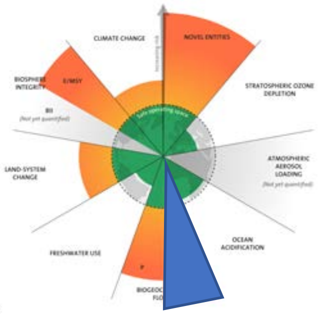
Urban Nitrogen Budgets – UNCNET

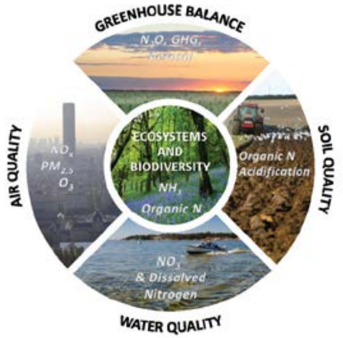
Project background

- Planetary boundary concept: N threshold exceeding



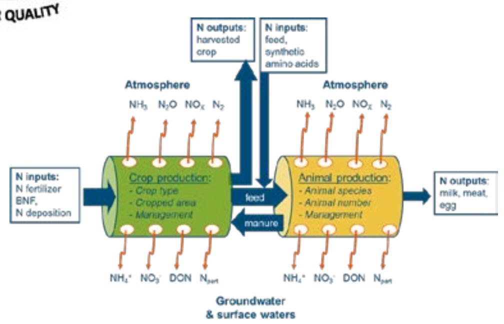
Persson et al., 2022

- N is responsible for multiple environmental effects



Sutton et al., 2012

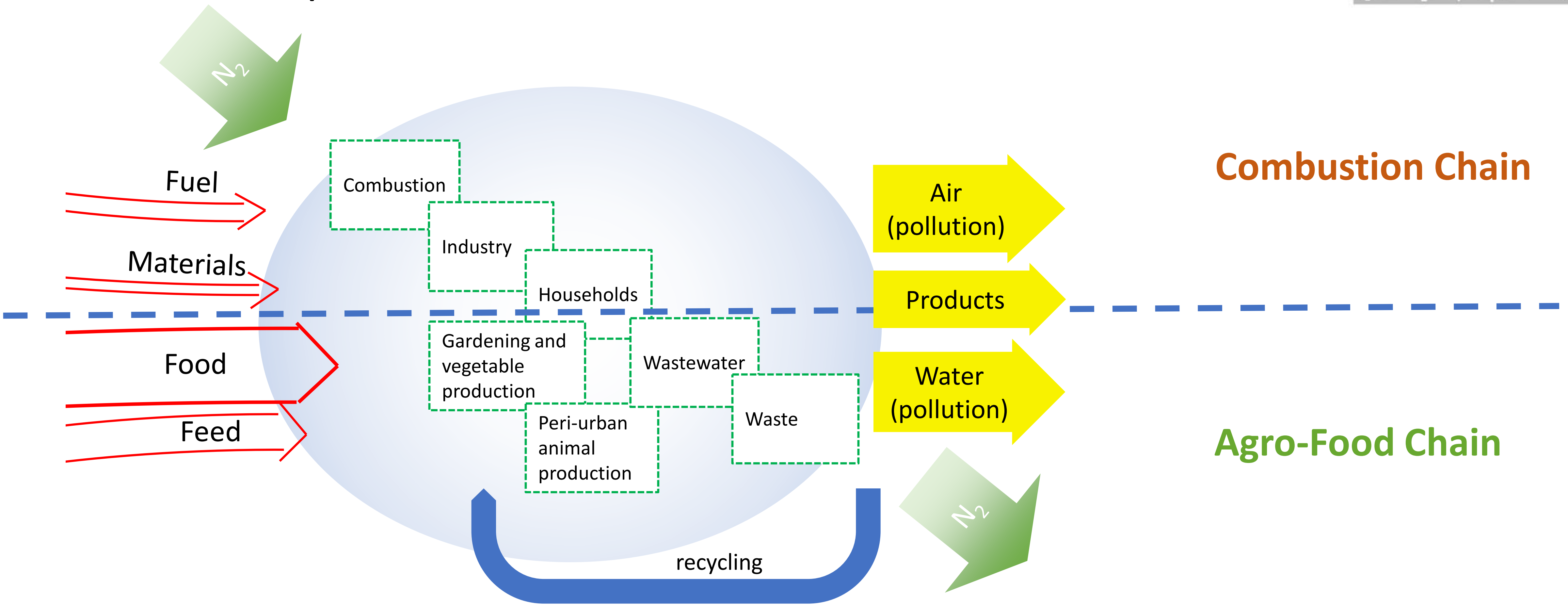
- N represents interaction between measures, processes, effects



Oenema et al., 2009

- Relevance of N in an urban environment?

Urban N pools and fluxes



Winiwarter et al., 2020

Project team and expertise

IIASA

Coordination
Concept and data integration
Industry and energy

Agriculture
Soils

Coordination China
Atmosphere
Hydrosphere and soils

Waste
Wastewater

UNIWERSYTET ZIELONOGÓRSKI

brainflows

stakeholders
dissemination

E.C.O. Institut für Ökologie

Test cities

IIASA

Klagenfurt

UNIWERSYTET ZIELONOGÓRSKI

brainbows

E.C.O. Institut für Ökologie

Collaboration and context

- Funding

URBAN EUROPE

国家自然科学基金委员会
National Natural Science Foundation of China

FFG
Promoting Innovation.

NATIONAL SCIENCE CENTRE
POLAND

- Related project activities

  Expert Panel on Nitrogen Budgets

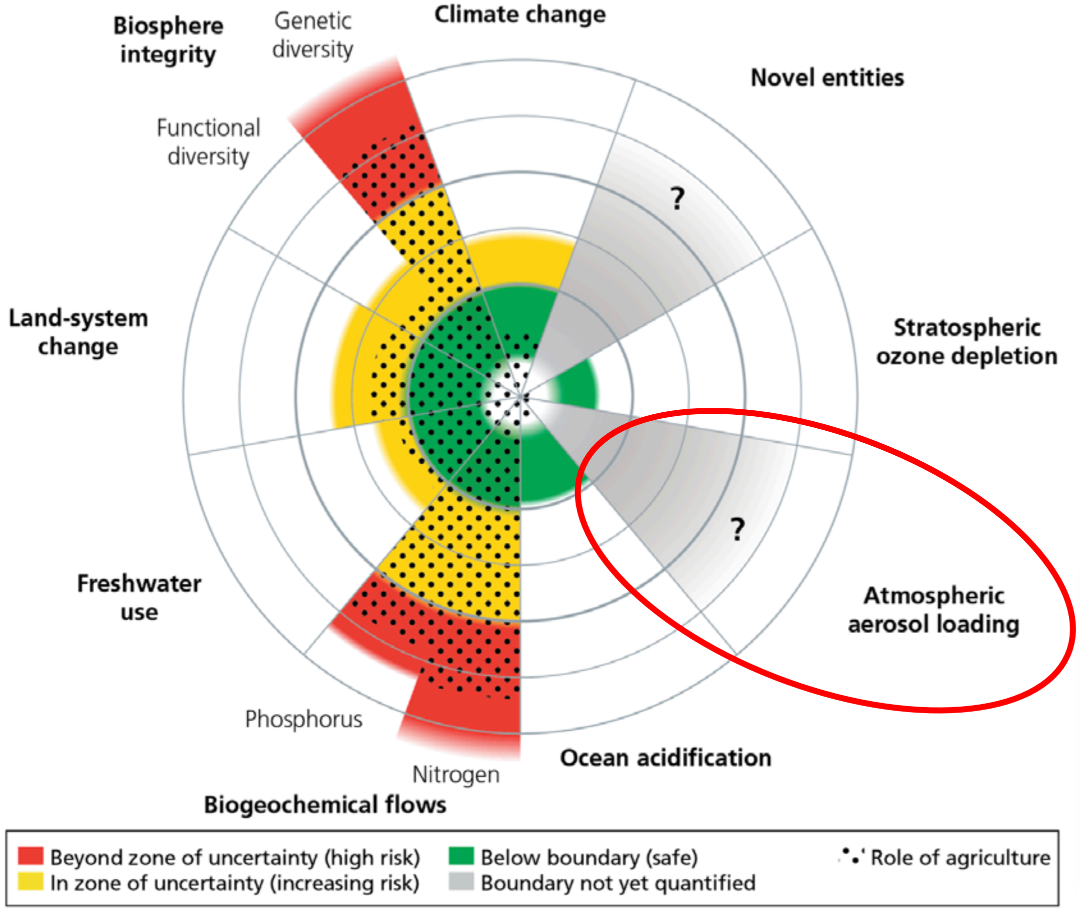
  LRTAP
  Long-range Transboundary Air Pollution

  INMS

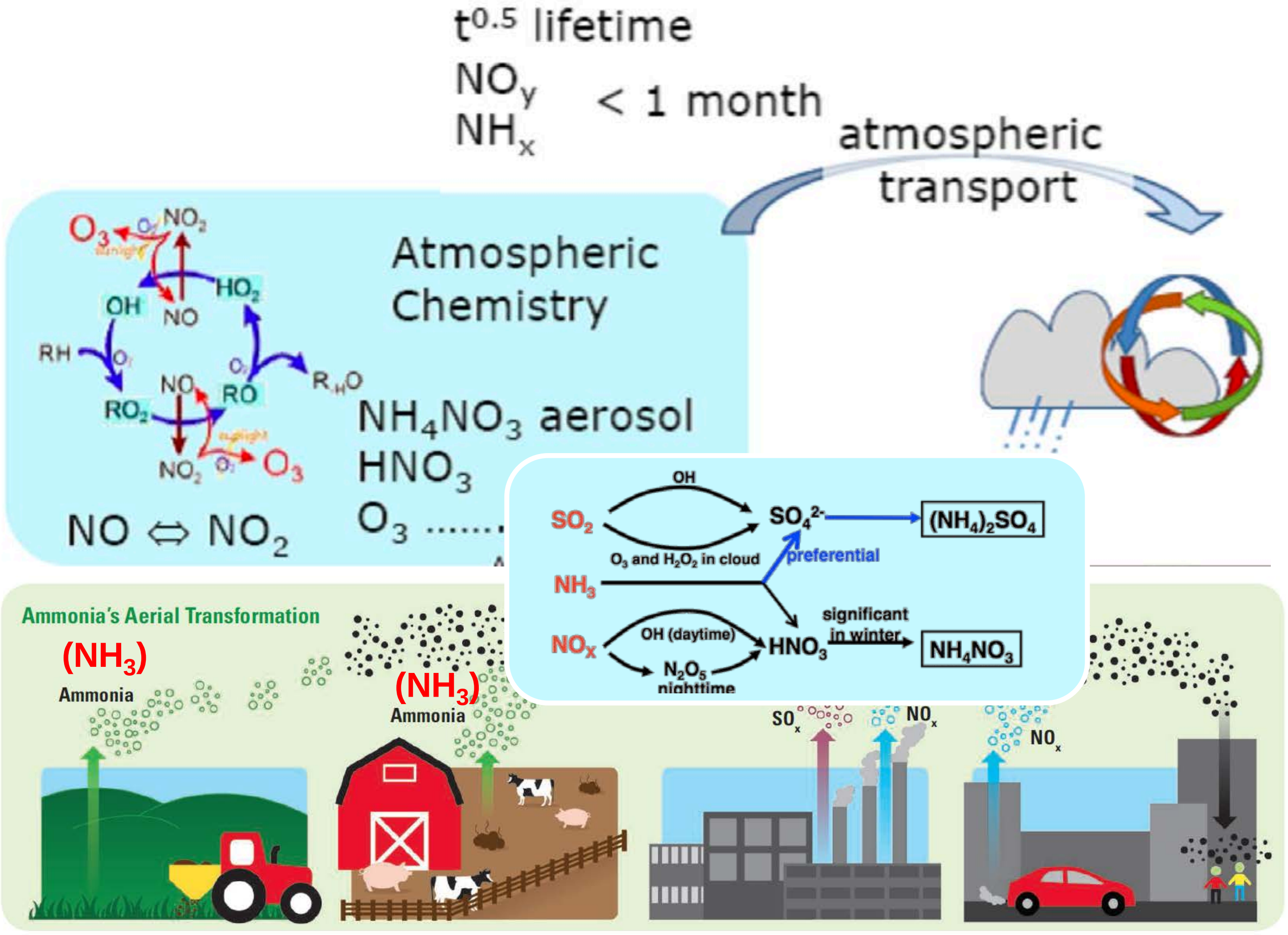
- Support and acknowledgments: MA22 (Vienna), Abt. Anlagentechnik (NÖ)
  BOKU Institute of Meteorology and Climatology
- See all details at www.uncnet.org

Atmospheric emissions and impacts

Agriculture largely drives the Earth system exceeding safe planetary boundaries



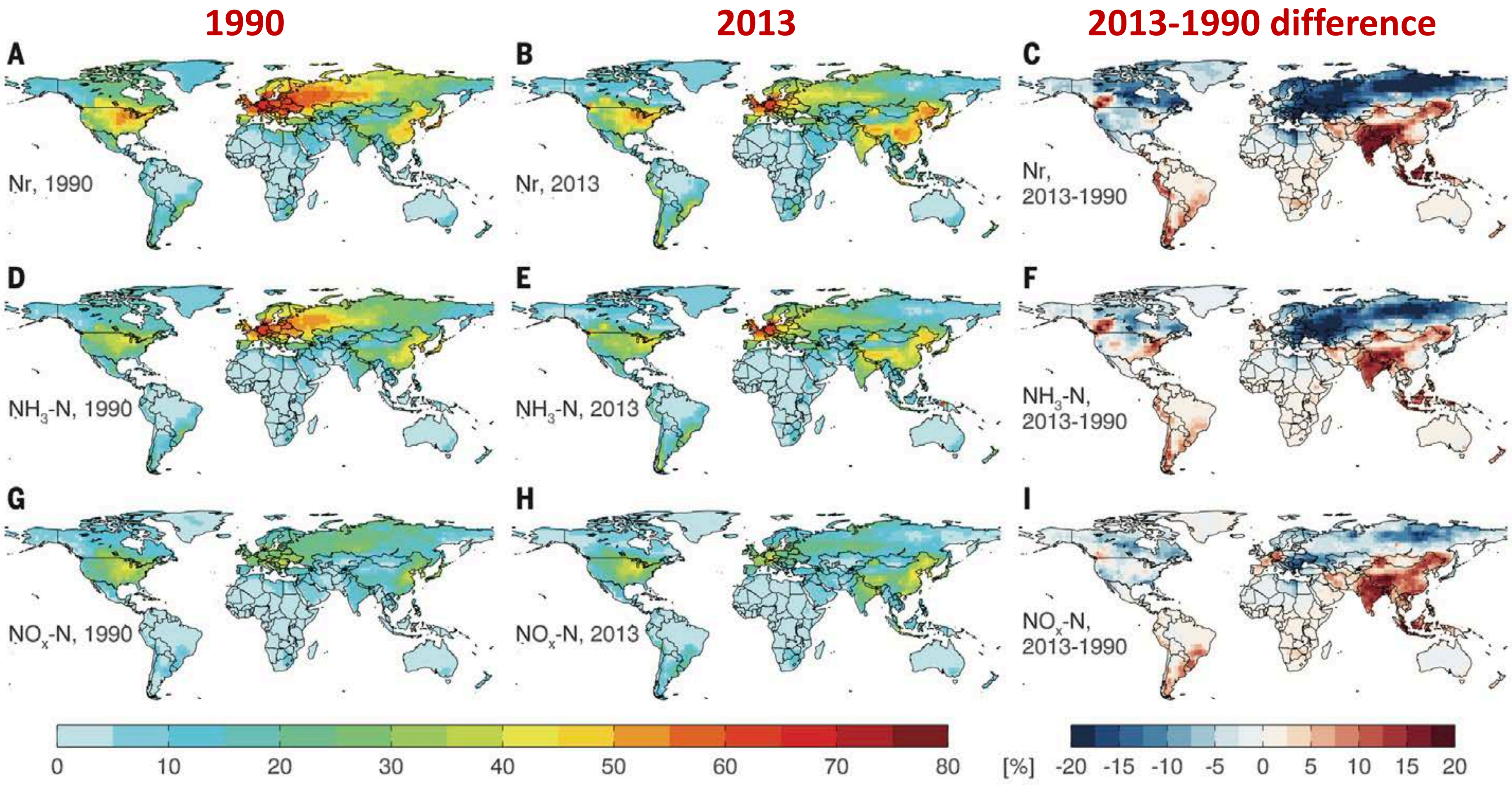
[Steffen et al., Science 2015; Campbell et al. E&S 2017]



[Erik Stokstad, 2014; Fowler et al. 2015]

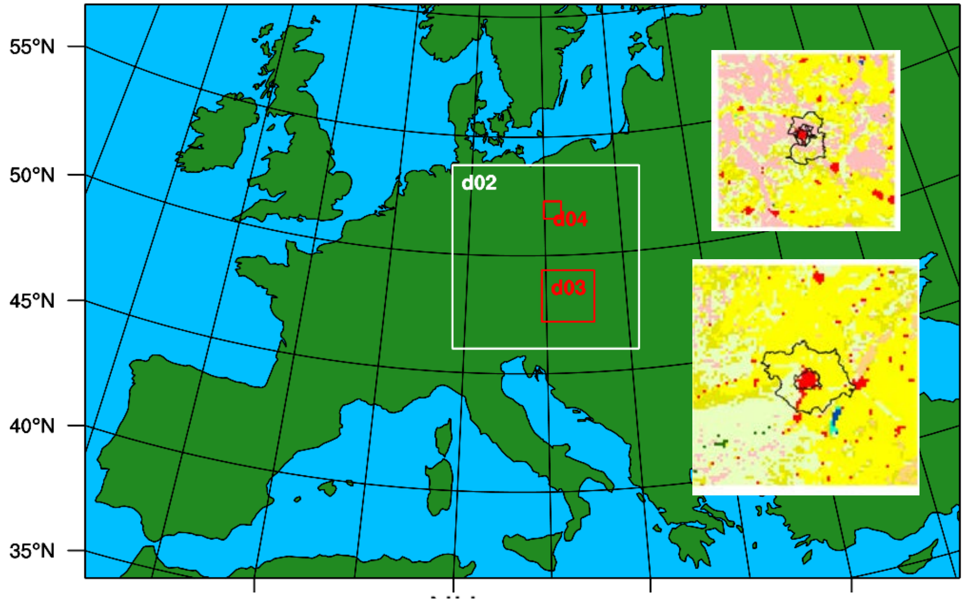
N-shares of $PM_{2.5}$ pollution and their 1990-2013 changes

- Global Nr-share of $PM_{2.5}$ pollution increased from 30% in 1990 to 39% in 2013
- NH_3-share increased from 25% in 1990 to 32% in 2013
- Large increases in Asia, South America; decreases in Europe and North America
- YYL caused by Nr emissions increased from **19.5 to 23.3 million years**.

