Experience in Lombardy in local ammonia emission factors and seasonal variation

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Air and Support to Political Decision Maker

Air Emissions Inventories

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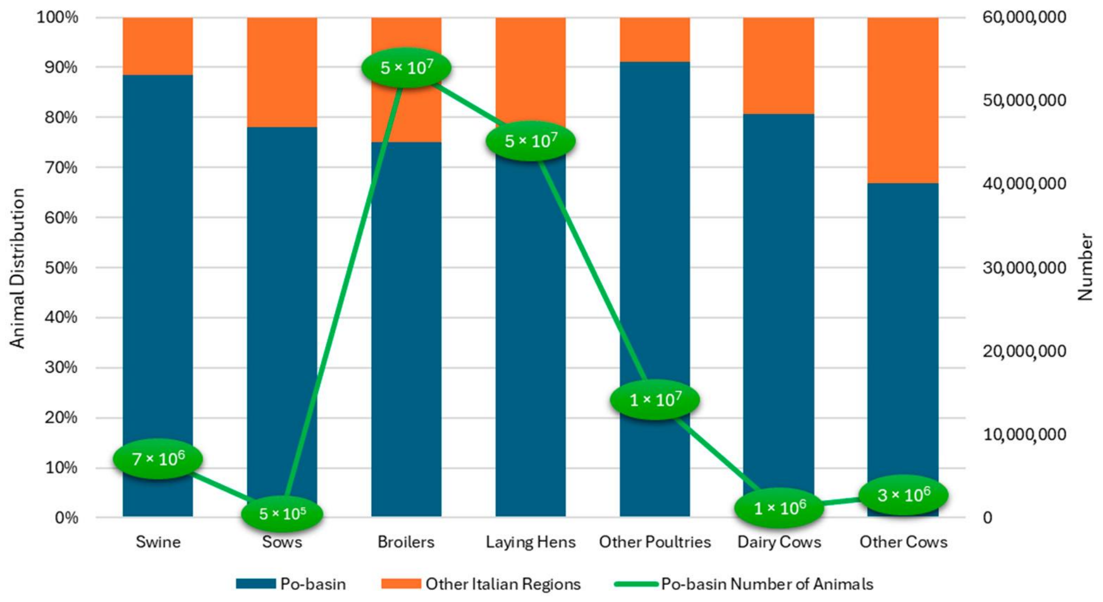
The BAT-Tool characteristics and functions

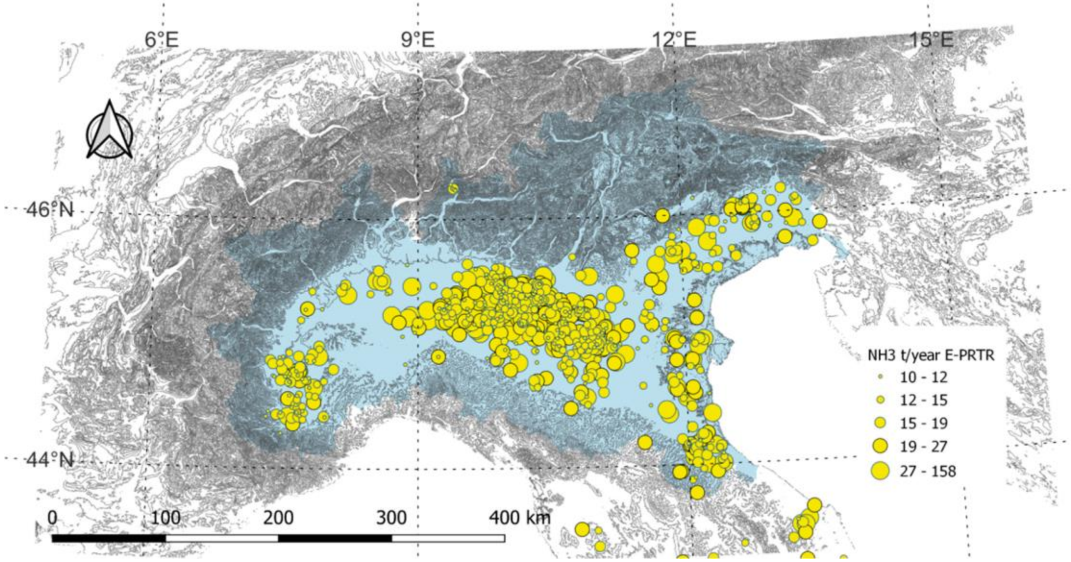
The BAT-Tool Plus was developed for the LIFE PREPARE project to estimate NH3 and GHG emissions from intensive farming in the PO-basin.
Its main characteristics and functions are:

- the alignment with EU BAT conclusions and Italian regulatory framework,
- based on a regional database on farm management practices, it ensures emission factors reflect actual techniques applied on farms,
- its scalability: from single farms to regional-scaled simulations,
- it is based on Nitrogen mass balance, allowing NH_3 emissions estimates in each manure management phase,
- the simulation of different scenarios with the application of different combinations of techniques and emissions estimations,
- it is an effective instrument in the decision support system for environmental policy and planning.

Geographic domain and livestock consistence

The Italian regions participating in the LIFE PREPAIR project are characterized by cultivated plain areas with a high density of livestock. The main emission points are mainly concentrated in the areas between the Lombardy, Veneto, and Emilia-Romagna regions.

