.7 times since 2004. Whereas in 2004 cereals accounted for 64% of the structure, in 2019 they accounted for 70%. Similar trends were typical for Latvia and Estonia.

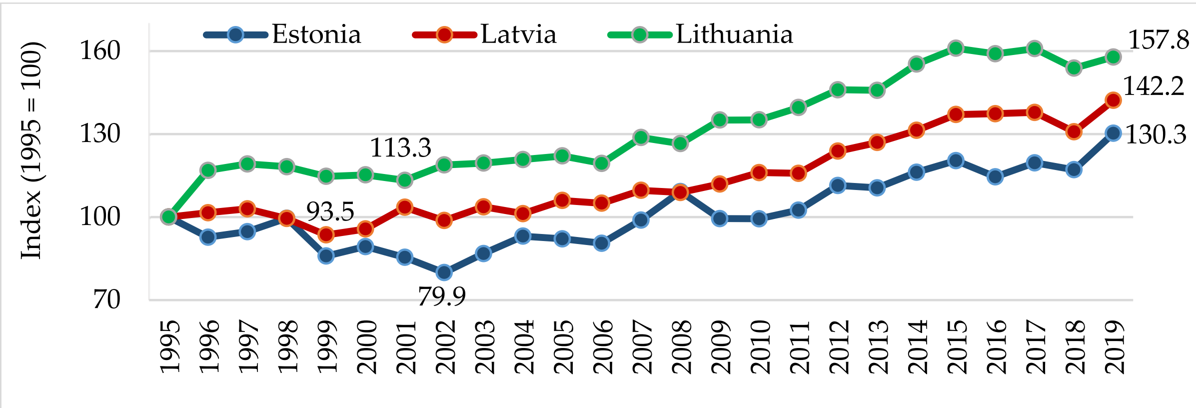


Figure 7. GHG emissions indices from managed agricultural soils in the Baltic States, 1995–2019.

In the long run, Lithuania stood out among the Baltic States with the highest growth rate of emissions from agricultural soils. In 2019, compared to 1995, pollution from this source increased from 1.47 million t to 2.32 million t (CO_2 equivalent) or 1.6 times. The average annual growth rate was as high as 1.92%. In Estonia, the amount of this pollution increased by almost a third (from 0.56 million t to 0.73 million t or 1.11% annually) and in Latvia by 42%. Fluctuations in the emissions of this source varied very little in all the Baltic States during the period under review, with emissions being higher in Lithuania (coefficient of variation of 13.7%), where emissions also grew the fastest during the period under review (Table 5).

Table 5. Dynamics of GHG emissions from managed agricultural soils in the Baltic States, 1995–2019.

Country	GHG Emissions, Thousand Tonnes, in CO_2 Equivalent		Rate of Growth, % 2019/1995	Average Annual Growth Rate, %	Standard Deviation, Thousand Tonnes	Mean, Thousand Tonnes	CV
	1995	2019					
Estonia	563.66	734.2	30.3	1.11	74.0	572.5	0.13
Latvia	791.15	1124.85	42.2	1.48	120.2	899.0	0.13
Lithuania	1469.21	2318.62	57.8	1.92	265.6	1940.7	0.14

GHG emissions from agricultural soils can be direct or indirect. Direct sources are those from which nitrous oxide is released directly into the atmosphere, i.e., on synthetic and organic fertilizers, livestock manure and urine residues in pastures, crop residues, organic soil management, and nitrogen mineralization related to the loss of organic carbon due to land use change. Indirect sources are related to nitrogen evaporation and nitrogen leaching/run-off. The study revealed that in all the Baltic States, more than four fifths of nitrous oxide from agricultural soils enters the environment directly, with Latvia accounting for the largest share of about 87%. Throughout the period under review, in Estonia (since 2011) and Latvia (since 2005) direct emissions to the atmosphere from this source exceed 1995 levels, while in Lithuania it was higher throughout the period considered. This type of direct pollution grew the fastest in Lithuania in 2019, compared to 1995; it increased by 52.2% or 1.77% annually and was slower in Latvia and Estonia by 33.8% and 27.9% or by 1.22% and 1.03% per year, respectively (Figure 8).

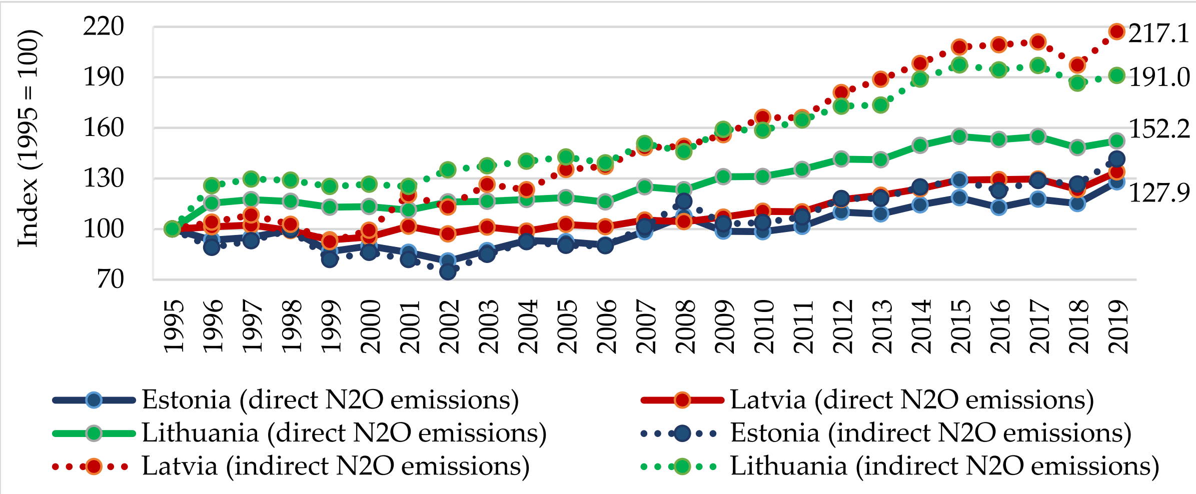


Figure 8. GHG emission indices from managed agricultural soils by the forms in the Baltic States, 1995–2019.

