Cracking the nitrogen code

Can Flanders lead the way to a sustainable nitrogen future?

Maarten Hens

Bio Talks | Universiteit Antwerpen | 23 oktober 2025

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1. Nitrogen cycle in a nutshell
2. Emissions and deposition of nitrogen
3. Programmatic Approach Nitrogen
4. Reduction of nitrogen emissions
5. Assessment frameworks for permitting
6. Looking forward & concluding remarks

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1. Nitrogen cycle in a nutshell

With focus on the cause and impact of nitrogen losses

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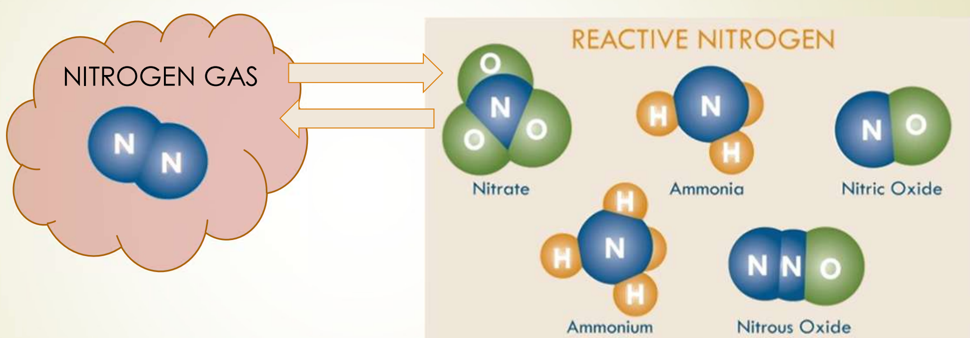
Reactive nitrogen ?



- All forms of life need reactive nitrogen
- N_2-fixation in chemical fertilizer is needed to feed the global population
- Biodiversity has evolved and is high under conditions of limited N availability
- Increase in reactive N harms human health and causes biodiversity loss

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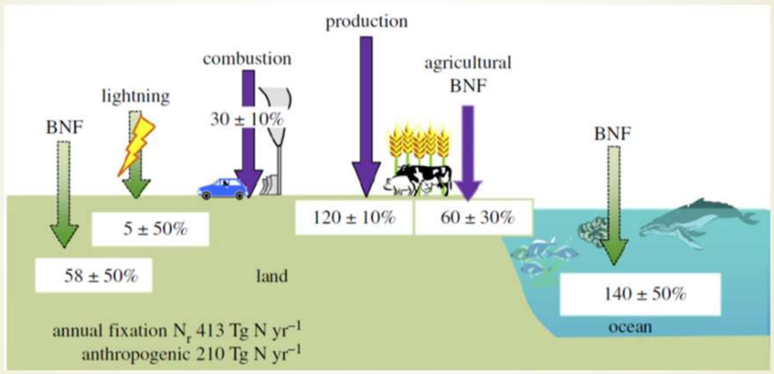
Natural *vs* anthropogenic N inputs



Global N fixation: +50% via 'anthropogenic' pathways

In agriculture: more than half via chemical fertilizers

Fowler et al. (2013)

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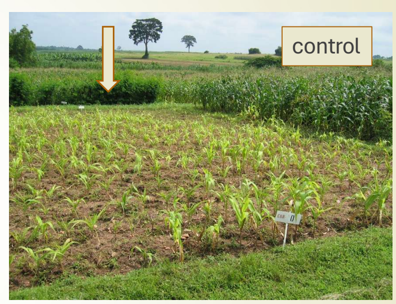
Effect of chemical N fertilizer on crop yield

- N fertilizer increases crop yield 3–6 fold
- Ca 50% of world population is being fed by N from chemical fertilizer
- In 2050 approx. 2 billion extra people need to be fed



20 years no chemical fertilizer

1 year no chemical fertilizer

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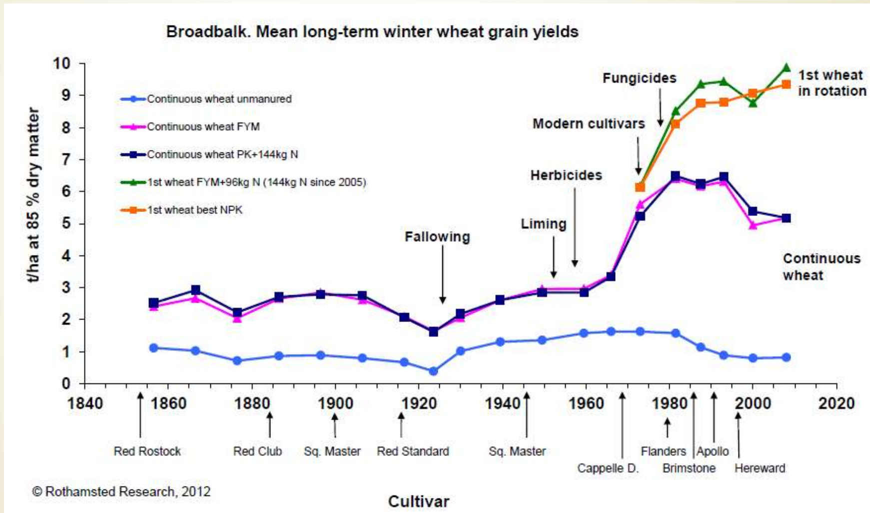
160 years of cropping without N: 10x lower yields



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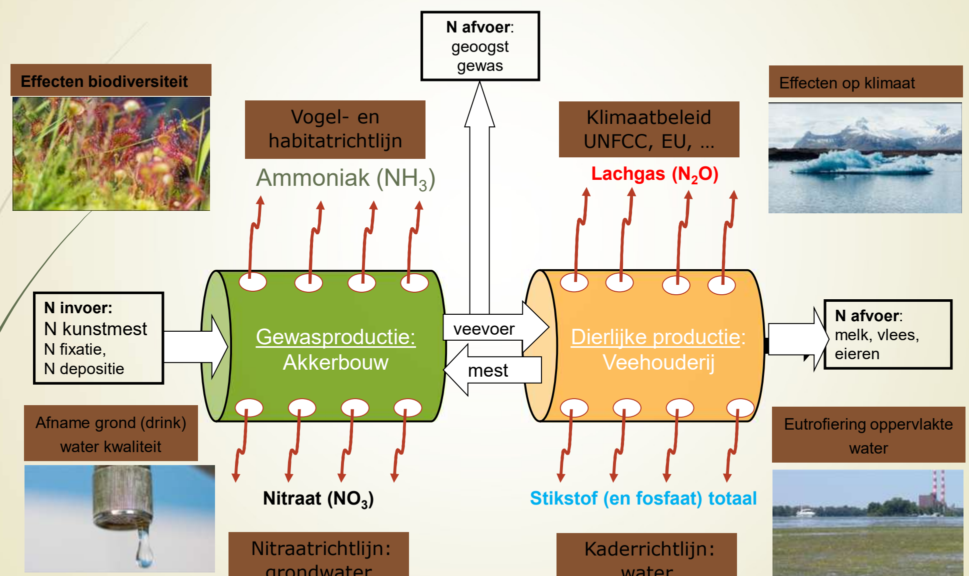
Leakages from the agricultural N cycle



