NTNU
Kunnskap for en bedre verden

Department of
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TEP4221 - Python for Sustainability Analysis

On agricultural pollutant emissions in the EU -

A time series analysis of ammonia and particulate matter emissions

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1 Introduction

Ammonia (NH_3) is the most frequently occurring air pollutant in the agriculture industry [12]. It is proven to be harmful to both the environment and humans by being a major contributor to $PM_{2.5}$ (particulate matter[1]) emissions causing millions of deaths each year [11]. Over the last 10 years more than 90% of the total ammonia emissions were created in the agriculture sector. In 2021, two thirds ($2.248kt$) could be attributed to livestock emissions, and one third ($884kt$) were emitted by industrially created fertilizer used for crop growth [12].

In the environment ammonia naturally occurs in gaseous form. It is released through bacteria in the soil, as well as decaying animals, plants and animal waste [1]. Because ammonia contains high amounts of nitrogen, a nutrient vital for plant growth, it is mainly used to produce fertilizer. It also turns manure into an optimal fertilizer. What can be problematic, however, is an excessive use which causes soil acidification, essentially creating toxic soil [5]. Ammonia can also negatively impact the adjacent natural flora and fauna [7]. The run of water caused by irrigation carries the nitrogen into the surrounding nature including lakes, rivers, and groundwater [5]. The nitrogen disturbs the biodiversity in the water bodies by causing an explosive growth of algae followed by a rapid decay once used up. This causes oxygen depletion in the water, making it uninhabitable for sea life. On land a similar problem occurs as the most adapted plants grow explosively, which usually leads to eutrophication [7].

Ammonia can also cause health problems if ingested by humans such as nose and throat irritations or coughing. In higher concentrations it can cause burns, blindness, lung damage and in extreme cases even death. This is due to the chemical reaction of ammonia with water, which creates ammonium hydroxide, a very corrosive alkaline attacking cells and tissue [1]. Since ammonia is lighter than air and therefore always rises after being emitted, it is rarely ingested in large quantities. It has been discovered that ammonia acts as an agent to bind nitrogen oxide (NO_x) and sulphur oxide (SU_x) particles together, resulting in $PM_{2.5}$ particles that can cause heart and lung diseases.

Therefore, ammonia is considered the pollutant causing the highest health cost compared to any other farm pollutant. It is estimated that one kilogram of ammonia leads to health cost of about \$10 to \$70, some studies even going up to \$100 [3]. The conversion ratio of ammonia to $PM_{2.5}$ is not well-established. It is assumed that agricultural emissions contribute about 40% of the $PM_{2.5}$ pollution in the EU [8]. This uncertainty is due to the fact that ammonia is mainly emitted in the countryside but only turns into $PM_{2.5}$ when it reaches areas with increased amounts of NO_x and SU_x, for example cities, therefore skewing the statistics [3].

As mentioned above, without the consideration of $PM_{2.5}$ ammonia is only harmful in highly concentrated quantities. Currently, there are no EU-wide emission restrictions for the atmospheric air [5]. The only admission levels for ammonia can be found in industrial production processes with confined spaces. The EU has a time-weighted average for a regular workday with exposure to ammonia at $20ppm$ (parts per gas per million parts of air) or $14mg/m^3$. The short-term exposure limit lies at $36mg/m^3$ and $50ppm$ [2]. The only atmospheric classification that can be related to ammonia is the $PM_{2.5}$ safe level which for the EU is $20\mu g/m^3$ [9].

[1] $PM_{2.5}$ contains 50% of particles with a diameter of 2.5µm, a higher proportion of smaller particles and a lower proportion of larger particles.

