European Commission

Global present and future nitrogen abatement potential and its impact on air quality and health

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Joint Research Centre

Outline

1. Present day analysis of nitrogen share in PM2.5
2. Specific SSP scenarios for NH_3 abatement (work in progress for International Nitrogen Assessment) – implications for air quality
3. Other Nr-relevant ongoing work

Paper: Abating ammonia is more cost-effective than nitrogen oxides for mitigating PM2.5 air pollution (Gu et al., Science 2021)

https://www.science.org/doi/10.1126/science.abf8623

Scope:

- How much do present-day Nr emissions (NO_x, NH_3) contribute to PM2.5 in a global perspective?
- What is the health impact attributable to Nr emissions? (Years of Life Lost, YLL)
- What is the welfare (marginal) cost per kg emitted NOx, NH3? What is abatement (marginal) cost?
- →Benefit/Cost evaluation for NO_x and NH_3 abatement

Methods

Emissions:

- CEDS 1990, 2013
  - with/without NO_x & NH_3 emissions

Chemistry-Transport Models:

- EMEP-WRF
- GEOS-Chem
- TM5-FASST

→ Share of Nr emissions in PM2.5

Health impact of Nr (YLL):

- Nr-share(PM2.5) x YLL(PM2.5)$_{\mathrm{GBD2013}}$

Welfare loss (World Bank – IHME, 2016)**:**

- $\mathrm{cost}_{c,n} = \mathrm{VOLY}_{\mathrm{c,n}} \times \mathrm{YLL}_{\mathrm{c,n}}$
- $\mathrm{VOLY}_{\mathrm{c,n}} = \mathrm{VOL}Y_{\mathrm{EU}} \times \left(\frac{\mathrm{Y}_{\mathrm{c,n}}}{\mathrm{Y}_{\mathrm{EU}}}\right)^{\mathrm{e}}$ $\mathrm{Y} = \mathrm{GDP/capita}$

Abatement costs:

- GAINS database

Nr share in PM2.5 formation

$$\mathrm{Nr\_SHARE} = \left(\frac{\mathrm{PM2.5}_{\mathrm{all\ emissions}} - \mathrm{PM2.5}_{\mathrm{emissions\ minus\ NOx,NH3}}}{\mathrm{PM2.5}_{\mathrm{all\ emissions}}}\right)$$

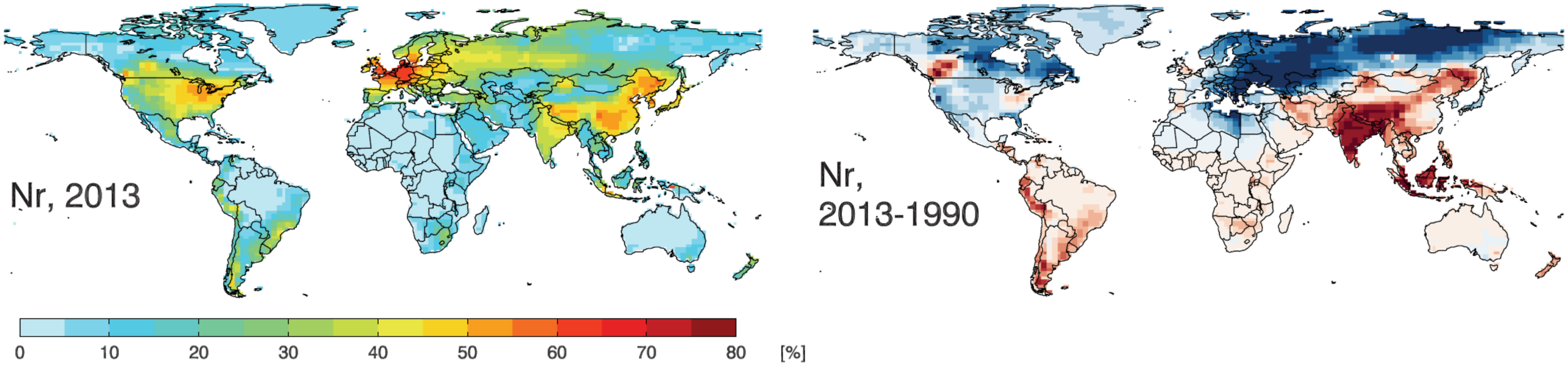
With applied emission reduction fraction (100%, 50%, 20%) → evaluate non-linearities

Note:

Nr_SHARE > fraction of (ammonium + nitrate) in PM2.5

due to feedbacks of NO_2 on OH and oxidation rate of SO_2, NO_2

Nr SHARE in PM2.5 formation (100% reduction)



Nr shares in PM2.5 formation (%)		
	1990	**2013**
Africa	5.9	7.3
Asia	31.0	42.3
Europe	57.9	47.4
Latin America	20.9	23.5
North America	46.3	44.2
Oceania	7.8	11.2
World	30.2	38.6

Premature death & welfare cost (2013)

Health impact of Nr (YLL):

YLL_{Nr} = Nr_share(PM2.5) x YLL(PM2.5)$_{GBD2013}$

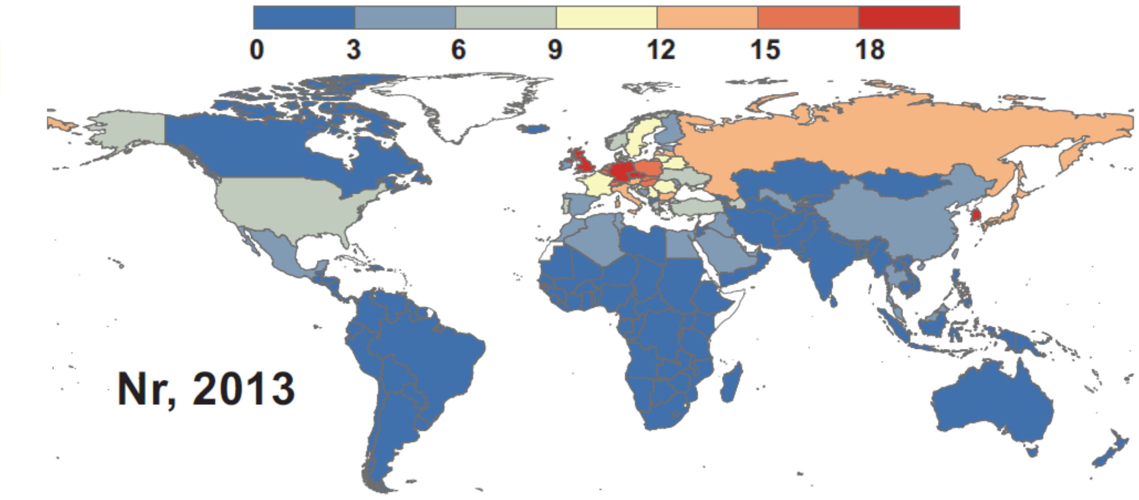
Welfare loss (WB – IHME, 2016):

$$\mathrm{cost}_{c,n} = \mathrm{VOLY}_{c,n} \times \mathrm{YLL}_{c,n}$$

$$\mathrm{VSL}_{c,n} = \mathrm{VOLY}_{EU} \times \left(\frac{\mathrm{Y}_{c,n}}{\mathrm{Y}_{EU}}\right)^{e}$$