4.3.2. From Liming

In Estonia and Latvia, soil liming is the second most important source of pollution from crop production, although GHG emissions from agriculture accounted for only 0.9% and 0.6% on average over the period under review, respectively. GHG emissions from soil liming were very dynamic in all Baltic countries during the period under review. In Estonia in 1998–2003, emissions from this source increased 5–7 times compared to 1995. Their growth rates also increased in 2016–2018. In Latvia, pollution from this source increased significantly in 2002, 2003, and 2011–2019 and exceeded the 1995 level by up to 36 times. In Lithuania, pollution due to soil liming also increased, but the highest rates were in 2013–2015, when emissions increased 4–6 times compared to 1995 (Figure 9).

During the period under review, Latvia stood out among the Baltic States with the highest growth rate of emissions due to soil liming. In 2019, as compared to 1995, pollution from this source increased from 1.24 thousand t to 44.63 thousand t (CO_2 equivalent) or 35 times (16.10% annually). This could be explained by the increase in lime consumption. As it was noted in Latvia's national inventory report 1990–2018 (2020) [56], Latvian agricultural land has a tendency of soil acidification. According to information provided by the State Plant Protection Service, 53.5% of agricultural land is required for liming to neutralise the soil acidity. Since 1992, soil liming has been characterised as insufficient. However, liming activities rapidly increased in recent years. In Estonia, the volume of this pollution increased more than 3 times (from 3.59 thousand t to 15.46 thousand t or 6.27% annually) and in Lithuania by 2.1 times or an average of 4.80% per year. The largest fluctuations in the emissions of this source were in Estonia; the coefficient of variation reached as high as 64.2% (Table 6).

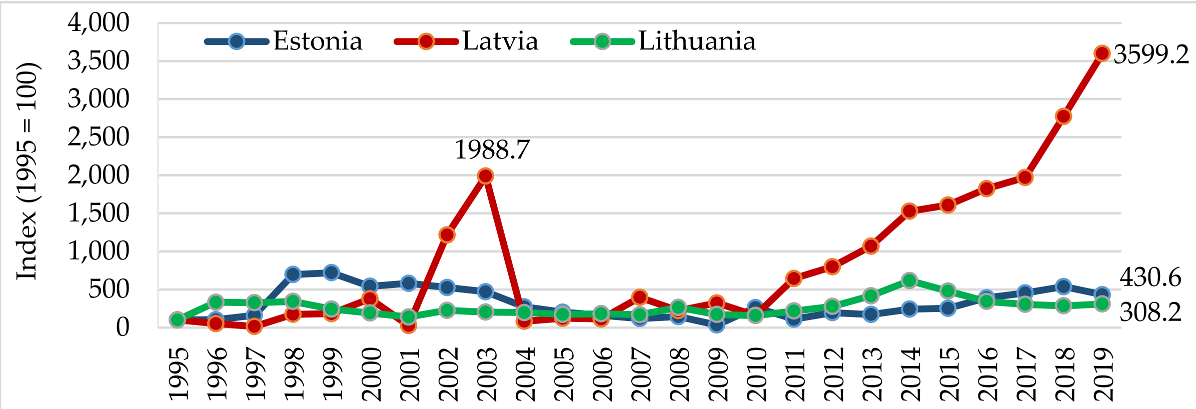


Figure 9. GHG emissions indices from liming in the Baltic States, 1995–2019.

Table 6. Dynamics of GHG emissions from liming in the Baltic States, 1995–2019.

Country	GHG Emissions, Thousand Tonnes, in CO_2 Equivalent		Rate of Growth, % 2019/1995	Average Annual Growth Rate, %	Standard Deviation, Thousand Tonnes	Mean, Thousand Tonnes	CV
	1995	2019					
Estonia	3.59	15.46	330.6	6.27	7.2	11.3	0.64
Latvia	1.24	44.63	3499.2	16.10	12.1	10.6	1.14
Lithuania	4.03	12.42	208.2	4.80	4.7	10.7	0.44

Research shows that liming causes CO_2 emissions to intensify by 13–18% compared to uncalcined soil [57].

4.3.3. From Urea Application

In Lithuania, urea application is the second most important source of pollution from crop production, although the structure of GHG emissions from agriculture in the period under review averaged only 0.5%. GHG emissions from the use of nitrogen fertilizers (urea) in Latvia and Estonia were very dynamic during the period under review. In Latvia, the growth rates of pollution from this source increased especially since 2007; in Lithuania, significant dynamics were observed in 2004–2010; Estonia stood out for its pollution reduction between 1996 and 2003 and especially since 2008 (Figure 10).

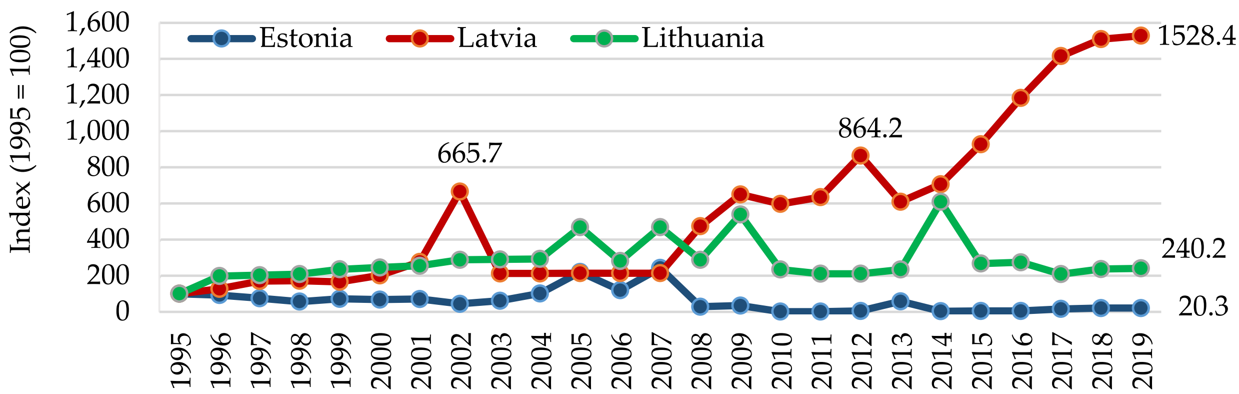


Figure 10. GHG emissions indices from urea application in the Baltic States, 1995–2019.