Nevertheless, there are regulations regarding the use of ammonia. The National Emission Ceilings Directive 2016/2284/EU published by the EU is directing every EU country to lower their ammonia output by, on average, 6% from 2005 until the year 2030. Until 2050 the output is supposed to be lowered by 19% [6]. More concrete values can be found in the Appendix, Table 7. To achieve that goal, the "Ammonia Guidance Document" was published. It contains methods and practices to lower ammonia emissions, e.g. reducing fertilizer emissions by at least 30%, manure emissions in storage by at least 60% and manure emissions on fields and in animal housing by at least 20% [4]. Considering both the effects of emitting ammonia and the EU directive to lower harmful emissions from industry sectors, the following question arises:

Does the Agriculture Sector sufficiently counteract the formation of $PM_{2.5}$ in the air based on its ammonia emissions?

To investigate this, both ammonia and $PM_{2.5}$ emissions from the agricultural sector are analysed from 1990 to 2021. The aim is to determine whether the regulations adopted during this period, some of which are still in place today, are sufficient in reducing pollutant emissions sustainably and proportionately in the agricultural sector.

2 Results

Looking at the emissions of ammonia and $PM_{2.5}$ in the agriculture sector, which are shown in Figure 1, it can be stated that emissions decreased for both pollutants between 1990 and 2021. However, the total emissions of $PM_{2.5}$ and ammonia from all industrial sectors differ significantly. In the agriculture industry, total $PM_{2.5}$ emissions amount to approximately 4% of ammonia emissions, on average (Appendix: Table 4, Table 5). By way of comparison, if we consider not only the agricultural sector but all economic sectors, the absolute amount of $PM_{2.5}$ emissions measures up to approximately 20% of the absolute ammonia emissions (Appendix: Figure 2, Table 2, Table 3).

Over the whole timeframe, the percentage reduction in ammonia emissions in the agriculture sector lies just under 25%; for $PM_{2.5}$ it lies just under 66%. Progress in the avoidance of particulate matter emissions therefore appears to be much easier to implement in agriculture. Differences can also be seen in the various regions of Europe. While comparatively little is emitted in the North, emissions are very high in the West. Eastern Europe has made hardly any noticeable progress in reducing ammonia emissions, while both the South and the West have been able to reduce theirs (Appendix: Table 4, Table 5).