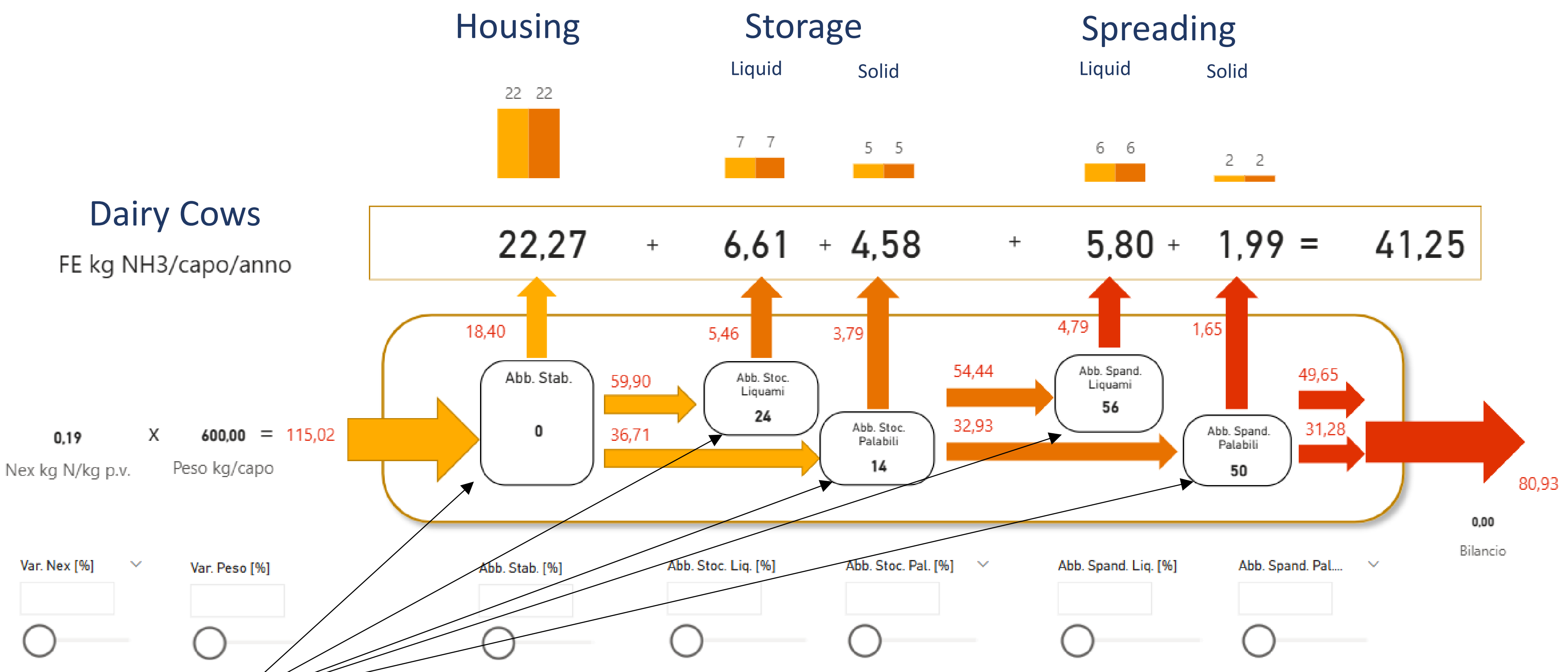




The majority (80%) of cows, swine, and poultry are farmed in the Po Valley.
This called for the development of a common methodology and tool for estimating NH_3 emissions, given ammonia role in the formation of $PM_{2,5}$.

Balboni, M.; Marongiu, A.; Vito, D. Estimating Ammonia Emissions and Nitrogen Mass Balance in the Po-Basin: Models, Tools, and Policy Implications. *Sustainability* **2025**, *17*, 10201. https://doi.org/10.3390/su172210201

Mass balance on Nitrogen – regional application



$$\eta_{phase} = \sum_{i=tech,phase} N_i \eta_i$$

Main input data are farms characteristics: from a complete local database on technologies for manure management, it was possible to replicate the Lombardy livestock sector.

Methodology for livestock EFs: the nitrogen mass balance

The estimate considers the nitrogen flux to estimate emissions from different phases of manure management:

- Housing for animals (N_h),
- Storage of effluents (N_s),
- Field application (N_d).

For each animal category the mass balance is verified:

- for the whole manure management, N_ex – N_h – N_s – N_d – N_field = 0,
- for each phase, for example: N_ex-N_h-N_ex_h = 0.

