Open Journal of Air Pollution, 2022, 11, 70-83
https://www.scirp.org/journal/ojap
ISSN Online: 2169-2661
ISSN Print: 2169-2653

Atmospheric Emission Sources in the Po-Basin from the LIFE-IP PREPAIR Project

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How to cite this paper: Marongiu, A., Angelino, E., Moretti, M., Malvestiti, G. and Fossati, G. (2022) Atmospheric Emission Sources in the Po-Basin from the LIFE-IP PREPAIR Project. *Open Journal of Air Pollution*, **11**, 70-83.
https://doi.org/10.4236/ojap.2022.113006

Received: June 7, 2022
Accepted: September 17, 2022
Published: September 20, 2022

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Abstract

This paper presents the focus on emission estimates in the Italian Regions of the Po-basin obtained by the development of a common air pollutant emission dataset on the Po-basin and Slovenia foreseen in the project LIFE PREPAIR (https://www.lifeprepair.eu/). The objective is to update emission inventories developed by the environmental protection agencies and regions of Lombardy, Emilia-Romagna, Piedmont, Veneto, Friuli Venezia Giulia, Valle d'Aosta, the province of Bolzano (participating as stakeholder) and the province of Trento. A data flux is defined considering the activities on emission estimates by the different administrations according to the current Italian legislation. This activity has allowed the completion of two different datasets on the area for 2013 and 2017. The estimates of primary emissions of the main atmospheric pollutants have a high spatial resolution defined at the municipal level. The non-industrial combustion of biomass in small domestic appliances is the main source of primary PM_{10} in the Po-basin. NO_x primary emissions are determined for quite of a half by road transport. Manure management and fertilization in the agriculture sector are the sources of NH_3. The ensemble of the collected data shows a very good comparability even if all local compilers perform independently the estimates, thanks to a good alignment in using reference methodologies and to projects of common methodological development, as reported by the INEMAR project (https://www.inemar.eu/). The estimates of PM_{10}, NO_x and NH_3 are comparable with data reported by the European Environment Agency EEA for the European Member States EU-28 (until 1 February 2020) and for Italy, reported under the UNECE Convention on Long-range Transboundary Air Pollution and European Union National Emission Ceiling Directive.

Keywords

Atmospheric Emissions, Po Valley, Emission Inventories

1. Introduction

The Po-basin is placed in the northern Italy and is the most populated area of the country. For its major part, it is a plain surrounded by the Alps and the Apennines mountains and is frequently characterized by atmospheric stagnation and thermal inversion conditions. According to the European and National Legislation [1] [2], the Italian Regions and autonomous provinces have different functions in the monitoring and management of air quality.

In the frame of these functions, the local administrations must compile and update an emission inventory every two or three years on their own territory. The EEA-EMEP Guidebook is the main technical reference in updating the emission inventories (https://www.eea.europa.eu/) both at National and local levels and plays a fundamental role in the comparability of the estimates [3] [4].

Emission inventories are crucial information in management of air quality and climate change. The accuracy of local emission inventories plays a relevant role in supporting Air Quality Plans and policymakers, prioritizing remediation measures and monitoring progress towards reduction targets. Robust and adequately spatially resolved emission are important inputs for modelling simulations. This work illustrates the main emission sources on the relatively large domain of the Po-basin with high spatial details putting together the estimates of dozens local technical compilers and showing their comparability on the whole area.

The Italian local emission inventories are generally compiled at a municipal detail and implement the SNAP source classification [5] [6]. This high spatial resolution can allow to better describe the emission pressure on the domain, but sometimes can lead to greater difficulties ensuring consistent time series due to lacks, gaps and changes in local information availability.

An important level of harmonisation in the realisation of atmospheric emission estimates can be attributed to the common development of the INEMAR system by almost all the regions and autonomous provinces in the Po-Basin [7]. INEMAR is a database and can give results from a combination of more than 250 activities and 35 fuels for pollutants of interest for air quality, greenhouse gases, PAHs, carbonaceous fraction of particulate and heavy metals.

The process of compiling local emission inventory begins with the collection of a huge amount of information such as activities indicators (e.g. fuel consumptions, traffic flows, industrial production), emission factors and statistical data for the spatial and time-based distribution of the emissions. The periodic update of these parameters and their level of details (defined as tier) affect the overall level of uncertainty in calculations. The highest tier methodologies require an increase in number and complexity of both the activity indicators and parameters for the emission factors definition. In the framework of the activities of the INEMAR system, the highest tier algorithms are implemented into modules of the database.