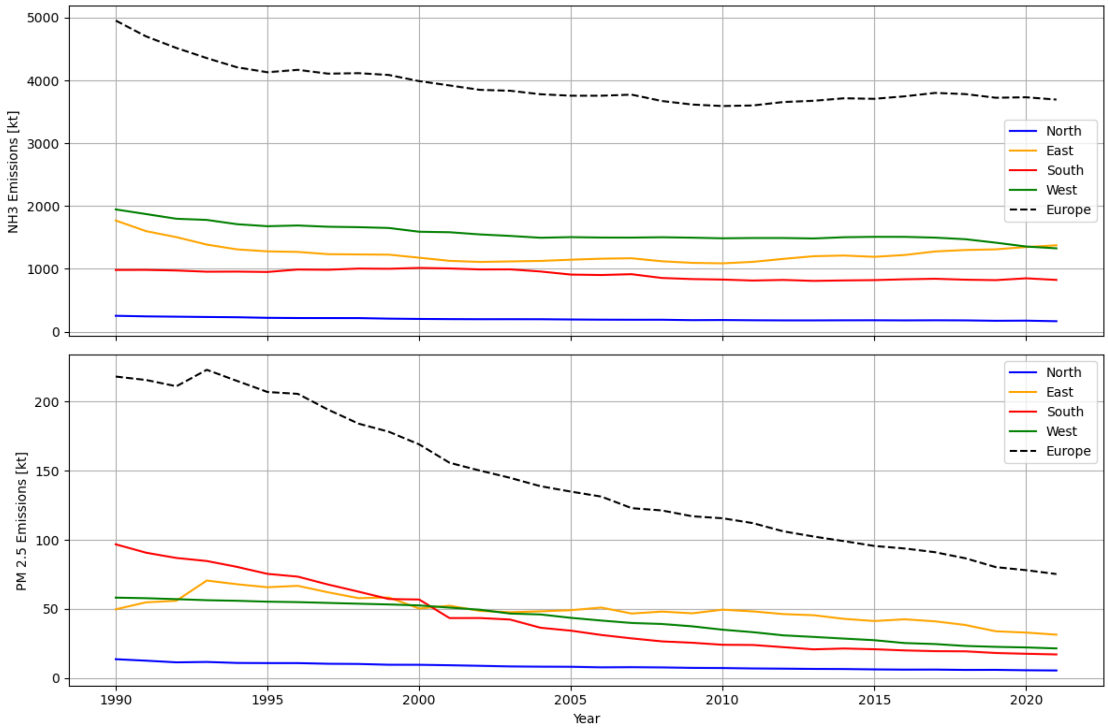

Figure 1: Agricultural NH_3 and $PM_{2.5}$ Emissions in Europe

Source: Based on [10], own illustration

Section 1 introduced the specific target values of the EU Member States for the reduction of air pollutant emissions, based on the mentioned EU directive 2016/2284/EU [6]. This paper will now examine the extent to which these targets have been achieved and where the trend is heading. Table 1 provides an overview of the regional reduction targets and actual values of relative emission reductions from the four European regions, showing both the total emissions and the emissions from only the agricultural sector.[2] The underlying breakdown of the countries into EU-regions is defined in Table 6 in the Appendix. There is also a country- and sector-specific overview of the respective emission targets and real values (Appendix: Table 7).

	NH_3			$PM_{2.5}$		
	Goal	Total	Agriculture	Goal	Total	Agriculture
North	20%	14%	12%	27%	42%	32%
East	6%	-17%	-19%	20%	4%	35%
South	6%	10%	8%	24%	25%	50%
West	4%	12%	11%	23%	44%	50%

Table 1: Relative Reduction Goals and Real World Reduction per region

Source: Based on [10] and [6], own illustration

Combining Figure 1 and Table 1, it can be noted that the relative decline of NH_3 emissions is greatest in Western and Northern Europe, at just under 30% each. The decrease in absolute emissions by $1273kt$ in Western Europe plays a decisive role in the reduction of total emissions.

[2]The target value for the relative reduction refers to the absolute emission values for each year from 2020-2029 compared to the annual value from 2005. In this table, the regional emission reduction targets are formed from the average of the targets for the individual countries that belong to the corresponding region. The current values from the "Total" and "Agriculture" sectors were determined on the basis of the absolute emission values from 2020 and 2021.

Overall, the regions of Eastern and Western Europe dominate in terms of ammonia emissions, while the South and especially the North emit relatively little. Looking at the NH_3 emission development, it is interesting to see that the North, which already has comparatively low emission levels, nevertheless shows such a strong improvement compared to the East, for example, which at least theoretically has a significantly higher optimization potential due to its high absolute emission levels. The target values for NH_3 have only been met in the western and southern regions of Europe with the current status of this report. In the East, ammonia emissions initially fell, but there has been a period of stagnation, with even a slight increase in recent years. Although the North has the highest decrease in emissions, it cannot meet the high target values. In comparison to the total emissions of all European industry sectors, the agricultural sector performs worse than average in all regions in terms of NH_3 emission reductions. In terms of $PM_{2.5}$ emissions, the balance looks much better. So far, the agricultural sector has not only been able to meet, but also to exceed all requirements set by EU Directive 2016/2284/EU.

3 Discussion

Section 1 and 2 clearly indicate that EU regulation has led to a reduction in both NH_3 and $PM_{2.5}$ emissions in the agricultural sector. However, the target values are only achieved in relation to $PM_{2.5}$, but not in the area of NH_3 emissions. This can be stated as problematic because of the mentioned potential of NH_3 to create $PM_{2.5}$ after being released into the air. Thus, with regard to the research question it can be stated that the agricultural sector partially, but not sufficiently, counteracts the formation of $PM_{2.5}$ in the air. This could indicate that more stringent measures and additional actions are needed from the EU to ensure that Member States meet the defined target values.