De Vries et al. (2021)

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Problem: environmental impact of excess reactive N

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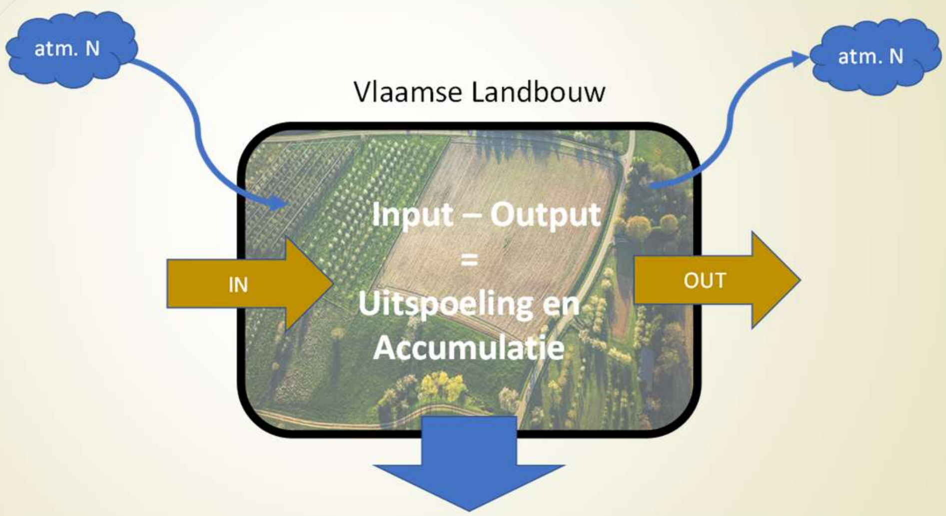
Nitrogen balance of Flemish agriculture



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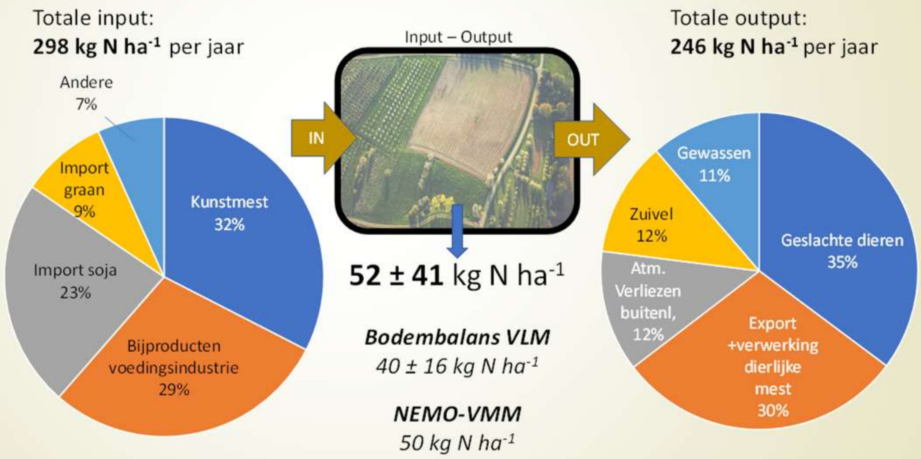
Nitrogen balance of Flemish agriculture



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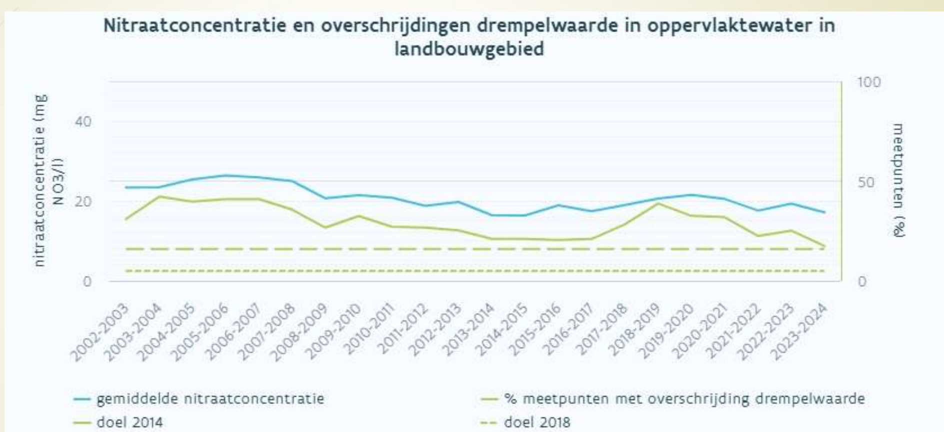
Nitrate in surface water in agricultural areas



→ 2023–24: in 51% of agricultural area NO_3-levels below target concentration of 18 mg/L

→ 2023–24: in 17,5% of monitoring locations NO_3-levels exceeded limit value of 50 mg/L

VLM (2024), VMM (2025)

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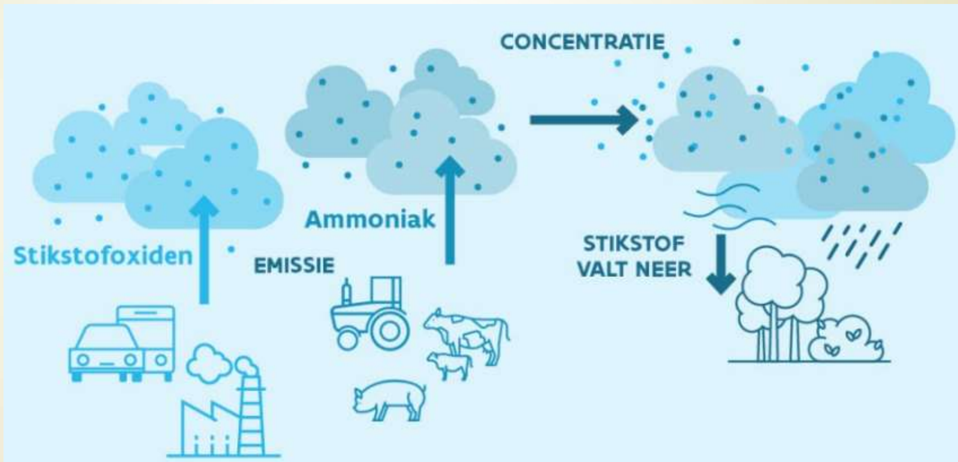
Atmospheric deposition of nitrogen



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Effects of nitrogen deposition on ecosystems

- **Nutrient enrichment (eutrophication)**
  - increased plant-availability of nitrogen
- **Soil acification**
  - decreasing levels of Ca, K, Mg → plant nutrition
  - increasing levels of toxic compounds (Al, H^+)
- Increased NH_4^+/NO_3^- ratios in soil solution
- Direct toxicity of atmospheric ammonia
- Specific effects on individual species and at community level
  - Complex disturbance chains
  - Decreasing species diversity