Point emission sources are directly defined when monitoring data are available at stack exit (e.g. large industrial plants). With a progressive increase of uncertainties, different algorithms are defined, chosen by the highest tier, where the number of parameters can drastically increase (e.g. on-road traffic). When detailed data are not available, or an emission source is spread over the territory (e.g. domestic heating), a statistical approach is used, with the definition of average indicators and emission factors.

2. Emission Estimate on the Po-Basin

The extent of the domain of analysis covers about 115,000 km^2 and encompasses a population of around 26 million inhabitants. Maps in **Figure 1** show the estimated emission density for three main pollutants: PM_{10}, NO_x and NH_3. The collected emission inventories show a good comparability, without relevant gaps and discontinuities and confirm the common technical base between different regions due to the use of same methodological reference (the EEA-EMEP Guidebook) and, in many cases, the same modelling system (INEMAR database).

The emission estimates and emission density indicators are based on the primary emitted pollutants released directly to the atmosphere. Atmospheric particulate matter is used to describe solid particles and liquid droplets found in the air and can be emitted directly or formed in the atmosphere from chemical reactions involving gaseous precursors. Among these, NO_x and NH_3 play a well identified significant role to secondary particulate matter formation in the Po-basin. Other precursors are SO_2 and other gases (e.g. particle-producing organic gases).

Table 1 illustrates the important role of non-industrial combustion and road traffic respectively on primary PM_{10}, CO and NO_x, while almost the total amount of primary emissions of NH_3 are accounted by agriculture. SO_2 is principally emitted by the residual content of sulphur in fuels used in industrial combustion. The positive effects on atmospheric emissions of the change from fuel-oil to natural gas is widely recorded by the literature and also focused by specific studies e.g. at the industrial level [9]. NMVOCs include also biogenic sources, which determine the largest contribution on the total amount. Primary emissions are generally widely spread on the domain, as shown in **Figure 1**, covering the areas with higher population density and heating demand (PM_{10}), the areas with high mobility and thermal energy demand (NO_x) and rural areas with high livestock density (NH_3). The overall per capita emissions and emission densities of SO_2, CO and PM_{10} on Po-basin are comparable or lower than the parameters calculated on the EU-28 (until 1 February 2020 UK is also accounted) and Italy [10]. NO_x per capita emissions on Po-basin are in the range between EU-28 and Italy. The same indicator for NMVOC in the Po-basin is not comparable to the estimates of Italy. The emissions of NMVOC on Po-basin account also the biogenic sources, while the national total reported for Italy exclude this contribution [11]. Per capita emissions and emission densities of NH_3 are higher than the calculated indicators at European and National level and these differences will be