While Latvian farmers used more nitrogen fertilizers than Estonians and Lithuanians (during the period under review, the use of nitrogen fertilizers in agriculture increased 6.7 times in Latvia, 4.5 times in Lithuania, and 2.2 times in Estonia) [58], GHG emissions due to the use of nitrogen fertilizers grew the fastest. In 2019, as compared to 1995, pollution from this source increased from 0.67 thousand t to 10.24 thousand t (CO_2 equivalent) or more than 14 times (12.03% annually). In Lithuania, this pollution increased 1.4 times from 6.74 thousand t to 16.19 thousand t (3.72% per year). In Estonia, the volume of this pollution decreased 4.9 times during the period under review (from 0.64 thousand t to 0.13 thousand t or 6.43% annually). The largest fluctuations in the emissions of this source were in Estonia; the coefficient of variation reached as much as 102.9% (Table 7).

Table 7. Dynamics of GHG emissions from urea application in the Baltic States, 1995–2019.

Country	GHG Emissions, Thousand Tonnes, in CO_2 Equivalent		Rate of Growth, % 2019/1995	Average Annual Growth Rate, %	Standard Deviation, Thousand Tonnes	Mean, Thousand Tonnes	CV
	1995	2019					
Estonia	0.64	0.13	−79.7	−6.43	0.4	0.4	1.03
Latvia	0.67	10.24	1428.4	12.03	3.0	3.8	0.81
Lithuania	6.74	16.19	140.2	3.72	7.8	19.1	0.41

As already mentioned, the increase in the amount of these emissions was influenced by the increase in the area of crops, especially cereals, in the Baltic States. This type of pollution is also influenced by the intensive use of nitrogen fertilizers [59,60] to increase yield [61]. Excessive use of nitrogen fertilizers in agriculture increases environmental pollution [62,63], which would also reduce GHG emissions.

Thus, in summary, it can be stated that the amount of GHG emissions in all Baltic countries from 1995 to 2019 was dynamic, and the pace of its change was determined by various factors, such as the integration of countries into the EU and increased opportunities for greater investment and public support for agricultural production, international agreements on reducing pollutants, animal welfare requirements, number of individual species, herd structure changes, application of manure management systems, innovations, technological solutions, and trade restrictions. The highest growth rate of GHG emissions from agriculture in the analysed period was in Latvia and Estonia, while in Lithuania the growth rate of GHG emissions in the analysed period was negative.

4.4. Decomposition Results

The LMDI method based on Kaya identity allows for the quantification of the contributions of different factors to the overall change in GHG emissions. The analysis was carried out in a chain-linked continent, and the results were aggregated for the whole research period from 1995 to 2019. Based on the LMDI method based on Kaya identity analysis, using Equations (1)–(7), the factors of the decomposition results were calculated for the GHG emissions in the Baltic States from agriculture, as shown in Table 8. The study revealed that the significance of the impact of individual factors on the amount of GHG emissions (in CO_2 equivalent) in agriculture was different in Estonia, Latvia, and Lithuania (Figure 11). In Latvia and Lithuania three factors and in Estonia two factors reduced GHG emissions, while in Latvia and Lithuania one factor and in Estonia two factors increased GHG emissions.

Table 8. Decomposition results of GHG emissions from agriculture in the Baltic States, 1996–2019, thousand tonnes, in CO_2 equivalent.