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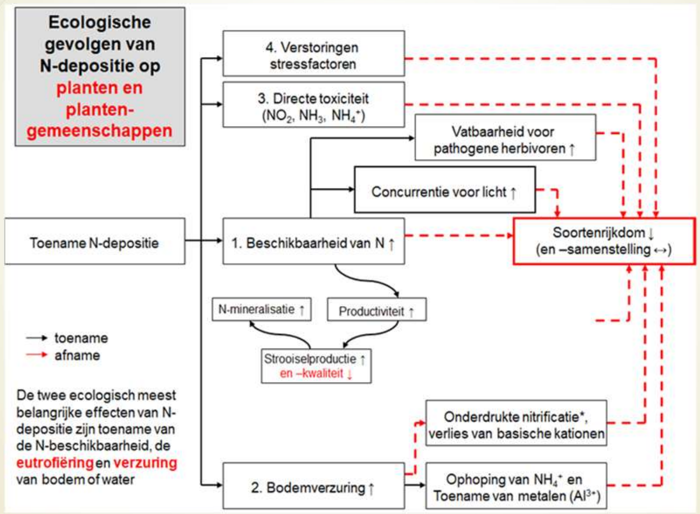
Effects of nitrogen deposition on ecosystems



INBO (2021)

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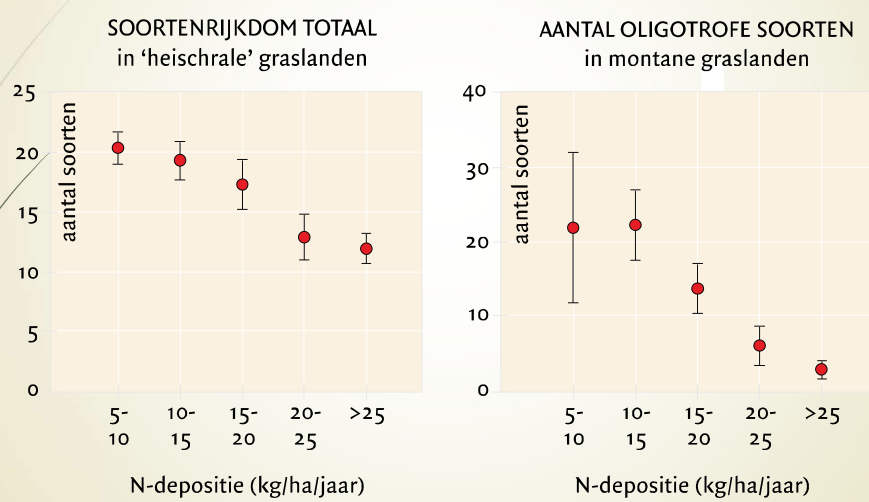
Relation between nitrogen deposition and species diversity in European grasslands



Bobbink et al. (2021)

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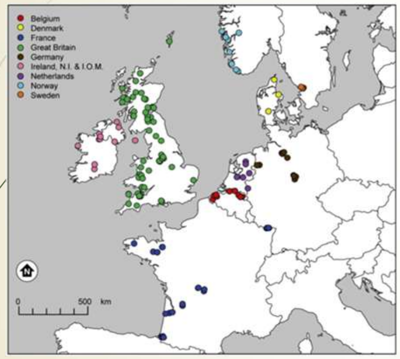
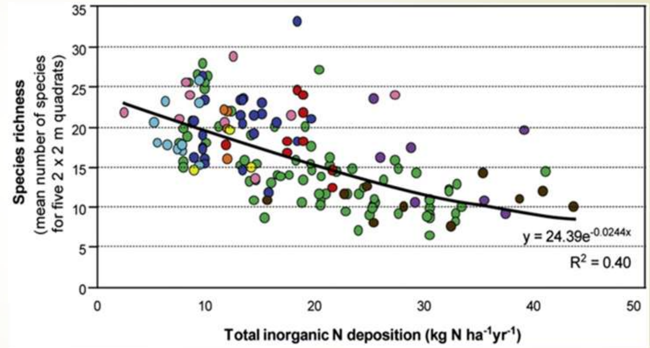
Relation between nitrogen deposition and species diversity in European grasslands





Stevens et al. (2010)

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Critical load (KDW)

- The critical load (‘kritische depositiewaarde’, KDW) is the threshold above which there is a risk that the quality of the habitat is significantly affected by the acidifying and/or eutrophying effects of atmospheric nitrogen deposition
- Empirical critical loads are being determined for each habitat type by:
  - Nitrogen enrichment (fertilization) experiments
  - Long-term monitoring of N deposition impacts
  - Comparison of habitat structure and functioning over spatial gradients
  - Model calculations
- UNECE/CLRTAP: Ranges of CL-values for each habitat type
- At country/regional scale: single values at habitat (sub)type level

UNECE/ Bobbink et al. (2022), INBO (2024)

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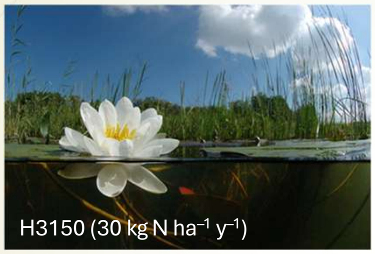
Critical loads (KDW) in Flanders



INBO (2024)

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2. Emissions and deposition of nitrogen

Sources, evolution and patterns in Flanders

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Emissions of NOx and NH_3 in Flanders

Tabel 2.1.

Emissie van stikstofoxiden (NOx), ammoniak (NH_3) en totaal van beide (totaal N) in Vlaanderen in 2021.

Sector	Emissie 2021					
	NOx		NH_3		Totaal N	
	ton N	Aandeel (%)	ton N	Aandeel (%)	ton N	Aandeel (%)
Huishoudens	1.445	5,5%	583	1,6%	2.028	3,4%
Industrie	6.180	23,4%	598	1,8%	6.778	11,2%
Energie	2.028	7,7%	9	0,0%	2.037	3,3%
Land- en tuinbouw	3.109	11,8%	32.271	95,0%	35.380	58,6%
Transport*	12.393	47,0%	390	1,1%	12.783	21,2%
Handel & diensten	568	2,2%	132	0,4%	700	1,2%
Off-road	669	2,5%	2	0,0%	671	1,1%
Totaal	26.391	100%	33.987	100%	60.378	100%

* Emissies van luchtvaart beperkt tot <3000 voet

PAS (2023)