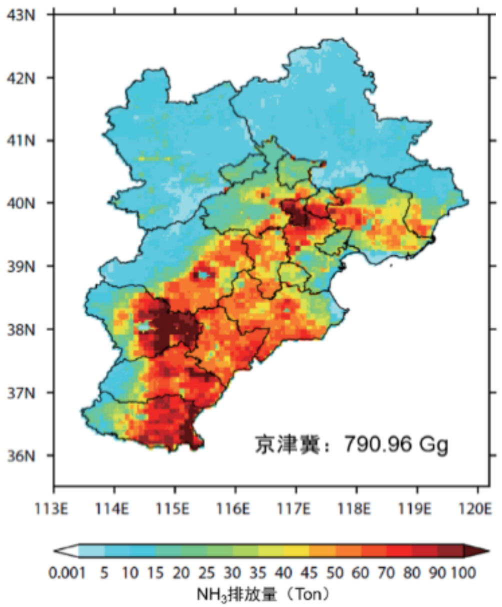


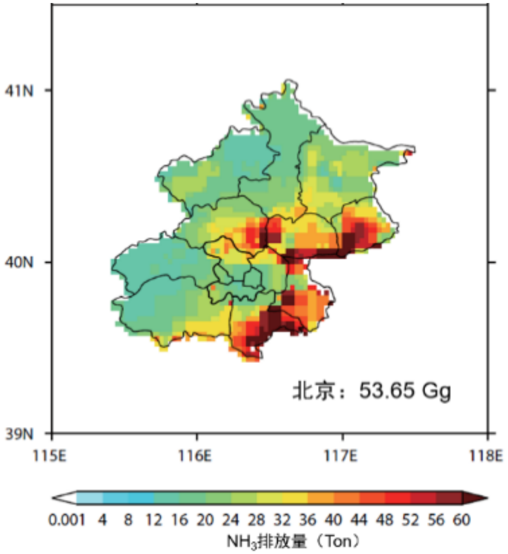
[Gu*, Zhang*, … Sutton*, *Science*, 2021]

Air quality modeling covering the Chinese and European cities

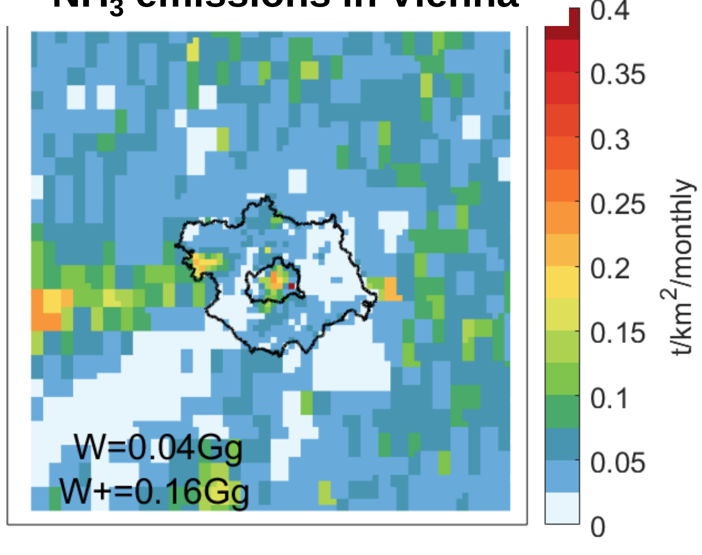


NH_3 emissions in Beijing



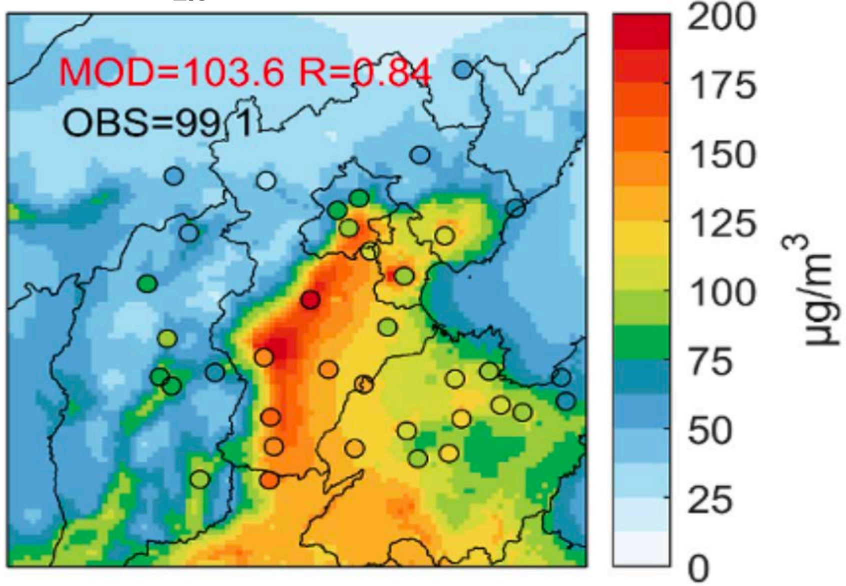


NH_3 emissions in Vienna

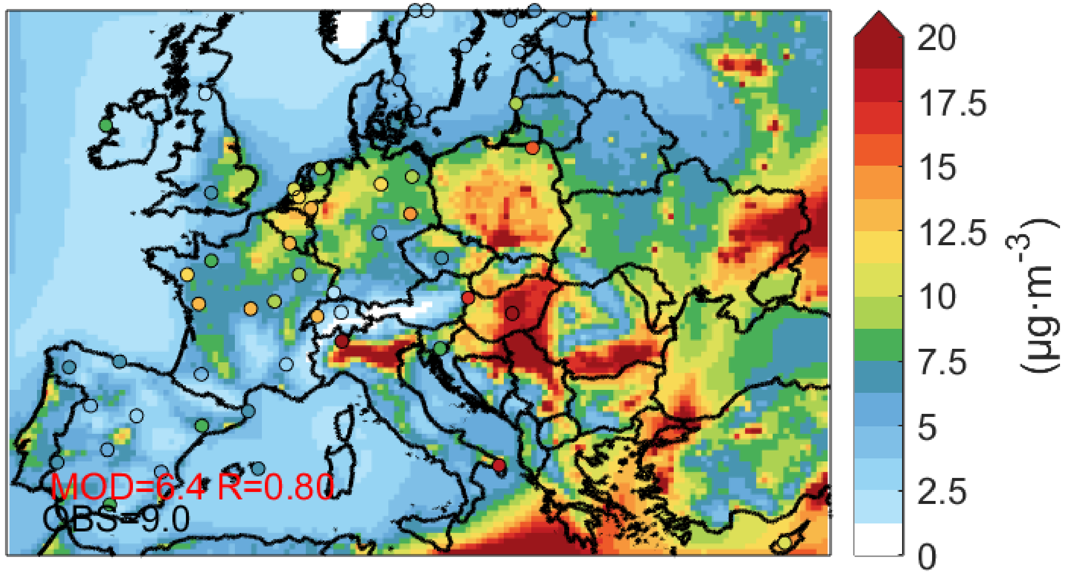


Observed and simulated January $PM_{2.5}$ air pollution

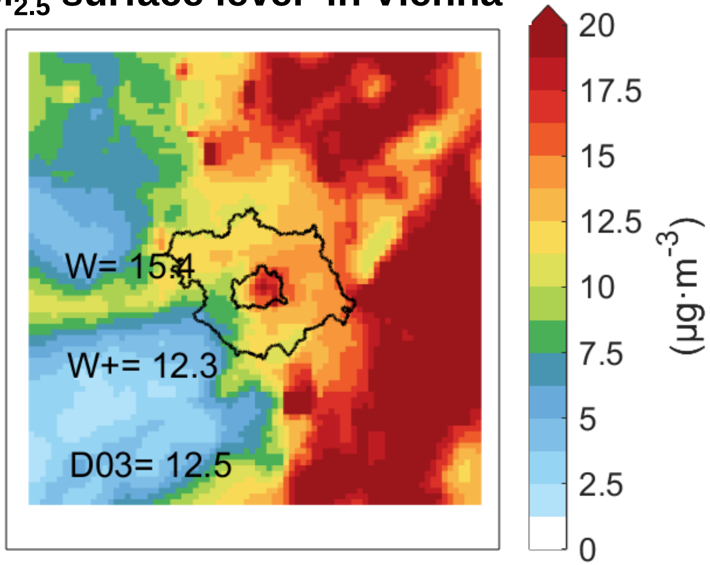
January $PM_{2.5}$ level over North China



January $PM_{2.5}$ level over Europe



$PM_{2.5}$ surface level in Vienna



January 2015:

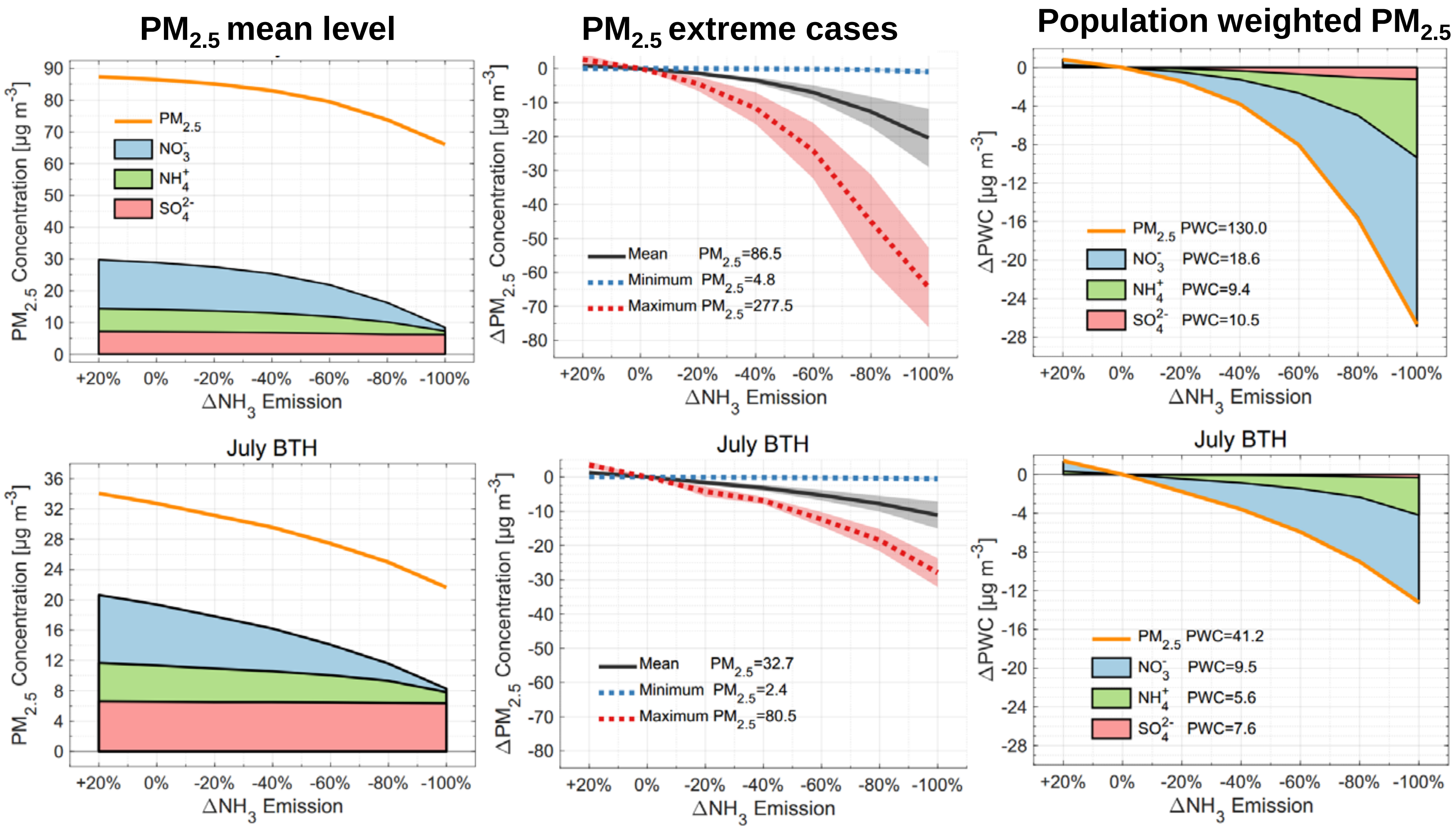
Beijing 85 ug/m³ vs. Vienna 15 ug/m³!

Impacts of NH_3 emission reductions on $PM_{2.5}$ air pollution – North China

Reduce NH_3 emissions over North China by 20%-100%

January 2015

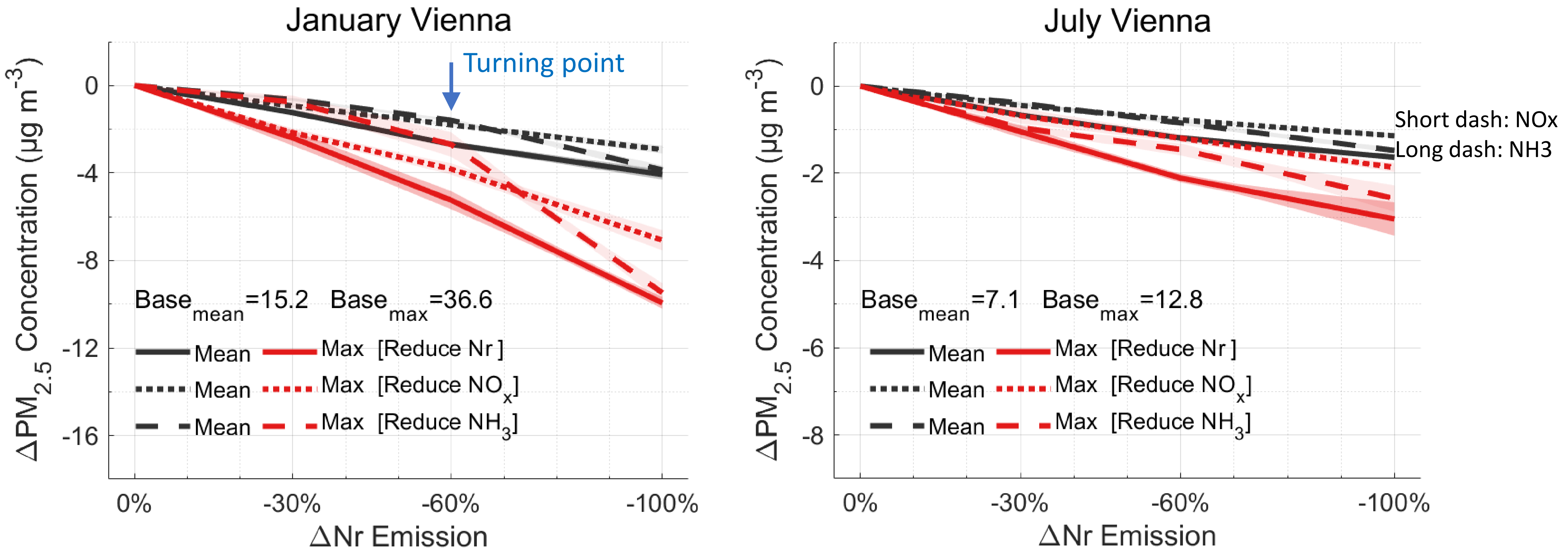
July 2015



- Strong nonlinear responses of $PM_{2.5}$ concentrations to NH_3 emission reductions;
- Increasing effectiveness with larger reductions

[Liu et al., *Environ. Res. Lett.*, 2021]

Impacts of Nr emission reductions on $PM_{2.5}$ air pollution – Vienna



For $PM_{2.5}$ air quality improvements in Vienna

- NH_3 emission controls become more effective than NO_x emission controls when the emission reduction percentage is higher than ~60% in January;
- always similar or more effective in July.

Measures to reduce agricultural NH_3 emissions

Scenario		Measures	North China 2015 emission [Gg]	Reduction %
Baseline		No mitigation measures	**639.7**	**/**
Manure	Feeding	**Use suitable feed for pigs and poultry**	**594.4**	**7.1%**
	Housing	**Floor management of the farm house**	**524.0**	**18.1%**
	Storage	**Use cover materials and change the pH for slurry; Use compaction, static piling and covering for solid**	**631.7**	**1.3%**
	Field application	**Band spreading, injection, incorporation digestate, and solid-liquid separate**	**560.6**	**12.4%**
Chemical fertilizer	Reduce application rate	**Optimize nitrogen use rate**	**600.7**	**6.0%**
	Improved application methods	**Change spreading to deep fertilization**	**548.2**	**14.3%**
	Addition	**Use urease inhibitor (LIMUS)**	**551.4**	**13.8%**
Combine		**All measures above**	**279.6**	**56.3%**

NSFC-EU Project – stakeholder conference

WP4–Soil N leaching, impacts, & mitigations

Feng Zhou, Wulahati Adalibieke, Wenjun Jiang
College of Urban and Environmental Sciences, Peking University

May 31, 2022, online

Objective and tasks of WP4

Objective—

We will quantify regional-scale N leaching from agricultural soils at high spatial resolution, as well as to optimize agricultural management practices to mitigate groundwater and air N pollution.

Key tasks—

Task 1. Development of high-resolution N inputs and irrigation datasets

Task 2. Land surface modeling simulation of N leaching and the associated N flow in aquifer groundwater under different agricultural management and climate change

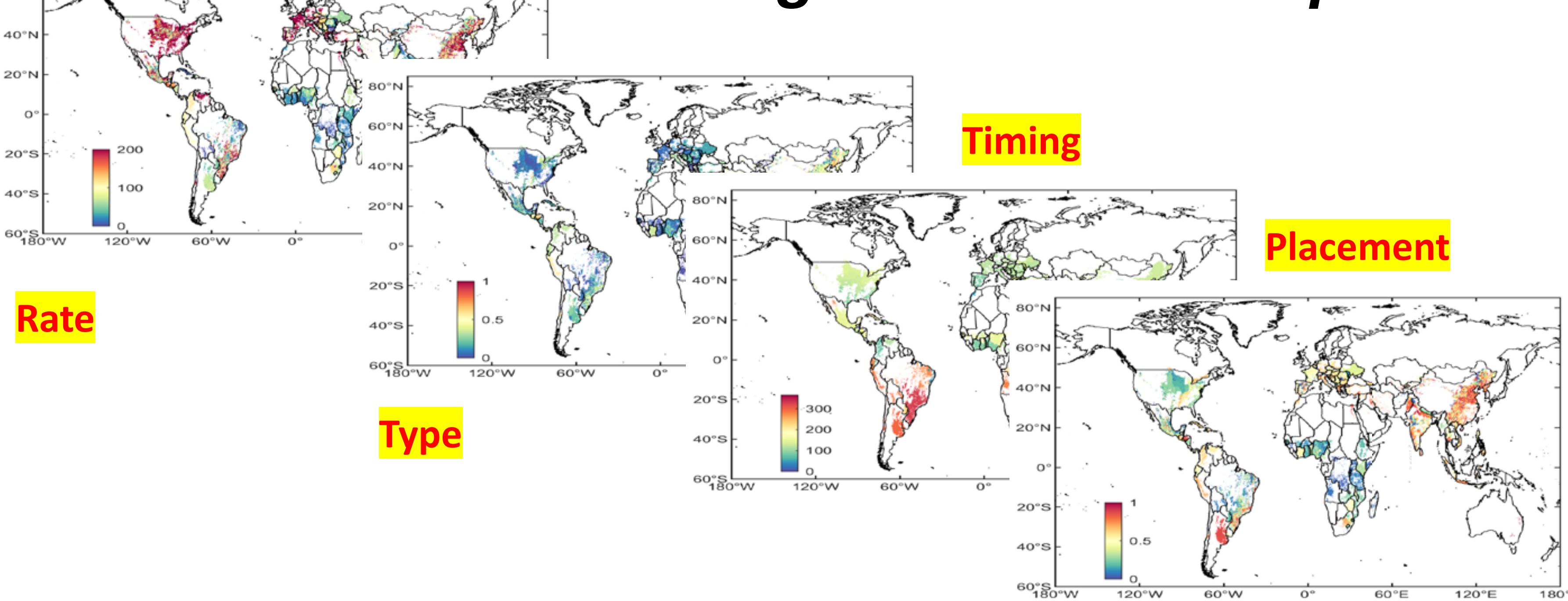
Task 3. Optimization of urban agriculture management to mitigate groundwater N pollution under different climate changes

WP4 Task 1

Global high-resolution vegetation-specific N-fertilizer application dataset (1961-2017, annual, 5-arc-minute, NetCDF file)

The N inputs are defined as the annual quantity of chemical fertilizers, manure, crop residues, and human excreta applied to soils.