	Estonia					Latvia					Lithuania				
Year	**Crop–Animal Husbandry GHG Intensity, kg CO_2 eq/PPG**	**Agricultural Structure, PPG/PPG**	**Agricultural Labour Productivity, PPG/AWU**	**Employment Labour of the Agriculture, Thousand AWU**	**Total Change of GHG Emissions from Agriculture, Thousand Tonnes**	**Crop–Animal Husbandry GHG Intensity, kg CO_2 eq/PPG**	**Agricultural Structure, PPG/PPG**	**Agricultural Labour Productivity, PPG/AWU**	**Employment Labour of the Agriculture, Thousand AWU**	**Total Change of GHG Emissions from Agriculture, Thousand Tonnes**	**Crop–Animal Husbandry GHG Intensity, kg CO_2 eq/PPG**	**Agricultural Structure, PPG/PPG**	**Agricultural Labour Productivity, PPG/AWU**	**Employment Labour of the Agriculture, Thousand AWU**	**Total Change of GHG Emissions from Agriculture, Thousand Tonnes**
1996	−64.69	1.56	5.45	−44.28	−101.96	21.99	9.90	−155.05	82.72	−40.44	−446.01	−16.17	471.33	166.34	175.49
1997	−8.11	1.11	26.14	−9.59	9.55	43.94	9.76	−152.78	81.51	−17.58	−330.66	21.84	175.69	170.40	37.27
1998	59.95	−1.72	−27.05	−8.44	22.73	−44.63	9.45	44.52	−113.56	−104.21	86.73	87.46	250.99	−548.31	−123.14
1999	−48.12	−49.43	−46.32	−27.84	−171.71	226.91	−107.53	−187.33	−120.44	−188.39	130.46	−1.71	29.03	−454.28	−296.50
2000	−166.52	20.48	163.20	−17.90	−0.74	−84.30	−5.40	174.37	−59.46	25.21	−25.79	27.34	942.03	−1111.00	−167.41
2001	−13.63	−1.41	141.45	−114.55	11.86	−25.63	37.58	139.19	−40.12	111.02	46.14	5.93	136.27	−342.13	−153.79
2002	−28.45	−18.74	29.95	−42.92	−60.16	−133.93	−68.83	200.46	−25.86	−28.16	−280.83	26.82	183.85	214.18	144.02
2003	46.79	3.58	408.58	−409.70	49.26	24.56	−102.90	149.57	−27.62	43.61	−213.33	−8.99	168.76	131.22	77.65
2004	31.52	5.67	21.97	−17.35	41.81	−176.80	25.41	94.76	−17.65	−74.28	−293.54	−83.14	908.49	−485.99	45.82
2005	−78.51	1.88	94.50	−13.61	4.26	−110.18	−22.52	212.38	−16.50	63.18	−340.84	−42.57	209.24	195.76	21.59
2006	28.64	−4.37	−11.35	−14.10	−1.18	36.76	−2.23	177.15	−212.05	−0.37	232.32	−70.02	16.27	−186.30	−7.74
2007	−119.90	29.12	294.40	−152.51	51.11	−145.31	39.75	433.58	−246.12	81.89	−179.32	8.00	524.57	−198.79	154.46
2008	109.00	−36.10	52.82	−67.09	58.63	−98.47	58.54	150.83	−147.89	−36.98	−371.93	−80.18	540.97	−190.90	−102.04
2009	−87.93	−5.50	115.30	−80.71	−58.83	34.24	0.08	107.78	−120.40	21.70	74.81	−19.38	147.26	−105.83	96.86
2010	65.69	12.50	127.24	−178.10	27.33	47.82	16.31	102.29	−146.91	19.51	284.23	−21.18	−204.81	−106.33	−48.09
2011	−82.53	−14.24	167.85	−50.41	20.66	0.37	−39.72	−0.67	52.19	12.16	−314.33	−52.99	432.75	−23.33	42.09
2012	−2.77	11.99	139.38	−67.61	80.99	−252.74	26.74	394.48	−85.27	83.21	−517.05	32.78	486.21	76.45	78.39
2013	−18.51	−12.27	116.02	−53.22	32.02	31.94	−19.62	85.05	−38.56	58.81	103.62	−50.66	−67.46	−11.74	−26.24
2014	−52.86	34.92	82.89	−19.15	45.80	−4.95	−9.28	259.05	−167.89	76.93	−153.58	21.24	198.60	150.63	216.89
2015	−123.79	2.74	234.47	−114.82	−1.40	−251.60	19.96	239.86	40.13	48.35	−253.22	−47.49	342.78	26.91	68.97
2016	212.99	5.75	−267.02	1.39	−46.89	185.18	−13.16	−117.79	−45.48	8.75	72.83	−110.68	−17.36	−59.71	−114.93
2017	−64.27	19.96	86.31	2.08	44.08	−18.34	−1.19	76.72	−44.36	12.83	−104.12	−48.15	173.92	−62.46	−40.82
2018	114.63	−32.03	−76.19	−16.93	−10.53	177.33	−58.88	−78.39	−123.73	−83.66	296.08	12.68	−353.07	−98.79	−143.09
2019	−265.35	41.78	389.76	−89.82	76.38	−386.70	40.36	467.38	−15.60	105.44	−402.04	9.59	673.39	−266.58	14.35
Total	−556.71	17.23	2269.75	−1607.20	123.07	−902.55	−157.41	2817.44	−1558.95	198.53	−2899.38	−399.65	6369.68	−3120.59	−49.94

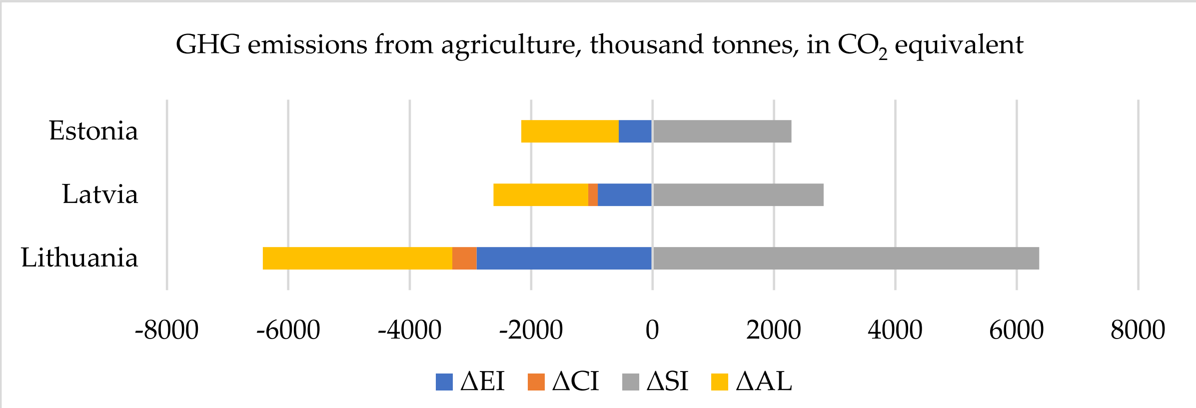


Figure 11. Decomposition of change in GHG emissions from agriculture in the Baltic States, 1995–2019.