However, it must also be noted that this interpretation should be treated with caution. After all, many more factors and types of emissions influence the concentration of $PM_{2.5}$ in the air than just direct emissions of $PM_{2.5}$ or ammonia. Exceptional situations such as Russia's war of aggression in Ukraine or energy shortages can also mean that certain EU standards in agriculture cannot be met, which is why the measures and solutions to be developed must be discussed and planned in a differentiated manner.

To summarise, ammonia is already considered by the European Environment Agency to be one of the most important pollutants whose emissions into the environment must be gradually reduced. $PM_{2.5}$ pollution has also become an important issue in recent years due to its potentially harmful effects on human health. As ammonia is not only harmful on its own, but can also react with other chemical compounds to form $PM_{2.5}$, the legal regulation of corresponding emissions is absolutely essential. Although progress has also been made in the agricultural sectors of the EU in recent years, a further reduction is necessary, which may involve additional regulatory requirements. The formation of $PM_{2.5}$ by ammonia will also have to be analysed more closely in the future so that the regulatory requirements and corresponding measures can have a targeted effect.

References

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[12] European Environment Agency. *Air pollutant emissions data viewer (Gothenburg Protocol, Air Convention) 1990-2021*. URL: https://www.eea.europa.eu/data-and-maps/dashboards/air-pollutant-emissions-data-viewer-5 (visited on 02/11/2023).