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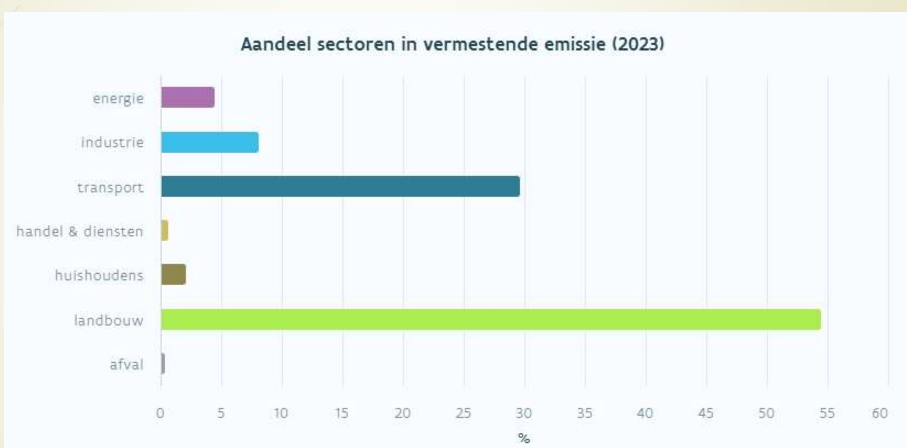
Emissions of NOx and NH_3 | sources



VMM (2025)

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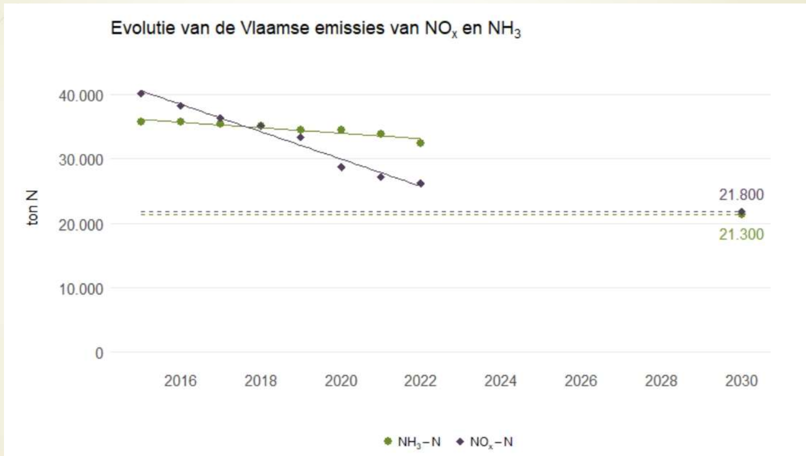
Emissions of NOx and NH_3 | evolution



→ Since 2015, NOx emissions have decreased 35% *vs* NH_3 9% → **total N –22,7%**

→ In the Netherlands, N emissions decreased with **–16,5%** in same period

Voortgangsrapport PAS (2025)

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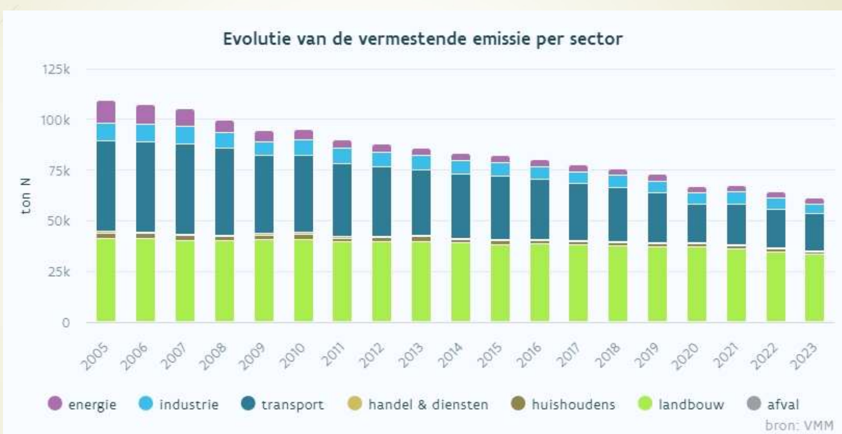
Emissions of NOx and NH_3 | sources



→ Since 2005, NOx emissions have decreased 58% *vs* NH_3 19% → combined = 44%

→ Contribution of agriculture steadily increased from 38% in 2005 to 54% in 2023

VMM (2025)

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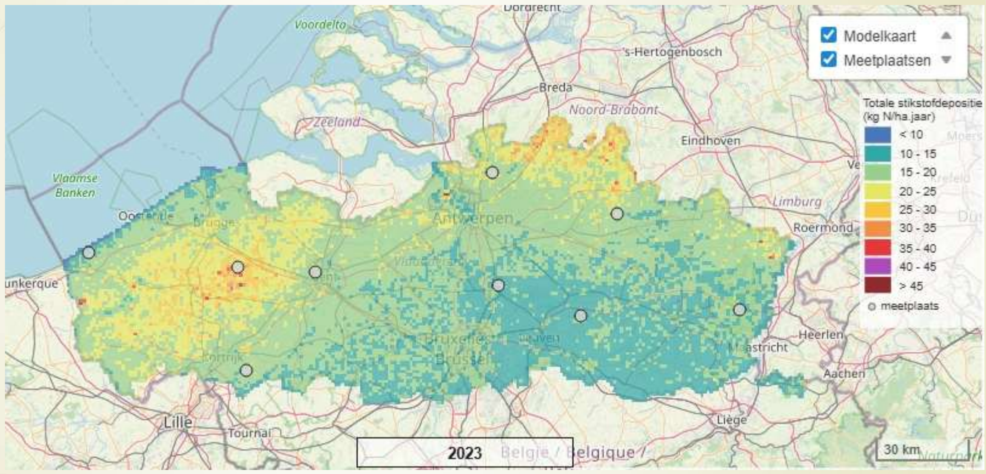
Nitrogen deposition | Flanders



Average deposition 2023: 17,5 kg N/ha - of which 71% NH_x-N and 29% NO_y-N

VMM (2025)

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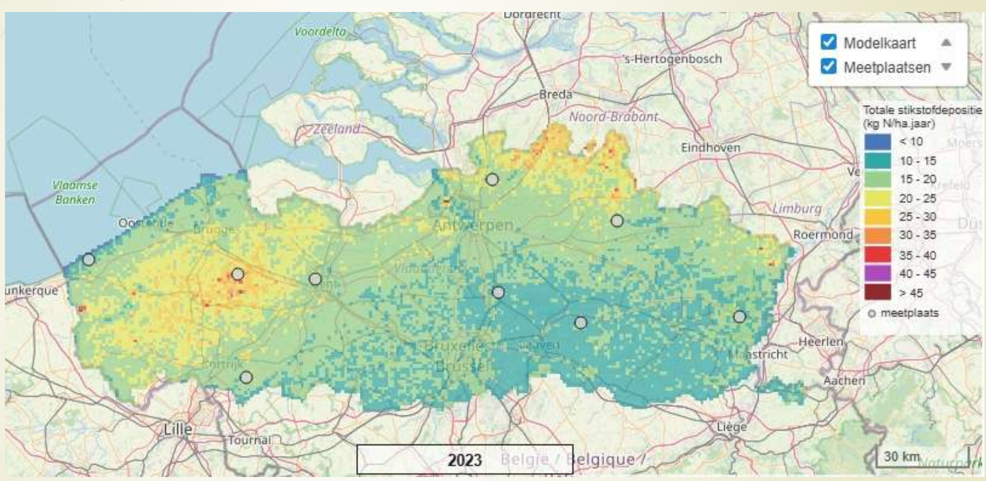
Nitrogen deposition | Flanders