VOLY_{EU} 50 000 USD
Y_{EU} 32 400 USD

Mortality cost per kg Nr emission (USD/kgN)



Total mortality cost of Nr in PM2.5 pollution (billion USD)		Marginal mortality cost (USD/kg N)
	2013	**2013**
Africa	9	1.1
Asia	212	4.1
Europe	125	13.1
Lat. America	19	2.1
N. America	54	6.8
Oceania	0.6	0.5
World	420	4.8

Mitigation costs and benefits of 50% Nr emission reduction in 2013

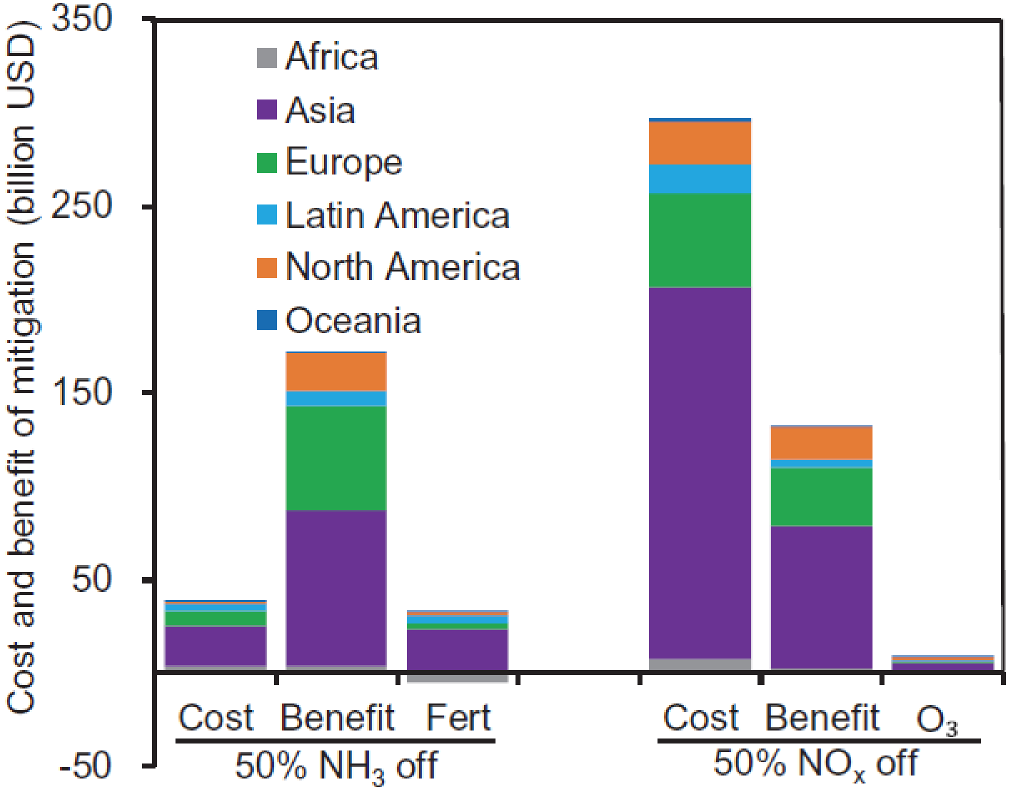
- Based on 50% emission reduction model runs and associated Nr share

- Abatement cost of Nr emissions = [investment costs + operation costs] for implementation of measures, obtained from GAINS database

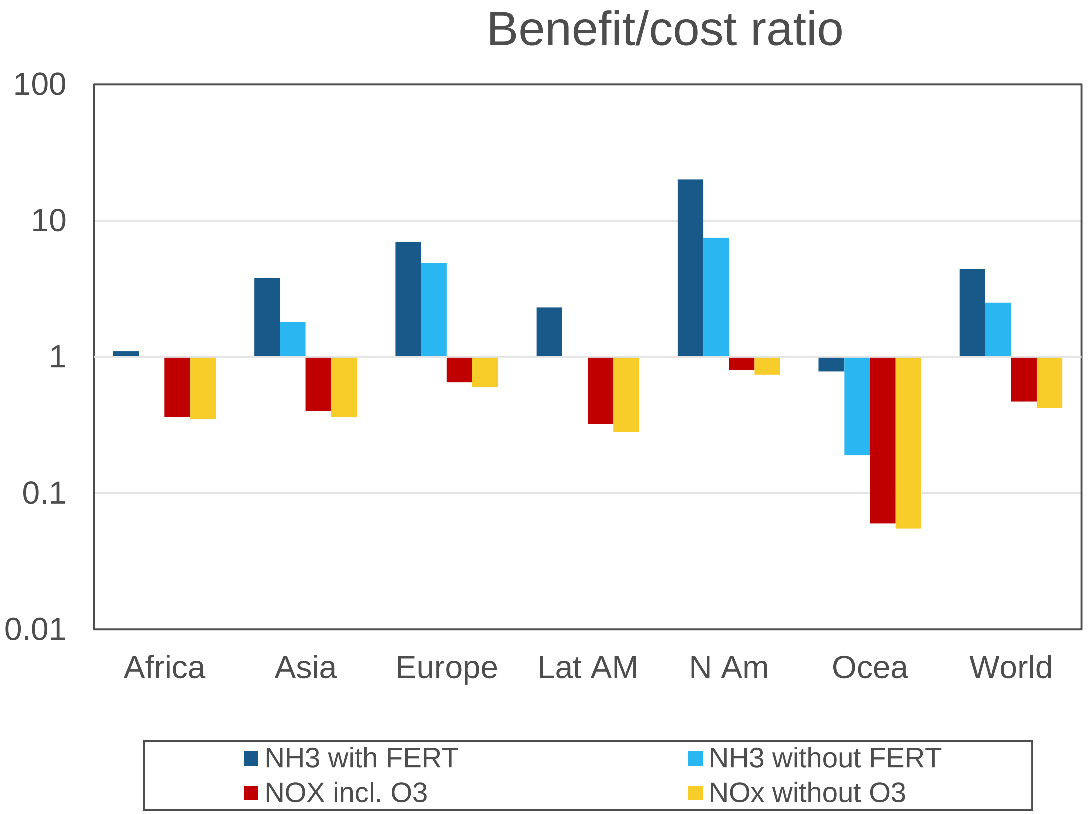
- NO_x reduction: most cost-effective measures already in place in high-income countries.
  - Benefits: PM2.5, O_3 health impacts (crop impacts not considered)

- NH_3 reduction: through improved agricultural management practices (IMPs) →reduce fertilizer use, manure recycling & management large reduction margin.
  - Benefits: PM2.5 health impact
    increased N use efficiency → more optimal fertilizer use (+/- 20% reduction)