Appendix

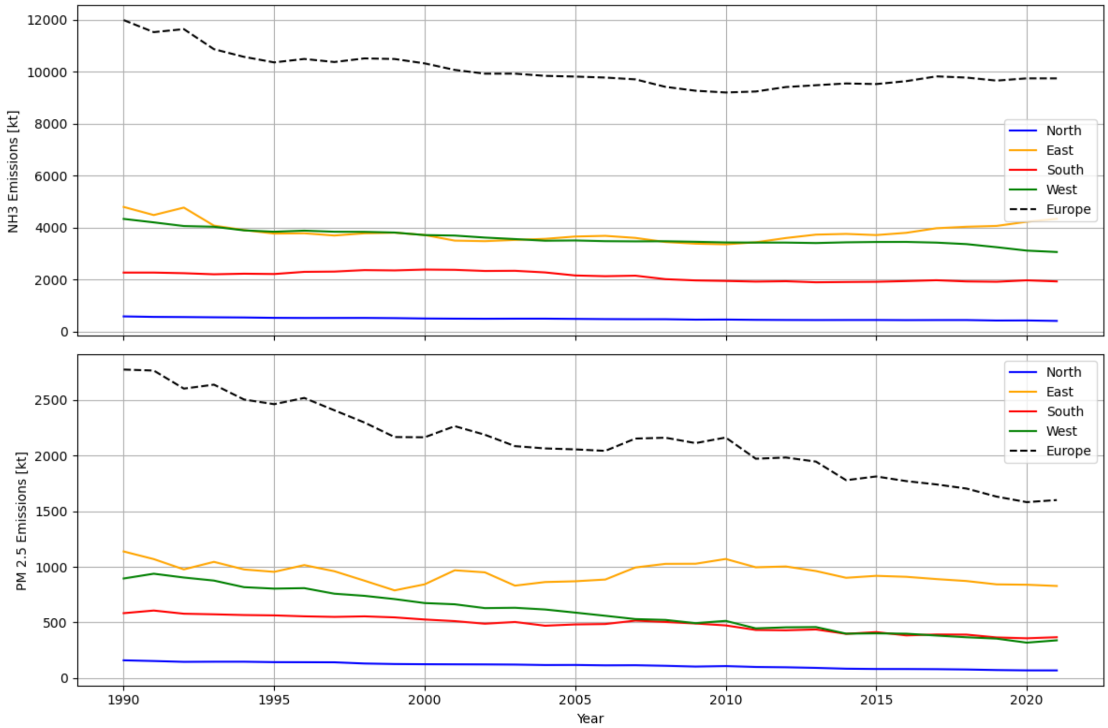

Figure 2: Total NH3 and PM 2.5 Emissions in Europe

Source: Based on [10], own illustration

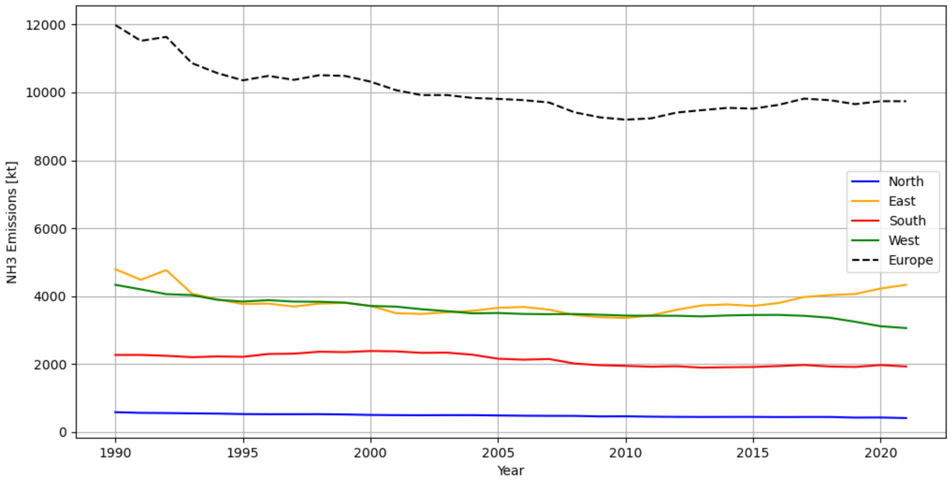

Figure 3: Total NH3 Emissions in Europe

Source: Based on [10], own illustration

Year	West	North	South	East	Europe
1990	4.334	584	2.270	4.793	11.981
1991	4.200	565	2.270	4.482	11.517
1992	4.059	559	2.246	4.769	11.633
1993	4.032	550	2.204	4.075	10.861
1994	3.893	543	2.226	3.903	10.566
1995	3.841	529	2.215	3.769	10.354
1996	3.883	524	2.297	3.781	10.485
1997	3.841	525	2.308	3.695	10.368
1998	3.836	526	2.365	3.780	10.506
1999	3.810	518	2.352	3.803	10.484
2000	3.712	504	2.385	3.714	10.315
2001	3.692	498	2.375	3.499	10.065
2002	3.616	495	2.331	3.478	9.919
2003	3.558	497	2.338	3.526	9.920
2004	3.495	498	2.276	3.567	9.835
2005	3.505	489	2.159	3.656	9.809
2006	3.477	481	2.131	3.682	9.771
2007	3.470	477	2.151	3.603	9.701
2008	3.475	476	2.016	3.445	9.412
2009	3.454	461	1.968	3.381	9.264
2010	3.428	464	1.948	3.357	9.197
2011	3.424	453	1.923	3.434	9.234
2012	3.423	447	1.936	3.599	9.406
2013	3.405	445	1.897	3.729	9.476
2014	3.433	446	1.907	3.757	9.544
2015	3.446	447	1.916	3.712	9.521
2016	3.449	442	1.942	3.799	9.632
2017	3.422	444	1.975	3.975	9.816
2018	3.365	445	1.929	4.031	9.770
2019	3.247	426	1.917	4.064	9.653
2020	3.115	429	1.971	4.224	9.739
2021	3.061	411	1.930	4.337	9.739

Table 2: Values for NH3 emissions from all sectors [kt]