Average deposition 2023: 17,5 kg N/ha - of which 71% NH_x-N and 29% NO_y-N

VMM (2025)

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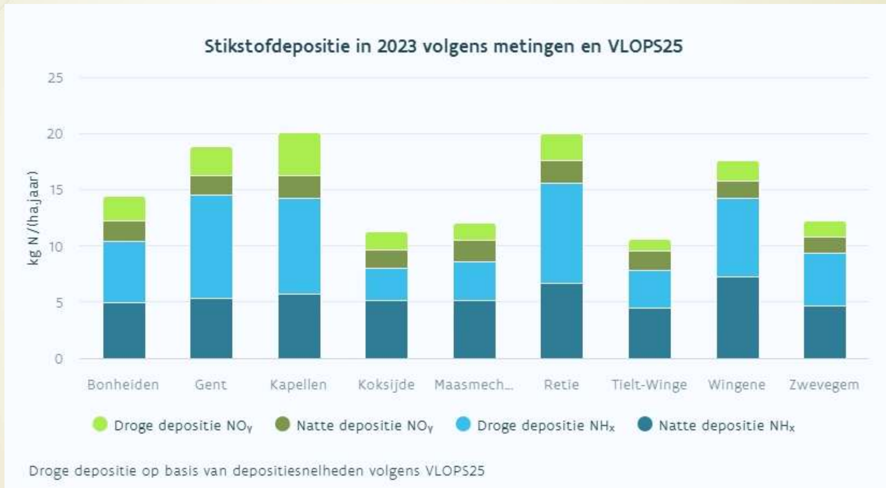
Nitrogen deposition | monitoring sites



VMM (2025)

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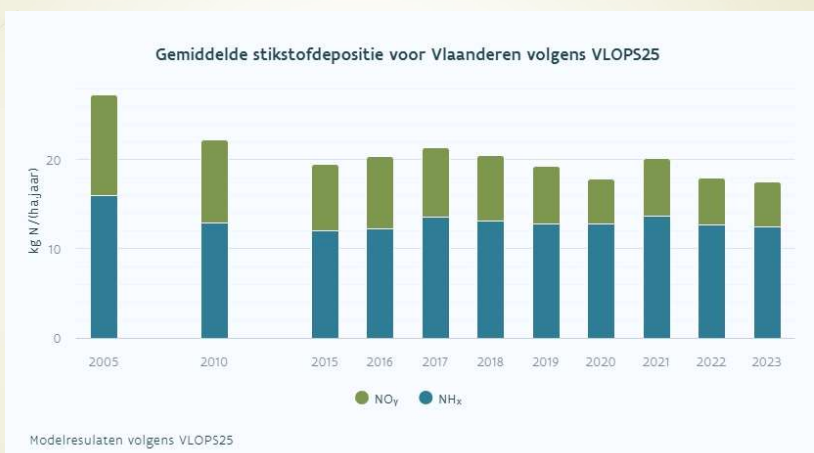
Nitrogen deposition | evolution since 2005



Evolution 2005–2023 : –10,8 kg N/ha (–40 %), of which NO_y –56% and NH_x –28%

Evolution 2015–2023 : –2,0 kg N/ha (–10 %), of which NO_y –33% and NH_x +4%

VMM (2025)

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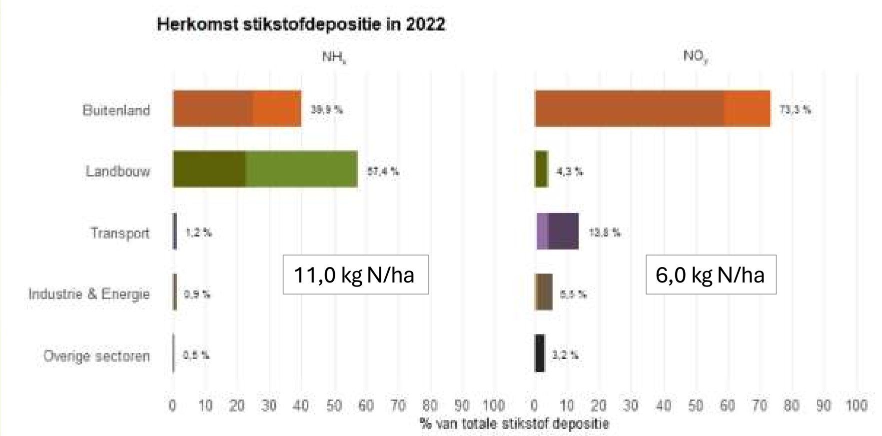
Nitrogen deposition | sources & origins



→ 52% of total deposition originates from non-Flemish sources (transboundary)

→ 77% of deposition from Flemish sources is NH_x from agriculture

Voortgangsrapport PAS (2025)

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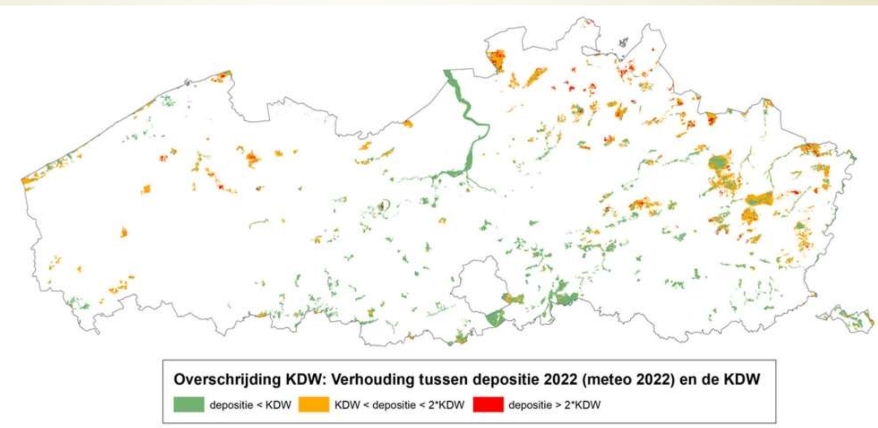
N deposition on Special Areas of Conservation



→ Total SAC area = 105.022 ha, containing 58.812 ha N-sensitive habitats

→ In 2022, deposition > critical loads on 52% of the area of N-sensitive habitats

Voortgangsrapport PAS (2025)

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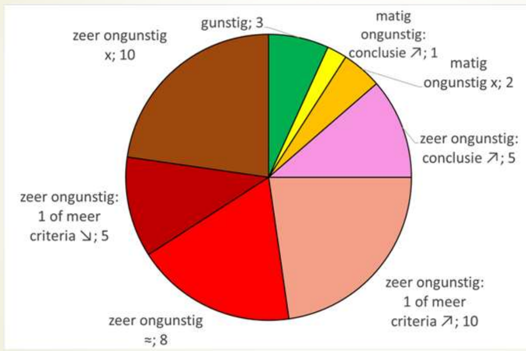
Conservation status of habitats