Mitigation costs and benefits of 50% emission reduction in 2013



Mitigation costs and benefits of 50% emission reduction in 2013



2013	Marginal mortality cost (USD/kg N)		Marginal abatement cost (USD/kg N)	
	NH3	NOx	NH3	NOx
Africa	1.2	2.4	1.2	9.9
Asia	5.8	6.8	1.6	21.6
Europe	22.9	14.5	4.0	12.0
Latin America	2.6	2.8	1.3	12.7
North-America	11.9	8.6	1.1	16.9
Oceania	0.6	0.5	1.0	7.6
World	6.9	7.3	1.5	16.0

Conclusions part 1

- Abating ammonia is in most world regions more cost-effective than nitrogen oxides for mitigating PM2.5 air pollution
  - The global average cost of reducing 50% NH_3 emission = 1.5 USD/kg NH_3-N
    associated welfare benefit = 6.9 (3.8 – 10.9) USD/kg NH_3-N
  - The global average cost of reducing 50% NO_x emission = 16.0 USD/kg NO_x-N
    associated welfare benefit = 7.3 (4.0 – 11.8) USD/kg NO_x-N
- North America, Europe and Asia have the highest benefit/cost ratio for NH_3 mitigation
- Note: Welfare valuation based on equal toxicity for all PM2.5 components.
  Not all benefits taken into account (market, ecosystems,…)

Part 2: Future scenarios for NH_3: impacts on air quality

Scope:

- New Nr narratives embedded in SSPs → N-relevant drivers (food, feed, consumption, waste,…) [*Kanter et al., 2020: A framework for nitrogen futures in the shared socio-economic pathways, Global Env. Change*]
- New Nr interventions across the food system (note: only NH_3, not NO_x)
  - Crop & livestock NUE improvement
  - Manure recycling increase
  - Dietary change
  - Food loss & waste reduction

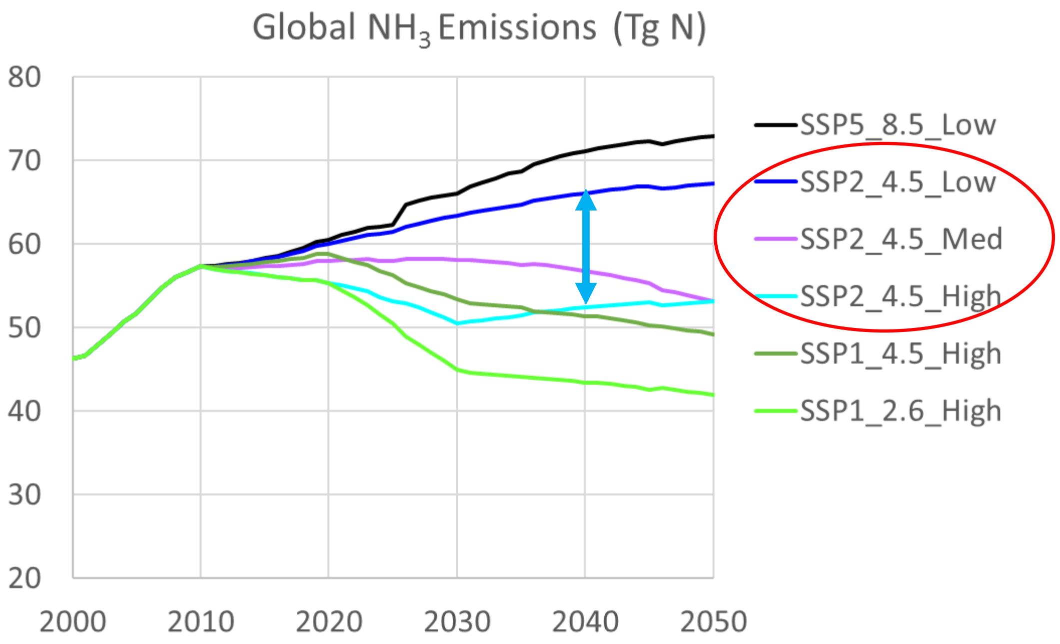
IMAGE → pollutant emissions

- TM5-FASST analysis: impacts of NH_3 intervention policies on AQ and health *(and deposition and short-lived climate forcers)*

Part 2: IMAGE NH_3 trajectories within SSP-RCP narratives (INA)

- Historical < 2010: EDGAR V4.3.2
- > 2010: EDGAR + IMAGE trends

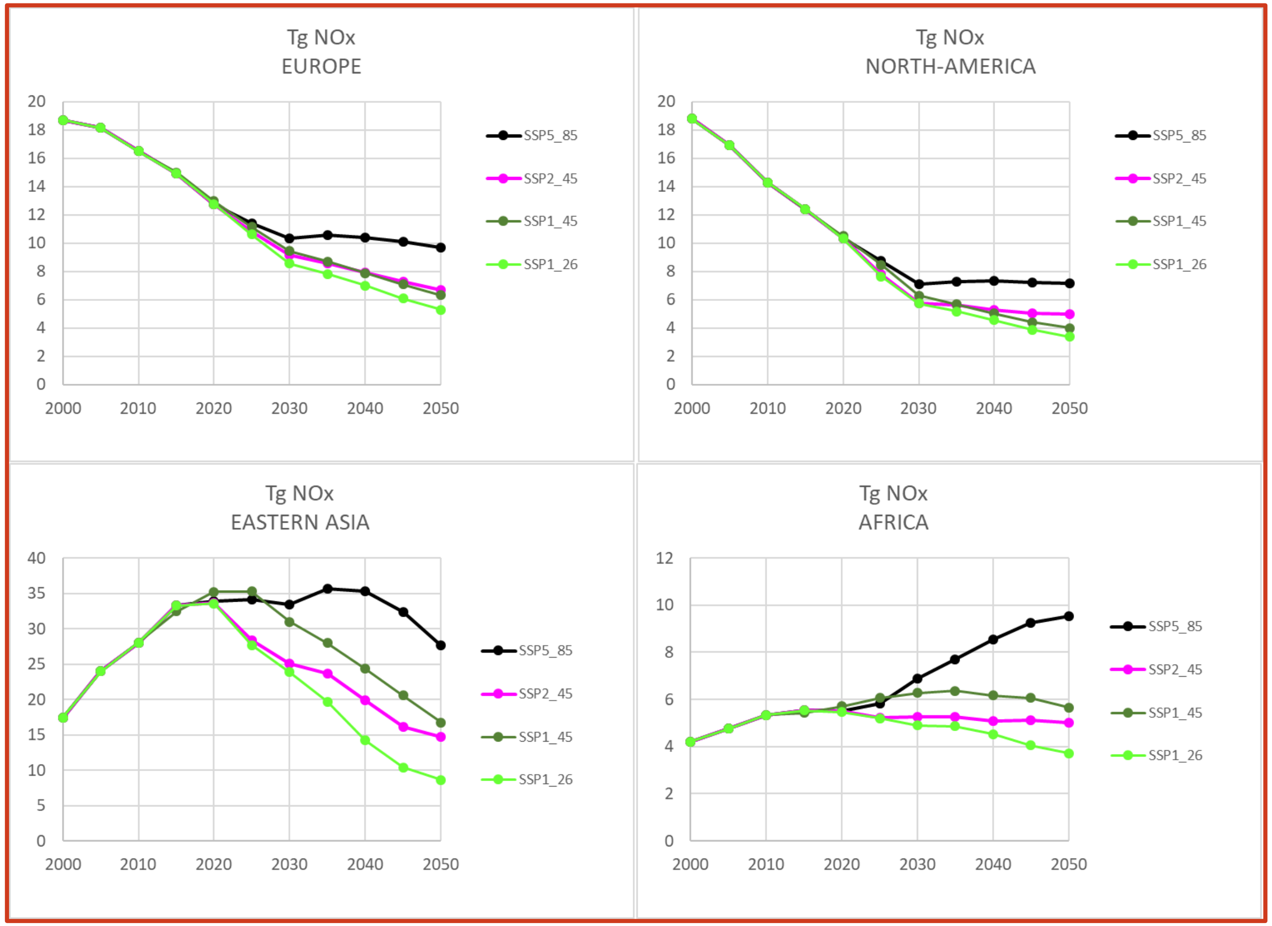
SSP	RCP	NH3 policies
SSP1 (sustainability)	2.6	High ambition
	4.5	High ambition
SSP2 (middle of the road)	4.5	High ambition
	4.5	Moderate ambition
	4.5	Low ambition
SSP5 (fossil-fueled)	8.5	Low ambition