Animal Category	N_ex	N_h	N_ex_h	N_s	N_ex_st	N_d	N_field
Laying Hens	0.598	0.067	0.531	0.047	0.484	0.120	0.364
Broilers	0.357	0.068	0.289	0.026	0.263	0.065	0.198
Other Poultries	0.949	0.174	0.775	0.069	0.706	0.175	0.531
Swine	10.362	1.873	8.489	0.747	7.742	1.024	6.718
Sows	23.484	3.384	20.100	1.766	18.335	2.422	15.913
Dairy Cows	114.88	18.381	96.499	9.154	87.346	7.315	80.030
Other Cows	41.667	6.667	35.001	3.333	31.668	2.355	29.312

Nitrogen flux parameters (kg of N of Year−1 Head−1) calculated with the BAT-Tool

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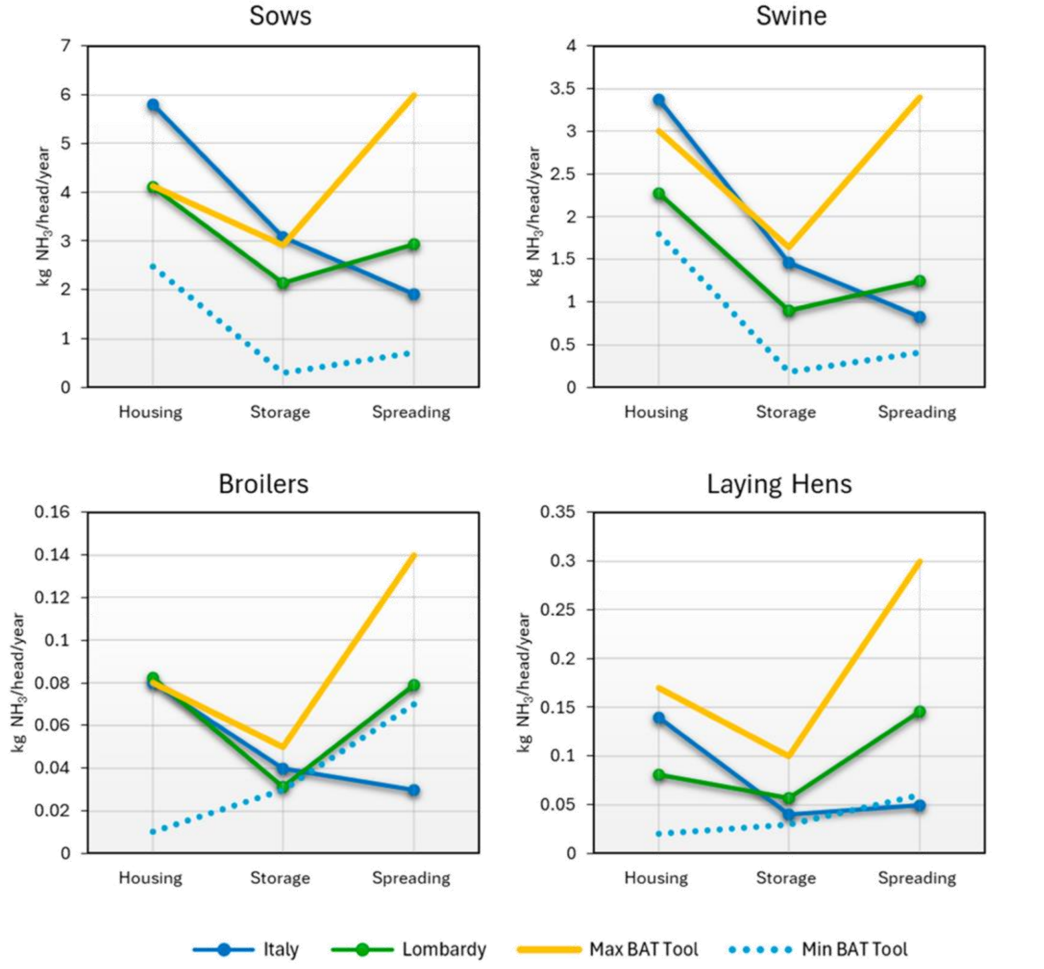
NH3 emission factors specific to the Lombardy region



Improvements introduced in the emission inventory

EMISSION FACTORS: use of the emission factors calibrated to the Lombardy region for all remaining farms and the effluents spreading phase. The calculation of these emission factors is based on the characteristics of Lombardy farms