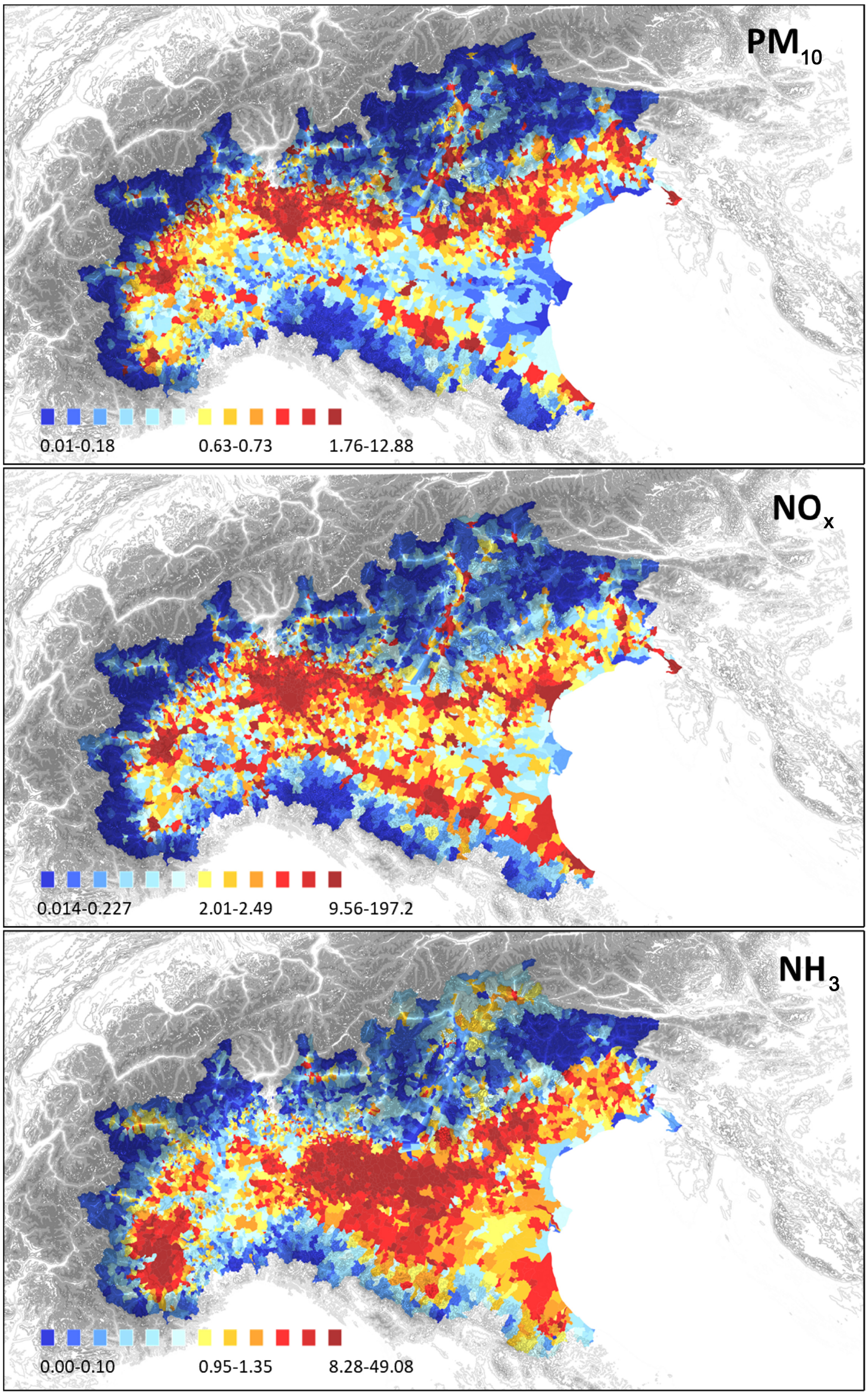

Figure 1. Emission density maps on the Po-basin from primary emissions on municipal basis expressed in t/km^2 overlapped on the elaboration on orography [8].

more detailed on the next paragraph on the agriculture sector.

3. Residential Wood Combustion

The group of activities classified in the non-industrial combustion spans over the heating sector in commercial, residential and agriculture activities. As reported in

Table 1. Emission share and total emission estimates on Po-basin compared to Italy and EU-28 also considering per-capita and overall emission density.

	SO_2	NO_x	NMVOC	CO	NH_3	PM_{10}
Total emission and emission share in Po-basin						
Total emission t/y	**39,358**	**338,773**	**826,683**	**741,137**	**255,029**	**69,311**
1) Combustion in energy and transformation industries	15%	7%	0%	2%	0%	1%
2) Non-industrial combustion plants	7%	11%	5%	51%	1%	56%
3) Combustion in manufacturing industry	48%	15%	1%	4%	0%	4%
4) Production processes	23%	3%	4%	6%	0%	3%
5) Extraction and distribution of fossil fuels and geothermal energy	0%	0%	3%	0%	0%	0%
6) Solvent and other product use	0%	0%	23%	0%	0%	3%
7) Road transport	1%	48%	6%	29%	1%	19%
8) Other mobile sources and machinery	3%	14%	1%	3%	0%	3%
9) Waste treatment and disposal	2%	1%	0%	0%	1%	0%
10) Agriculture	0%	1%	24%	1%	97%	5%
11) Other sources and sinks	1%	0%	34%	5%	0%	5%
Per capita emissions g/inhabit/y						
EU-28	**3967**	**13,199**	**12,970**	**36,553**	**7130**	**3592**
Italy	**1933**	**10,677**	**15,288**	**37,388**	**6131**	**3187**
Po-basin	**1503**	**12,941**	**31,578**	**28,310**	**9742**	**2648**
Emission density kg/km^2						
EU-28	**453**	**1509**	**1482**	**4178**	**815**	**411**
Italy	**388**	**2143**	**3069**	**7504**	**1231**	**640**
Po-basin	**343**	**2950**	**7199**	**6454**	**2221**	**604**

Table 2, the largest amount of primary pollutant emitted in the Po-basin for the non-industrial combustion is due to the biomass burning in the residential sector. More than 96% of the total amount of PM_{10} is estimated deriving from small domestic appliances burning biomass. These appliances are also a relevant source of NMVOC in the macrosector. Residential system burning natural gas are very widespread in the Po-basin, with exception for some alpine areas not covered or partially covered by the distribution network. The area in the Po-basin with high heating energy demand is defined by the combination of high population density and high heating demand due to lower winter temperatures. Very often more than one heating system is present in the dwellings, determining a possible switch from fossil fuels to biomass burning [12].