Source: Based on [10], own illustration

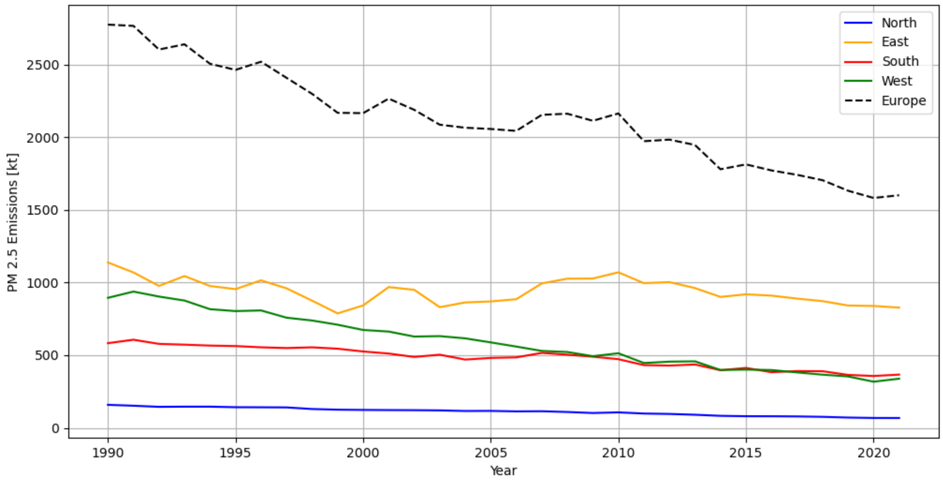

Figure 4: Total PM 2.5 Emissions in Europe

Source: Based on [10], own illustration

Year	West	North	South	East	Europe
1990	895	159	583	1.138	2.775
1991	938	152	607	1.069	2.766
1992	904	145	578	977	2.603
1993	876	146	573	1.045	2.639
1994	817	146	566	976	2.505
1995	804	142	563	955	2.463
1996	808	142	554	1.015	2.519
1997	758	141	549	960	2.408
1998	739	130	554	875	2.298
1999	710	125	545	788	2.168
2000	674	124	526	843	2.166
2001	663	123	511	969	2.265
2002	628	122	488	950	2.188
2003	631	120	504	831	2.086
2004	616	116	470	863	2.065
2005	588	117	482	870	2.057
2006	559	114	485	885	2.043
2007	530	115	516	994	2.154
2008	522	109	504	1.027	2.162
2009	493	102	490	1.028	2.113
2010	513	107	473	1.070	2.163
2011	446	99	432	996	1.973
2012	456	96	429	1.003	1.983
2013	458	90	436	962	1.947
2014	398	83	397	901	1.780
2015	401	80	413	919	1.813
2016	398	80	383	910	1.771
2017	382	79	391	890	1.741
2018	366	76	390	872	1.704
2019	354	71	365	842	1.632
2020	318	68	357	839	1.582
2021	339	68	366	828	1.601

Table 3: Values for PM 2.5 emissions from all sectors [kt]