In Estonian agriculture from 1995 to 2019, two factors from the four examined (changes in the intensity of GHG emissions and the number of people employed in agriculture) reduced GHG emissions cumulatively by 2163.91 thousand t (CO_2 equivalent) from 1996 to 2019; the other two factors (changes in agricultural structure and labour productivity) increased them cumulatively by 2286.98 thousand t (CO_2 equivalent) (Table 8). Compared with 1995, these two factors cumulatively achieved 18.6 times the GHG emissions from agriculture from 1996 to 2019. Taken together, the other two factors significantly reduced GHG emissions by 17.6 times. The decrease in GHG emissions was mainly due to the decrease in the number of people employed in agriculture, i.e., due to the decrease in the number of employees in Estonian agriculture. GHG emissions (in CO_2 equivalent) decreased on average by 66.97 thousand t annually. Because of this factor, the total amount of GHG emissions in agriculture decreased in all the analysed years, except in 2016 and 2017. It should be noted that during the period under review, the number of people employed in the country decreased by as much as 51.55 thousand AWU or 5.34% annually. This annual change was the largest among all the Baltic countries. The change in GHG intensity, which reflects pollution in agricultural production, was the second factor that cumulatively increased GHG emissions in Estonian agriculture from 1996 to 2019 by 556.71 thousand t (CO_2 equivalent). Crop–animal husbandry GHG intensity, which represents the efficiency factor of agricultural production in the country, decreased from 1.79 kg CO_2 equivalent/PPS to 1.15 kg CO_2 equivalent/PPS or by an average of 1.80% per year. This means that more efficient and environmentally friendly use of agricultural tools and technologies in Estonian agriculture had a positive effect on GHG emissions and reduced GHG emissions by an average of 23.20 thousand t (CO_2 equivalent) per year. It is important to note that in 8 of the 24 cases examined, this factor increased the total amount of GHG emissions in agriculture, while the following year they decreased. Changes in the structure of agriculture had a negligible effect on GHG emissions in the country's agriculture during the period under review. Compared with 1995, this factor cumulatively increased by 17.23 thousand t (CO_2 equivalent) of GHG emissions from agriculture from 1996 to 2019. This shows that changes in the structure of agriculture had a negative impact on the environment and contributed to the increase of GHG emissions in Estonian agriculture, on average 0.72 thousand t annually. Labour productivity in the country's agriculture in the period under review had a strong upward trend, increasing from 11.86 thousand PPS/AWU to 74.00 thousand PPS/AWU, i.e., 6.2 times or 7.93% annually. Labour productivity in Estonia grew the fastest among all Baltic countries. However, the growing economy of the sector at the same time increased GHG emissions, although in some years this factor contributed to reducing pollution in agriculture.

In Latvian agriculture from 1995 to 2019, GHG emissions (in CO_2 equivalent) were reduced by three factors (they decreased cumulatively by 2618.91 thousand t from 1996 to 2019), and labour productivity increased (Table 8). This shows that the growing economy of the sector and rising labour productivity, which increased 4.4 times over the period under review or by an average of 6.41% per year, contributed to the increase in agricultural pollution. It should be noted that the impact of this factor was stronger than the factors that reduced pollution in the country. The decrease in GHG emissions (in CO_2 equivalent) was mainly due to the decrease in the number of people employed in agriculture (they decreased by 91.18 thousand AWU or by an average 3.42% per year). Due to the impact of this factor on the country's agriculture, GHG emissions (in CO_2 equivalent) decreased on average by 64.96 thousand t annually. There was a decrease in GHG intensity of crop–animal husbandry (average of 1.95% per year). GHG emissions from Latvian agriculture from 1995 to 2019 decreased quite significantly and cumulatively by 902.55 thousand t (CO_2 equivalent) or by an average of 37.61 thousand t every year. Changes in the structure of agriculture reduced overall GHG emissions in Latvia, but not significantly. Compared with 1995, because of this factor, the GHG emissions from agriculture increased cumulatively by 157.41 thousand t (CO_2 equivalent) from 1996 to 2019 or by an average of 6.56 thousand t every year.

In Lithuanian agriculture from 1995 to 2019, GHG emissions (as with Latvia) were reduced by three factors (cumulatively 6419.62 thousand t from 1996 to 2019), and labour productivity increased (cumulatively 6369.68 thousand t) (Table 8). As in other Baltic countries, the decrease in GHG emissions (in CO_2 equivalent) was mainly due to the decrease in the number of people employed in agriculture. In Lithuania, the number of people employed in agriculture decreased by almost half during the period under review or by an average of 3.11% annually. Due to the impact of this factor, pollution in agriculture decreased cumulatively by 3120.59 thousand t (CO_2 equivalent) from 1996 to 2019 or by an average of 130.02 thousand t annually. GHG intensity also significantly reduced pollution in the country's agriculture cumulatively by 2899.38 thousand t (CO_2 equivalent) from 1996 to 2019 or by an average of 120.81 thousand t annually. The GHG intensity of these activities in the country halved in 24 years from 1.93 kg CO_2 equivalent/PPS to 0.97 kg CO_2 equivalent/PPS. This means that more efficient use of agricultural tools and technologies in Lithuanian agriculture had a significant positive effect on the overall reduction in GHG emissions (CO_2 equivalent). As with Latvia, changes in the structure of agriculture also contributed to the reduction in total GHG emissions in Lithuanian agriculture, but the impact of this factor was not very significant during the period under review. However, this reduced pollution by cumulatively 399.65 thousand t (CO_2 equivalent) from 1996 to 2019 or by an average of 16.65 thousand t annually. These changes indicate the continuous optimization of the agricultural structure. The growing economy of the agricultural sector in Lithuania, as well as in Estonia and Latvia, contributed to the increase in pollution in agriculture.

The decomposition of GHG emissions in agriculture showed temporal developments in the factors (Figure 12). The study found that in all the Baltic States since 2001 more or less crop–animal husbandry GHG intensity reduced GHG emissions. This was due to the fact that even before joining the EU, the Baltic States were able to take advantage of preferential terms and financial support to acquire new or used, but less polluting, western agricultural machinery and technologies. These processes intensified as countries joined the EU. On the other hand, the rapid decline in the number of people employed in agriculture (with a few exceptions) and the increase in agricultural output during the period under review led to an increase in labour productivity, which contributed to an increase in agricultural pollution.