During the time the use of fuel oil in heating has been decreased drastically thanks to specific regulation. The lower level on emission share of fuel oil is due quite to the absence of its use. Gas oil and natural gas can determine also relevant

Table 2. Non-industrial combustion emission share and total emission estimates on Po-basin compared to Italy and EU-28 also considering per-capita and overall emission density.

	SO_2	NO_x	NMVOC	CO	NH_3	PM_{10}
Total emission and emission share in Po-basin						
Total emission t/y	**2770**	**35,867**	**37,565**	**375,818**	**1486**	**39,021**
2.1 - Commercial and institutional plants—natural gas	4%	20%	3%	1%	0%	0%
2.1 - Commercial and institutional plants—gas oil	3%	0%	0%	0%	0%	0%
2.1 - Commercial and institutional plants—LPG	0%	0%	0%	0%	0%	0%
2.1 - Commercial and institutional plants—biomass	1%	0%	4%	2%	1%	3%
2.2 - Residential plants—natural gas	9%	48%	7%	3%	0%	0%
2.2 - Residential plants—fuel oil	0%	0%	0%	0%	0%	0%
2.2 - Residential plants—gas oil	37%	3%	0%	0%	0%	0%
2.2 - Residential plants—LPG	0%	2%	0%	0%	0%	0%
2.2 - Residential plants—biomass	43%	25%	86%	93%	99%	97%
2.3 - Plants in agriculture, forestry and aquaculture—natural gas	0%	0%	0%	0%	0%	0%
2.3 - Plants in agriculture, forestry and aquaculture—biogas	0%	0%	0%	0%	0%	0%
2.3 - Plants in agriculture, forestry and aquaculture—gas oil	3%	0%	0%	0%	0%	0%
2.3 - Plants in agriculture, forestry and aquaculture—LPG	0%	0%	0%	0%	0%	0%
Per capita emissions g/inhabit/y						
EU-28	**520**	**1002**	**1877**	**16,353**	**150**	**1523**
Italy	**167**	**1254**	**3294**	**24,236**	**28**	**1859**
Po-basin	**105**	**1370**	**1393**	**14,108**	**56**	**1473**
Emission density kg/km^2						
EU-28	**59**	**115**	**215**	**1869**	**17**	**174**
Italy	**33**	**252**	**661**	**4865**	**5.5**	**373**
Po-basin	**24**	**312**	**318**	**3216**	**13**	**336**

contribution to the emissions sector of NO_x. This data is explained by the relative higher indicator of consumption of natural gas compared to biomass and by their comparable emission factors. According to the energy balance based on 2018 on the Po-basin, the natural gas cover 70% of the total energy burned in the heating sector and biomass 18% [12]. This relevant difference is balanced in the emission of PM_{10} by the large difference between emission factors. Comparing the results of the LIFE PREPAIR project with the estimates of the national statistical institute (ISTAT) for 2013, pellet consumption has been increased of about 25% with a complementary wood-logs consumption reduction of about 20%. This trend can affect the timeseries of emission of primary PM_{10} considering that the emission factors for a wood-log appliance are in the range of 840 - 280 g/GJ and the pellets devices 60 - 19 g/GJ [13].

4. Road Traffic

The NO_x emission density map, reported in Figure 1, is a valid proxy for representing the mobility demand and transportation of goods on the roads. The main highways interconnections are highlighted around the largest cities of the Po-basin. They cover the directive East-West from Turin to Trieste, the Sud-North between Bologna and Milan and the Brenner connection between Italy and Austria. In Table 3, NO_x emissions from road transport are reported: the

Table 3. Road transport emission share and total emission estimates on Po-basin compared to Italy and EU-28 also considering per-capita and overall emission density.