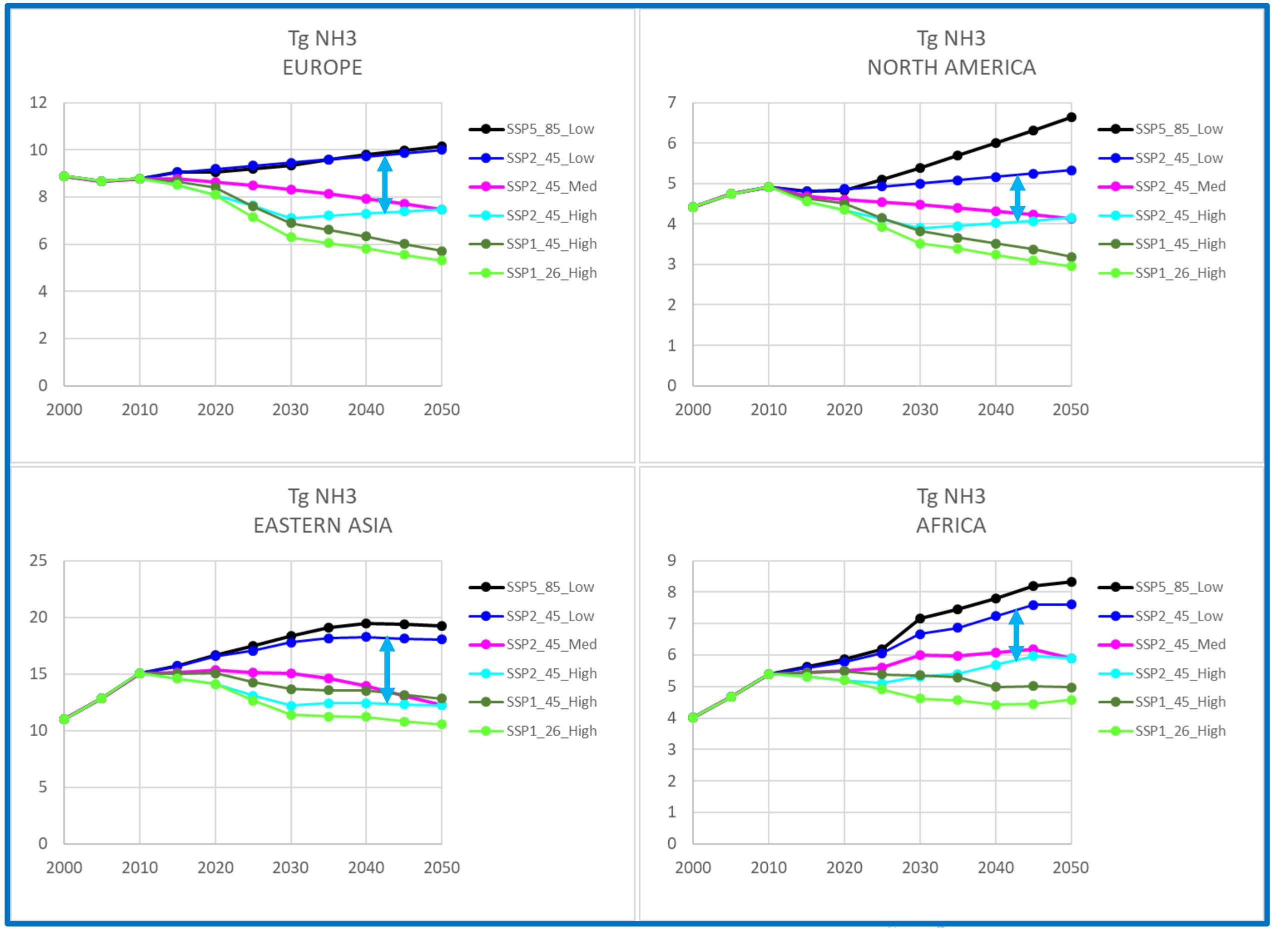
- **High ambition**: the frontier of technical feasibility in a timeframe largely consistent with the Sustainable Development Goals, which run until 2030 – thereafter constant EF.
- **Moderate ambition**: reaches the same frontier over a longer time horizon (2050 or 2070)
- **Low ambition:** either no improvement or a continuation of current trends, which can be negative (e.g. decreasing NUE) = +/- original SSP emissions