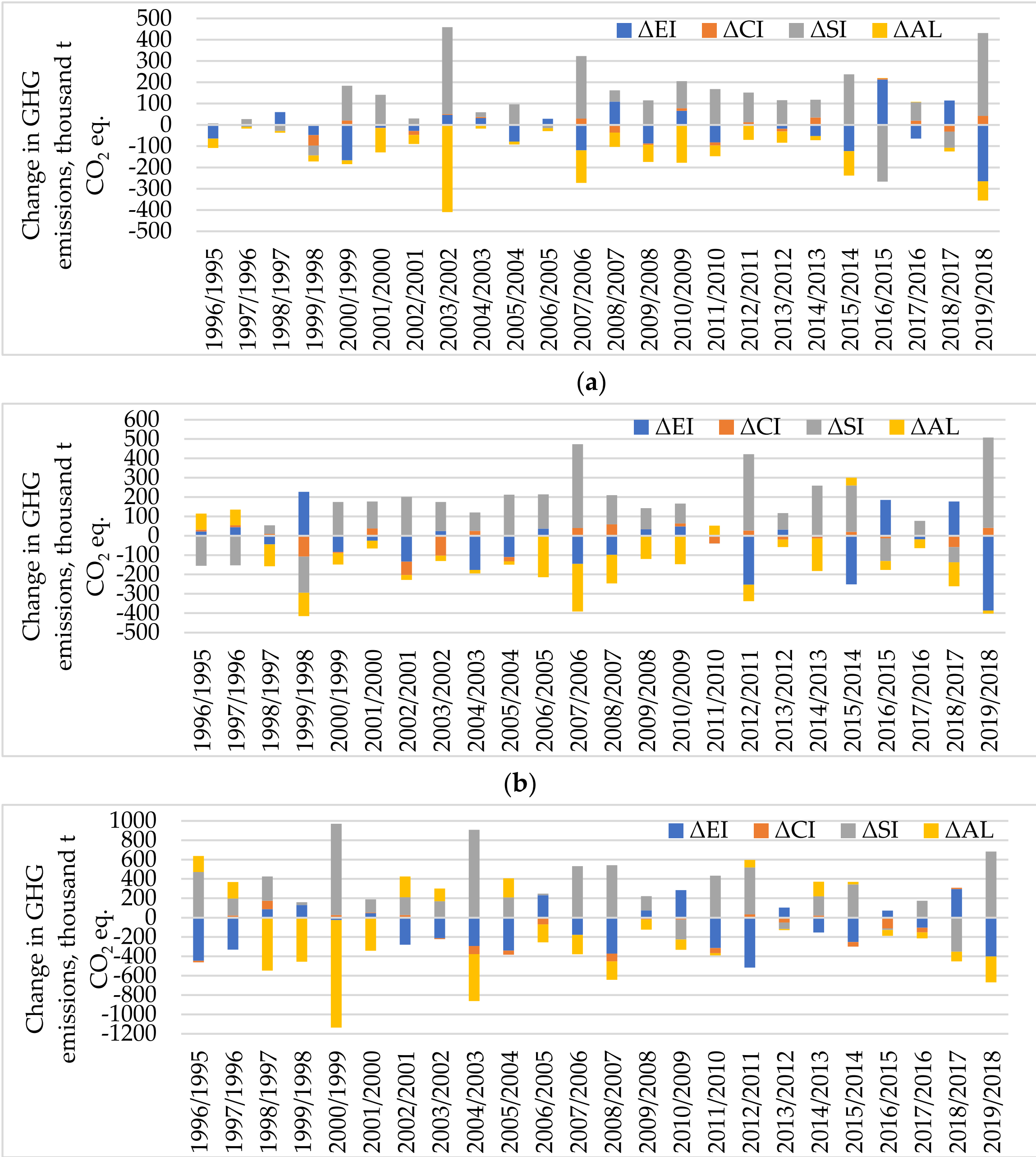


Figure 12. The chain-linked decomposition of the change in the GHG emissions from agriculture in Lithuania, 1995–2019. (**a**) Estonia. (**b**) Latvia. (**c**) Lithuania.

4.5. Results of a Multivariate Regression Analysis of Agricultural GHG Emission Factors

The multivariate regression analysis was performed in the study to determine the relationship between independent (explanatory) and dependent (explained) variables. Using the Estonian, Latvian, and Lithuanian statistics from 1995 to 2019

$$y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \varepsilon \quad (8)$$

where the dependent variable was the GHG emissions from agriculture (y), and the independent variables were the crop–animal husbandry GHG intensity (X_1), agricultural structure (X_2), and agricultural labour productivity (X_3); and ε was the model error, i.e., all other factors on which the dependent variable under investigation may still depend.

The level of statistical reliability $\alpha = 0.05$ was chosen.

The obtained results show (Table 9) that using this model for Estonian data, all variables were statistically significant. Using data from Latvia and Lithuania, the variable for crop-animal husbandry GHG intensity was statically insignificant. The results presented in the table show that the highest coefficient of determination was obtained for Estonian data ($R^2 = 0.93$); it was slightly lower for Latvian data ($R^2 = 0.84$) and the lowest for Lithuanian data ($R^2 = 0.54$). This shows that the factors studied in Estonia may explain almost 93%, almost 84% in Latvia, and 54% in Lithuania of GHG emissions from agriculture.

Table 9. Results of a multivariate regression analysis.

Country	Coefficients					
	GHG Emissions from Agriculture	**Crop–Animal Husbandry GHG Intensity**	**Agricultural Structure**	**Agricultural Labour Productivity**	**F**	**R^2**
Estonia	−1557.90 $p < 0.01$	469.64 $p < 0.001$	2098.25 $p < 0.001$	8.01 $p < 0.001$	89.88 $p < 0.001$	0.93
Latvia	166.72 $p = 0.701$	−55.98 $p = 0.072$	1728.31 $p < 0.001$	17.50 $p < 0.01$	36.39 $p < 0.001$	0.84
Lithuania	14084.74 $p < 0.001$	−800.71 $p = 0.094$	−8276.69 $p < 0.001$	−49.53 $p < 0.05$	8.252 $p < 0.001$	0.54

It should be noted that the developed model has shortcomings in that not all variables were statistically significant, therefore more detailed research is needed to search for dependencies.

Figure 13 shows the correlogram or correlation matrix of Estonia, Latvia, and Lithuania that analyses the relationship between each pair of numeric variables of a matrix. The correlation is visualised as a scatter plot. The diagonal represents the distribution of each variable with a density plot.