	SO_2	NO_x	NMVOC	CO	NH_3	PM_{10}
Total emission and emission share in Po-basin						
Total emission t/y	**281**	**163,637**	**47,088**	**215,892**	**2592**	**13,247**
7.1 - Passenger cars—gasoline	24%	5%	19%	38%	68%	2%
7.1 - Passenger cars—diesel oil	40%	38%	2%	3%	9%	21%
7.1 - Passenger cars—LPG	0%	1%	7%	12%	11%	1%
7.1 - Passenger cars—natural gas	0%	0%	3%	4%	4%	0%
7.1 - Passenger cars—road, tyre and brake wear	0%	0%	0%	0%	0%	33%
7.2 - Light duty vehicles < 3.5 t—gasoline	0%	0%	0%	1%	1%	0%
7.2 - Light duty vehicles < 3.5 t—diesel oil	13%	15%	2%	3%	2%	9%
7.2 - Light duty vehicles < 3.5 t—LPG	0%	0%	0%	0%	0%	0%
7.2 - Light duty vehicles < 3.5 t—natural gas	0%	0%	0%	1%	0%	0%
7.2 - Light duty vehicles < 3.5 t—road, tyre and brake wear	0%	0%	0%	0%	0%	6%
7.3 - Heavy duty vehicles > 3.5 t and buses—gasoline	0%	0%	0%	0%	0%	0%
7.3 - Heavy duty vehicles > 3.5 t and buses—diesel oil	20%	39%	5%	8%	4%	13%
7.3 - Heavy duty vehicles > 3.5 t and buses—natural gas	0%	0%	0%	0%	0%	0%
7.3 - Heavy duty vehicles > 3.5 t and buses road, tyre and brake wear	0%	0%	0%	0%	0%	11%
7.4 - Mopeds and motorcycles < 50 cm^3—gasoline	0%	0%	28%	9%	0%	2%
7.4 - Mopeds and motorcycles < 50 cm^3—road, tyre and brake wear	0%	0%	0%	0%	0%	0%
7.5 - Motorcycles > 50 cm^3—gasoline	2%	1%	19%	21%	1%	2%
7.5 - Motorcycles > 50 cm^3—road, tyre and brake wear	0%	0%	0%	0%	0%	1%
7.6 - Evaporative emissions	0%	0%	13%	0%	0%	0%
Per capita emissions g/inhabit/y						
EU-28	**8.4**	**5294**	**1119**	**7673**	**85**	**371**
Italy	**6.2**	**4453**	**1861**	**6656**	**84**	**346**
Po-basin	**11**	**6251**	**1799**	**8247**	**99**	**506**
Emission density kg/km²						
EU-28	**1.0**	**605**	**128**	**877**	**10**	**42**
Italy	**1.3**	**894**	**373**	**1336**	**17**	**69**
Po-basin	**2.4**	**1425**	**410**	**1880**	**23**	**115**

main contributions arise respectively from diesel use in heavy-and light-duty vehicles and passenger cars. The emission share of PM_{10} from road transport is quite different from the one shown for NO_x. The main source of primary PM_{10} in road traffic is due to tyres, brakes, and road surface consumption from passenger cars and the second source is due to the exhaust flue gas of diesel passenger cars. These data put into evidence how the mobility request can be relevant even the circulating fleet is progressively renewed by improved emission categories. On the other side the exhaust gas emission of PM_{10} from diesel cars confirms the pollution relevance of this fuel. The main amount of primary NO_x emissions is estimated from the exhaust gases of diesel heavy duty vehicles and passenger cars.