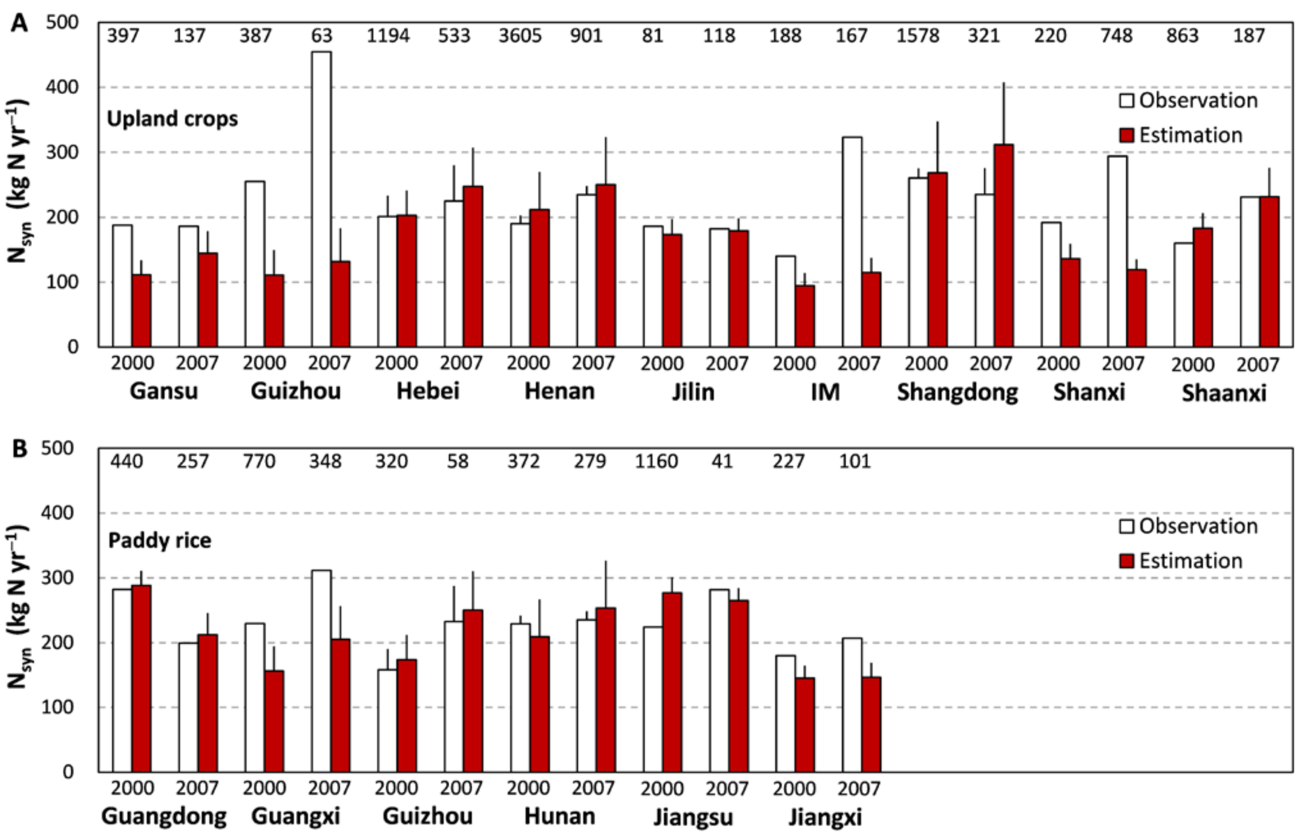
Taking maize for example



WP4 Task 1

Global high-resolution vegetation-specific N-fertilizer application dataset (1990-2017, annual, 5-arc-minute, NetCDF file)

The N inputs are defined as the annual quantity of chemical fertilizers, manure, crop residues, and human excreta applied to soils.

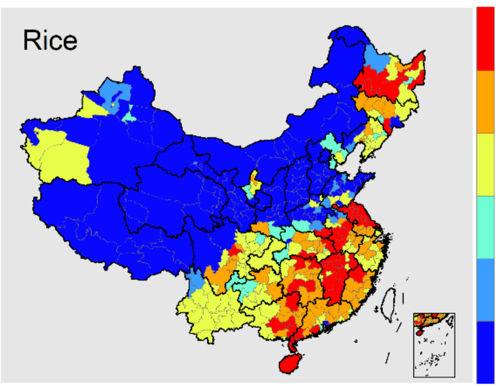


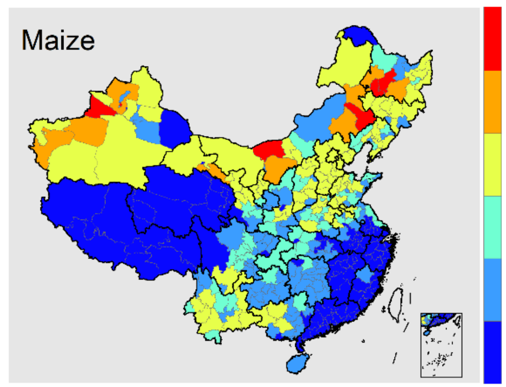
WP4 Task 1

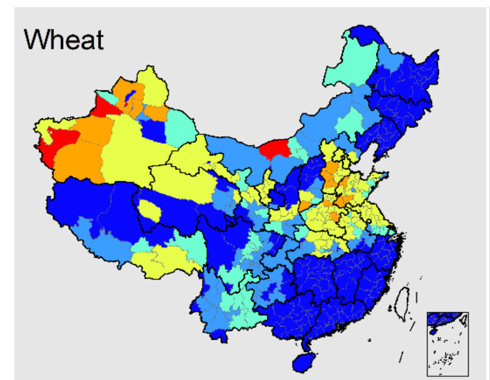
China's high-resolution crop-specific irrigation water use dataset

(1990-2017, annual, municipality, Excel file)

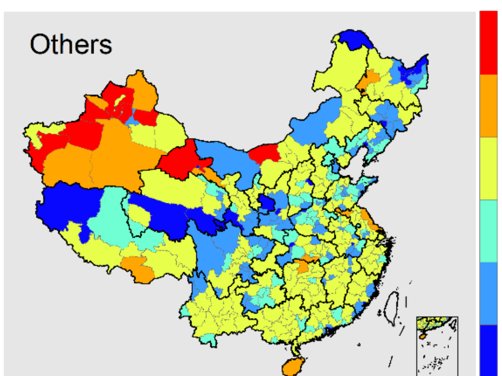
Irrigation water inputs are defined as the annual quantity of water withdrawn for irrigation including the losses during conveyance and field application.

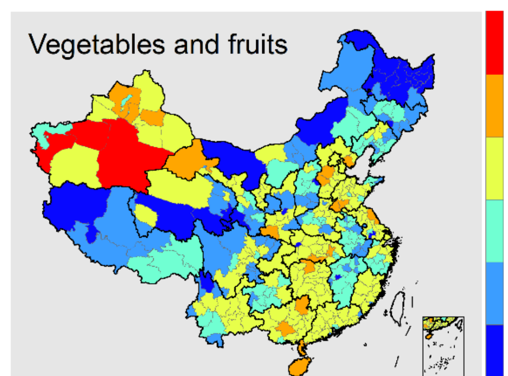




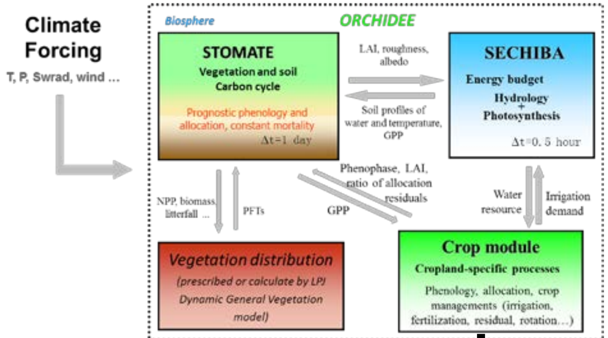


Unit:
million m3

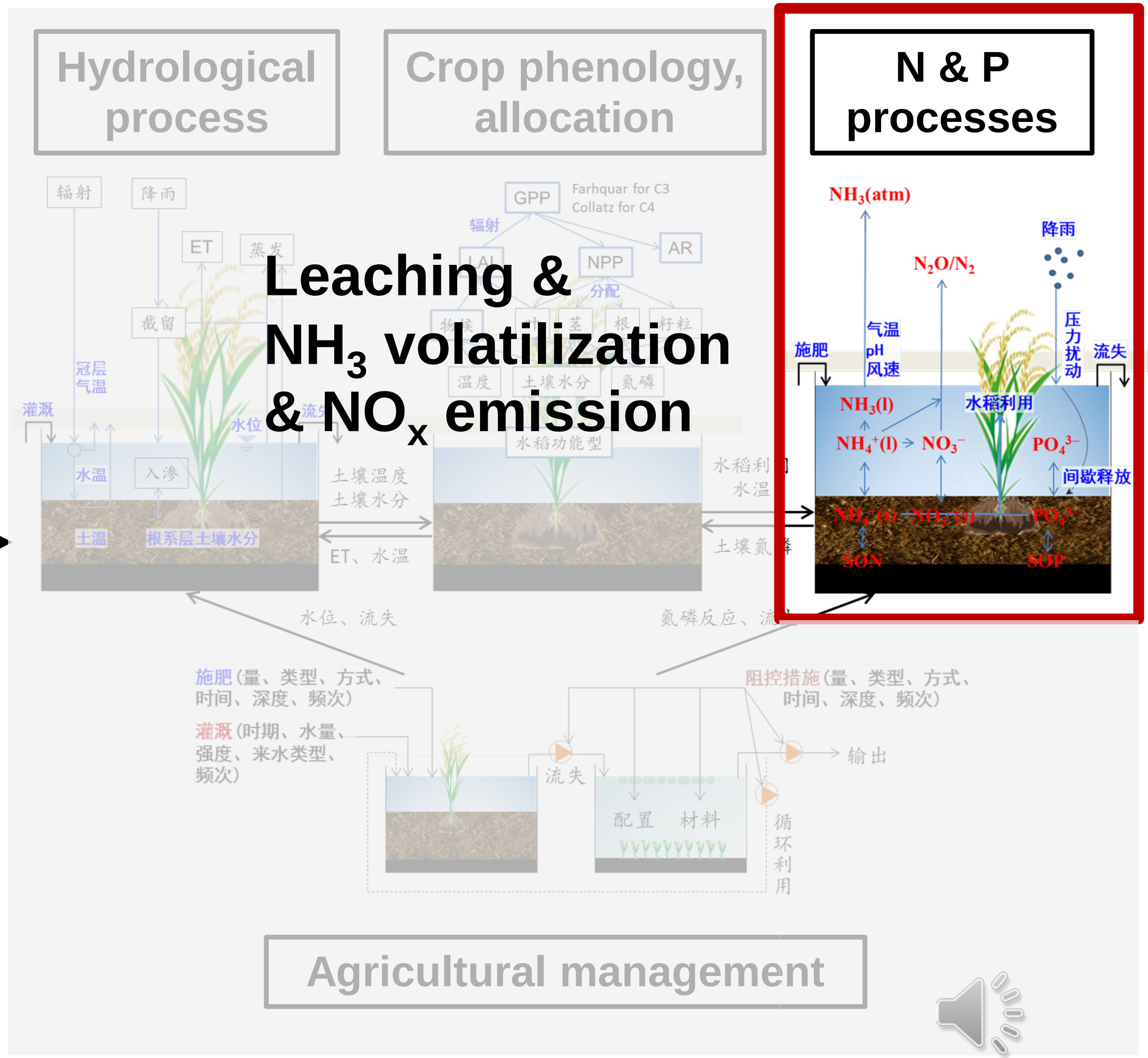




WP4 Task 2 – Modeling



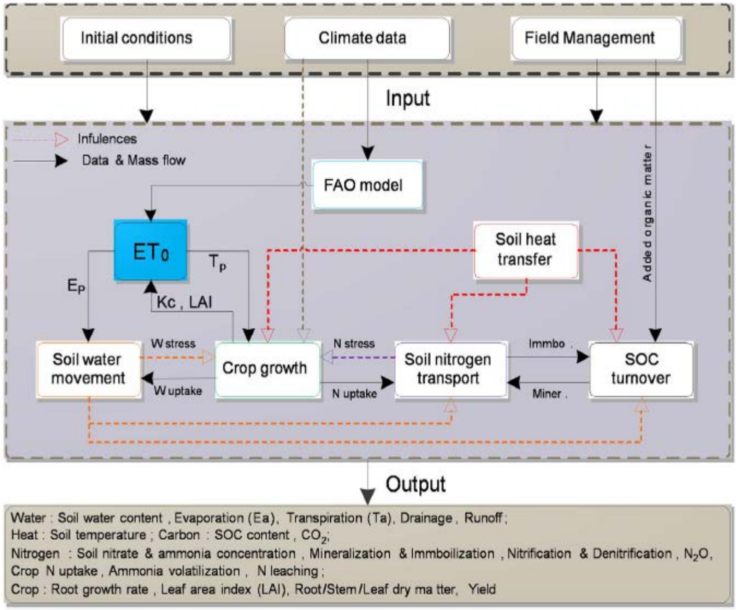
Rice paddies module



D4/2: Land surface modeling simulation of N leaching (PKU)

Jiang et al. 2021

WP4 Task 2 – Modeling



Jiang et al. 2021, Environ. Pollut.

Soil water infiltration

$$f = K_s\left(1 + \frac{h_f \triangle \theta}{F}\right) \quad \text{Green-Ampt equation}$$

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial z}\left[k(h)\left(\frac{\partial h}{\partial z} + 1\right)\right] - S_w \quad \text{Richard's equation}$$

Soil solute transport of NH_4^+-N and NO_3^--N

$$\frac{\partial C_1}{\partial t} = \mathrm{D}\frac{\partial^2 C_1}{\partial z^2} - v\frac{\partial C_1}{\partial z} + K_n C_2 - K_{den} C_1 - K_{bio}$$

The initial conditions:

$$C_1 = C_{10}(z), \qquad (0 \le z \le \infty,\ t = 0)$$
$$C_2 = C_{20}(z), \qquad (0 \le z \le \infty,\ t = 0)$$

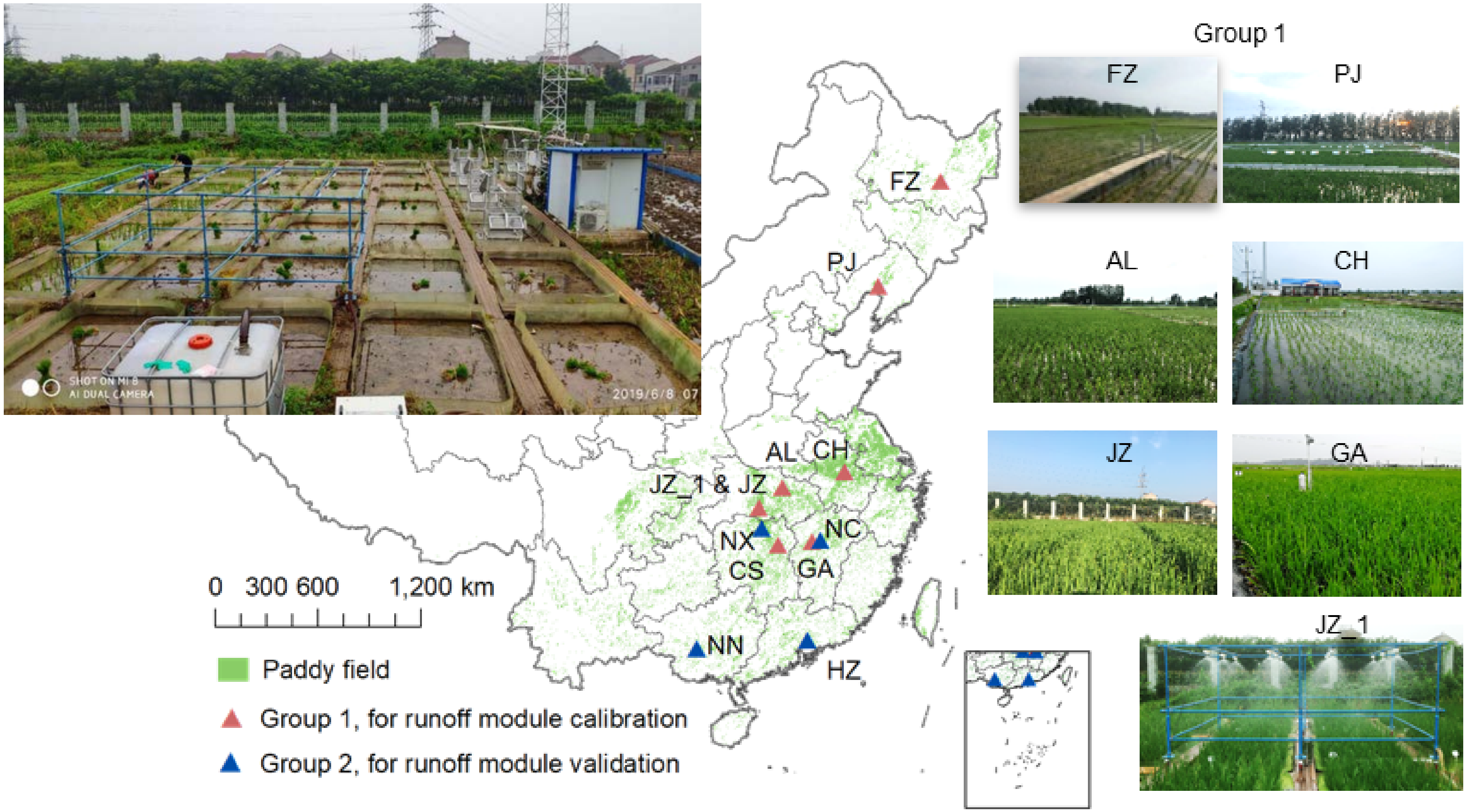
Boundary conditions:

$$D\frac{\partial C_{01}}{\partial z} = 0 \quad (z = 0, t \ge 0); \quad C_1 = C_{11}(t)\ (z \to \infty, t \ge 0)$$

$$\left(1 + \frac{\rho}{\theta} K_d\right)\frac{\partial C_2}{\partial t} = \mathrm{D}\frac{\partial^2 C_2}{\partial z^2} - v\frac{\partial C_2}{\partial z} + K_{min} - K_n C_2$$

$$D\frac{\partial C_{02}}{\partial z} = 0 \quad (z = 0, t \ge 0); \quad C_2 = C_{12}(t)\ \ (z \to \infty, t \ge 0)$$

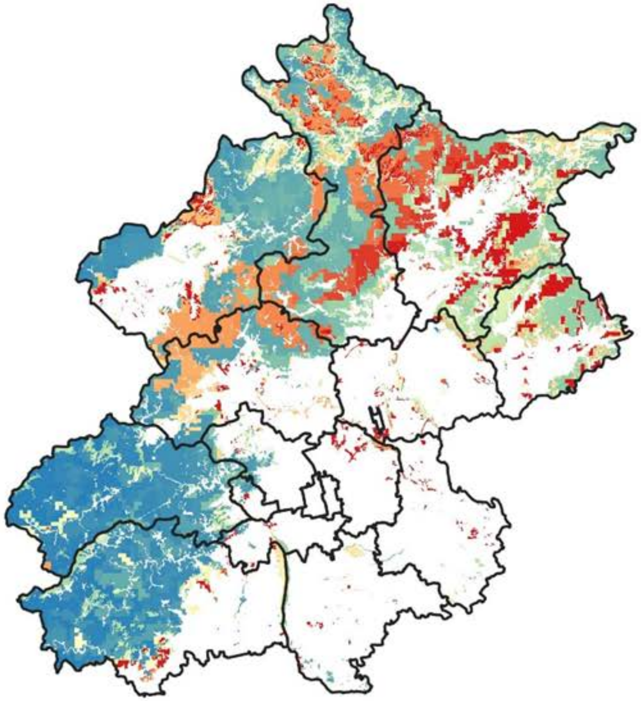
Field experiments (6 sites) for model validation



- running from May 2017 to Sept. 2019
- Indicators: climate, soil, crop growth, all budget fluxes of water and nitrogen (including N leaching)
- Resolution: daily