Flanders, Article 17 assessment report (2013–2018)



46 Annex I habitats

3 favourable
3 unfavourable-inadequate
38 unfavourable-bad
2 not assessed

N-sensitive habitats

40 out of 46 habitats are N-sensitive
N deposition was assessed as:

- a medium or high **pressure** for 31
- a medium or high **threat** for 25

Paelinckx et al. (2019), PAS (2023)

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3. Programmatic approach nitrogen

Towards an integrated policy package to enable achieving Natura 2000 goals and to accommodate environmental permitting

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PAN policy goals

- Contribute to the **realization of the conservation goals** for European protected habitats and species through a structural reduction of N deposition and N impacts on Special Areas of Conservation designated under the Habitats Directive
- Provide a futureproof, workable and legally sound **framework for environmental permitting**, taking into account ecological, social, and economic constraints

UNECE/ Bobbink et al. (2022), INBO (2024)

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Considerations, choices and principles

- Overall time horizon = 2050, with 2030 as in-between target
- How to attribute emission reductions: 'flat rate' ? spatial differentiation? Sectoral differentiation?
- Differentiate between ammonia and NOx
- Measures based on socio-economic cost-benefit analysis
- Preferably an encompassing, integrated approach, supporting multiple environmental, economical and social policy goals
- Strong scientific foundation needed, fed by data and models
- Strong legal foundation needed

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PAN components

1. **Reduction of N emissions**
2. **Assessment framework for environmental permitting**
3. **Nature restoration programme**
4. **Economic support package for agriculture**
5. **Monitoring & compliancy mechanisms**

→ PAN approved by Flemish Government on 10 March 2023
→ Budget: 3,6 billion EUR (2023–2030)
→ PAN Decree ('Nitrogen Decree'): entered into force on 23 Feb 2024

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4. Reduction of nitrogen emissions

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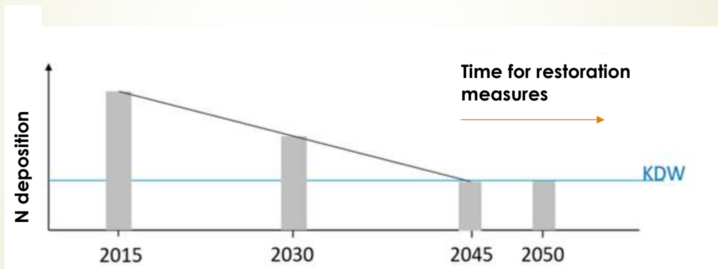
2030 Target

- For all nitrogen-sensitive habitats, critical load exceedances should be halved by 2030 relative to 2015



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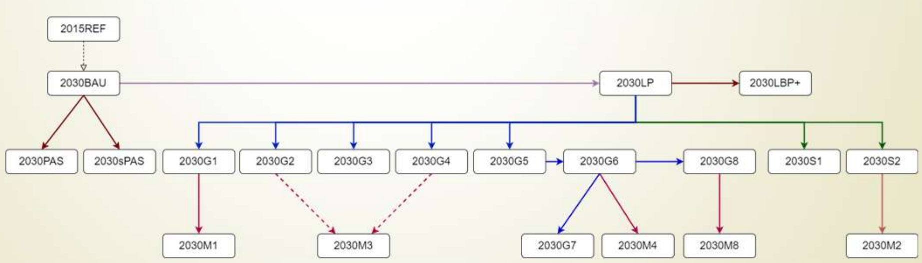
Quantifying emission reductions needed

- Complex, spatially-explicited attribution problem
- Business-as-usual inadequate
- Extra reduction of NH_3 necessary
- Different spatial strategies: local *vs* generic
- A total of about 20 emission reduction scenarios have been spatially-explicitly modelled



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Final package of reduction measures

- Timely and complete implementation of measures Air Policy Plan 2030
- Cessation of emissions from peak emitters
- Measures for livestock farms
  - Pigs and poultry: Emissions –60% by 2030
  - Cattle: Emissions –15% by 2030
  - Reduction of pig herd by 30% by 2030
- Manure processors: emission reduction -30%
- No use of fertilizers in green destinations in SACs
- Nutrient emission allowances
  - Skimming off unused rights
  - Transforming into a closed marketW
- Road traffic: additional reduction of NOx emissions by 2,2 kt by 2030

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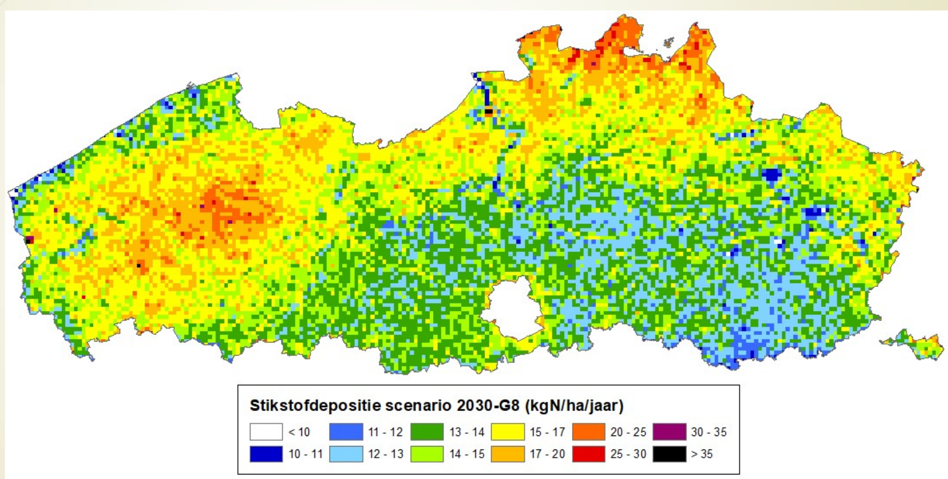
Deposition 2030 with PAN measures



PAS (2023)

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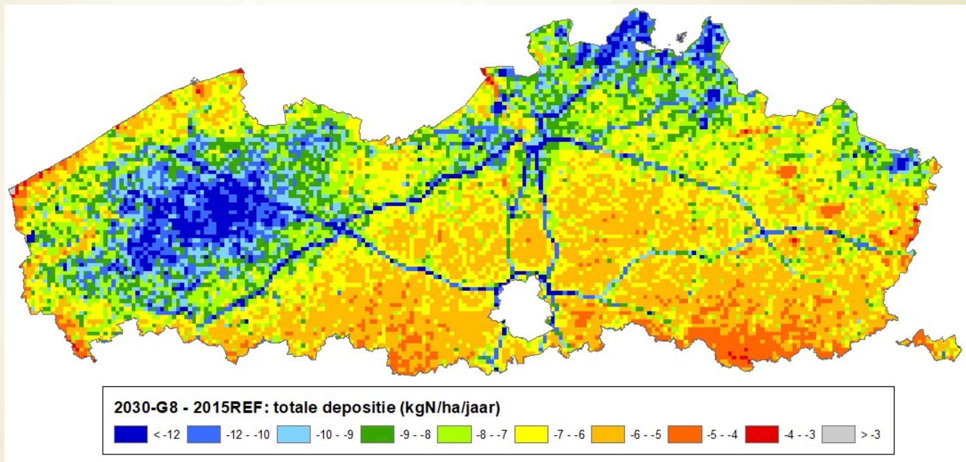
Deposition gains: PAN 2030 *vs* 2015