Figure 2 reports the evolution of the fleet in the Po-basin for heavy-duty

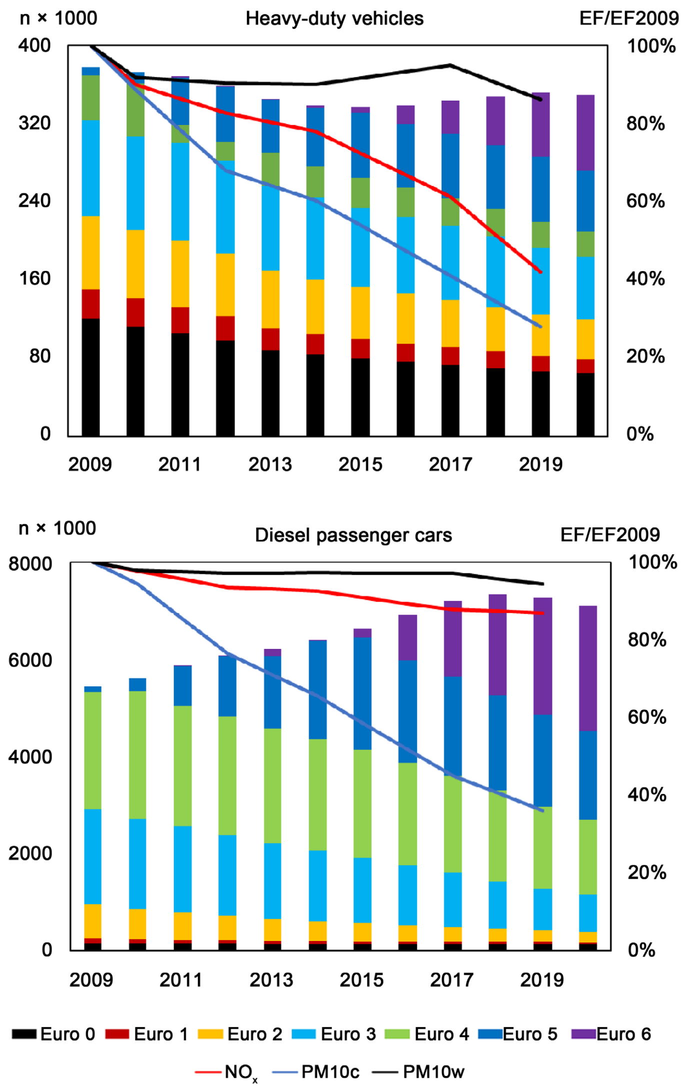

Figure 2. Time series of the emission factors of PM_{10} and NO_x and vehicles number on the Po-basin. Implied emission factor starting point in 2009 [g/km/vehicle]: heavy-duty (NO_x = 7.16; PM_{10}_w = 0.12; PM_{10}_c = 0.19), diesel passenger cars (NO_x = 0.68; PM_{10}_w = 0.03; PM_{10}_c = 0.04).

vehicles and diesel passenger cars according to the European legislation on emission levels [14]. The technology turnover is clearly shown in the figures. The oldest vehicles belonging to higher emission stages are in the time substituted by new and higher performing categories. For the heavy-duty-vehicles the higher presence of Euro 0 compared to diesel passenger cars confirm the relative higher mileage of the trucks. On the same figures are also reported the trend analysis on implied emission factors for NO_x, PM_{10} exhaust (PM_{10} c) and PM_{10} from wear (PM_{10} w).

The implied emission factors are calculated based on the fleet, average mileage, and emission factors of the EEA-EMEP Guidebook [7] and defined as pollutant mass emission per kilometer and vehicle. The time series are defined as the ratio between estimated emission factor in the year and the value in 2009.

The emission of wear is due mainly due to abrasion of breaks, tyres and roads. The slope of implied emission factors of PM_{10} w is then quite stable in the years being connected to the mileage of the vehicles. Higher performances are shown for primary emissions of PM_{10} from the exhaust both for heavy-duty vehicles and passenger cars. The implied emission factor of NO_x shows a different behavior between cars and trucks, showing a more positive effect in the fleet renewal of the heavy-duty vehicles than the passenger cars.

5. Agriculture

The role in the Po-basin of the NH_3 emissions in the formation of secondary particulate matter by chemical reactions is focused by different studies [15]. According to the emission estimates, the use of mineral fertilizers contributes for 15% to emissions of NH_3. The larger contribution on total emissions is due to manure management of livestock (83%). In this sector are estimated the emissions of the different phases of manure management: housing, manure management and stocking and spreading.

Figure 3 illustrates the amount of animal heads for the most emissive categories and their related emission factors. Data reported by BDN—Anagrafe Nazionale Zootecnica [16] show that the most (about of 80%) of cows, swine and poultry are bred in the regions of Po valley. This distribution can be observed for dairy cattle, other cows, swine and sows, the most emissive categories, as demonstrated by ammonia emission factors estimated by ISPRA [17]. This analysis explains the relative higher emission density of the Po valley area compared to Italy and EU-28 (**Table 4**).

6. Timeseries Analysis on Primary Emissions

The activities performed in the PREPAIR project allow to update the emission estimates starting from the reference year of 2013. These updating covers the period between 2013 and 2017 and the estimates can be put into relation with the emission trend reported by the EEA for the EU-28 and for Italy.

Figure 3 depicts the timeseries of primary pollutants estimates comparing the

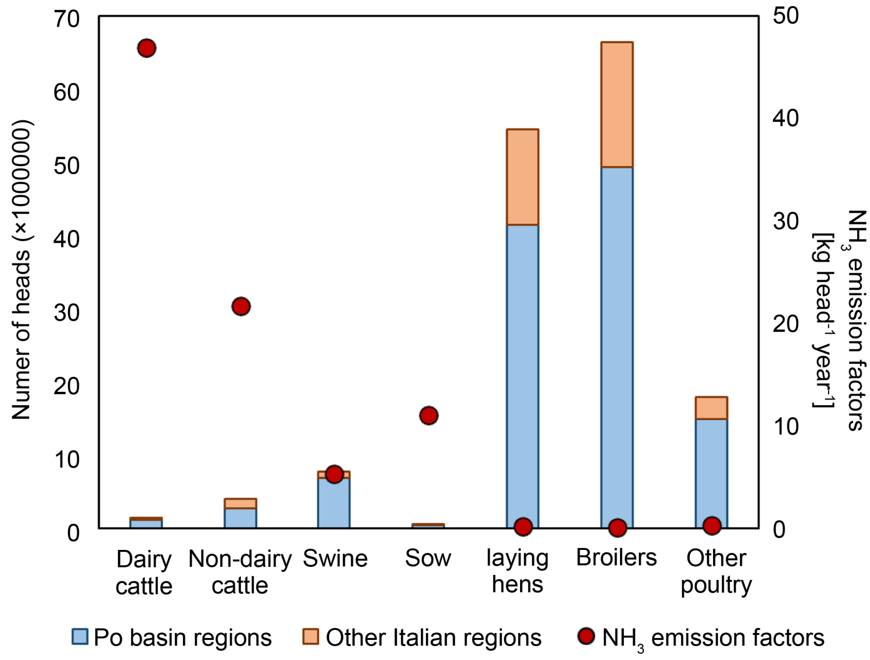

Figure 3. Number of heads for the main animal categories present in the Po basin regions and in other Italian regions and relative emission factor.