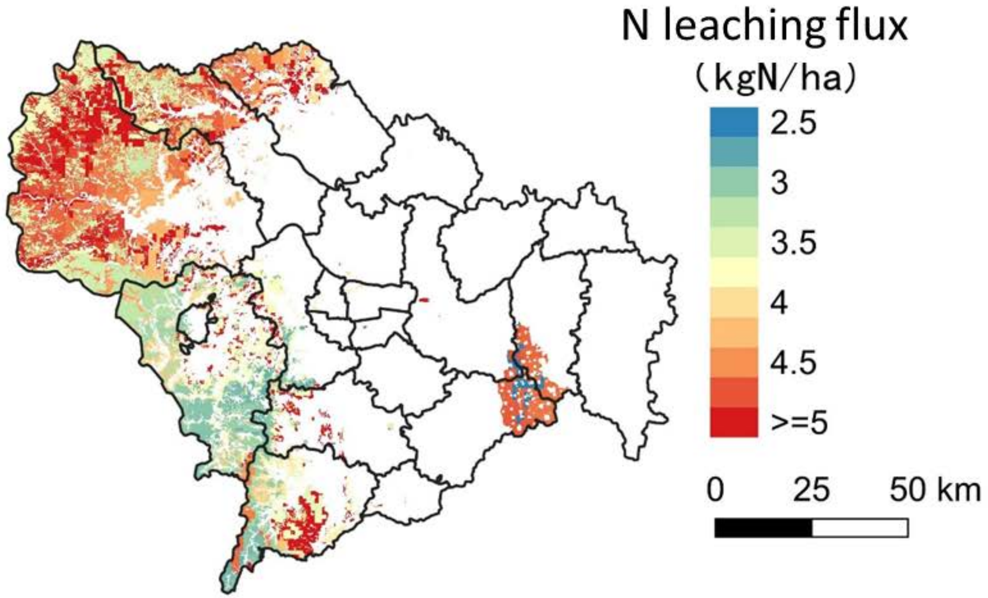
WP4 Task 2 – applications

N leaching flux over forest and grassland in Beijing



Mean: 3.4 kgN/ha

N leaching flux over forest and grassland in Shijiazhuang

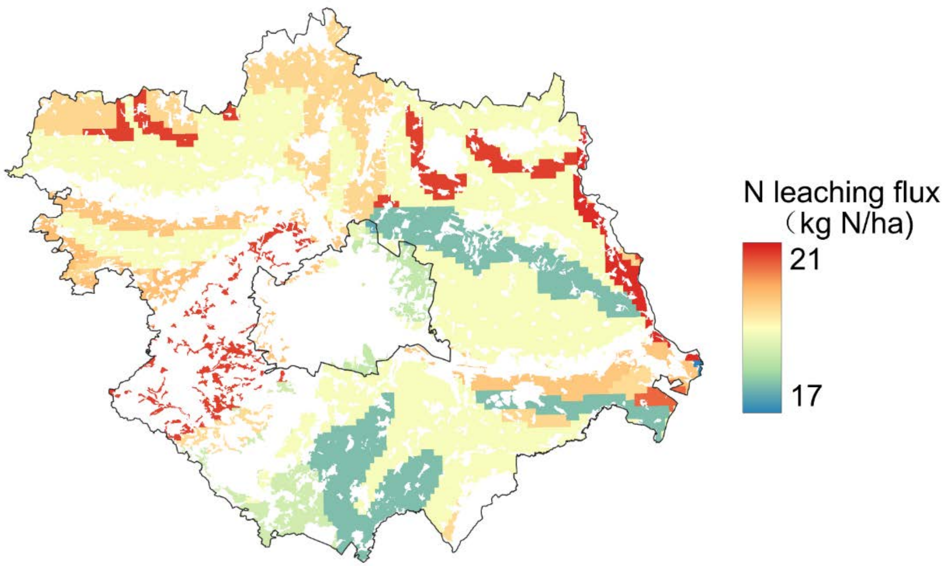


Mean: 4.4 kgN/ha

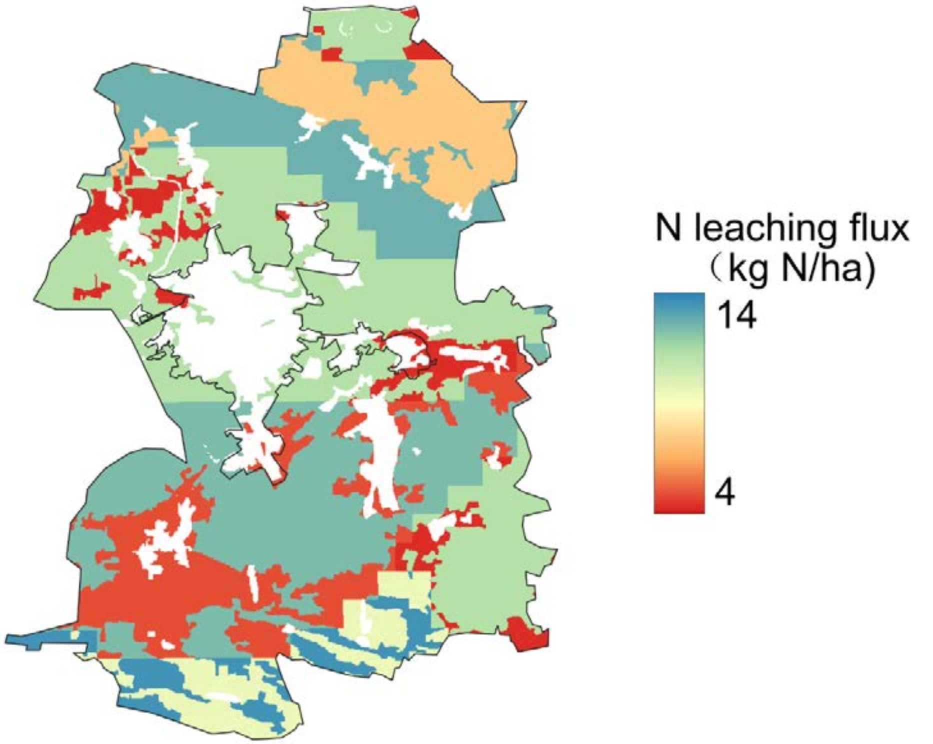
Threshold of N leaching: 22.6 kgN/ha (De Vries et al., 2013)

WP4 Task 2 – applications

Vienna



Zielona Góra

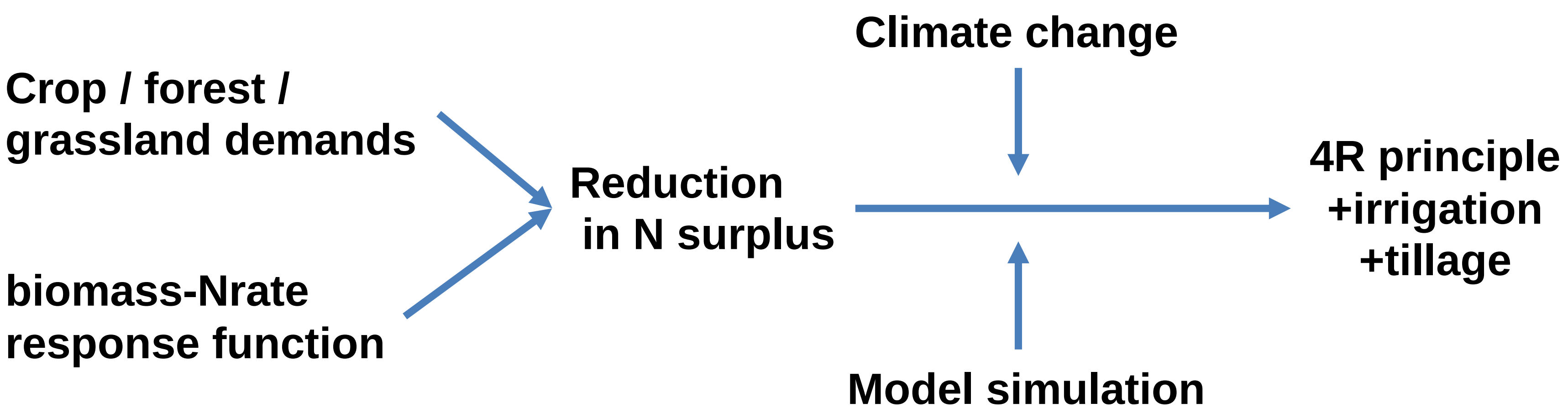


Total N leaching flux (kg N/ha):
Vienna core area: 18.54
Vienna surrounding area:19.0012
Total: 18.9978

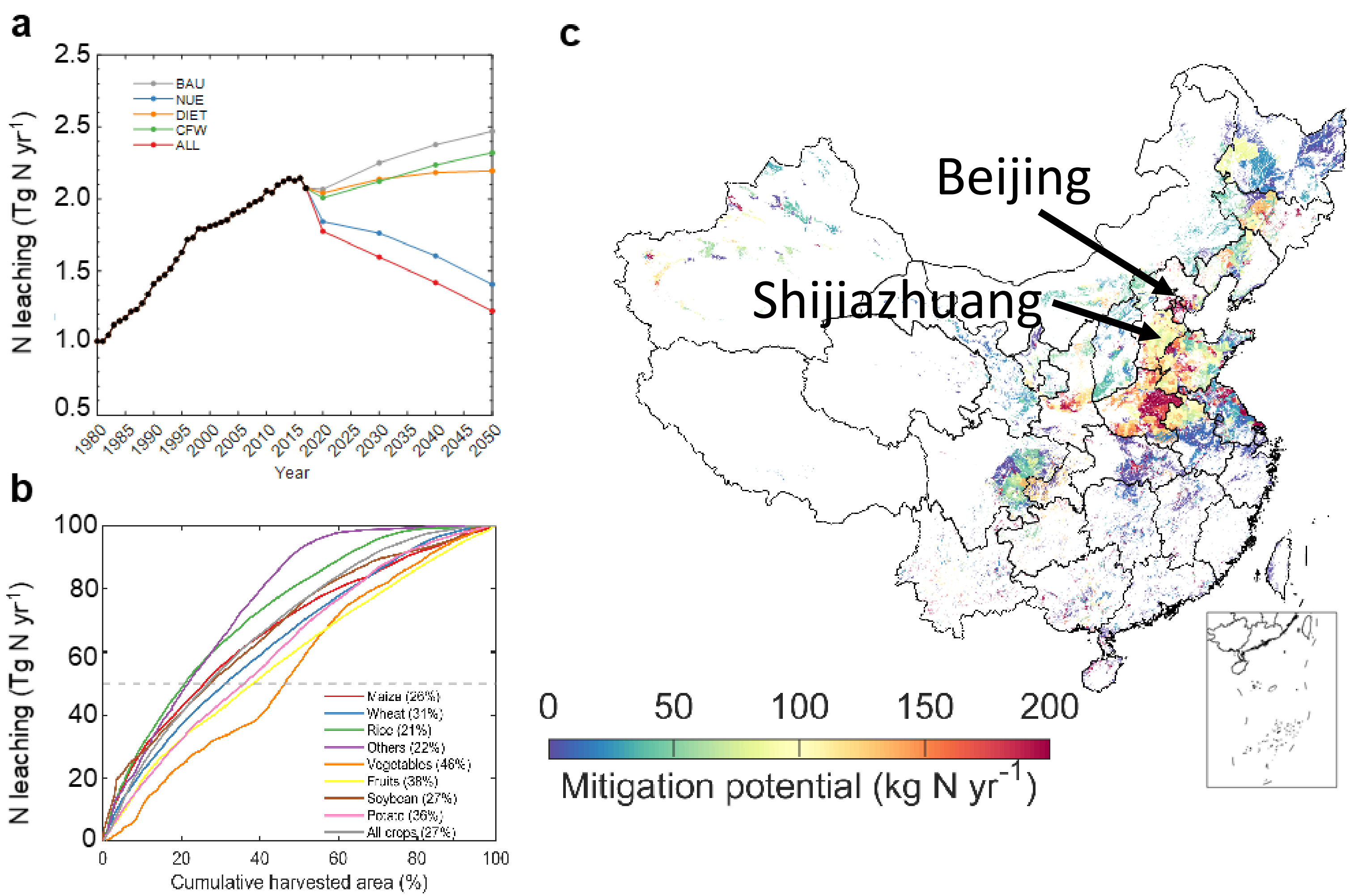
Total N leaching flux of 2018 (kg N/ha):
Zielona Góra City: 7.14
Zielona Góra New District:8.00
Total: 7.89

WP4 Task 3 – Optimization

D4/3: Optimization of urban agriculture management to mitigate groundwater and air N pollution under different climate changes (PKU) **(Month 30)**

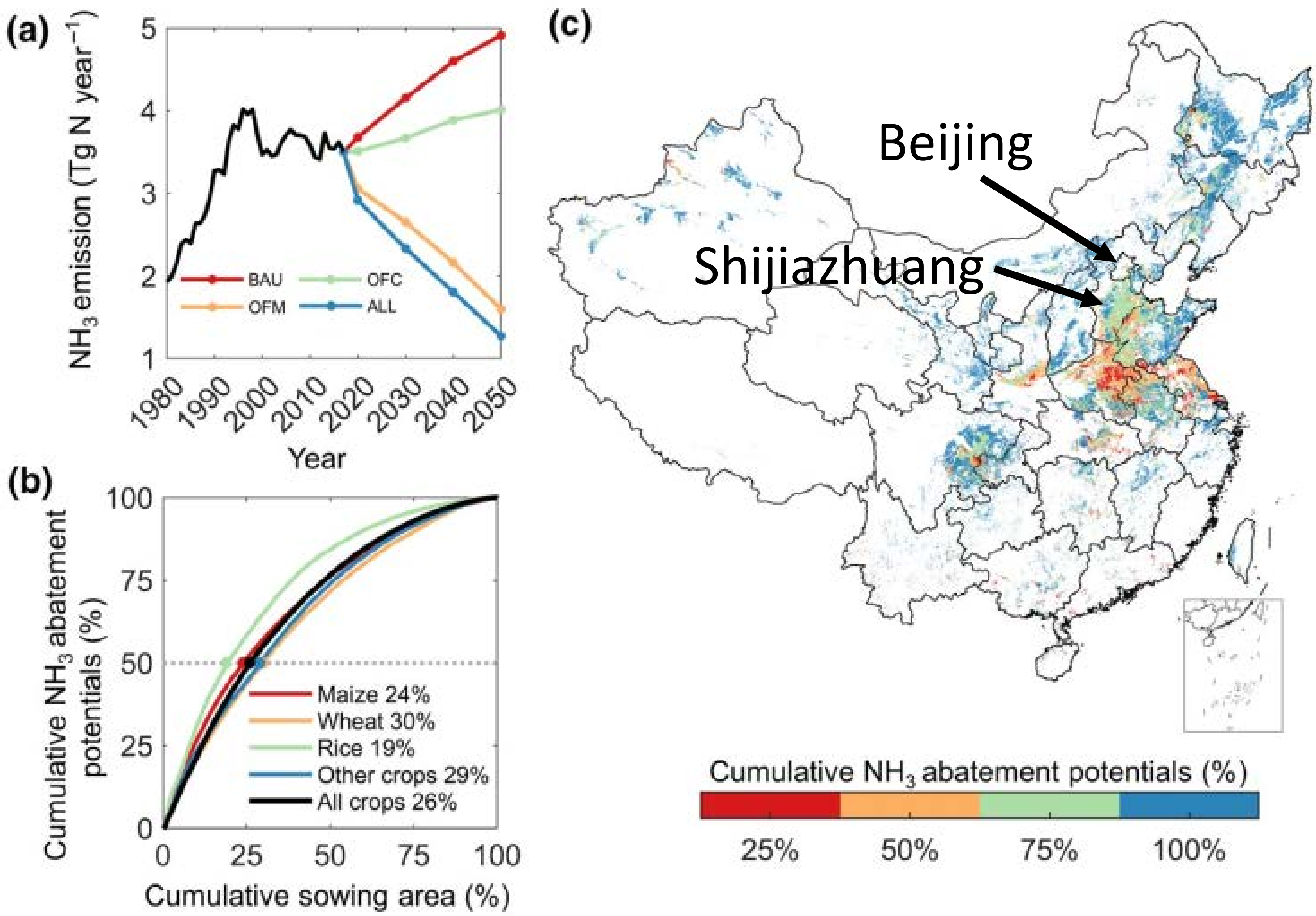


WP4 Task 3 – Optimization



China's cropland N leaching mitigation potentials

WP4 Task 3 – Optimization



China's cropland-NH_3 mitigation potentials.

Thanks for your attention!

1. **Zhou, F.*** et al. (2020) Deceleration of China's human water use and its key drivers. *Proceedings of the National Academy of Sciences* 117, 7702-7711
2. Cui, X.[#]; **Zhou, F.***; et al., Global mapping of crop-specific emission factors highlights hotspots of nitrous oxide mitigation. *Nature Food*. 2021, 2, 886-893.
3. Adalibieke, W.[#]; Zhan, X.[#]; ..., **Zhou, F.***, Decoupling between ammonia emission and crop production in China due to policy interventions. *Global Change Biology*. 2021, 27(22): 5877-5888.
4. Zhan, X.[#]; Adalibieke, W.[#]; …, **Zhou, F.***, Improved estimates of ammonia emissions from global croplands. *ES&T*. 2021, 55(2): 1329-1338.
5. Jiang, W.[#]; Huang, W.[#]; …, **Zhou, F.***, Is rice field a nitrogen source or sink for the environment? *Environmental Pollution*. 2021, 283: 117122.