Source: Based on [10], own illustration

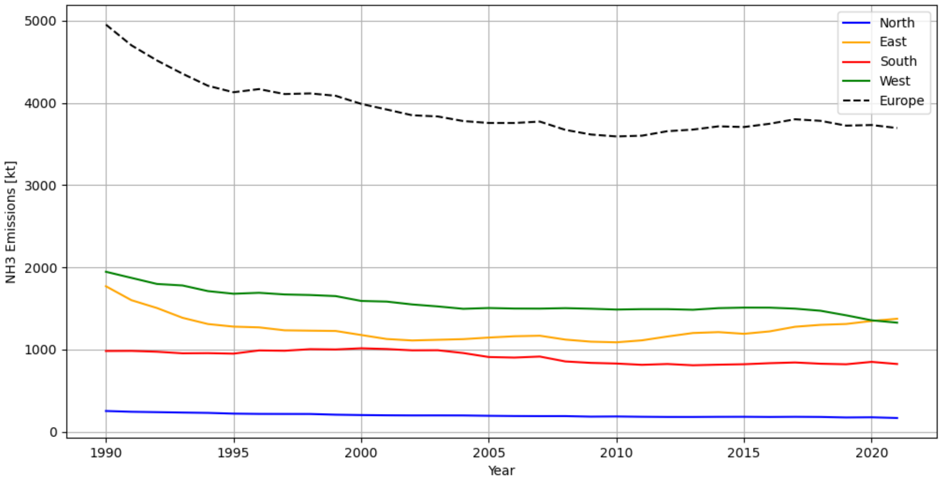

Figure 5: Agricultural NH3 Emissions in Europe

Source: Based on [10], own illustration

Year	West	North	South	East	Europe
1990	1.946	253	983	1.770	4.952
1991	1.872	244	984	1.601	4.700
1992	1.798	239	974	1.505	4.516
1993	1.780	234	955	1.387	4.355
1994	1.711	230	956	1.311	4.208
1995	1.679	221	951	1.279	4.130
1996	1.691	218	990	1.270	4.168
1997	1.670	217	986	1.234	4.107
1998	1.664	217	1.005	1.230	4.115
1999	1.651	208	1.002	1.226	4.087
2000	1.591	204	1.016	1.177	3.988
2001	1.583	201	1.007	1.129	3.920
2002	1.549	199	991	1.111	3.850
2003	1.525	199	992	1.119	3.835
2004	1.496	199	958	1.127	3.779
2005	1.506	195	910	1.146	3.756
2006	1.499	192	903	1.162	3.756
2007	1.498	191	915	1.169	3.773
2008	1.504	191	856	1.121	3.672
2009	1.497	185	838	1.096	3.616
2010	1.487	187	830	1.089	3.592
2011	1.492	183	815	1.112	3.602
2012	1.492	181	825	1.159	3.656
2013	1.484	181	809	1.202	3.676
2014	1.504	182	816	1.212	3.715
2015	1.510	183	822	1.192	3.707
2016	1.510	181	834	1.221	3.746
2017	1.498	183	843	1.278	3.801
2018	1.472	181	828	1.301	3.782
2019	1.417	174	821	1.311	3.724
2020	1.356	177	850	1.348	3.731
2021	1.327	168	825	1.375	3.695

Table 4: Values for NH3 emissions from agriculture [kt]