Table 4. Agriculture emission share and total emission estimates on Po-basin compared to Italy and EU-28 also considering per-capita and overall emission density.

	SO_2	NO_x	NMVOC	CO	NH_3	PM_{10}
Total emission and emission share in Po-basin						
Total emission t/y	**143**	**2552**	**194,454**	**7517**	**247,711**	**3282**
10.1 - Cultures with fertilizers	0%	72%	94%	0%	15%	0%
10.2 - Cultures without fertilizers	0%	0%	6%	0%	1%	0%
10.3 - On-field burning of stubble, straw	100%	28%	0%	100%	0%	26%
10.4 - Enteric fermentation	0%	0%	0%	0%	1%	1%
10.5 - Manure management regarding organic compounds	0%	0%	0%	0%	0%	0%
10.9 - Manure management regarding nitrogen compounds	0%	0%	0%	0%	83%	0%
10.10 - Particulate emissions from animal husbandry	0%	0%	0%	0%	0%	74%
Per capita emissions g/inhabit/y						
EU-28	**1.5**	**1335**	**3129**	**259**	**6661**	**544**
Italy	**1.3**	**851**	**2069**	**205**	**5748**	**379**
Po-basin	**5 .4**	**97**	**7428**	**287**	**9462**	**125**
Emission density kg/km^2						
EU-28	**0.2**	**153**	**358**	**30**	**761**	**62**
Italy	**0.3**	**171**	**415**	**41**	**1154**	**76**
Po-basin	**1.2**	**23**	**1694**	**66**	**2157**	**29**

slope of the Po-basin with national and European estimates. Analyzing the Italian timeseries by autoregressive integrated moving average (ARIMA), it is possible to get a confidence band representing the possible evolution also of the Po-basin to 2019. As shown by the graphs in Figure 4, the emission trend of primary PM_{10} in Italy seems to be affected by technology improvement and by