Urban nitrogen cycles: new economy thinking to master the challenges of climate change

Urban Agricultural Model and Nitrogen flow characteristics

Xiangwen Fan, Zhaohai Bai, Lin Ma

Center for Agricultural Resources Research, IGDB, CAS

Content

- Background
- Methodology and aim
- Model construction
- Result
- Conclusion

Content

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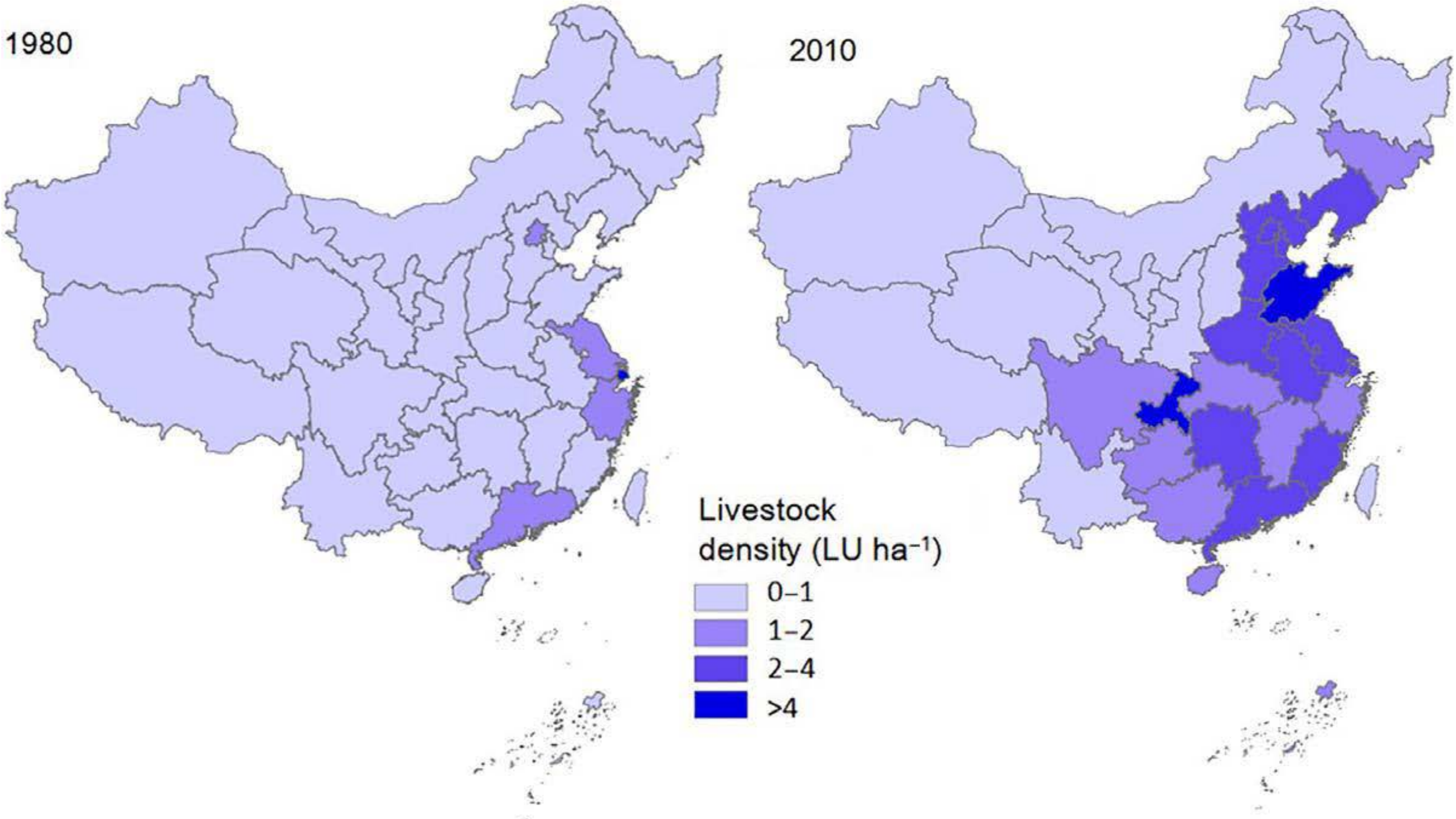
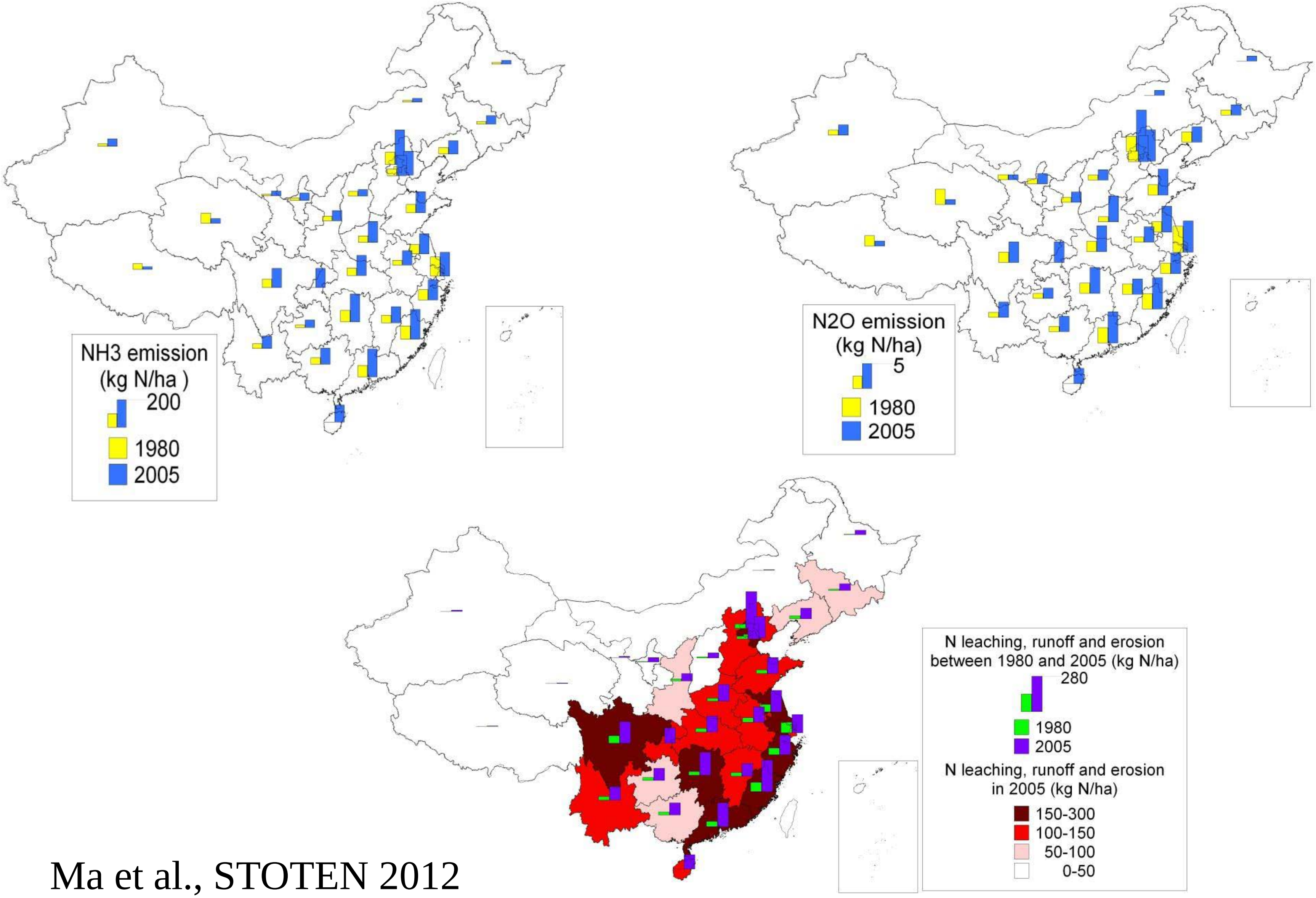
Uneven distribution of livestock production across China, especially in metro cities



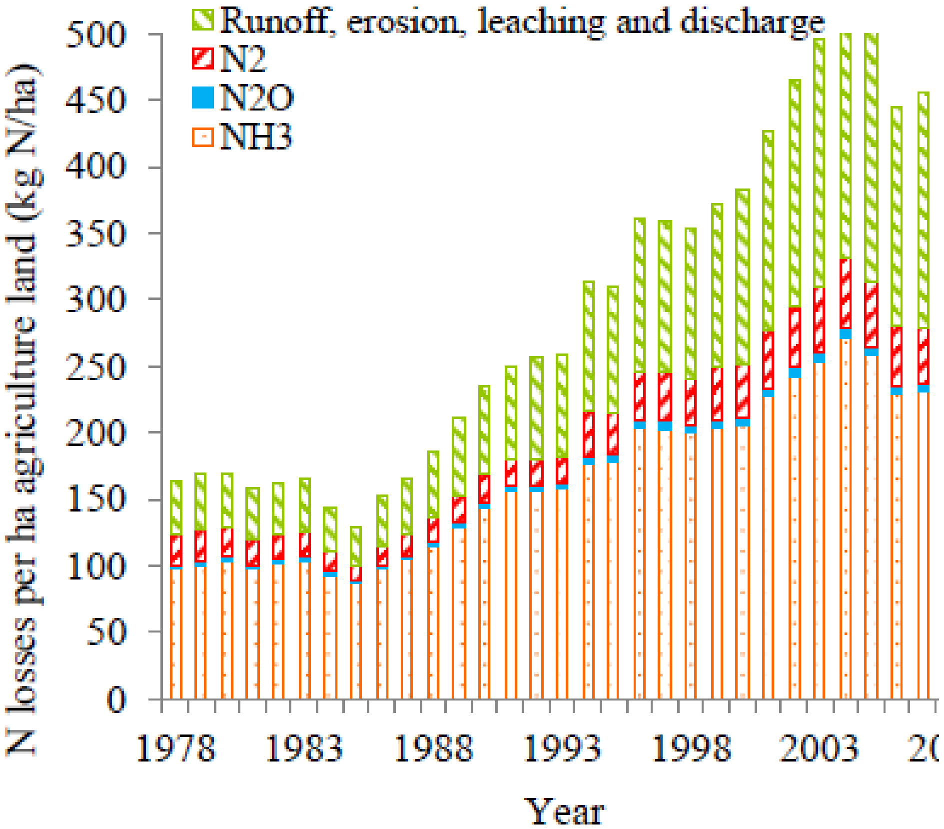
Bai et al.,2018 Science Advances

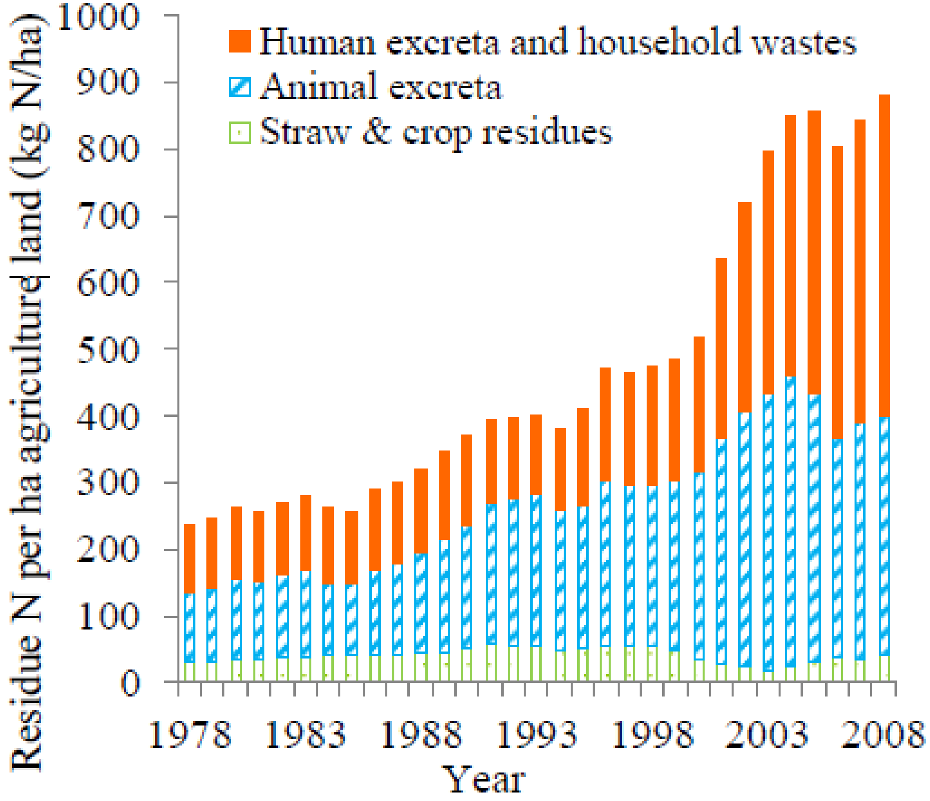
High nitrogen losses occurred in metropolitan



Ma et al., STOTEN 2012

Urban expansion increased N losses and residues in city





Ma et al., GEC 2014

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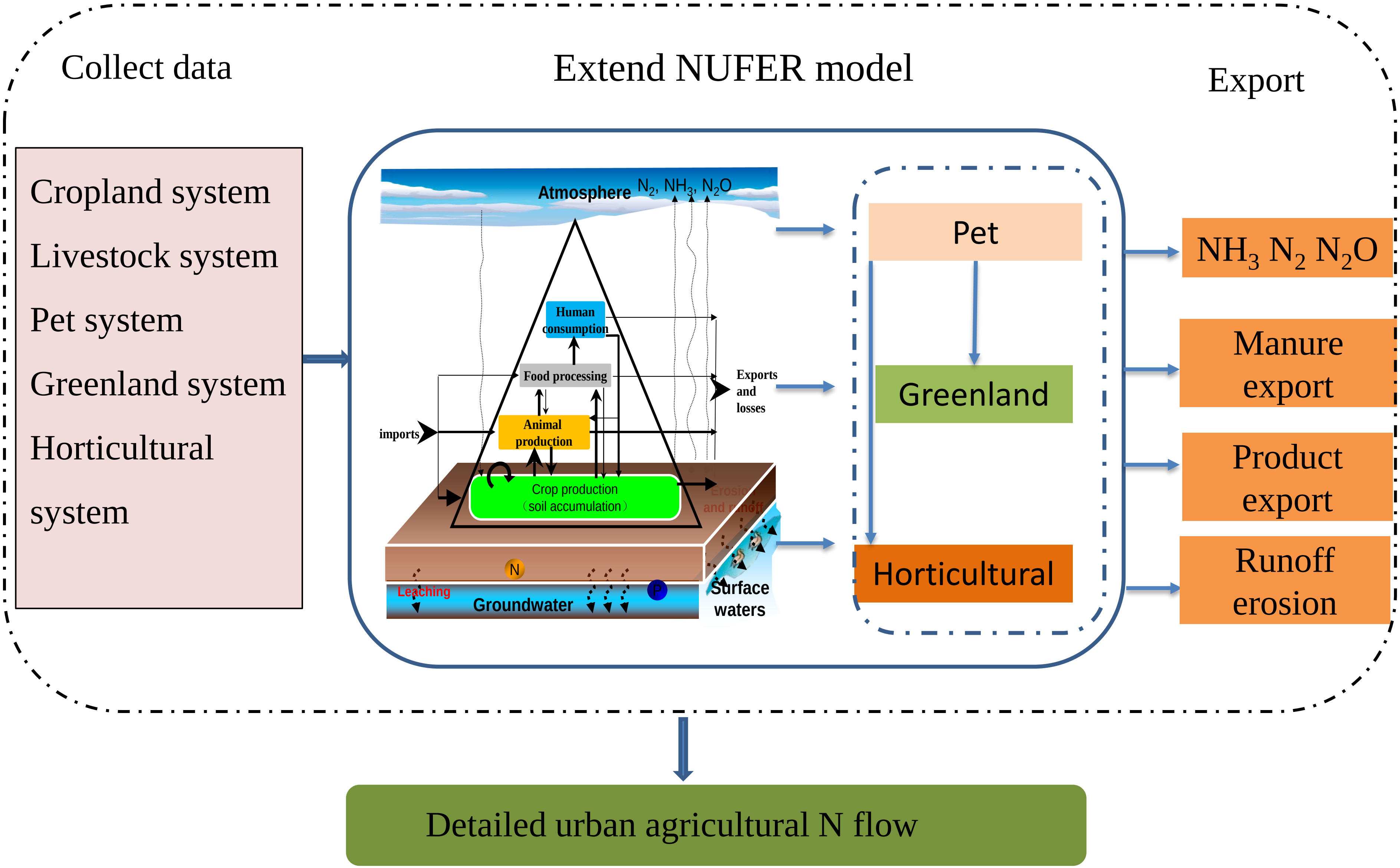
Methodology and aim



Content

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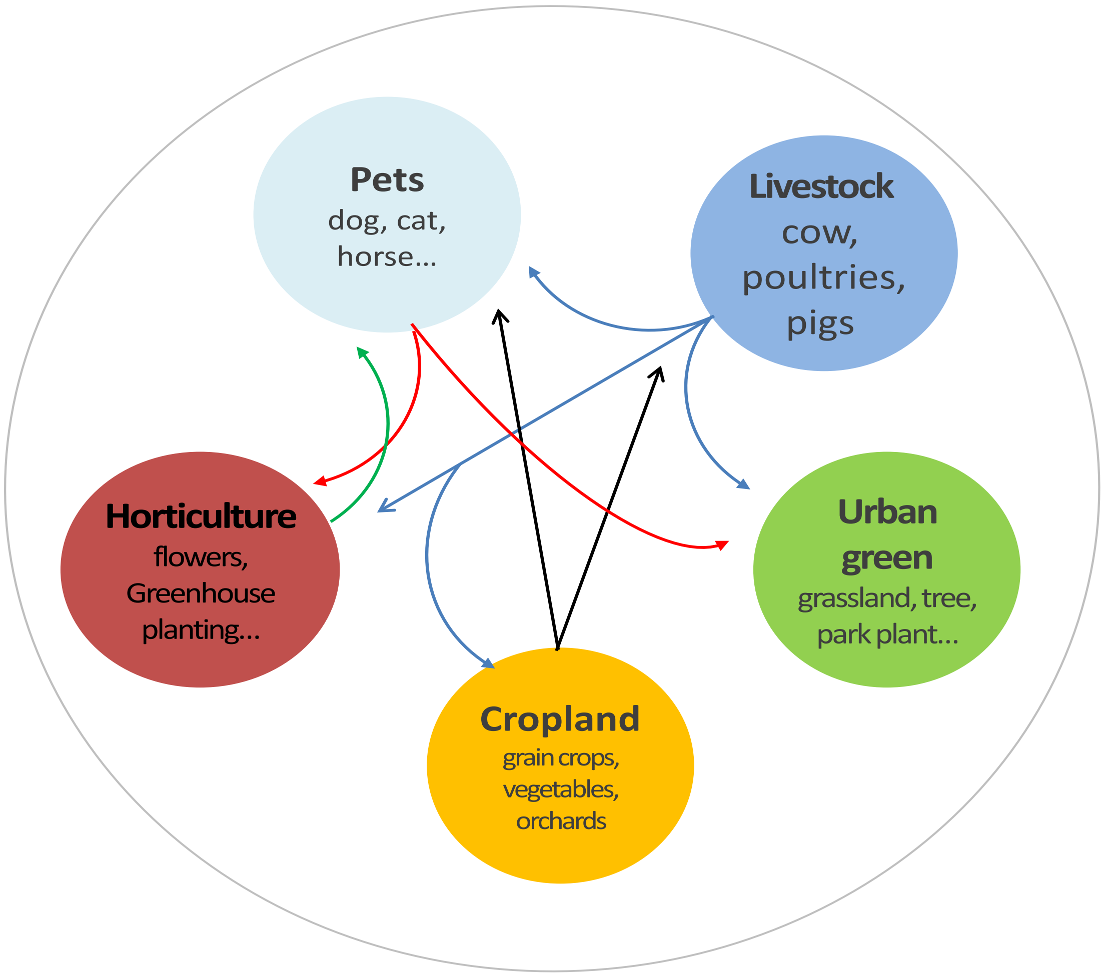
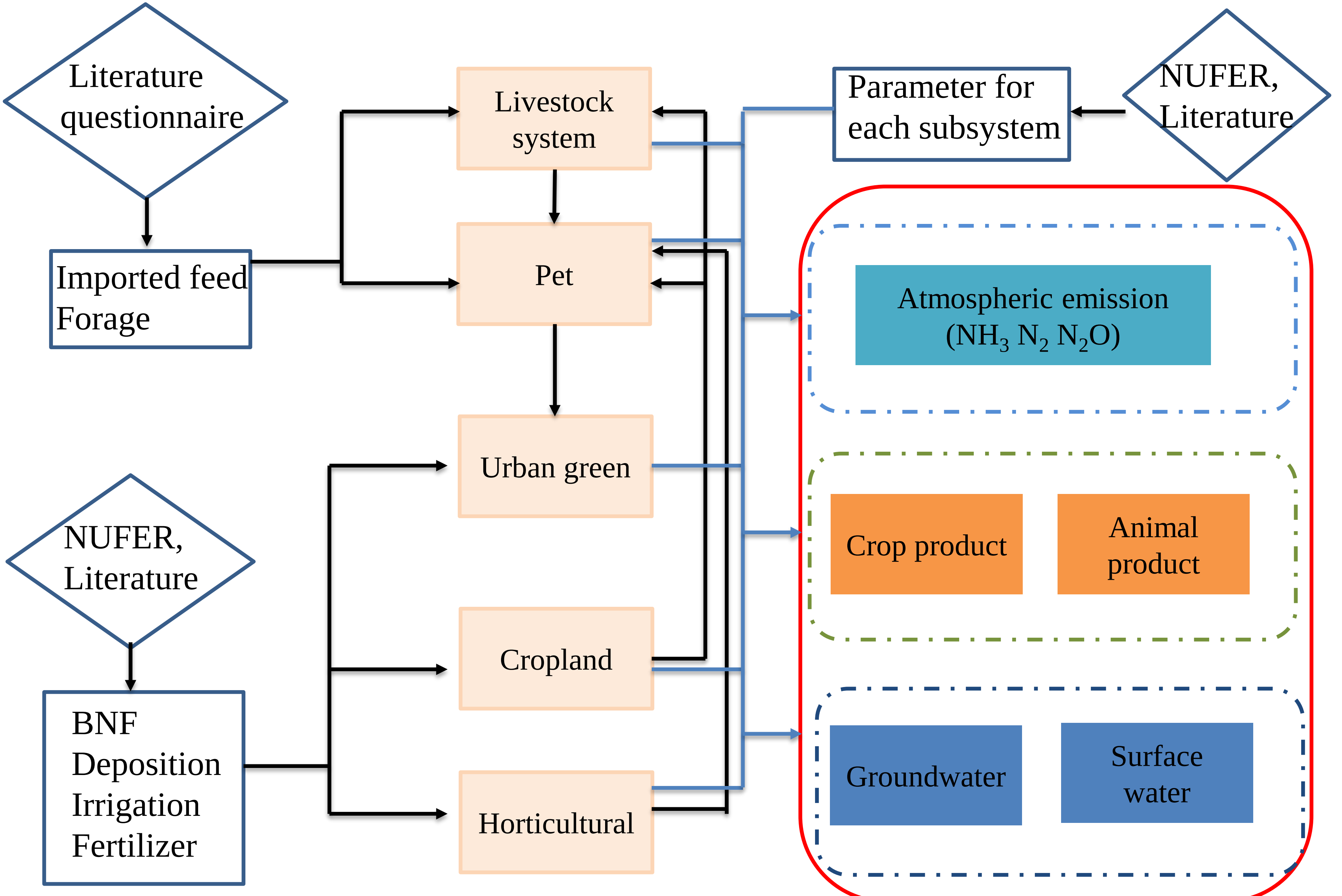
Build the detailed urban agricultural N flow