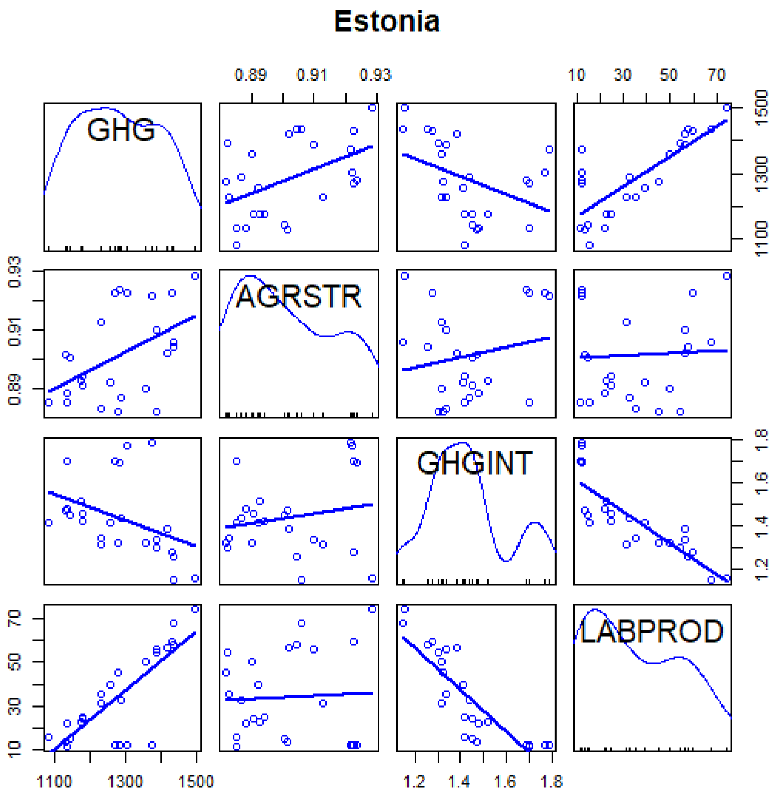
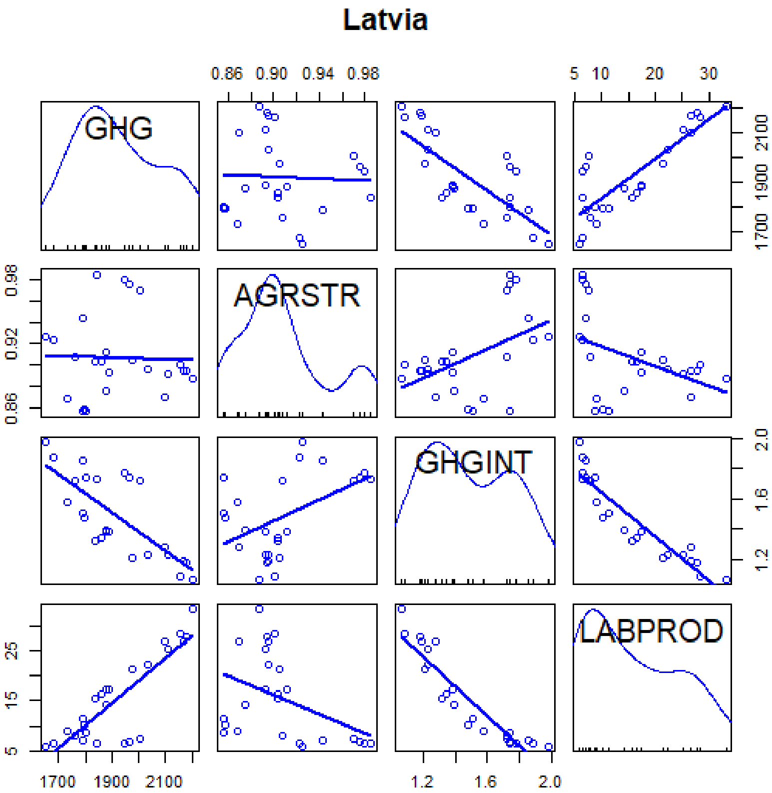


Figure 13. *Cont.*



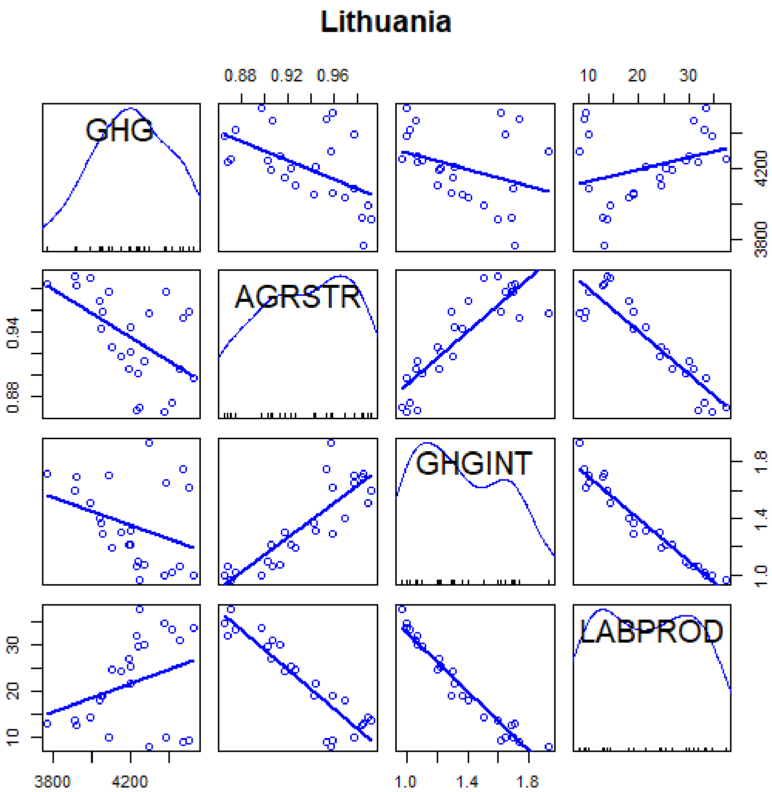


Figure 13. Estonian, Latvian, and Lithuanian correlograms. Note: GHG–GHG emissions from agriculture, GHGINT–crop–animal husbandry GHG intensity, AGRSTR–agricultural structure, and LABPROD–agricultural labour productivity.

5. Discussion and Conclusions

The European Climate Act [64], which is a part of the European Green Course [65], sets a mandatory EU climate target to ensure neutrality of a climate by 2050. As an intermediate step towards this goal, the EU has committed to reduce GHG emissions by 2030 by at least 55% compared to the 1990 level. To meet these targets, GHG emissions must be reduced in all EU countries and in all sectors, including agriculture. EU countries together account for about 10% of GHG emissions from agriculture (2019); Latvian and Lithuanian agriculture generates about one fifth of GHG emissions, while Estonia generates only about one tenth of the country's GHG emissions [66].