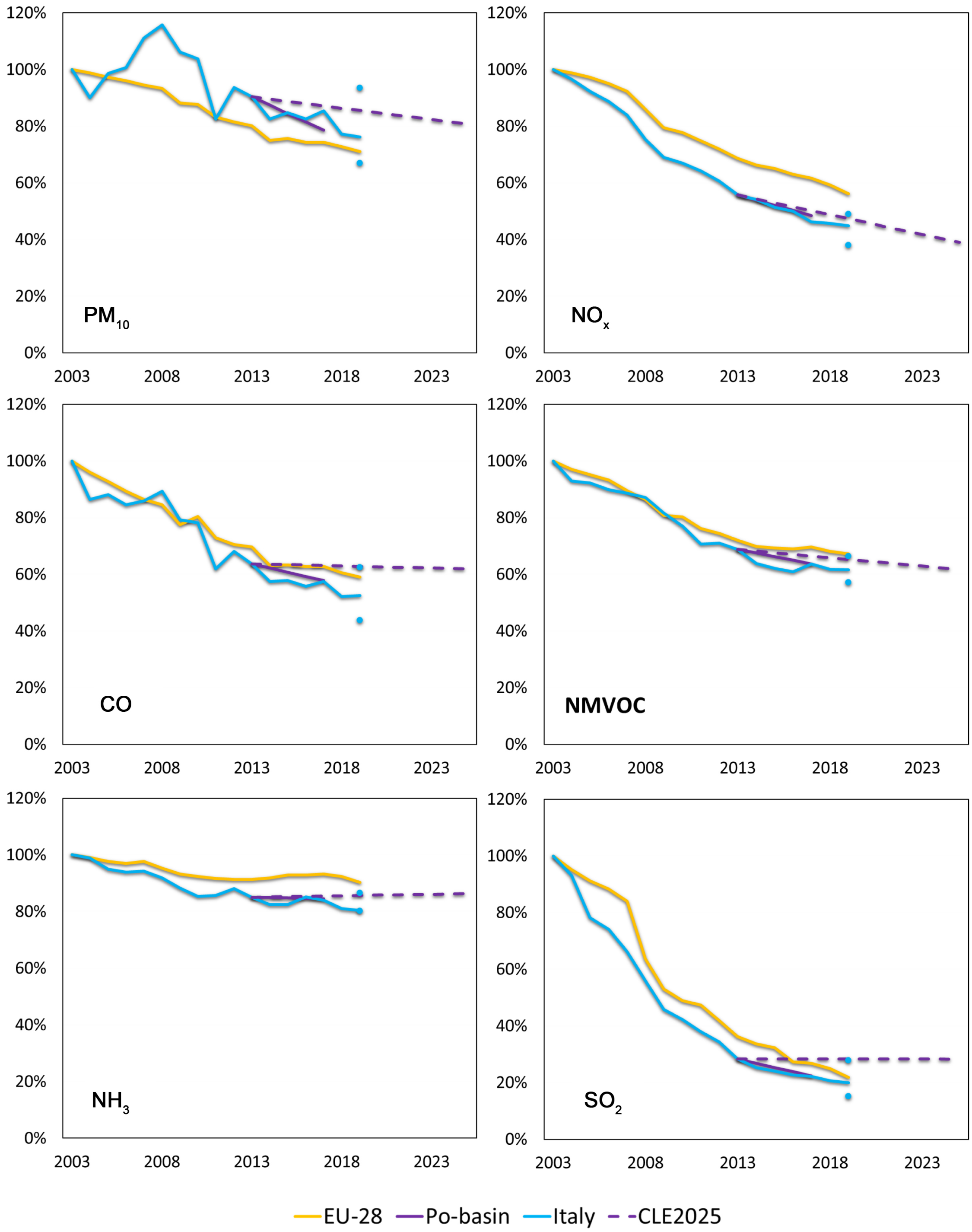

Figure 4. Emission trend analysis, comparison between EU-28, Italy, and LIFE PREPAIR emission dataset. Data are expressed as E_{year}/E_{2003}.

seasonal heating demand calculated for biomass burning in the residential heating. The Institute for Environmental Protection and Research (ISPRA) reports that the annual amount of wood for heating is estimated on the annual energy total biomass demand of households considering the heating degree time series, the number of households, the energy efficiency of equipment and fuel consumption statistics for the other fuels [11]. As a matter of facts, larger uncertainties on emission trend can affect the trend analysis of PM_{10} than NO_x emissions.

The initial trend analysis on Po-basin can be put also in comparison with the emission scenario developed to 2025 and representing the implementation of the current legislation (CLE 2025). These projections were estimated, for each Italian region, by a time proxy for each sector and activity [18] obtained from the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS)-Italian national model managed by National Agency for new Technologies Energy and Sustainable Economic Development (ENEA).

According to a previous paper [19], the further emission reductions due to the full application of local air quality plans were applied to the CLE 2025 defining the action-plans scenario (APS2025). The estimates on Po-basin can be compared to what was foreseen according to the current legislation scenario. The differences in slope between the updating of the emission dataset and the CLE 2025 can be also put into relation to the progression of the local plan actuations. It must be reminded that in some cases the comparison can be also affected by differences not directly connected to the technology turnover but due to seasonal parameters as in the case of the average temperatures connected to the heating demand during the year.

7. Conclusion

The paper reports the outcomes of the EU LIFE-IP Clean Air Program Po Regions Engaged to Policies of Air (PREPAIR) project regarding the assessment of the primary pollutants' emissions. The common dataset collected on Po-basin is a reference element for supporting air quality policies, the starting point for emission scenarios development and for the modelling simulations of air quality on the peculiar area of the Po-basin, frequently characterized by atmospheric stagnation and inversion conditions. The different update of the assessment on 2013 and 2017 has been compared to the timeseries of emission in EU-28 and Italy and to the emission scenario foreseen for 2025 (CLE 2025). The differences in slope between dataset evaluation and CLE 2025 can be a relevant element to confirm the enforcement of national and supranational legislation by the overall actuation of the local air quality plans.

Acknowledgements

The authors would acknowledge all the Environmental Agencies beneficiaries of the project LIFE-IP PREPAIR: Regional Agency for Environment of Emilia-Romagna, Regional Agency for Environment of Veneto, Regional Agency for

Environment of Piedmont, Regional Agency for Environmental Protection of Lombardy, Environmental Protection Agency of Valle d'Aosta, Environmental Protection Agency of Friuli Venezia Giulia, Slovenian Environment Agency and Autonomous Province of Trento and Bolzano.

Funding

This study was developed under the project LIFE-IP PREPAIR (Po Regions Engaged to Policies of AIR), which was co-funded by the European Union LIFE Program, in 2016, Grant Number LIFE15 IPE/IT/000013.

Conflicts of Interest

The authors declare no conflict of interest.

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