Concept of nitrogen flows in urban agriculture

Build the detailed urban agricultural N flow



Content

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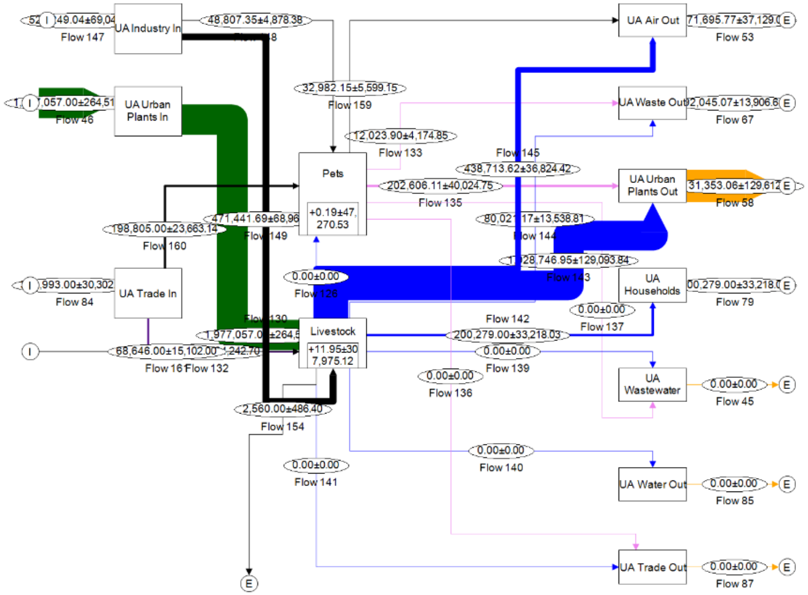
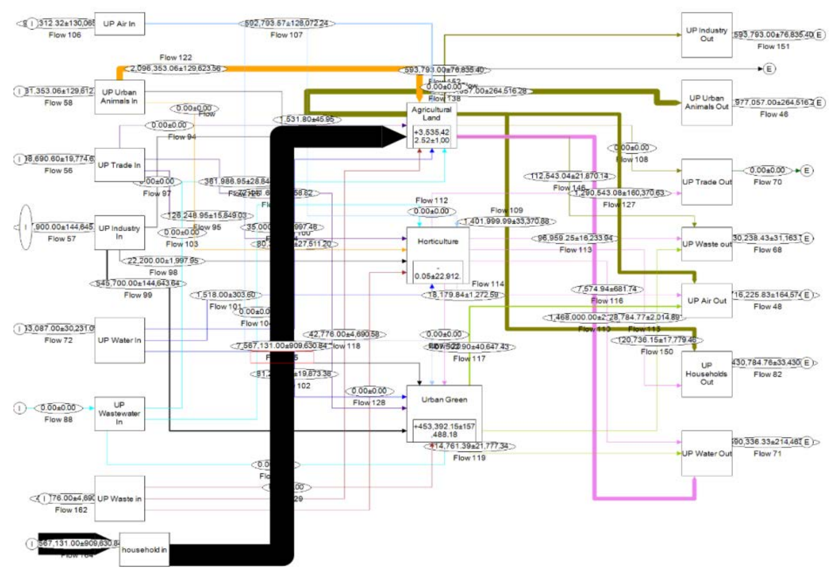
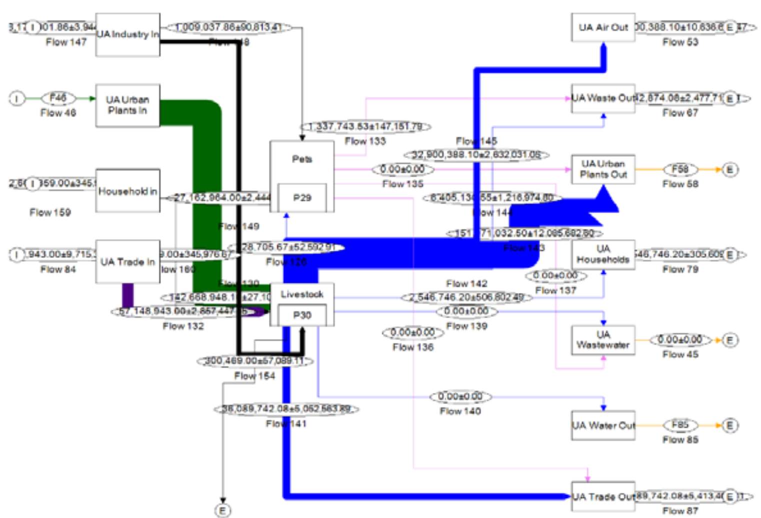
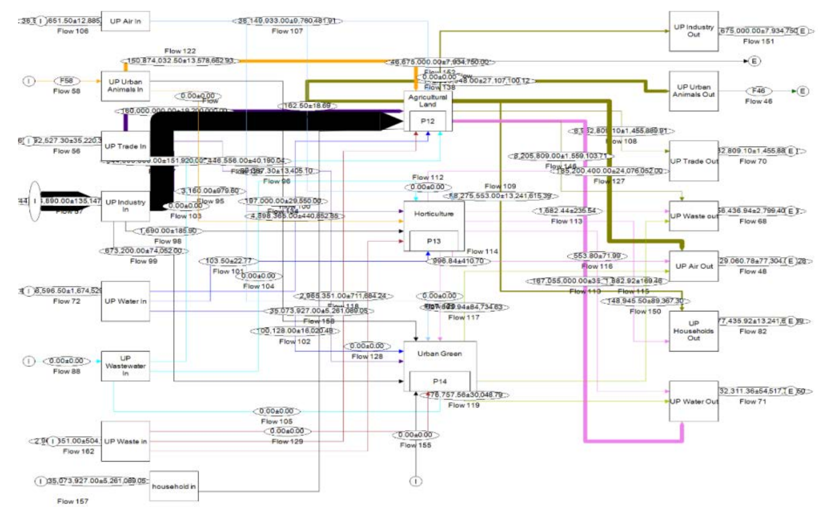
Simulation of urban agriculture flows in Shijiazhuang





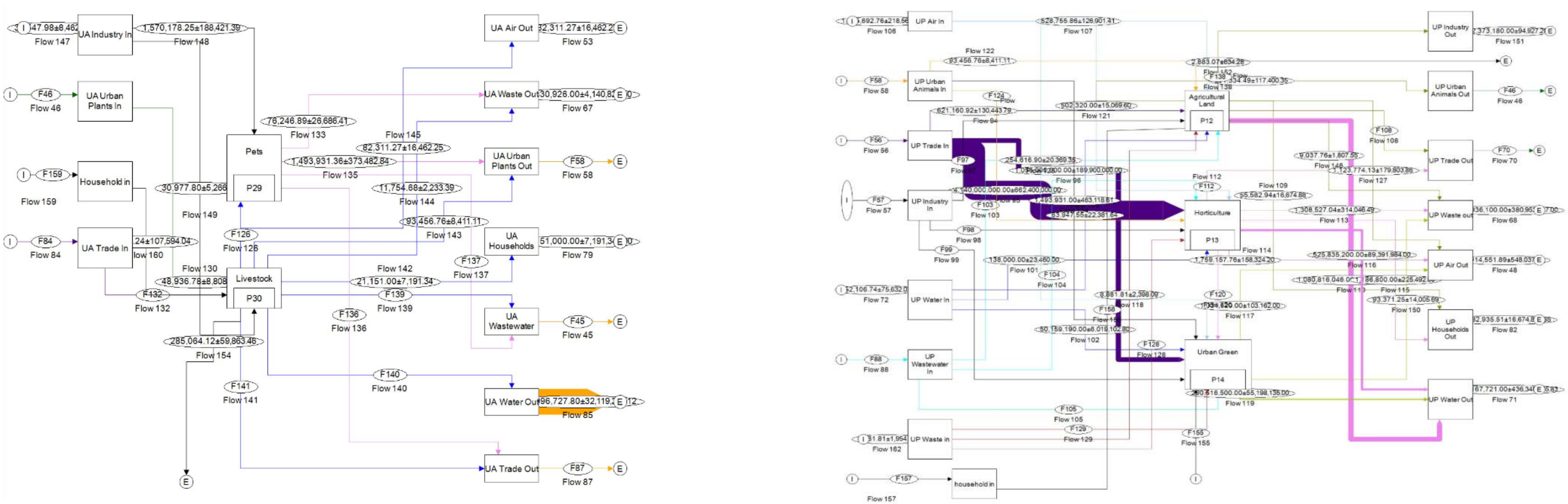
Agricultural N flow in Shijiazhuang city



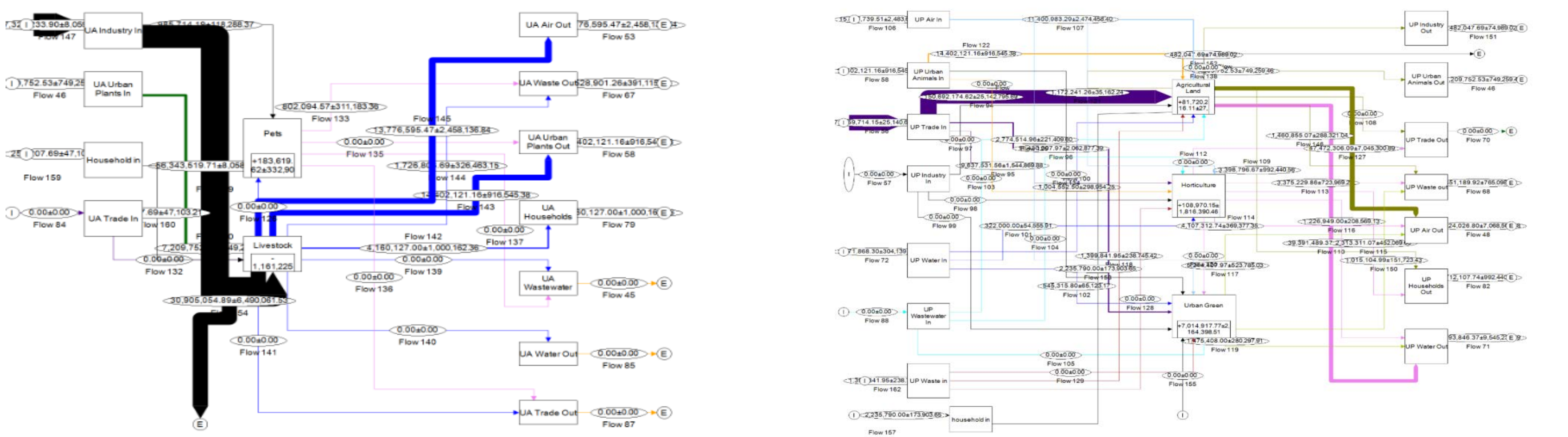


Agricultural N flow in Shijiazhuang surrounding area

Simulation of urban agriculture flows in Beijing



Agricultural N flow in Beijing city



Agricultural N flow in Beijing surrounding area

Characteristics of agricultural N flow

1. The NUE of urban area is higher than surrounding area;

2. Due to high agricultural production in surrounding area, the plant products self-sufficiency, fodder self-sufficiency and livestock products self-sufficiency are higher in surrounding area;

3. Coupling rate of crop and livestock and ratio of annual manure N excretion to annual crop N uptake both are low in city and surrounding area;

4. Share of N in food and feed imports in city are higher than surrounding areas in order to meet high population needed.

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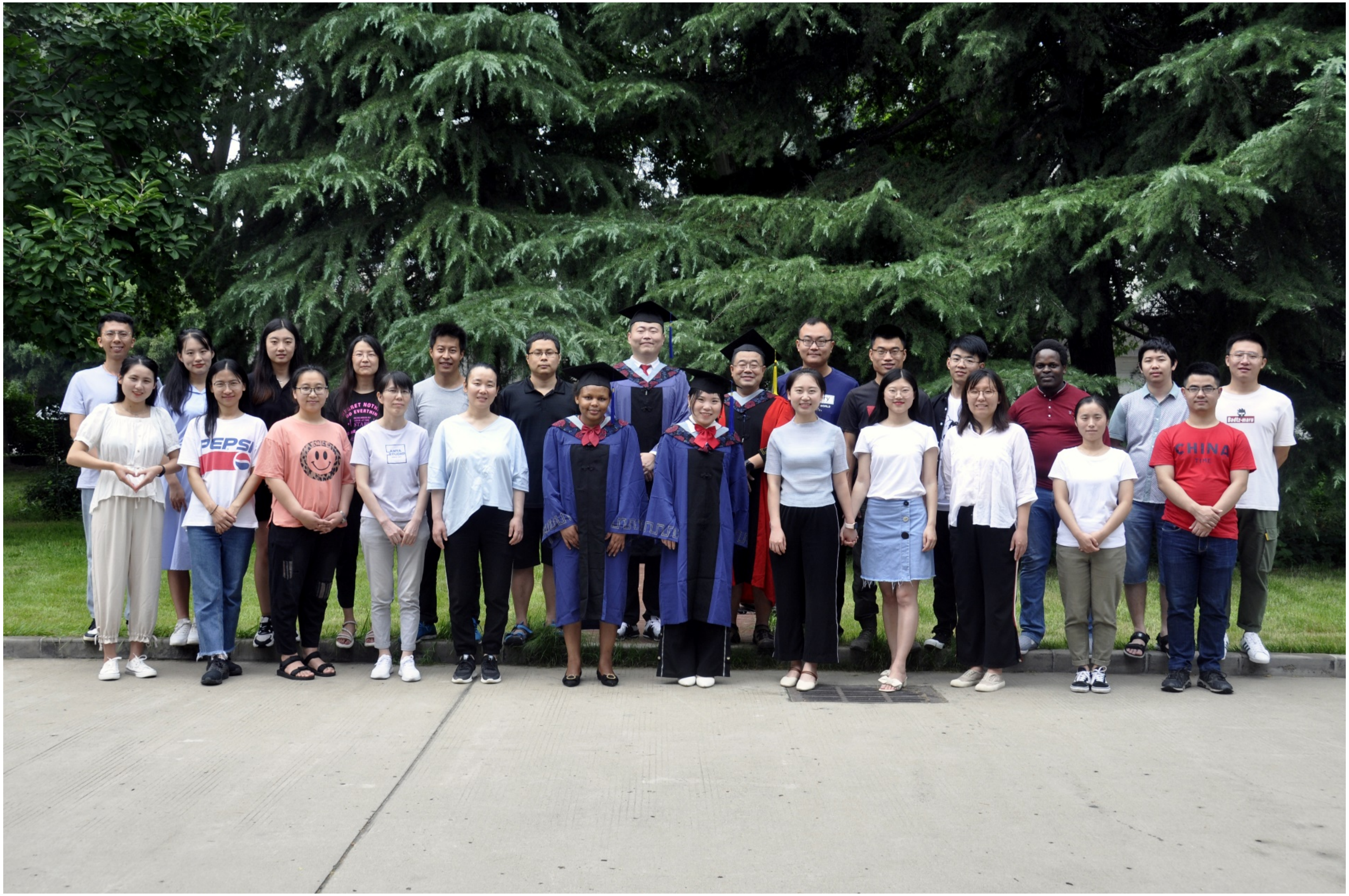
Conclusion

1.Greatly increased total N input to agricultural system to meet high population may caused high losses of ammonia and N_2O to air and N to groundwater and surface waters;

2. Optimizing livestock diet and on-farm manure management in livestock systems can serve as a powerful instrument to tackle N pollution ;

3. Increased coupling rate of crop and livestock and manure applied to field can reduce N imported and N losses.

Thank you！



UNCNET

E.C.O. brain bows UNIVERSITY OF ZIELONA GÓRA IIASA

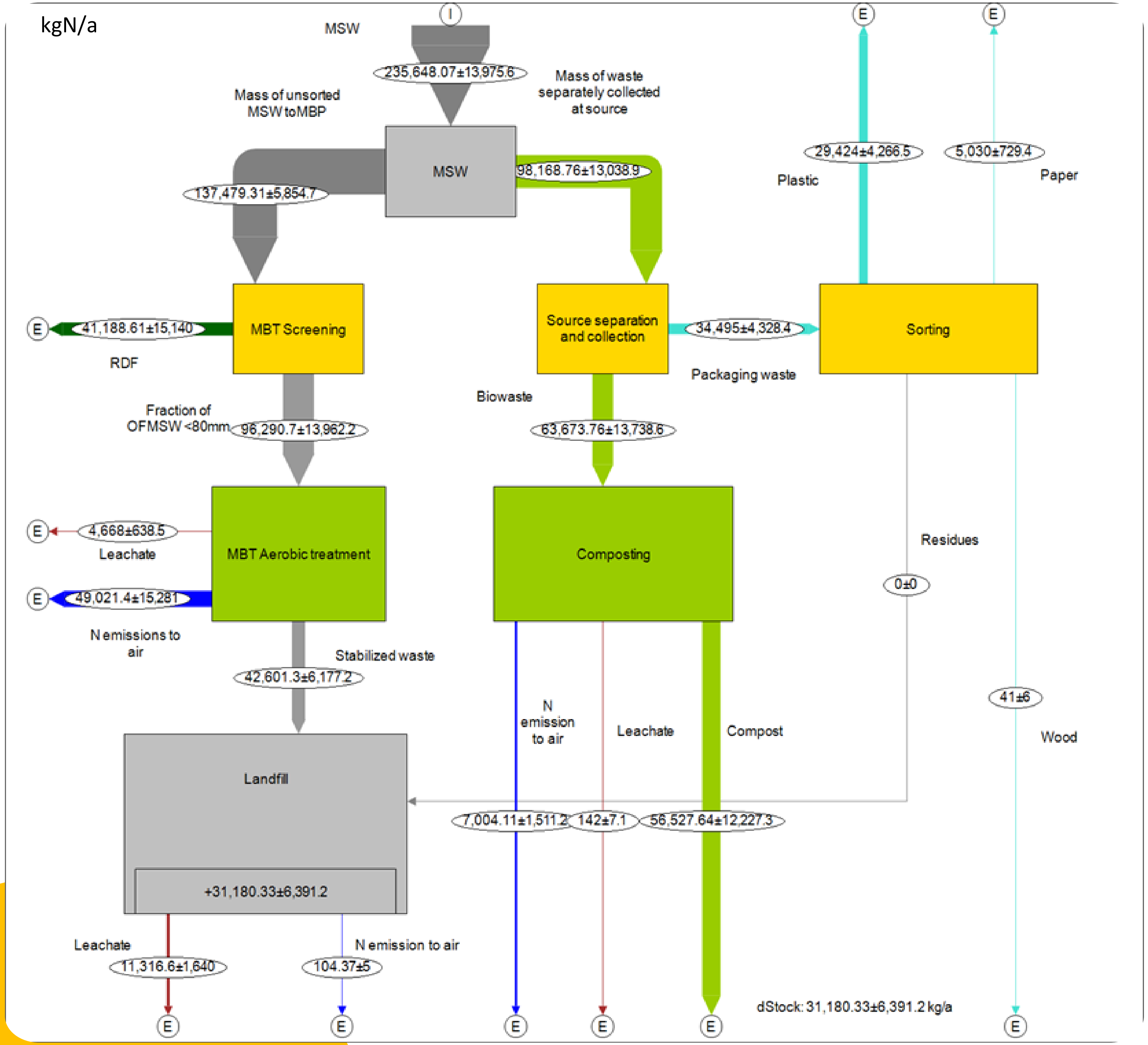
Urban Nitrogen Cycles:
New Economic Thinking to master the challenges of climate change

Nr emissions from wastewater and waste in cities

Nr emissions from wastewater and waste in cities

- The rate of nitrogen emissions from wastewater and waste is significantly correlated with the **dynamics of changes in the number of people living in urban areas**, producing waste/wastewater, and on their physical and chemical composition.
- The physical and chemical components of waste/wastewater and their mass depend on: **eating habits, standard of living, degree of commercial activity, season, dynamics of economic development, cultural conditions, technical and sanitary equipment, type of industry and its efficiency**, etc.
- The type of waste and wastewater **treatment technology** used, how it is collected and transported, and **the amount of nitrogen recovery and reuse** have a significant impact on nitrogen emissions.