PAS (2023)

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5. Assessment frameworks for environmental permits

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Appropriate Assessment

- Art. 36ter, §3 Natuurdecreet
  - *“An **activity**, **plan** or **programme** subject to authorisation which, either **individually or in combination** with one or more existing or proposed activities, plans or programmes, is likely to cause **significant adverse effects** on the integrity of a special area of conservation, and that activity, plan or programme which requires authorisation must not be directly connected with or necessary to the management of a site in the special area of conservation in question must be subject to the **appropriate assessment** as regards the significant effects for the special area of conservation.”*
- ‘Significant adverse effects’
  - Impediment to the realisation of the site-specific conservation objectives set in 2014 (= damage threshold)

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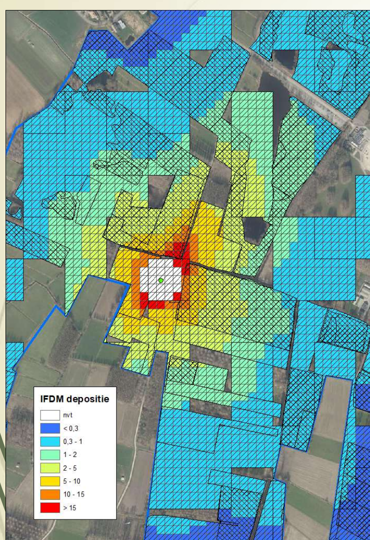
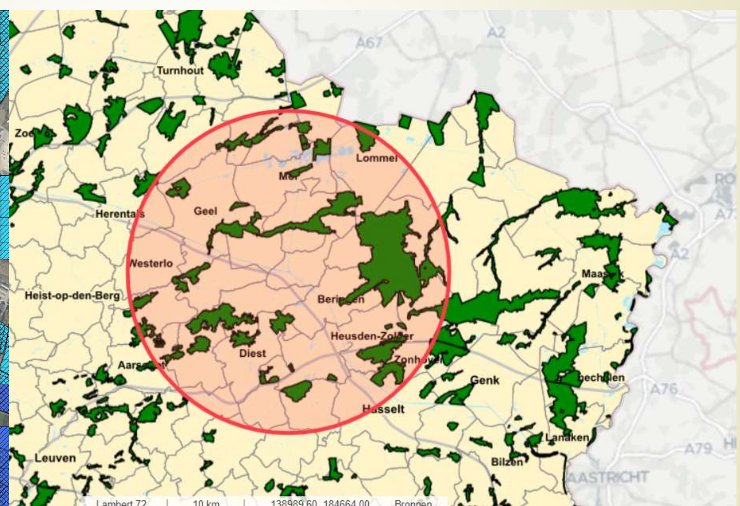
The impactscore: a new metric





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The impactscore: a new metric

= the highest ratio (%) of the project-specific deposition to the critical load of N-sensitive habitats in a 20-km zone around the N source

- Can vary from 0 to >100%
- Only habitats were the critical load is exceeded are considered
- Can be calculated using tools offered by Flemish authorities
- Example: project deposition of 0,6 kg N/ha/y on a habitat with critical load 15 kg N/ha/y → impactscore = 4%
- Typical values:
  - NOx emissions from combustion: typically <1%
  - NH_3 emissions from livestock farms: ca 8% of farms >1%
  - Peak emitters have an impactscore >50%

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Use of threshold values

- *De minimis* thresholds
  - Drempel waaronder betekenisvolle impact van project op SBZ-H kan uitgesloten worden → geen individuele passende beoordeling nodig op projectniveau
  - Opgevat als systemische risico-drempel ingebed in een programmatische aanpak: wetenschappelijk onderbouwd & gunstig passend beoordeeld
  - Gebruik drempels slechts mogelijk mits gegarandeerde daling stikstofdepositie
- Principles underpinning the thresholds
  - Totale depositie die vrijgesteld wordt voor vergunningsplichtige ammoniakbronnen en NOx-bronnen van zelfde omvang → gelijke behandeling
  - Cumulatieve depositiebijdrage van alle projecten onder drempel leidt nergens binnen SBZ-H tot impact >5% van de kritische depositiewaarde → risicogrens
- Threshold values
  - Beoordelingskader ammoniak: **impactscore ≤ 0,025%**
  - Beoordelingskader NOx: **impactscore ≤ 1%**

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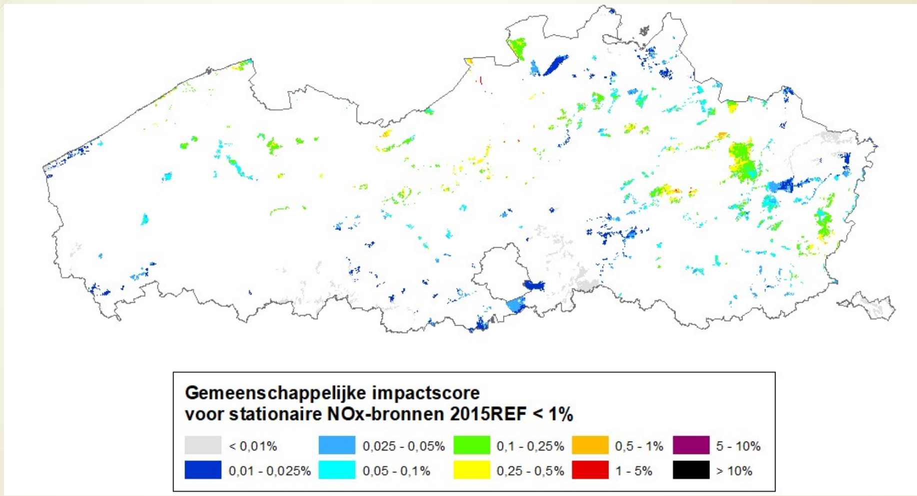
1% NOx threshold



PAS (2023)