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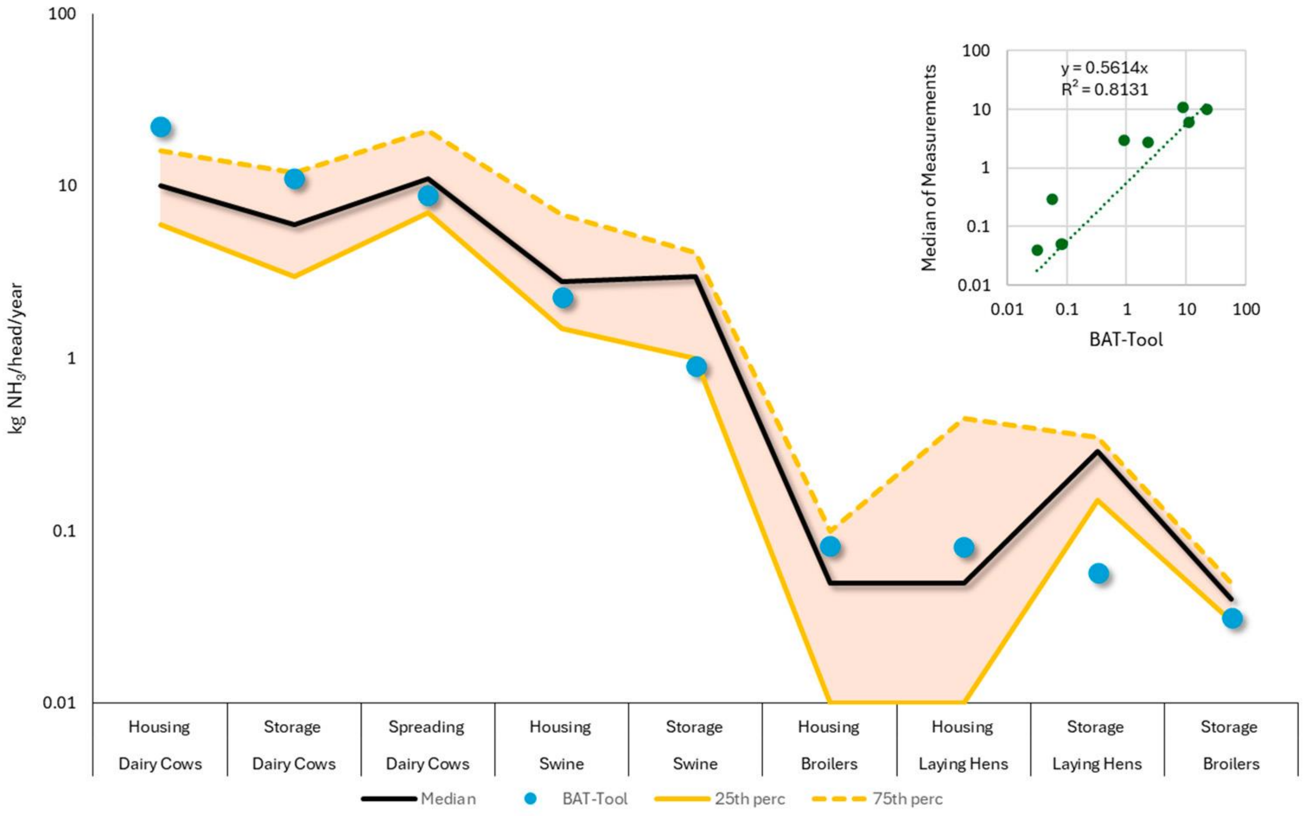
Validation and comparisons: local EFs and DATAMAN

The local EFs were validated and compared with measurements obtained from DATAMAN:
the EFs are in very good agreement considering the large variability in the measurements.
This variability can be explained by many factors (e.g., meteorological conditions, technology, manure, and soil characteristics).
The R^2>0.8, and a comparison was performed only for animals and phases where the measured data were sufficiently numerous.



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Results: N fluxes from livestock and fertilization for the Po-basin

N mass balance in 2023 for the entire Po Valley (kt of N)

Animal Category	N_ex	N_h	N_ex_h	N_s	N_ex_st	N_d	N_field
Laying Hens	27.7	3.1	24.6	2.2	22.4	5.5	16.9
Broilers	19.0	3.6	15.4	1.4	14.1	3.5	10.6
Other Poultries	11.4	2.1	9.3	0.8	8.5	2.1	6.4
Swine	69.4	12.5	56.8	5.0	51.8	6.9	45.0
Sows	11.2	1.6	9.6	0.8	8.7	1.2	7.6
Dairy Cows	137.5	22.0	115.5	11.0	104.6	8.8	95.8
Other Cows	109.8	17.6	92.2	8.8	83.4	6.2	77.2
Total	**386.0**	**62.5**	**323.5**	**30.0**	**293.5**	**34.1**	**259.4**

N emitted into Air

N applied to soil

N remaining on field

N mass balance from mineral fertilization in the Po-basin (kt of N)

Fertilizer	N_app	N_d	N_field
Nitrogen–phosphates	19.85	0.85	19.00
Nitrogen–potassium	3.80	0.16	3.63
Ternari	16.05	0.69	15.36
Other nitrogens	18.78	0.88	17.90
Calcium cyanamide	2.04	0.27	1.77
Nitrates (ammonium and calcium)	27.98	0.18	27.79
Ammonium sulphate	10.00	0.76	9.24
Urea	178.52	23.38	155.14
Simple nitrogens	3.82	0.18	3.64
Compounds	8.95	0.42	8.53
Total	**289.78**	**27.77**	**262.02**

Urea contributes to the largest part of the emissions derived from mineral fertilization.

Conversion factor N to NH3 = 1.21 (NH_3/N)

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Nitrogen losses from livestock and fertilizers

Around 33% of the total N excreted by livestock in the Po-basin is lost to the atmosphere as NH3:

$$N_{loss} = \frac{(N_h + N_s + N_d)}{N_{ex}}.$$

Using an adapted formula, the nitrogen release in the atmosphere for mineral **fertilizers is around 10**%.