100,000 inhabitants

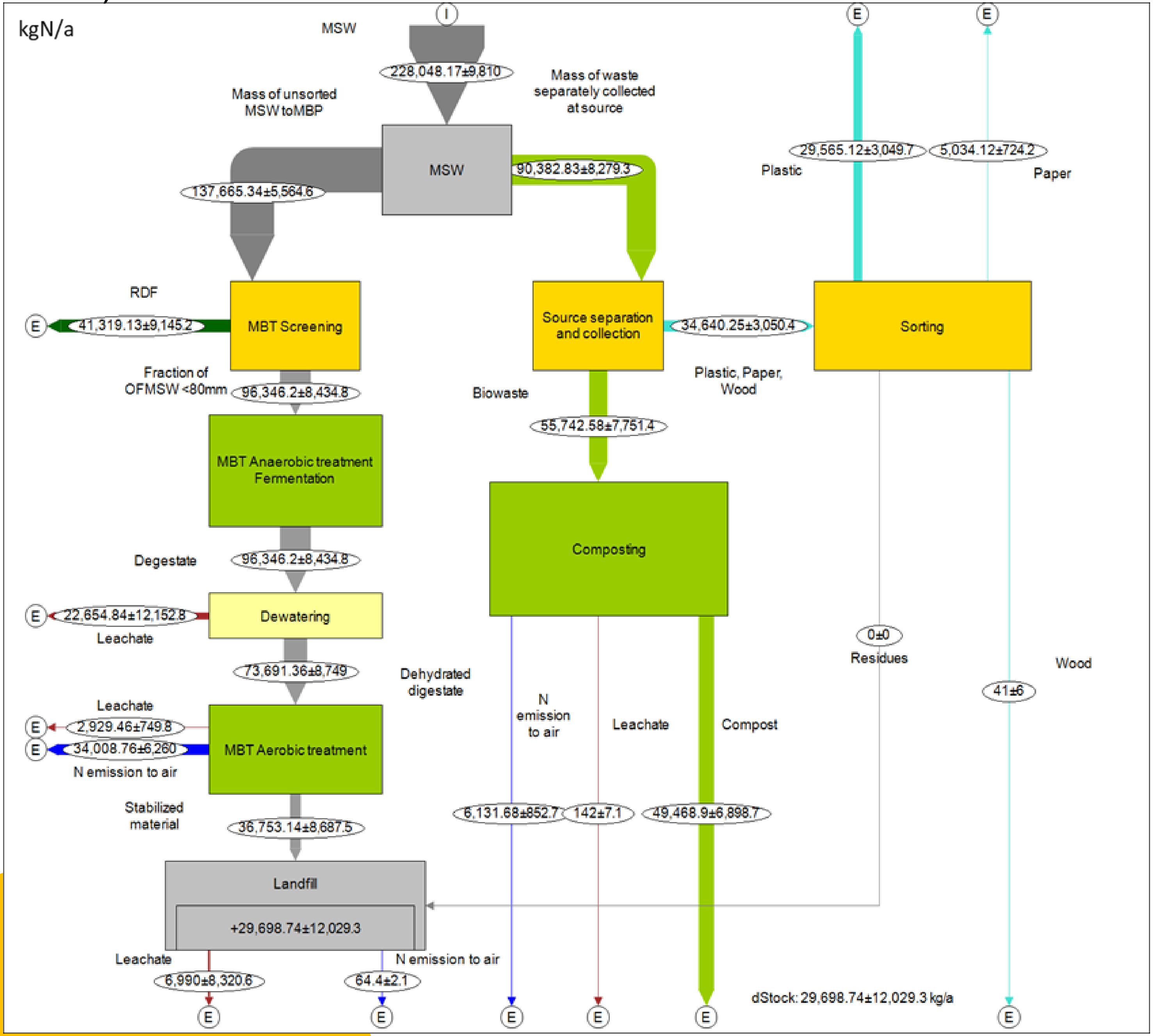


Mechanical-biological treatment of waste

Typical waste management in cities is carried out in mechanical-biological waste treatment plants which aim to:

- biologically stabilize the biodegradable fraction of municipal waste,
- reduce the waste deposited in landfills,
- recover materials.

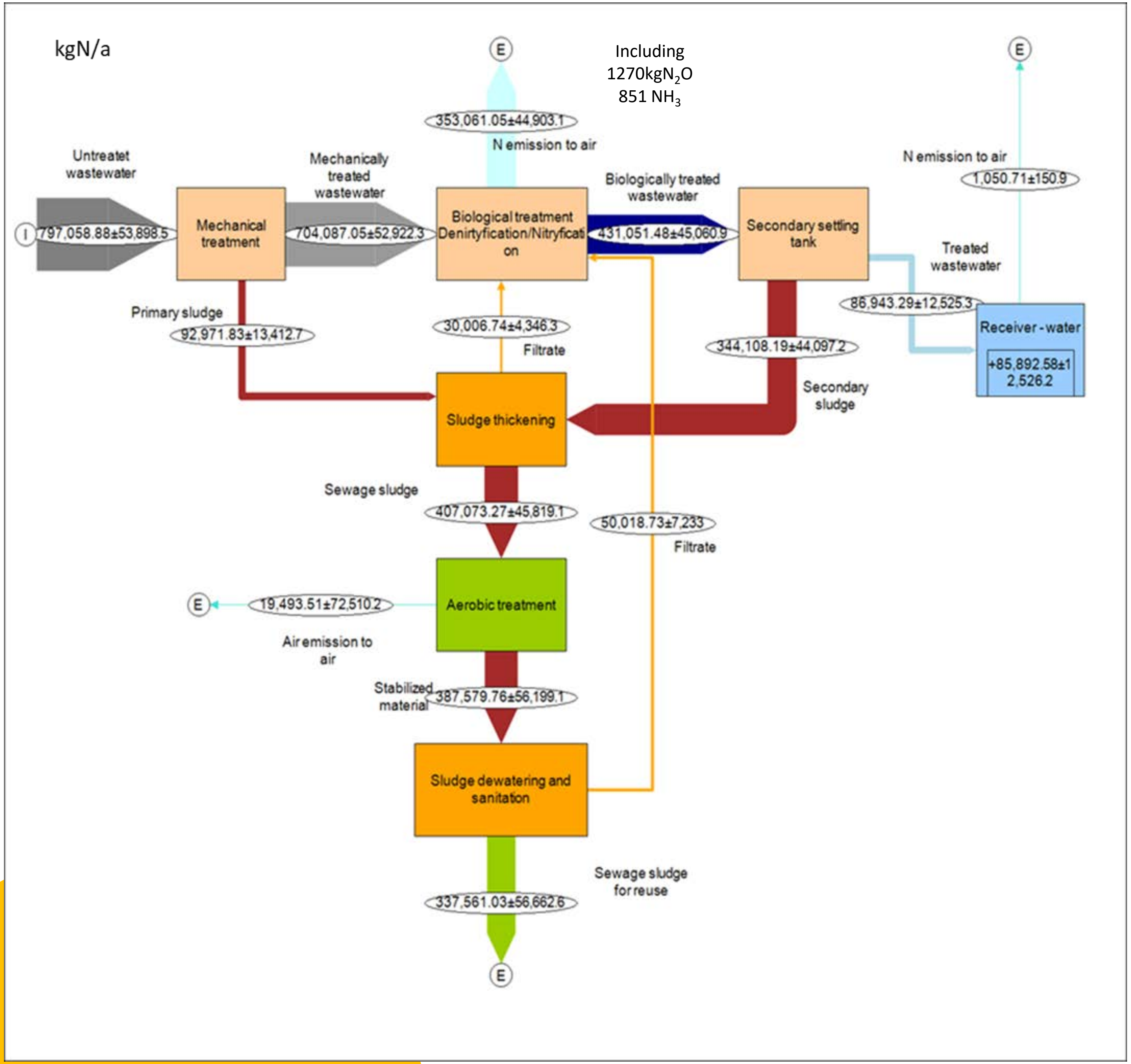
100,000 inhabitants



Mechanical-biological treatment of waste

- Biological stabilization of MSW and collected at source bio-waste can be carried out by aerobic and anaerobic methods. In anaerobic method there is additional energy recovery. And in case of bio-waste there is no emission of Nr to air.

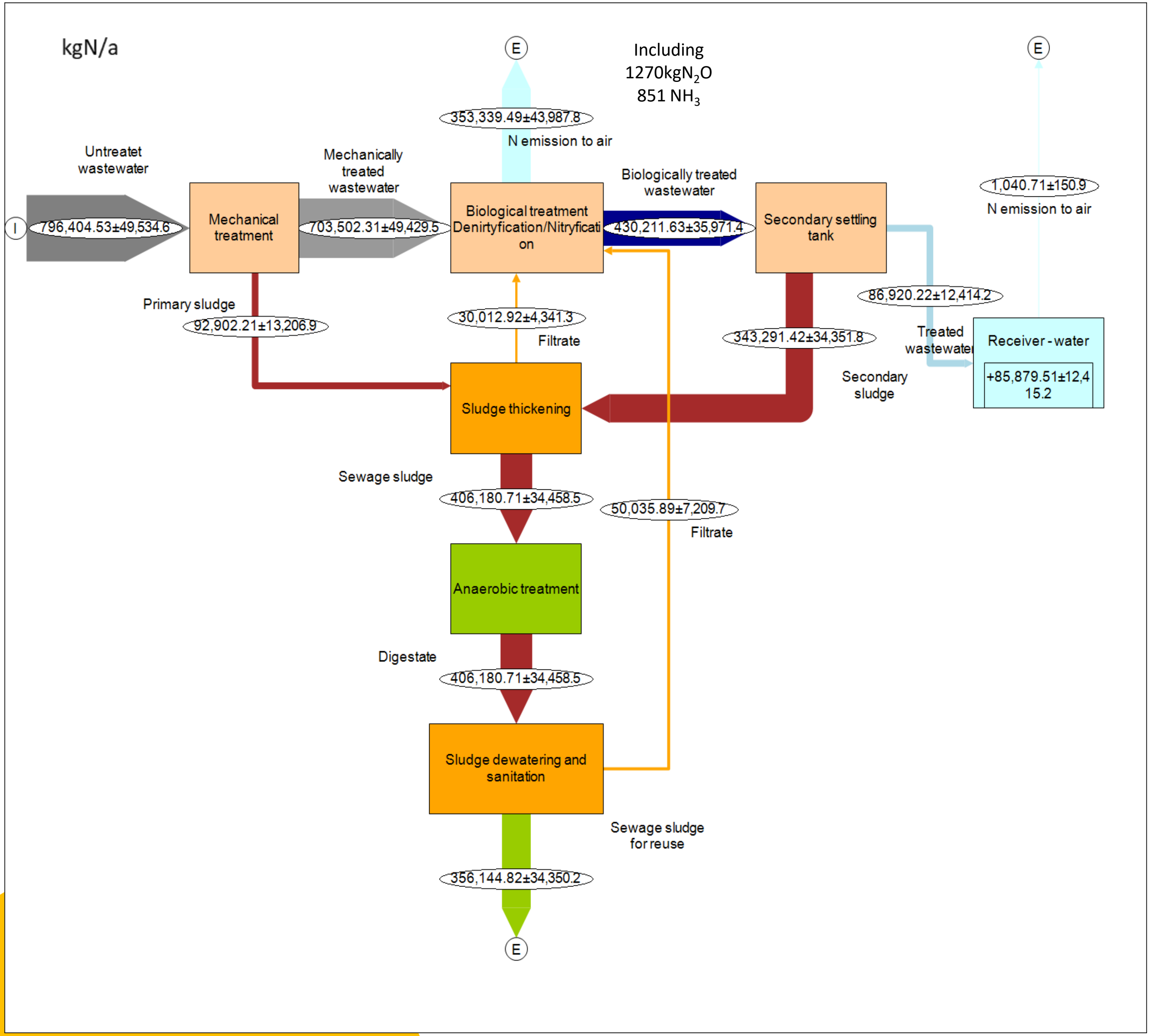
100,000 inhabitants



Wastewater treatment plant

- Typical wastewater treatment is mechanical-biological treatment in activated sludge plants. The main nitrogen emissions during the process occur during the biological nitrogen removal process, nitrification and denitrification. Most of the gaseous nitrogen is emitted during the process, while emissions of nitrous oxide and ammonia are much smaller.
- The main nitrogen stream to be managed is in sewage sludge and treated wastewater. Sewage sludge can be treated under aerobic and anaerobic conditions and these processes result in a product that can be used for nature or agriculture.

100,000 inhabitants



Nitrogen reuse and recovery from wastewater and sewage

A popular method Nr recovery is the production of struvite (ammonium-magnesium phosphate) - mineral fertilizer from sedimentary liquid by precipitation reactions.

Other methods which are at the stage of research and implementation are:

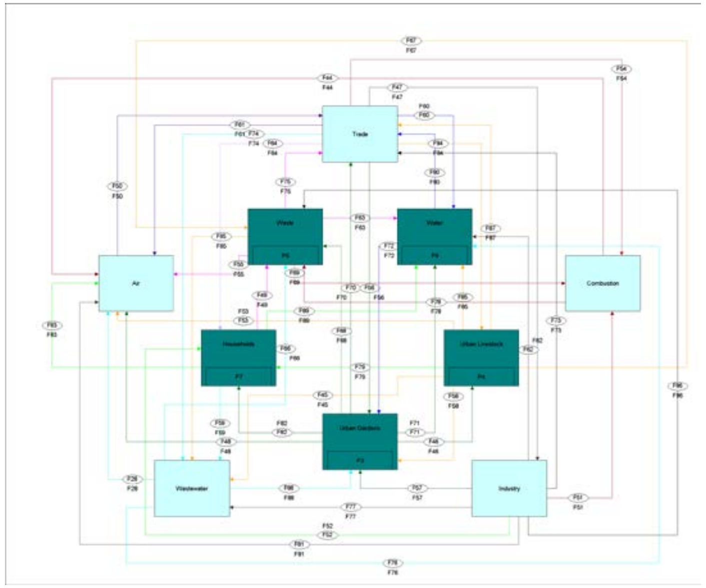
- recovery of ammonia from wastewater and digestion liquids in membrane technologies
- stripping of ammonia in stripping towers with recovery of concentrated solution of ammonium sulfate, ammonium nitrate or ammonia water
- use of urea from wastewater as a catalyst in hydrogen generators
- use of microbial fuel cells (MFC)

How to reduce the amount of nitrogen emitted to the environment

- Increase nitrogen recovery and/or reuse
- Use highly efficient methods to treat nitrogen from wastewater (the higher the efficiency, the lower the N_2O emissions)
- Reuse of treated wastewater
- Increase separate collection of packaging waste and biowaste
- Use anaerobic digestion processes for waste and sludge