The analysed data on quarterly GHG emissions from agriculture in the Baltic States span a long time, which allowed us to assess and draw conclusions about the pollution trends in the sector. The long-term time series showed that two periods of GHG emissions from agriculture can be distinguished in the Baltic States. The study showed that from 1995 to 2001–2002, they decreased, but later they exceeded the 1995 level (except for Lithuania, where gas emissions gradually decreased since 2015). In the first period, the reduction in GHG emissions in the Baltic States may have been influenced by the fact that agriculture experienced a sharp decline in production and capital after the restoration of independence [67]. This included the transition from a planned to a market economy, the development of new forms of farming through the privatization of collective enterprises and the consolidation of private land ownership, the abolition of exceptional support for agriculture [67], the lack of farming experience, small farms, material, and technical lack of financial resources, etc. In the second period, the increase in GHG emissions was due to the countries' integration into the EU and increased opportunities for greater investment in and public support for agricultural production, in other words, modernization and mechanization in the countries' agricultural sector related to CAP implementation and other support measures. The opening of new export opportunities for agricultural products promoted growth in crop areas, increased production, including the use of more synthetic and organic fertilizers, as well as the development of beef cattle farming and the resulting pollution problems.

With regards to animal husbandry and GHG emissions generated from animal gut fermentation and manure handling systems, the analysis of the research data revealed that emissions from intestinal fermentation in the Baltic States from 1995 to 2019 had a declining trend. On the one hand, this was due to a significant reduction in livestock numbers during the first period (1995–2001). However, with the accession of countries to the EU and the increase in direct payments and investment support to livestock farmers, the number of animals, especially butchers, began to increase, as did emissions. On the other hand, strict animal husbandry regulations from an environmental point of view, increasing international competition, rising animal husbandry costs and low increases in purchase prices, unstable or even declining milk purchase prices, restrictions on the pig business due to African swine fever, and competition between local pork producers and its importers are some of the main reasons for the decline of the livestock business in the Baltic States and the reduction in pollution. Importantly, CAP measures and the growing environmental awareness of farmers through changes in herd structure, the use of a complete, balanced ration, and the application of new farm management systems also reduced GHG emissions from the livestock business. The reduction in GHG emissions from manure handling systems was related both to the reduction in the number of animals and to the application and development of advanced manure management systems, through other innovations.

In the crop business, GHG emissions from agricultural soils accounted for the largest share of agricultural pollution in the Baltic States, and the impact of this source on overall pollution increased. Such negative trends may have been caused by the rapid increase in the area of crops, especially cereals, fertilizers, use of pesticides and other plant protection products, which started to increase rapidly in the Baltic States after the accession to the EU, due to new international trade opportunities and rising product prices.

The study revealed that the GHG intensity in agriculture in the Baltic States decreased on average by 2–3% annually, and the fastest decrease was in Lithuania. The number of people employed in the agricultural sector decreased due to lower birth rates, higher rural mortality than in urban areas, as well as rapid emigration and increasing employment in other economic activities. Similar trends are likely to continue into the future. However, the sector's economy grew in the countries. Although the number of people employed in agriculture decreased by half or more (in Estonia by as much as three quarters), the value of the agricultural output in 2010 grew at constant prices in the period under review: in Estonia by 67.4%, in Latvia by 92.8%, and in Lithuania by as much as 2.2 times. As a result, productivity increased as much as 4–6 times.

The decomposition of GHG emissions in agriculture based on the Logarithmic Mean Divisia Index (LMDI) method showed that GHG emissions in the Baltic States were mainly increased by pollution due to the growing economy of the sector, and their decrease was mainly influenced by two factors: the decrease in the number of people employed in agriculture and the decreasing intensity of GHGs in agriculture. In all the Baltic countries, the agricultural labour productivity and, in Estonia, the agricultural structure increased the GHG emissions from agriculture in varying degrees. The results are shown in Table 8. Latvia and Lithuania are similar in their decomposition profiles, as crop–animal husbandry GHG intensity, agricultural structure, and employment laboratory of agriculture contributed to a decrease in GHG emissions, whereas increased agricultural labour productivity had the opposite effect. In Lithuania, the mentioned three factors compensated for the impact of the labour productivity factor on pollution, and therefore GHG emissions from agriculture decreased by 49.94 thousand t in the reviewed period (CO_2 equivalent) or 1.16%. In Latvia, the combined effect of these three factors on pollution was insufficient and did not outweigh the pollution caused by the factor of labour productivity, therefore GHG emissions from agriculture increased by 198.53 thousand t in the reviewed period (CO_2 equivalent) or 9.91%. Although in Estonia the factors of increasing and decreasing pollution in agriculture had a similar effect, GHG emissions increased by 123.07 thousand t in the reviewed period (CO_2 equivalent) or 8.96%.

According to the analysis of the research results, it can be predicted that the reduction in GHG emissions in the Baltic States will be mainly influenced by the number of people employed in agriculture and GHG intensity, and CAP measures will continue to promote structural changes that will in future contribute to reducing agricultural pollution due to the factors discussed above. Knowledge, education, and recommendations will further increase farmers' environmental awareness, and new science-based technologies and innovations and their application in farms will contribute solutions to reduce GHG emissions in agriculture.

The multivariate regression analysis method was used to determine the dependence of GHG emissions in agriculture on the factors used for the decomposition analysis. It showed that three factors—crop–animal husbandry GHG intensity, agricultural structure, and agricultural labour productivity—accounted for almost 93% of GHG emissions from agriculture in Estonia, almost 84% in Latvia, and 54% in Lithuania. The model developed for the Estonian data showed that all variables were statistically significant. Meanwhile, using data from Latvia and Lithuania, only the variable crop–animal husbandry GHG intensity was statically insignificant. Thus, the developed model has shortcomings; not all variables were statistically significant, therefore more detailed research is needed in the future to search for new factors and dependencies.

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