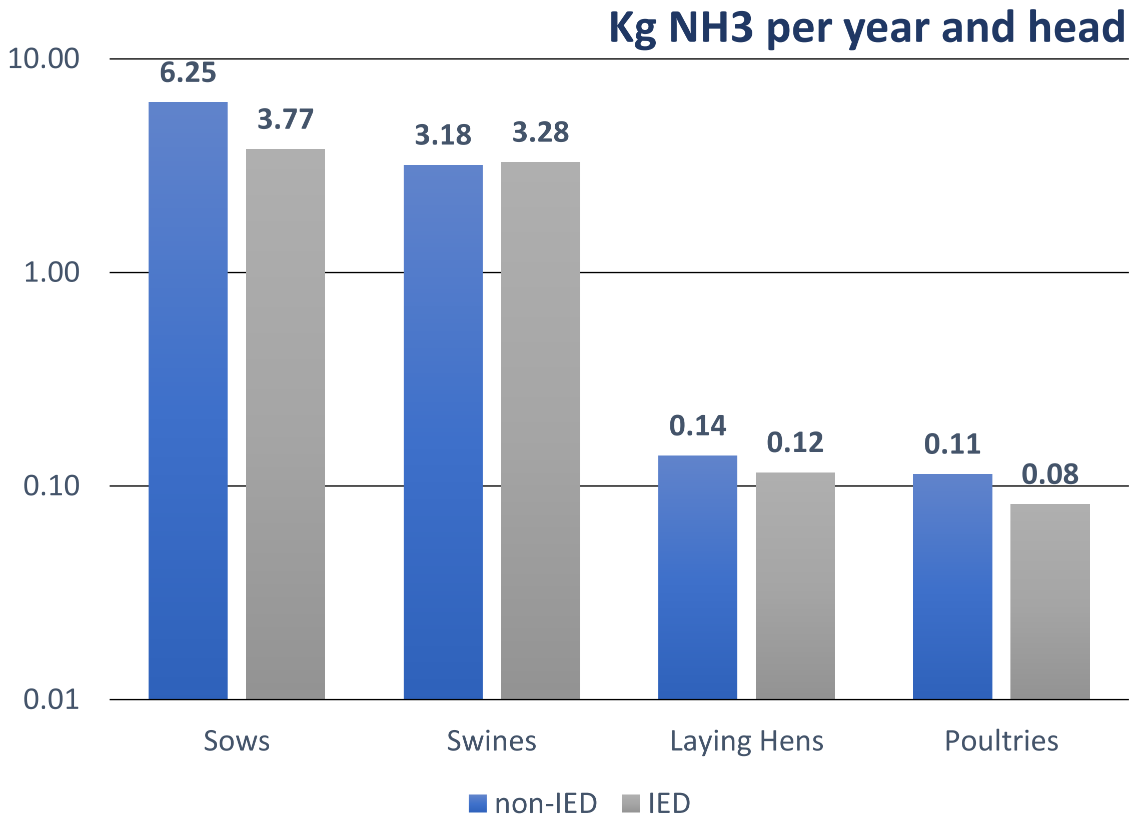
The Utilized Agricultural Area (UAA) in the Po-basin amounts to 4 345 341 ha (data from National Buro of Statistics of Italy). The overall load of nitrogen to a field is the ratio between:

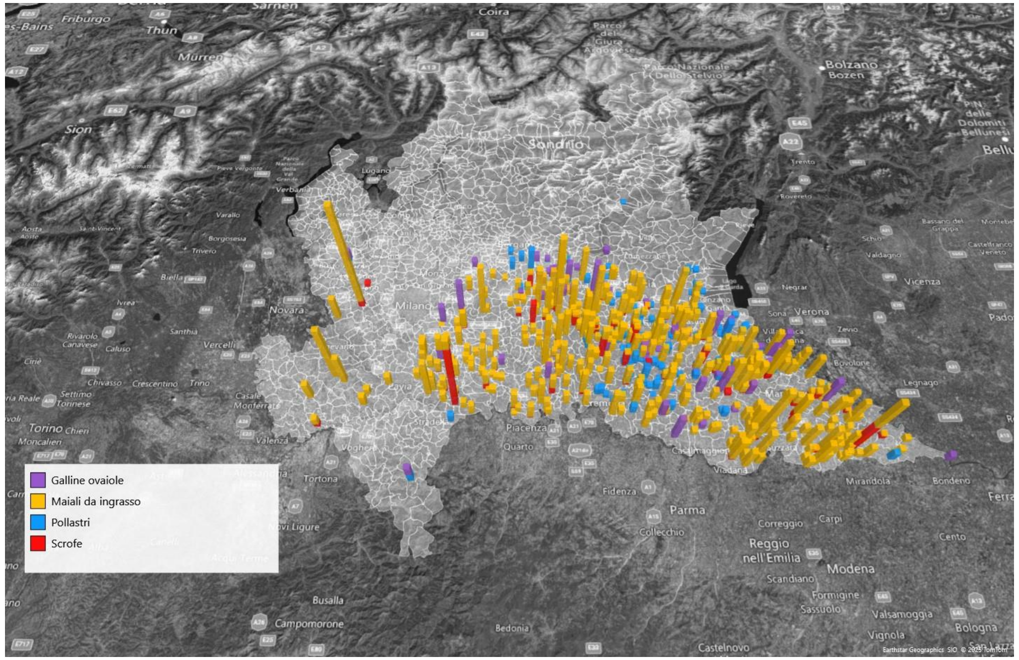
- N_{ex_st} and UAA = 68 kg N/ha for manure,
- N_{app} and UAA = 67 kg N/ha for mineral fertilizers.

Then for the entire Po-basin, the total N_{load} = 134 kg N/ha.
Compared to the maximum threshold established by the Nitrates Directive (170 kg N/ha) this value is relatively lower.

This results show that N_{load} in fields from mineral fertilizers are comparable to those from manure (~67–68 kg N/ha), highlighting the need for integrated strategies targeting both sources.