Regional Nr emission trends

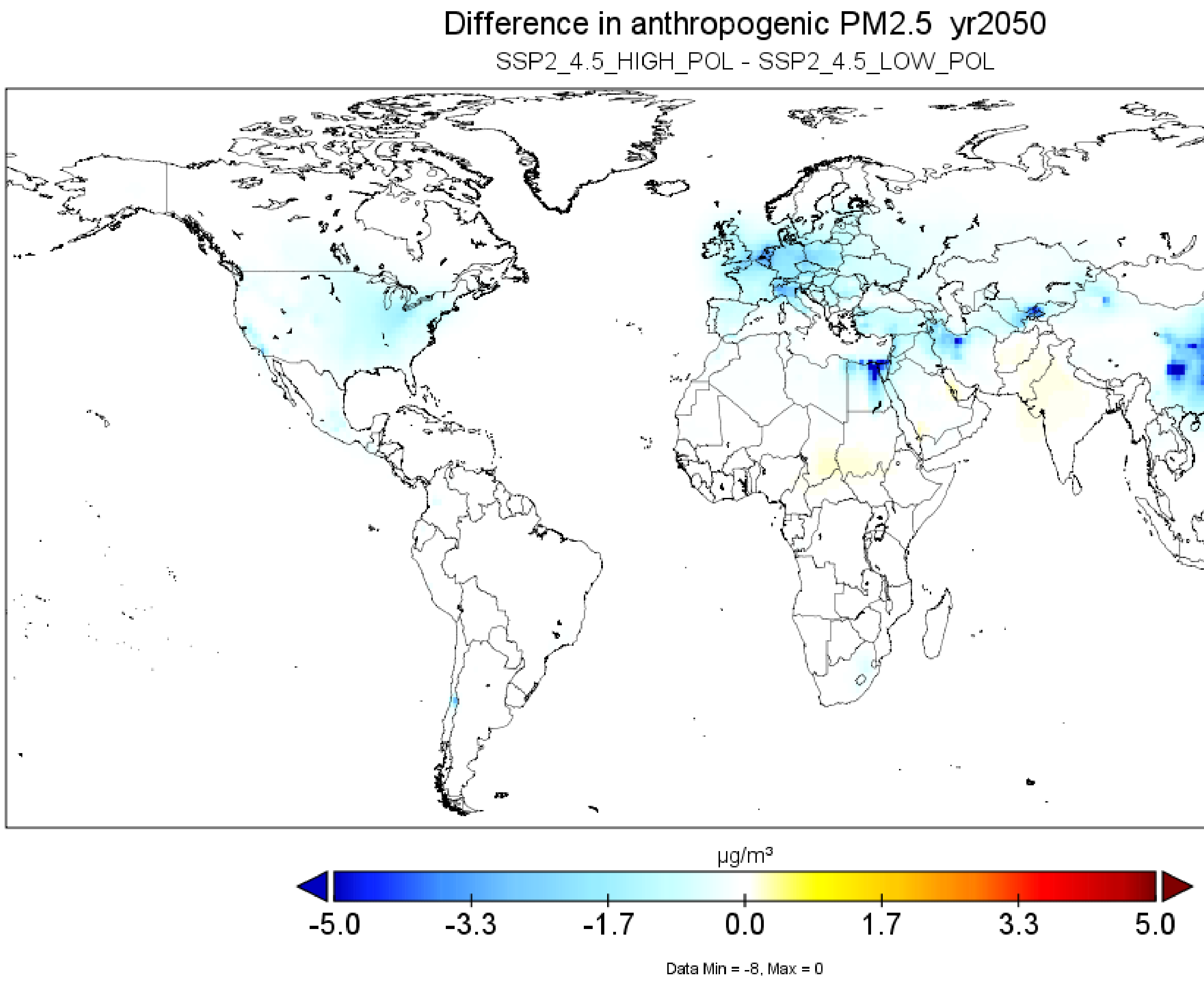
NO_x (not affected by new policies)