Source: Based on [10], own illustration

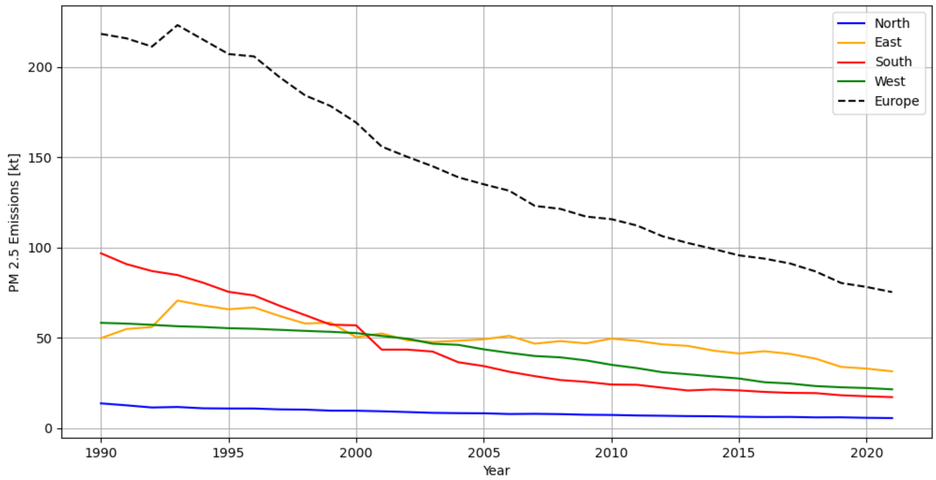

Figure 6: Agricultural PM 2.5 Emissions in Europe

Source: Based on [10], own illustration

Year	West	North	South	East	Europe
1990	58	14	97	50	218
1991	58	13	91	55	216
1992	57	11	87	56	211
1993	56	12	85	71	223
1994	56	11	80	68	215
1995	55	11	75	66	207
1996	55	11	73	67	206
1997	54	10	68	62	194
1998	54	10	62	58	184
1999	53	10	57	58	178
2000	53	10	57	50	169
2001	51	9	43	52	156
2002	49	9	43	49	150
2003	47	8	42	48	145
2004	46	8	36	48	139
2005	44	8	34	49	135
2006	42	8	31	51	131
2007	40	8	29	47	123
2008	39	8	27	48	121
2009	37	7	26	47	117
2010	35	7	24	49	116
2011	33	7	24	48	112
2012	31	7	22	46	106
2013	30	7	21	45	102
2014	29	6	21	43	99
2015	27	6	21	41	96
2016	25	6	20	42	94
2017	25	6	19	41	91
2018	23	6	19	38	87
2019	23	6	18	34	80
2020	22	6	18	33	78
2021	21	5	17	31	75

Table 5: Values for PM 2.5 emissions from agriculture [kt]

Source: Based on [10], own illustration

Country	Assigned Region	Notation
Austria	West	
Belgium	West	
Bulgaria	East	
Croatia	East	
Cyprus	South	
Czech Republic	East	
Denmark	North	
Estonia	East	
Finland	North	
France	West	
Germany	West	
Greece	South	
Hungary	East	
Iceland	North	*not mentioned in EU Directive
Ireland	West	
Italy	South	
Latvia	East	
Liechtenstein	West	*not mentioned in EU Directive
Lithuania	East	
Luxembourg	West	
Malta	South	
Netherlands	West	
Norway	North	*not mentioned in EU Directive
Poland	East	
Portugal	South	
Romania	East	
Slovakia	East	
Slovenia	East	
Spain	South	
Sweden	North	
Switzerland	West	*not mentioned in EU Directive
Türkiye	East	*not mentioned in EU Directive

Table 6: Assignment of regions to European countries, own illustration

Source: own illustration

Member State	NH3			PM 2.5		
	Goal	Overall	Agriculture	Goal	Overall	Agriculture
Belgium	2%	15%	17%	20%	49%	38%
Bulgaria	3%	1%	-2%	20%	22%	45%
Czech Republic	7%	0%	0%	17%	0%	0%
Denmark	24%	20%	17%	33%	43%	18%
Germany	5%	15%	13%	26%	39%	28%
Estonia	1%	2%	1%	15%	41%	21%
Greece	7%	16%	20%	35%	49%	45%
Spain	3%	5%	4%	15%	20%	39%
France	4%	12%	11%	27%	46%	62%
Croatia	1%	22%	19%	18%	36%	79%
Ireland	1%	-3%	-5%	18%	34%	29%
Italy	5%	15%	11%	10%	21%	61%
Cyprus	10%	13%	11%	46%	54%	39%
Latvia	1%	-5%	-13%	16%	37%	9%
Lithuania	10%	0%	1%	20%	22%	23%
Luxembourg	1%	-6%	-6%	15%	54%	33%
Hungary	10%	4%	-2%	13%	8%	28%
Malta	4%	17%	20%	25%	52%	-17%
Netherlands	13%	20%	21%	37%	49%	54%
Austria	1%	-5%	-7%	20%	40%	54%
Poland	1%	7%	10%	16%	6%	36%
Portugal	7%	3%	2%	15%	22%	6%
Romania	13%	19%	18%	28%	6%	-18%
Slovenia	1%	11%	8%	25%	38%	50%
Slovakia	15%	20%	18%	36%	50%	22%
Finland	20%	21%	18%	30%	45%	54%
Sweden	15%	10%	7%	19%	48%	29%

Table 7: Relative Emission Reduction Goals and Real World Reduction per Country

Source: Based on [10] and [6], own illustration