EFs in housing and storage – single farm application

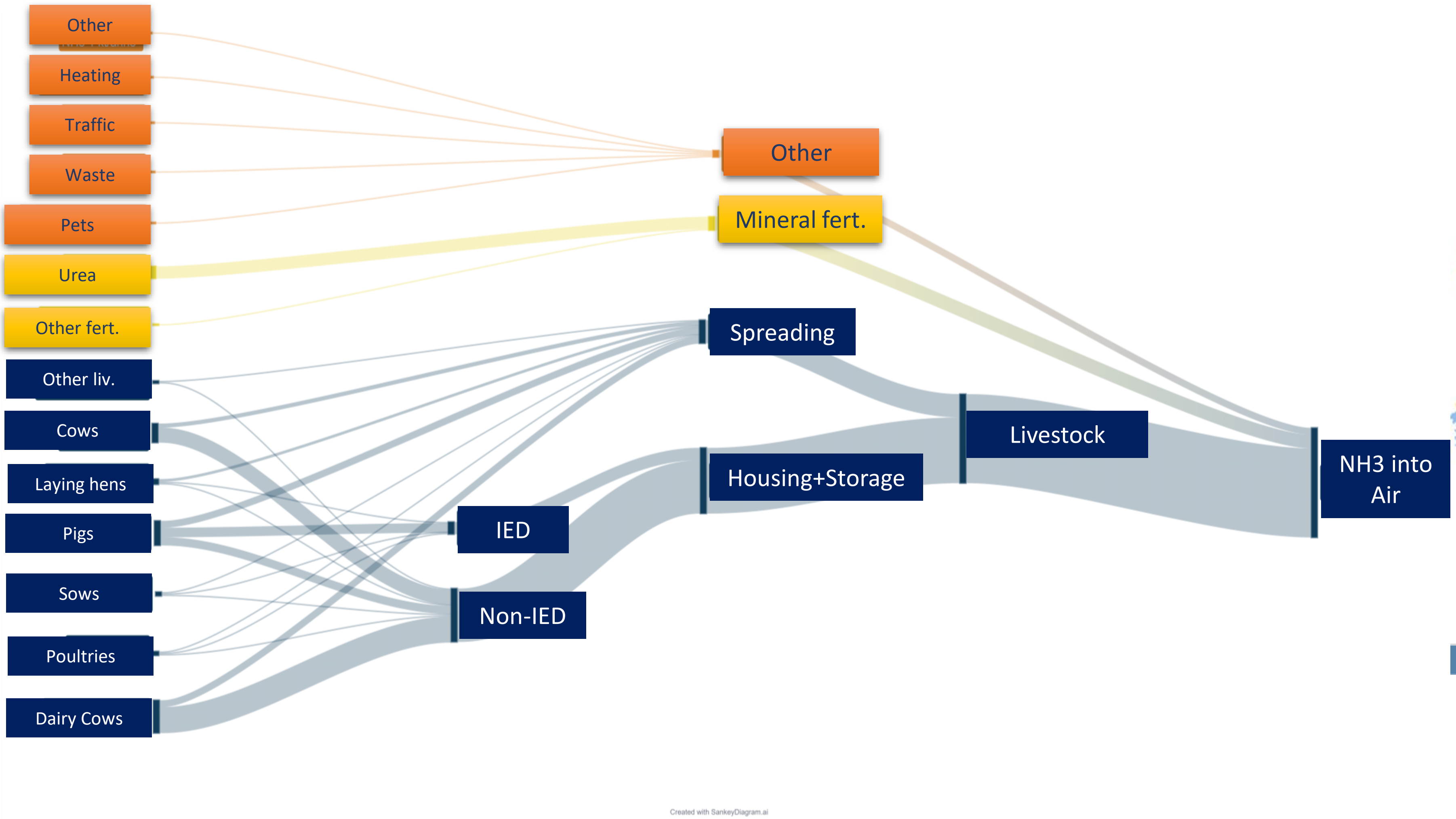




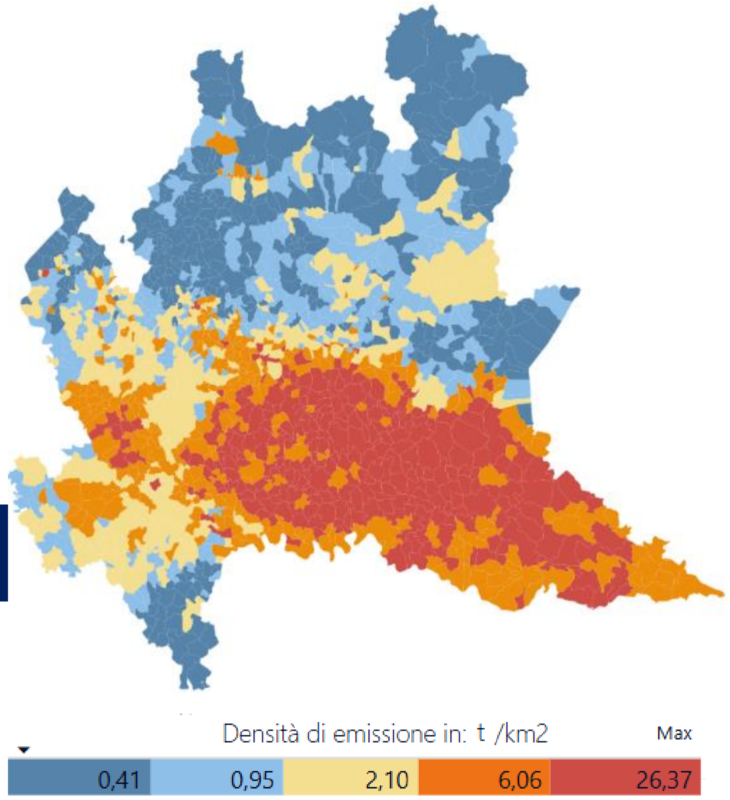
Atmospheric emissions data of single farms

The inventory included emissions from approximately **700 poultry and pig farms authorized under the IED**. The farms reported using the BAT-Tool software for almost all the data, and the estimates contain emissions from the housing and storage phases.