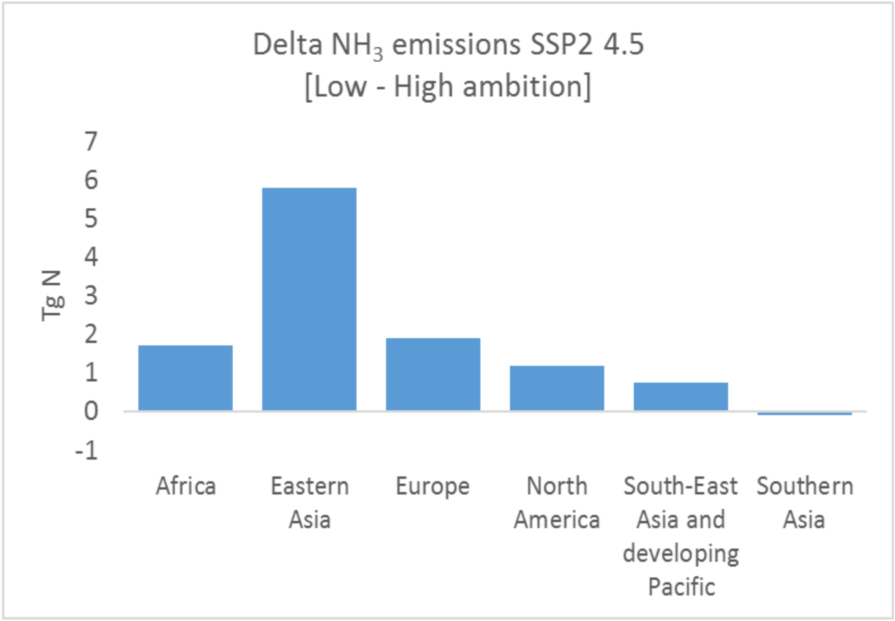


NH_3



DELTA Impact (High – Low) NH_3 policy ambition under SSP2 4.5

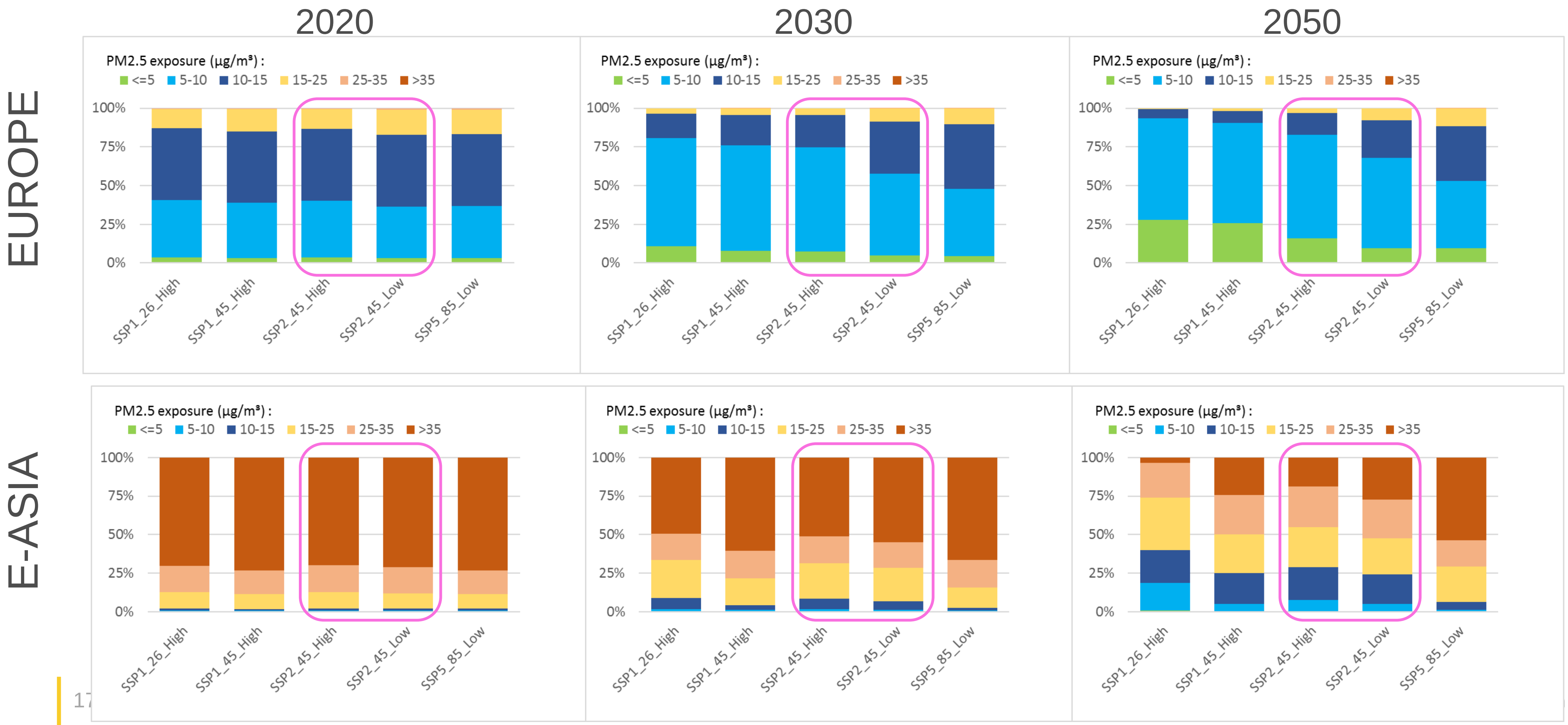




Abatement potential under SSP2-4.5 (High – Low ambition)

	Change in PM2.5 (SSP2_LOW – SSP2-HIGH)			
	2030		**2050**	
	µg/m^3	% reduction	µg/m	% reduction
Europe	1.2	17%	1.3	20%
Eurasia	0.6	14%	0.7	18%
Asia-Pacific Developed	0.8	15%	0.7	18%
Eastern Asia	2.9	10%	3.0	17%
North America	0.7	14%	0.7	15%
Middle East	0.7	8%	0.9	15%
Africa	0.3	4%	0.3	7%
Latin America and Caribbean	0.1	2%	0.2	3%
South-East Asia and developing Pacific	0.1	1%	0.1	1%
Southern Asia	-0.1	0%	-0.1	0%

Fraction of population exposed to WHO PM2.5 targets



Conclusions part 2

- Additional NH_3-policy dimension added to SSP scenario family (IAMs: IMAGE, GLOBIOM, MagPIE)
- TM5-FASST → associated pollutant levels and impacts for INA
  - PM2.5, O_3 concentrations and exposure metrics, N-share
  - N deposition
  - short-lived climate forcer metrics (CO2e)
- Ambitious NH_3 mitigation policies in the agricultural sector can significantly improve exposure to PM2.5 in Eastern Asia, Europe, N. America and contribute to WHO PM2.5 exposure guideline level, but other measures are needed to reach targets.

Part 3: Other ongoing N-related work:

- EDGAR-FOOD database: https://edgar.jrc.ec.europa.eu/edgar_food
- Application paper: **Global environmental impacts from food system emissions**

Crippa et al. (submitted to Nature Food)

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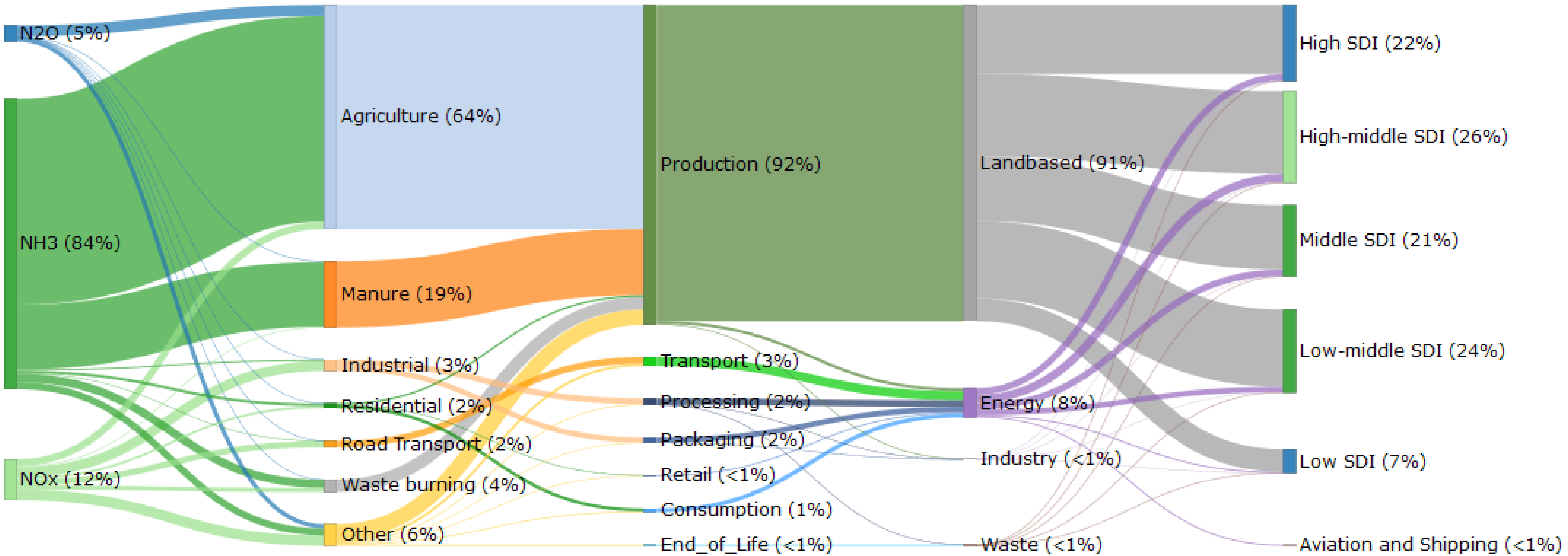
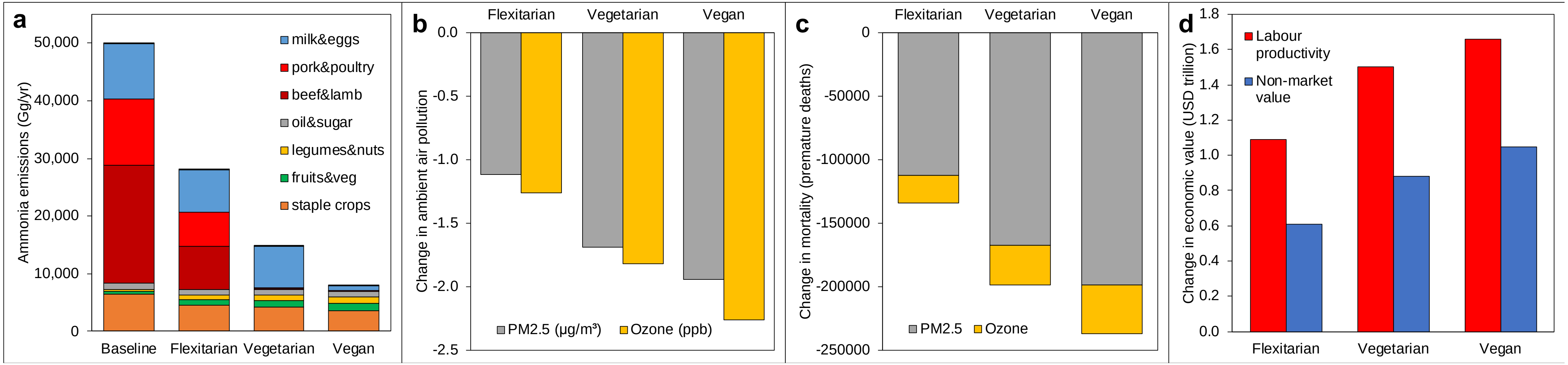