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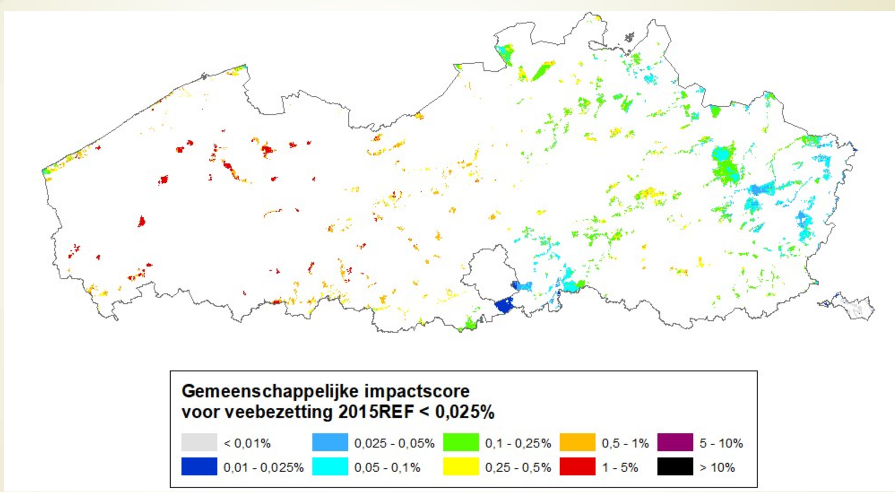
0,025% NH_3 threshold



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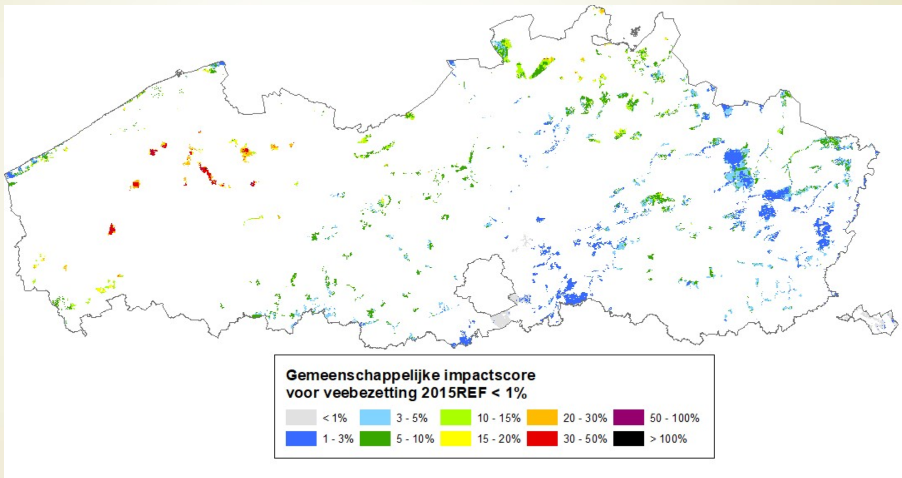
1% NH_3 threshold



PAS (2023)

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6. Concluding remarks & looking forward

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Lessons learned & what's next

- Evidence-based policy making *vs* societal concerns *vs* politics
- Science *vs* legislation *vs* court rulings
- Modelling and data key in evidencing measures needed
- After 2030: shift to so-called 'emission-based' approach (?)
- Nitrogen Decree being appealed at Constitutional Court

  → *Importance of sound scientific underpinning of policies*

- Netherlands: still no final take on their (urgently needed) nitrogen policy

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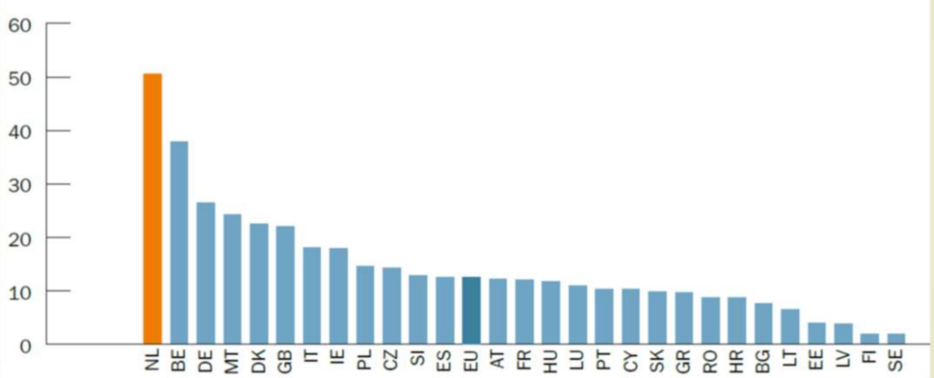
Nitrogen emission densities in EU

Average N surplus (kg N per hectare) in EU countries



Livestock density (animals/ha): EU-average = 0,8; highest in the Netherlands (3,8), lowest in Bulgaria (0,2)
N surplus (N input – crop offtake) in Netherlands ca 3 times the EU average

CEIP (2019)

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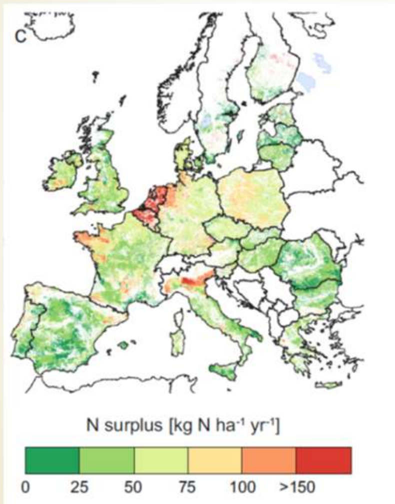
Flanders is not alone in Europe

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Spatially explicit boundaries for agricultural nitrogen inputs in the European Union to meet air and water quality targets

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N surplus = N input – crop offtake

N input = fertiliser + BNF + deposition + excretion

de Vries et al. (2021)

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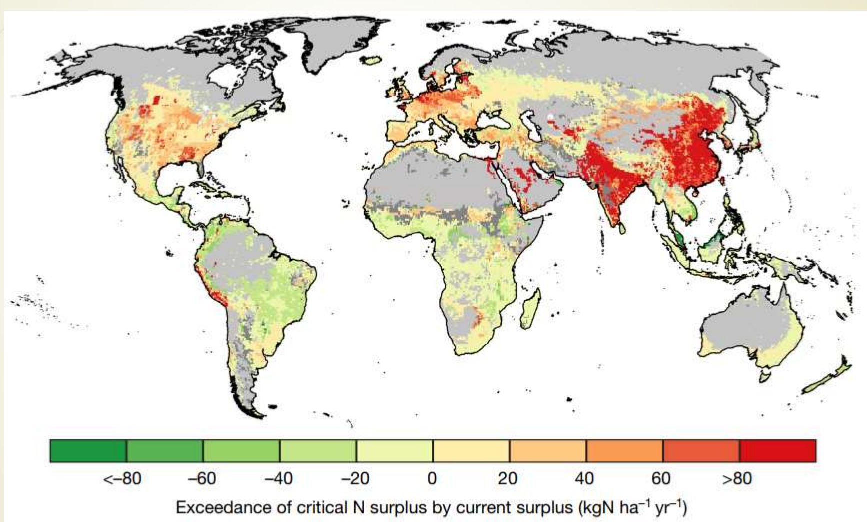
and also not in the world…



Schulte-Uebbing et al., Nature 2022

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