Ammonia emissions in Lombardy

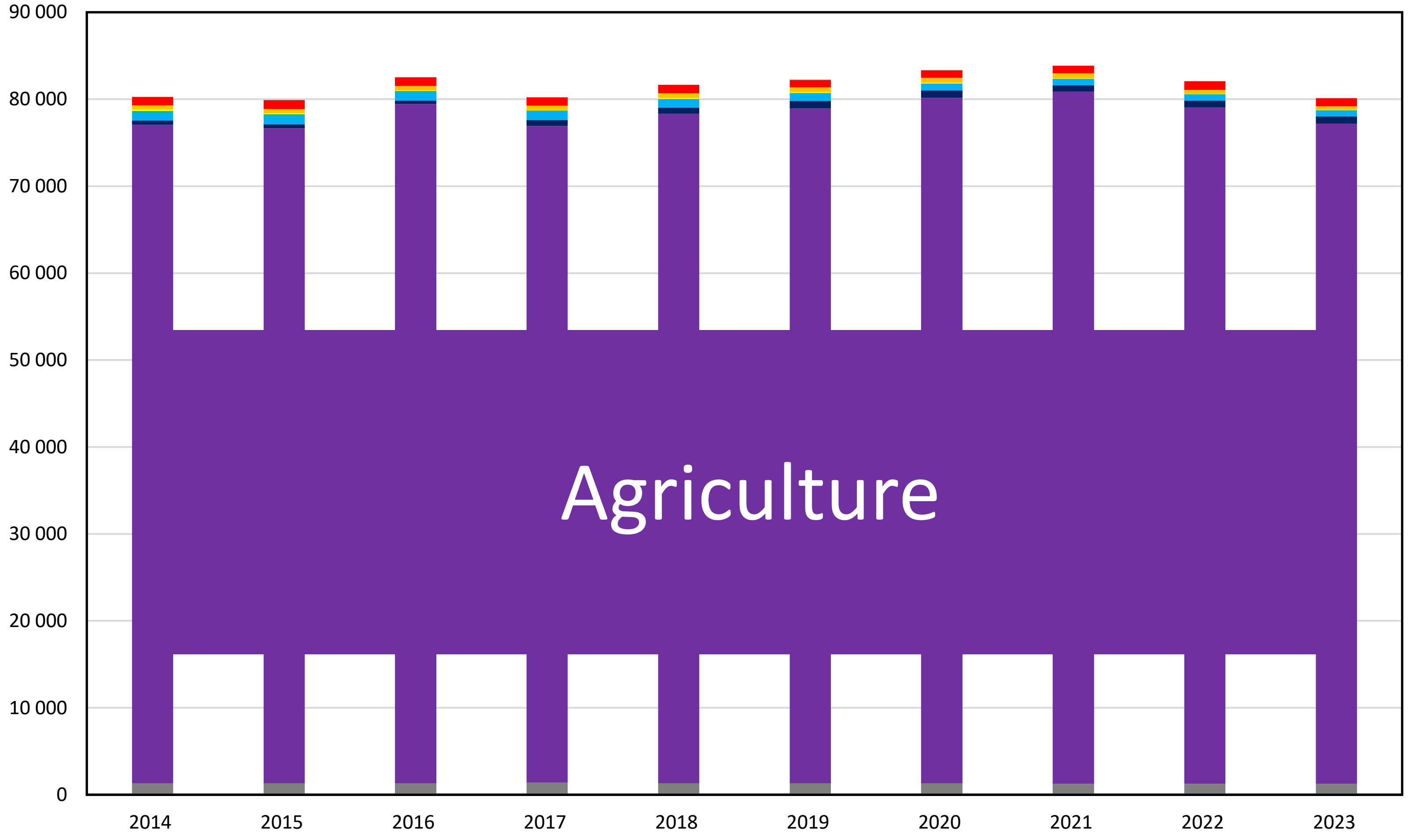


80 kt/year



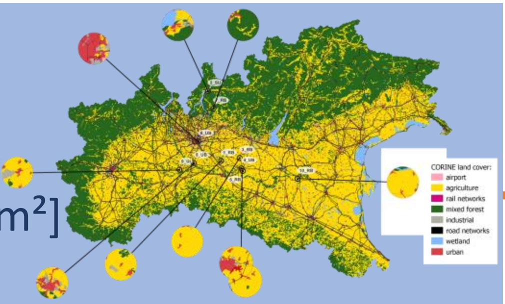
Ammonia emissions trend in Lombardy

Ammonia emissions decreased by 4% between 2021 and 2023. This decrease is due to a reduction of livestock consistence and a reduction of mineral fertilizer consumption.