Part 3: Other ongoing N-related work:

The global and regional air quality impacts of dietary change

Marco Springmann, Rita Van Dingenen, Toon Vandyck, Catharina Latka, Peter Witzke, Adrian Leip

(Submitted to Nature Communications)



Global impacts of dietary changes on agricultural emissions (**a**), air pollution (**b**), premature mortality (**c**), and economic output (**d**) in the year 2030.

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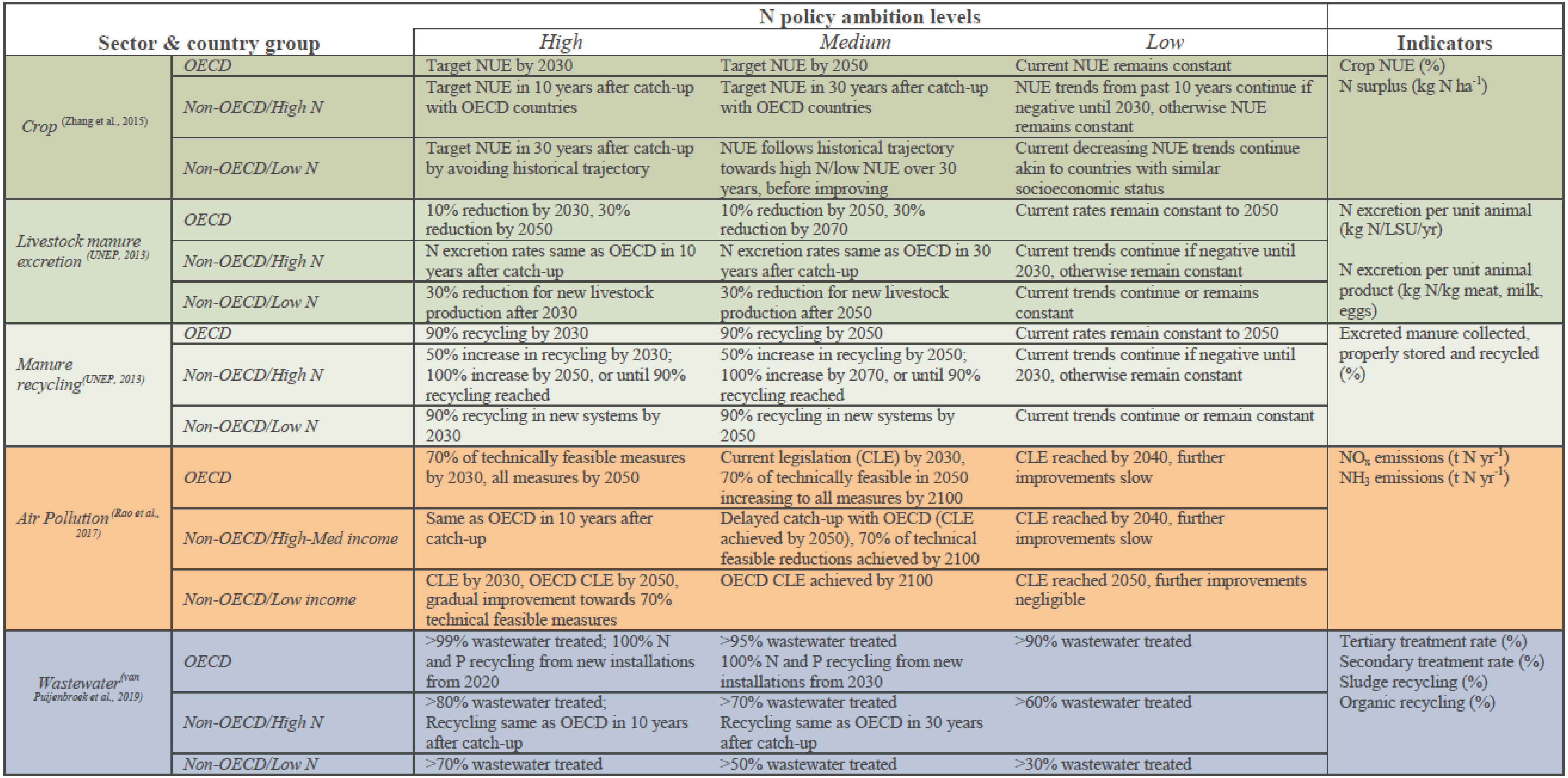
Thank you