Urban Nitrogen Budgets Comparison and Indicators

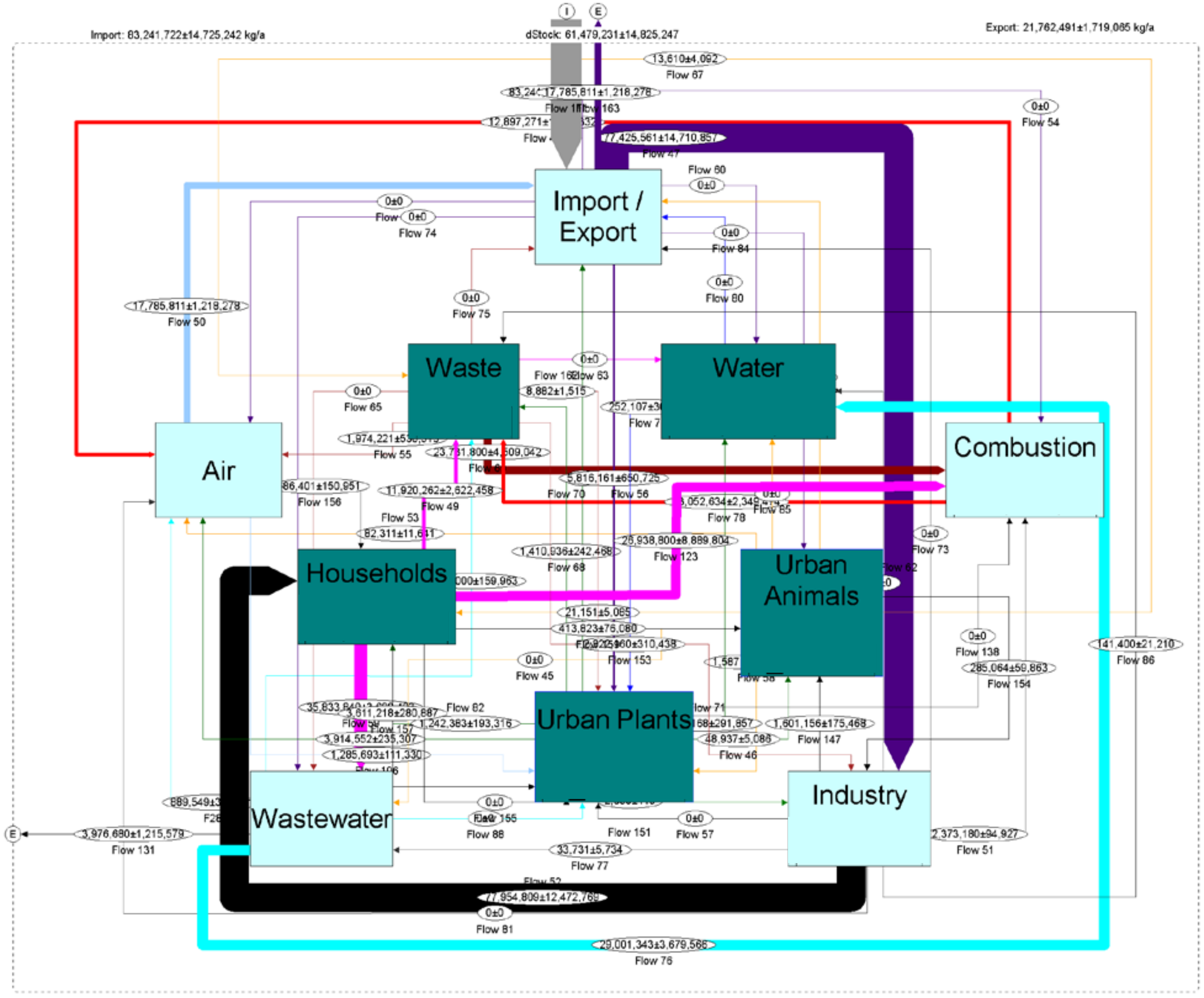
Methodology & Purpose

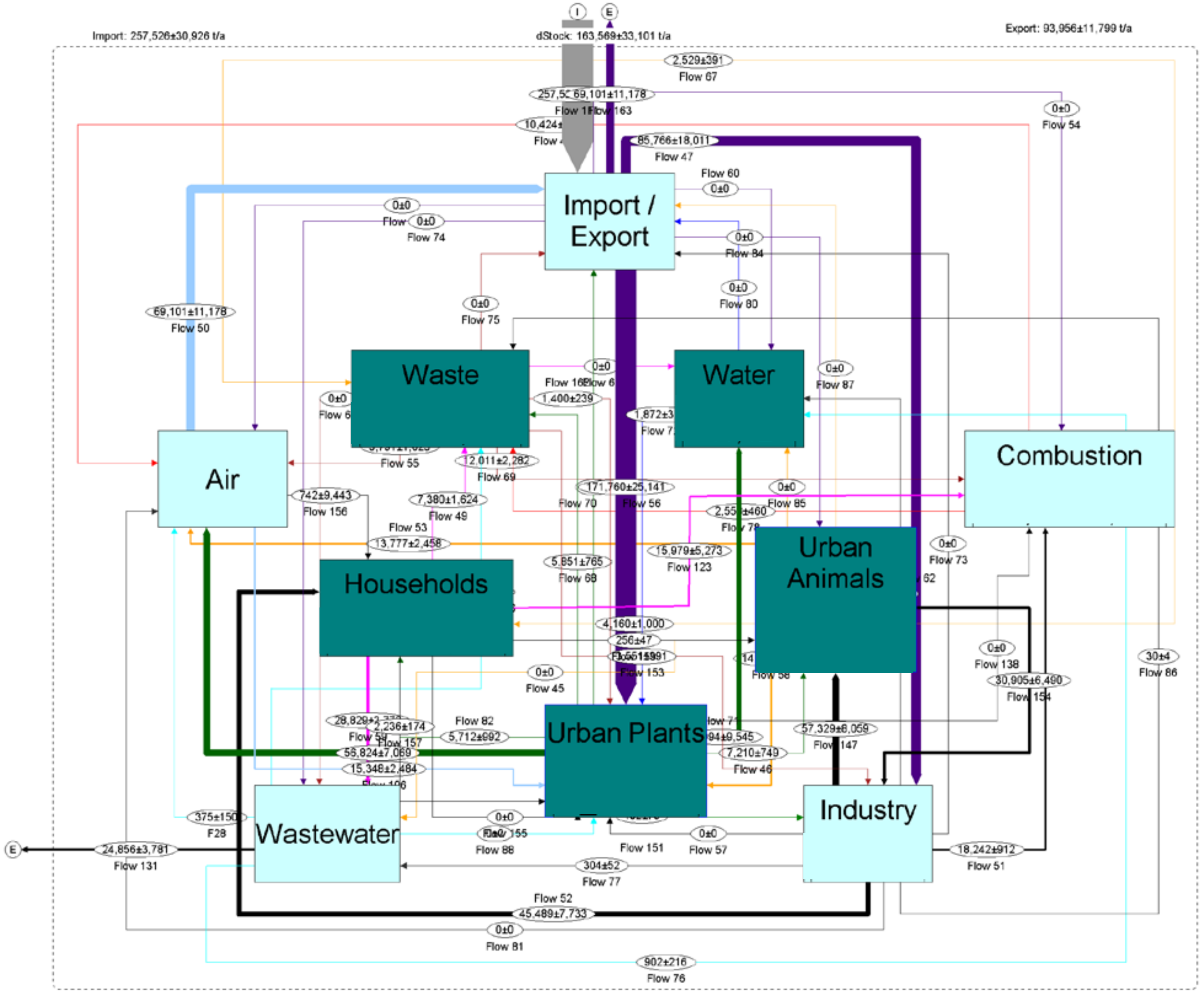


- Characterize system & find patterns
  - Biggest flows per pool and in overall budget
  - Identification of N sinks and sources
  - Flows per capita & per area where relevant
- Evaluate (environmental) impacts
  - Using indicators: NUE, N surplus - planetary boundaries, SDGs
- Evaluate potentials/solutions supporting the development of a circular economy
  - Recycling rate

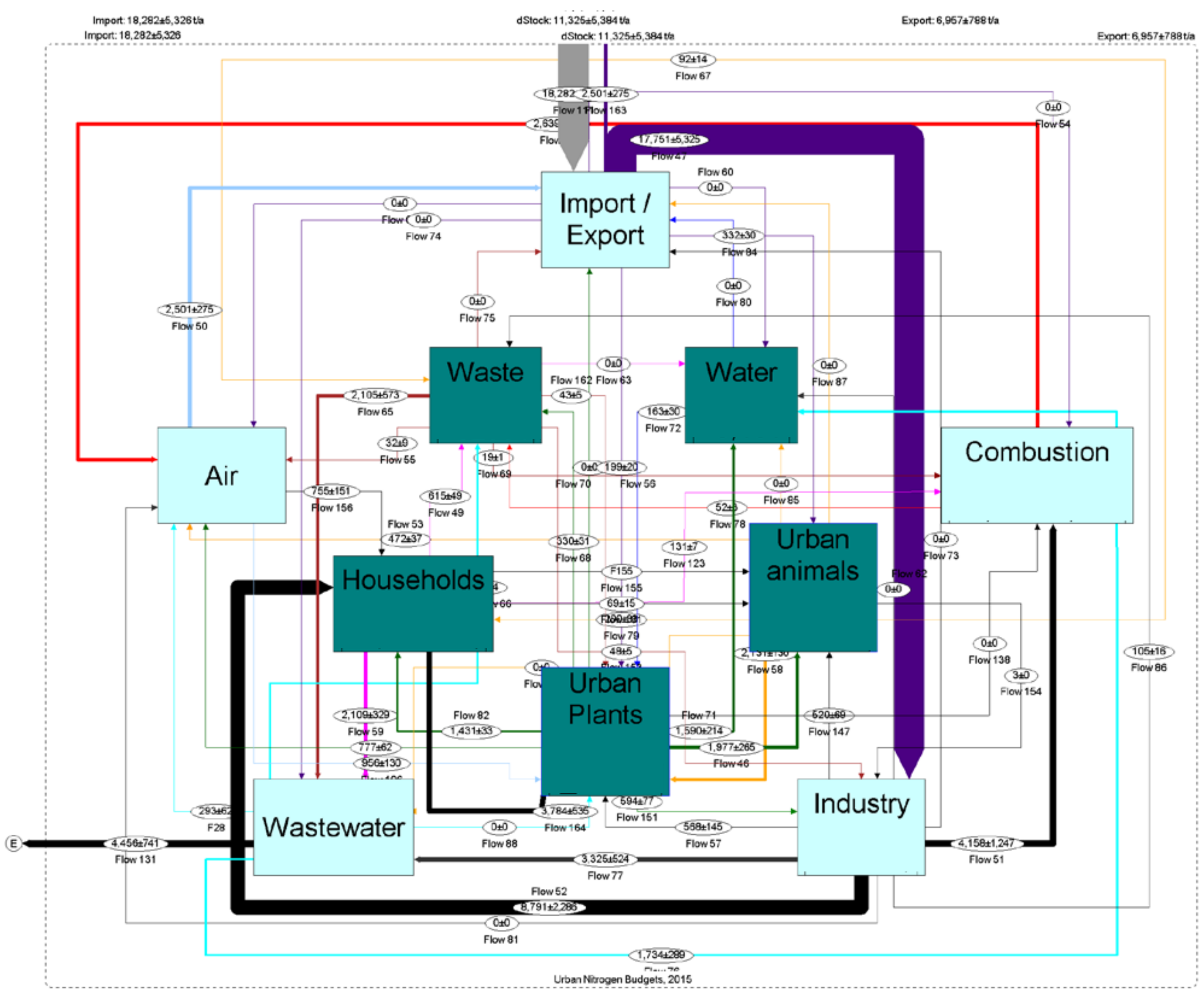
Beijing

Beijing Surrounding

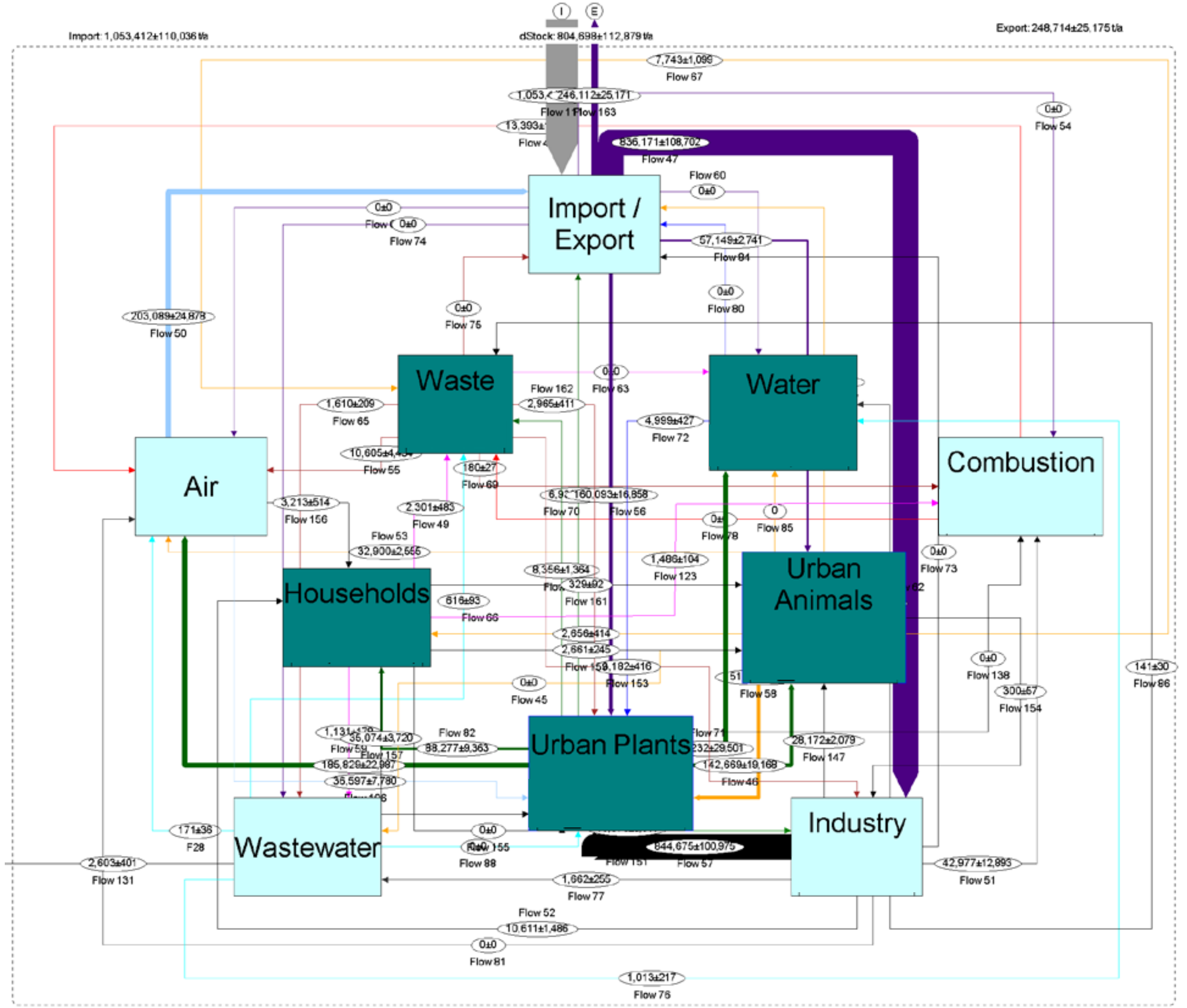


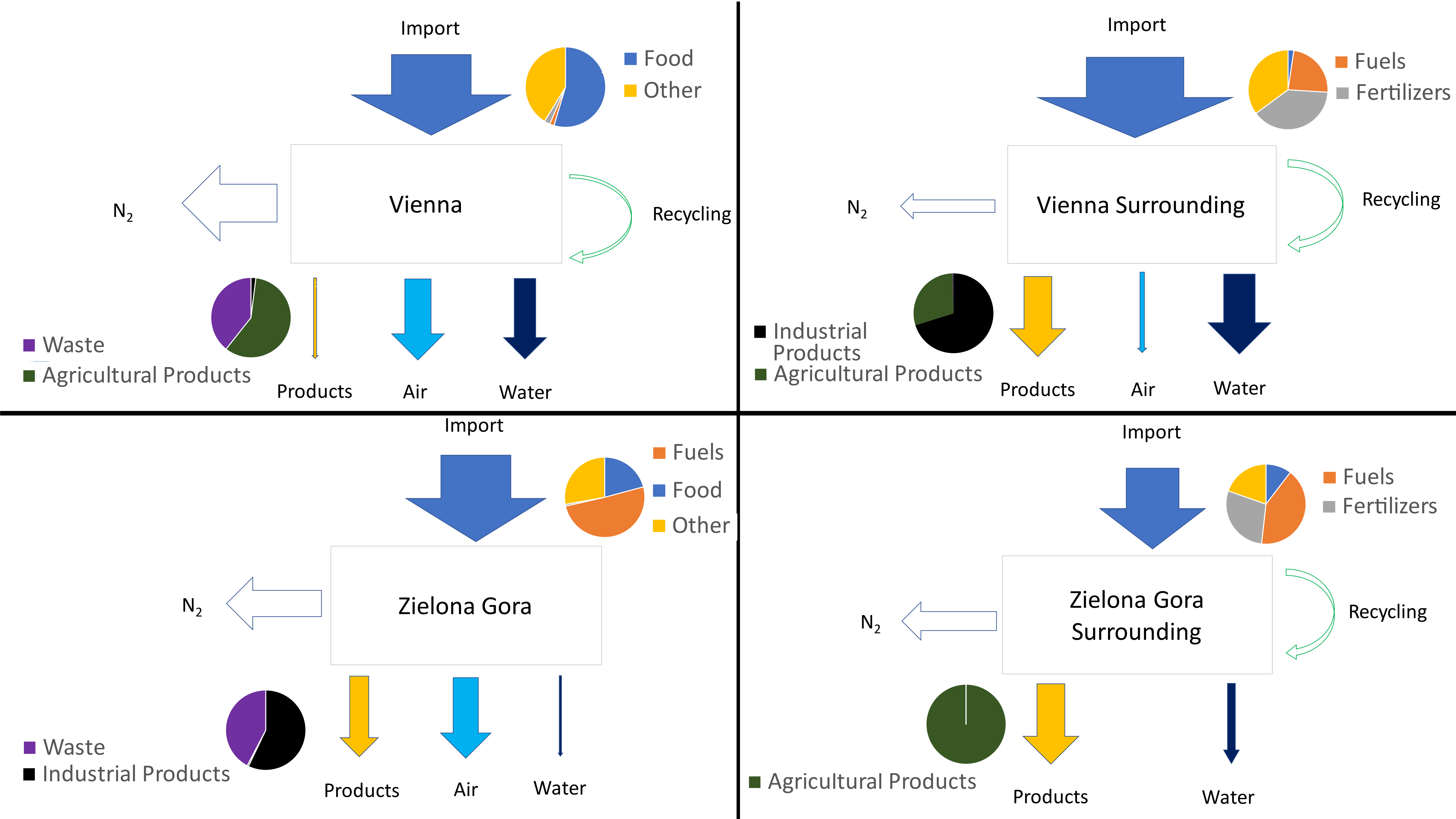


Shijiazhuang



Shijiazhuang Surrounding



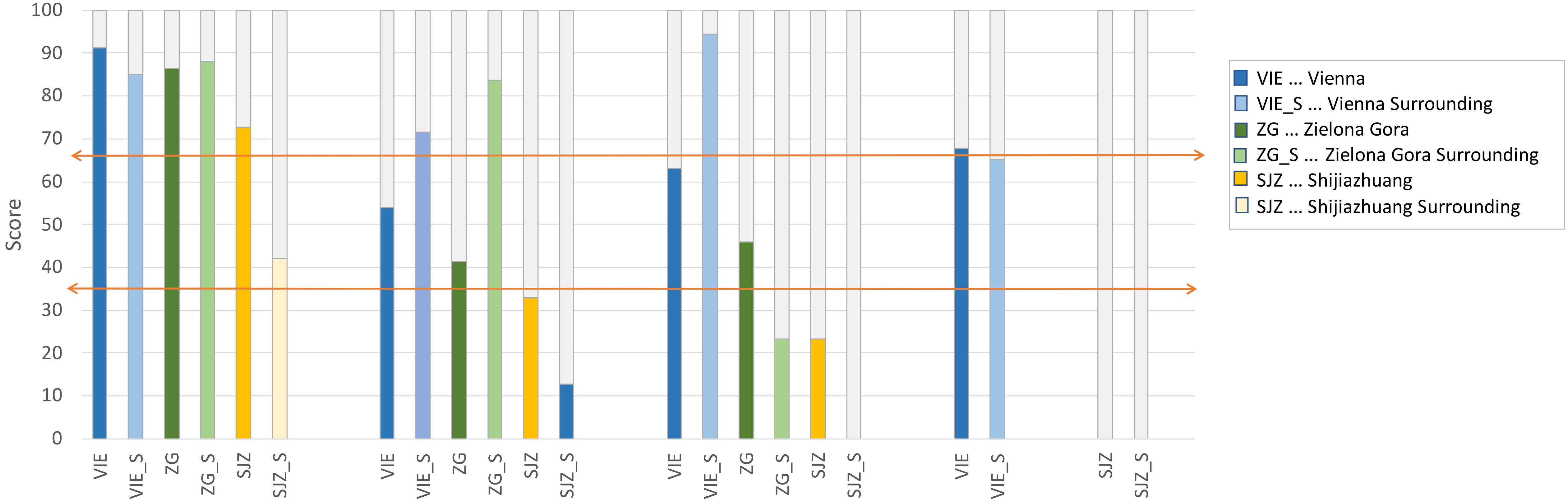


Import
Food
Other
Vienna
N2
Recycling
Waste
Agricultural Products
Products
Air
Water
Import
Fuels
Fertilizers
Vienna Surrounding
N2
Recycling
Industrial Products
Agricultural Products
Products
Air
Water
Import
Fuels
Food
Other
Zielona Gora
N2
Waste
Industrial Products
Products
Air
Water
Import
Fuels
Fertilizers
Zielona Gora Surrounding
N2
Recycling
Agricultural Products
Products
Water

Analysis and Indicators

	Vienna	Vienna Surrounding	Zielona Gora	Zielona Gora Surrounding	Shijiazhuang	Shijiazhuang Surrounding	Beijing	Beijing Surrounding
General								
Recycling (% of import)	4%	6%	0%	13%	32%	19%	8%	8%
Agri-Food Chain								
Self-sufficiency Plant Food	3%	317%	9%	66%	59%	69%	25%	28%
Self-sufficiency Livestock Products	0%	38%	0%	65%	41%	84%	37%	48%
Self-sufficiency Feed	728%	276%	0%	49%	48%	88%	13%	20%
NUE on agricultural land	58%	73%	49%	82%	42%	26%	45%	31%
N surplus [kgN/ha]	53.39	36.55	62.36	20.44	74.00	117.00	65.00	93.00
Emissions (including Combustion Chain)								
N deposition per hectare [kgN/ha]	16.60	12.84	15.78	16.78	24.00	26.00	32.71	47.32
Emission per hectare [kgN/ha]	110.13	15.68	207.39	7.24	40.00	22.00	133.84	15.59
Livestock (% of total emissions)	0%	6%	0%	11%	10%	14%	0%	16%
Agricultural Land (% of total emissions)	1%	21%	0%	25%	8%	76%	6%	56%
Combustion (% of total emissions)	89%	52%	94%	62%	63%	6%	65%	12%
Waste (% of total emissions)	8%	11%	5%	0%	1%	4%	10%	4%
Wastewater (% of total emissions)	1%		0%	0%	7%	0%	5%	0%
Urban Greens (% of total emissions)	1%	10%	0%	2%	10%	0%	5%	6%
Horticulture (% of total emissions)	0%	0%	0%	0%	0%	0%	9%	5%

Urban Nitrogen Budgets and Sustainable Development Goal Scores



NH3 Emissions from Agriculture

NUE

N Surplus

N Losses to Surface