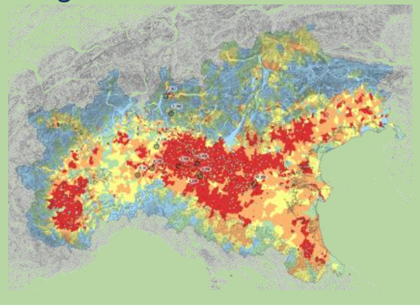


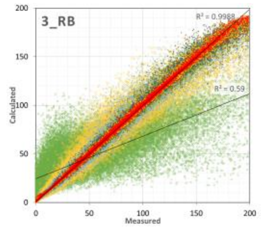
Ammonia dinamic emission inventory on the Po-basin

Hourly based measurements:
- wind direction (WD) [°]
- precipitation (PR) [mm]
- global solar radiation (GSR) [W/m²]
- ambient temperature (AT) [°C]
- relative humidity (RH) [%]
- wind speed (WS) [m/s]
- NH_3 concentrations (NH3) [μg/m³]



Annual based estimates from inventory:
- NH_3 emission [t/year]





ML
Random Forest
(train and test)

NH_3 concentrations prediction

Prediction vs Measurements

Correction of Hourly emission rate

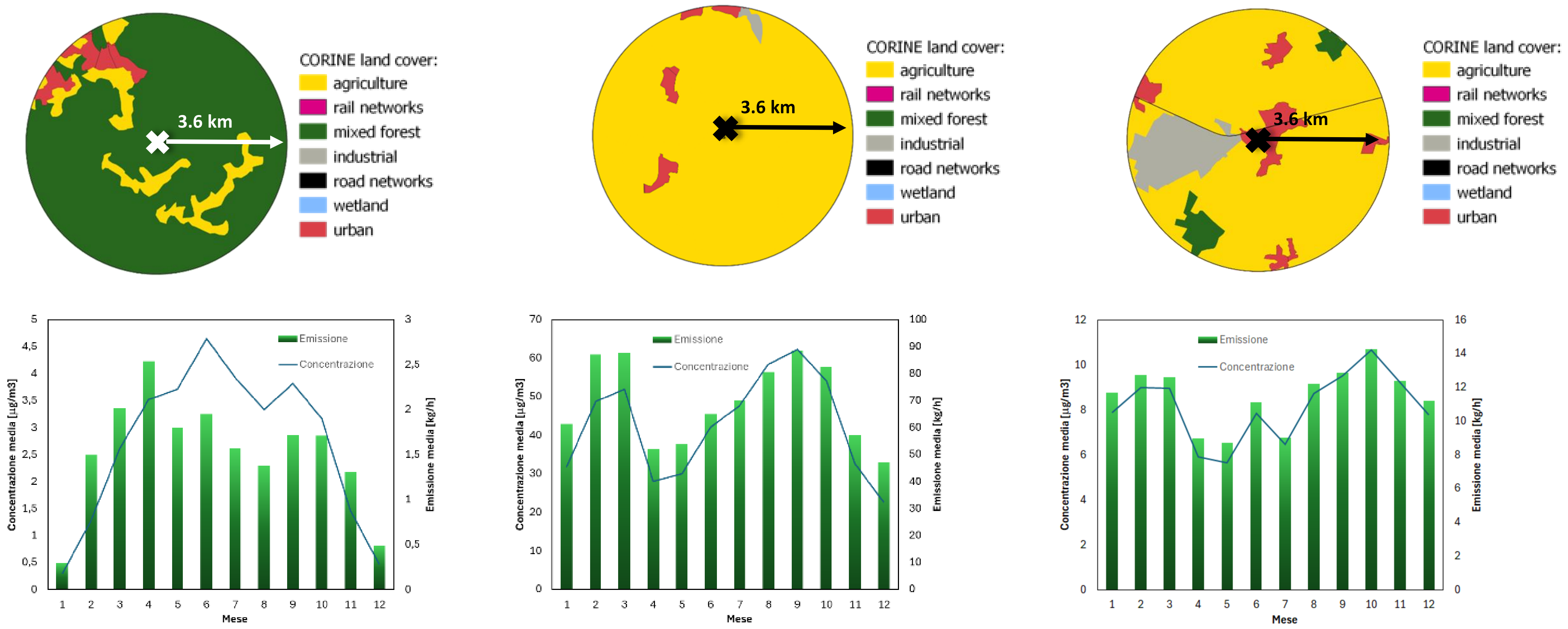
Hourly emission rate:
- NH_3 emission [kg/h]

ML
Random Forest

Hourly emission rate on the whole domain

Marongiu, A., Colombo, L. & Collalto, A.G. Dynamic emission inventory of ammonia in northern Italy by machine learning. Air Qual Atmos Health 18, 3793–3811 (2025). https://doi.org/10.1007/s11869-025-01779-4

Emissions seasonal variation



Different seasonal patterns for different surrounding areas

Elaboration on: Marongiu, A.; Collalto, A.G.; Distefano, G.G.; Angelino, E. Application of Machine Learning to Estimate Ammonia Atmospheric Emissions and Concentrations. *Air* **2024**, *2*, 38-60. https://doi.org/10.3390/air2010003