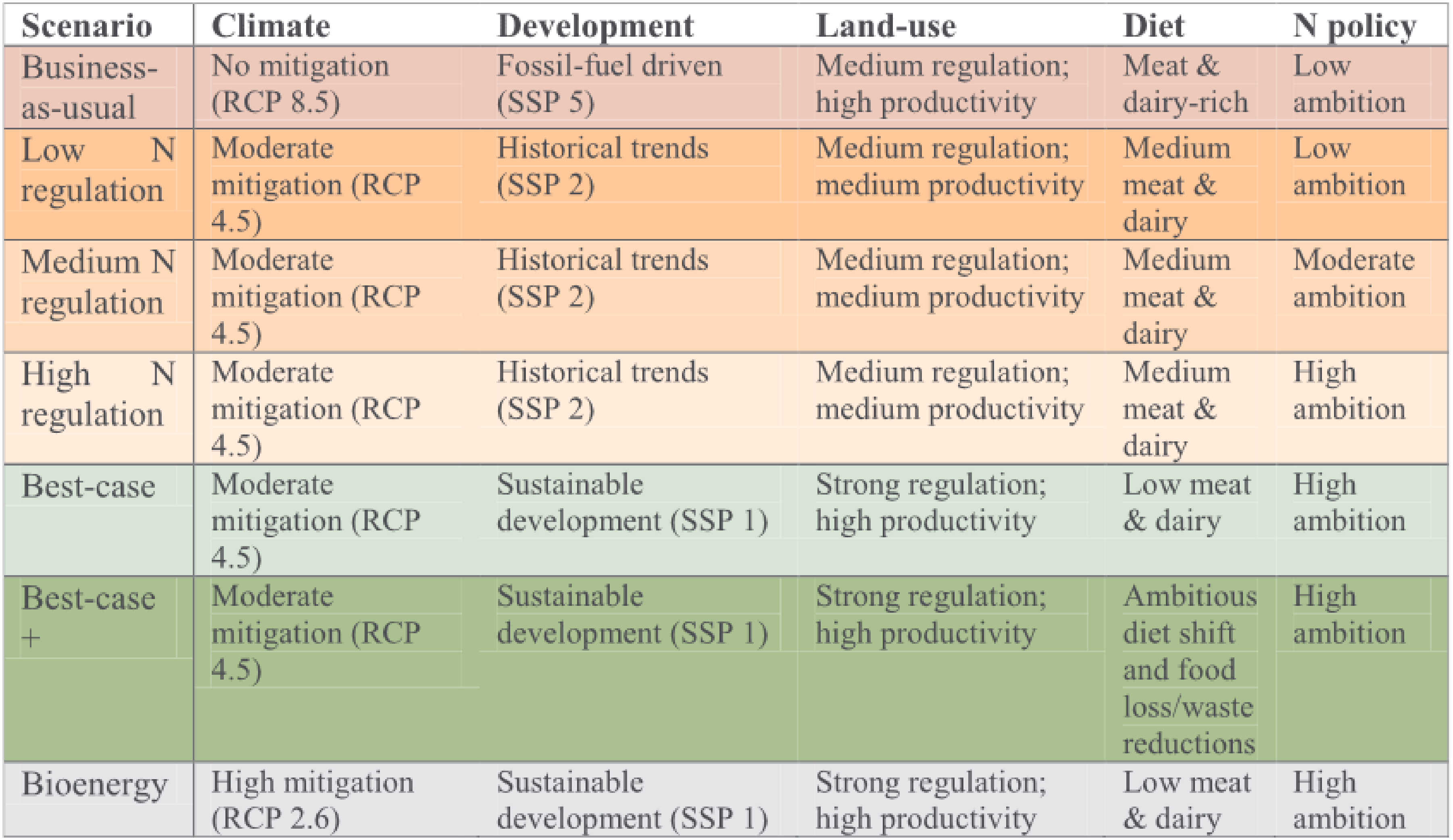
Additional material



Sector & country group		**N policy ambition levels**			**Indicators**
		High	*Medium*	*Low*	
Crop (Zhang et al., 2015)	*OECD*	Target NUE by 2030	Target NUE by 2050	Current NUE remains constant	Crop NUE (%) N surplus (kg N ha^{-1})
	Non-OECD/High N	Target NUE in 10 years after catch-up with OECD countries	Target NUE in 30 years after catch-up with OECD countries	NUE trends from past 10 years continue if negative until 2030, otherwise NUE remains constant	
	Non-OECD/Low N	Target NUE in 30 years after catch-up by avoiding historical trajectory	NUE follows historical trajectory towards high N/low NUE over 30 years, before improving	Current decreasing NUE trends continue akin to countries with similar socioeconomic status	
Livestock manure excretion (UNEP, 2013)	*OECD*	10% reduction by 2030, 30% reduction by 2050	10% reduction by 2050, 30% reduction by 2070	Current rates remain constant to 2050	N excretion per unit animal (kg N/LSU/yr) N excretion per unit animal product (kg N/kg meat, milk, eggs)
	Non-OECD/High N	N excretion rates same as OECD in 10 years after catch-up	N excretion rates same as OECD in 30 years after catch-up	Current trends continue if negative until 2030, otherwise remain constant	
	Non-OECD/Low N	30% reduction for new livestock production after 2030	30% reduction for new livestock production after 2050	Current trends continue or remains constant	
Manure recycling (UNEP, 2013)	*OECD*	90% recycling by 2030	90% recycling by 2050	Current rates remain constant to 2050	Excreted manure collected, properly stored and recycled (%)
	Non-OECD/High N	50% increase in recycling by 2030; 100% increase by 2050, or until 90% recycling reached	50% increase in recycling by 2050; 100% increase by 2070, or until 90% recycling reached	Current trends continue if negative until 2030, otherwise remain constant	
	Non-OECD/Low N	90% recycling in new systems by 2030	90% recycling in new systems by 2050	Current trends continue or remain constant	
Air Pollution (Rao et al., 2017)	*OECD*	70% of technically feasible measures by 2030, all measures by 2050	Current legislation (CLE) by 2030, 70% of technically feasible in 2050 increasing to all measures by 2100	CLE reached by 2040, further improvements slow	NO_x emissions (t N yr^{-1}) NH_3 emissions (t N yr^{-1})
	Non-OECD/High-Med income	Same as OECD in 10 years after catch-up	Delayed catch-up with OECD (CLE achieved by 2050), 70% of technical feasible reductions achieved by 2100	CLE reached by 2040, further improvements slow	
	Non-OECD/Low income	CLE by 2030, OECD CLE by 2050, gradual improvement towards 70% technical feasible measures	OECD CLE achieved by 2100	CLE reached 2050, further improvements negligible	
Wastewater (van Puijenbroek et al., 2019)	*OECD*	>99% wastewater treated; 100% N and P recycling from new installations from 2020	>95% wastewater treated 100% N and P recycling from new installations from 2030	>90% wastewater treated	Tertiary treatment rate (%) Secondary treatment rate (%) Sludge recycling (%) Organic recycling (%)
	Non-OECD/High N	>80% wastewater treated; Recycling same as OECD in 10 years after catch-up	>70% wastewater treated Recycling same as OECD in 30 years after catch-up	>60% wastewater treated	
	Non-OECD/Low N	>70% wastewater treated	>50% wastewater treated	>30% wastewater treated	

Kanter et al., 2020

Selected RCP – SSP – N scenarios



Scenario	Climate	Development	Land-use	Diet	N policy
Business-as-usual	No mitigation (RCP 8.5)	Fossil-fuel driven (SSP 5)	Medium regulation; high productivity	Meat & dairy-rich	Low ambition
Low N regulation	Moderate mitigation (RCP 4.5)	Historical trends (SSP 2)	Medium regulation; medium productivity	Medium meat & dairy	Low ambition
Medium N regulation	Moderate mitigation (RCP 4.5)	Historical trends (SSP 2)	Medium regulation; medium productivity	Medium meat & dairy	Moderate ambition
High N regulation	Moderate mitigation (RCP 4.5)	Historical trends (SSP 2)	Medium regulation; medium productivity	Medium meat & dairy	High ambition
Best-case	Moderate mitigation (RCP 4.5)	Sustainable development (SSP 1)	Strong regulation; high productivity	Low meat & dairy	High ambition
Best-case +	Moderate mitigation (RCP 4.5)	Sustainable development (SSP 1)	Strong regulation; high productivity	Ambitious diet shift and food loss/waste reductions	High ambition
Bioenergy	High mitigation (RCP 2.6)	Sustainable development (SSP 1)	Strong regulation; high productivity	Low meat & dairy	High ambition

Kanter et al., 2020