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UNCNET

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

D5/3: Final urban agricultural N flows with uncertainties and relationship with urban sustainable development goals

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Dissemination Level		
PU	Public	☒
PP	Restricted to other programme participants (including funding agencies)	☐
RE	Restricted to a group specified by the consortium (including funding agencies)	☐
CO	Confidential, only for members of the consortium (including funding agencies)	☐

1. Executive Summary

Based on an extended version of the NUFER model, the urban agricultural N flows in Shijiazhuang and Beijing (urban centers as well as surrounding areas) have been calculated. The surrounding areas are the larger producers of reactive nitrogen, and synthetic fertilizer contributed substantially to increased food production in order to supply to city centre. Excess Nr input to city areas and surrounding areas is known to cause air and water pollution. This study presents a complete Nr budget for Shijiazhuang and Beijing and for 10 sub-pools and evaluates environmental consequences of excess Nr. Our analyses demonstrate that anthropogenic Nr creation not only causes increased N input to meet human demand and consumption, but also is responsible for a rapid increase in Nr fluxes to atmosphere and hydrosphere. The characteristics of urban impacts on the N cycle suggests that increasing coupling rate of crop and livestock production could achieve reductions in Nr creation. Besides, this study also creates a relationship between urban agricultural N flow and urban sustainable development goals. Based on this relationship, we explored new indicators of agricultural N flow and corresponding scores. The scores of these new indicators will help inform urban policies to advance sustainable development goals related to urban agriculture.

All activity data (e.g. fertilizer application, crop production, sown area, livestock number, irrigated area, fossil fuel use etc.) were collected from statistical yearbooks and the official website of China National Bureau of Statistics (China Statistical Yearbook, 2015). The parameters (e.g., emission factor, N content, N loss ratio, straw return ratio, manure return ratio) were collected from the NUFER and CHANS models (Ma et al. 2010; Gu et al. 2015).

2. Objectives:

(1). Estimating urban agricultural N flows through cities and surrounding areas.

(2). Linking the urban agricultural N flows with urban sustainable development goals.

(3). Design of new indicators and SDG score calculation.

3. Activities:

Quantify all nitrogen fluxes of agricultural land in urban and peri-urban areas and demonstrate results for Shijiazhuang and Beijing.

Qualitative analysis of the relationship between (urban) agricultural N flows and urban sustainable development goals.

Exploring new nitrogen indicators.

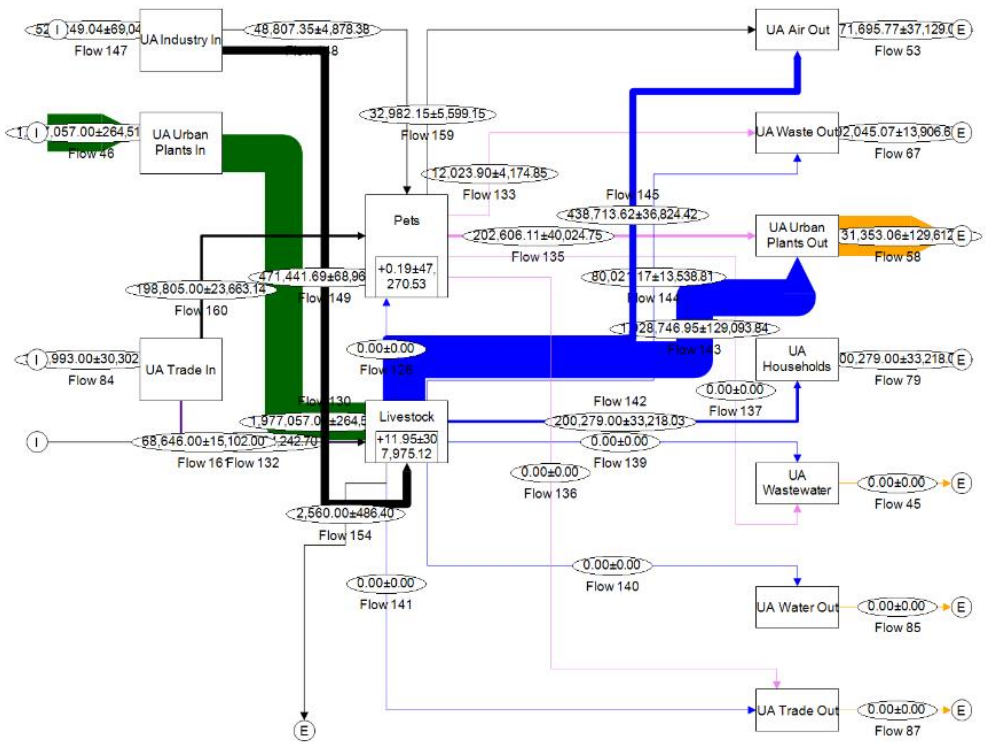
4. Results:

Based on the analysis of urban agriculture, the urban agricultural Nr flow includes the agricultural land pool, the horticultural pool, the urban green pool, the livestock pool and the pet pool. Methods used have been described in detail in earlier UNCNET reports, specifically in UNCNET D5/2 (Bai et al., 2021). The detailed N fluxes among 5 sub-pools for the extended city area of Shijiazhuang and Beijing can be found in Fig 1-4.

<u>Shijiazhuang</u>

The total Nr input in agricultural land pool in Shijiazhuang city centre is 8.2 Gg N. The anthropogenic dominating inputs included household, animal manure and BNF, which account for 46%, 25% and 11%, respectively (see Fig. 1). Total Nr inputs in urban green and horticultural land are less than in agricultural land: the total Nr input of urban green is 1.1 Gg N and total Nr input of horticultural land is 0.2 Gg N. Fertilizer and deposition are dominating inputs of the urban green sub-pool, which account for 50% and 33%, respectively. Shijiazhuang barely plants horticulture and most horticultural products are imported from other areas. Because of that, the imported N is the dominating input in the horticulture sub-pool, accounting for 88% of the total Nr input. The total Nr input of the livestock pool is 2.7 Gg N, among which 75% comes from harvested crops used as feed, and 18% from industrial Nr creation. For the pet pool, all N input comes from pet food.

a.



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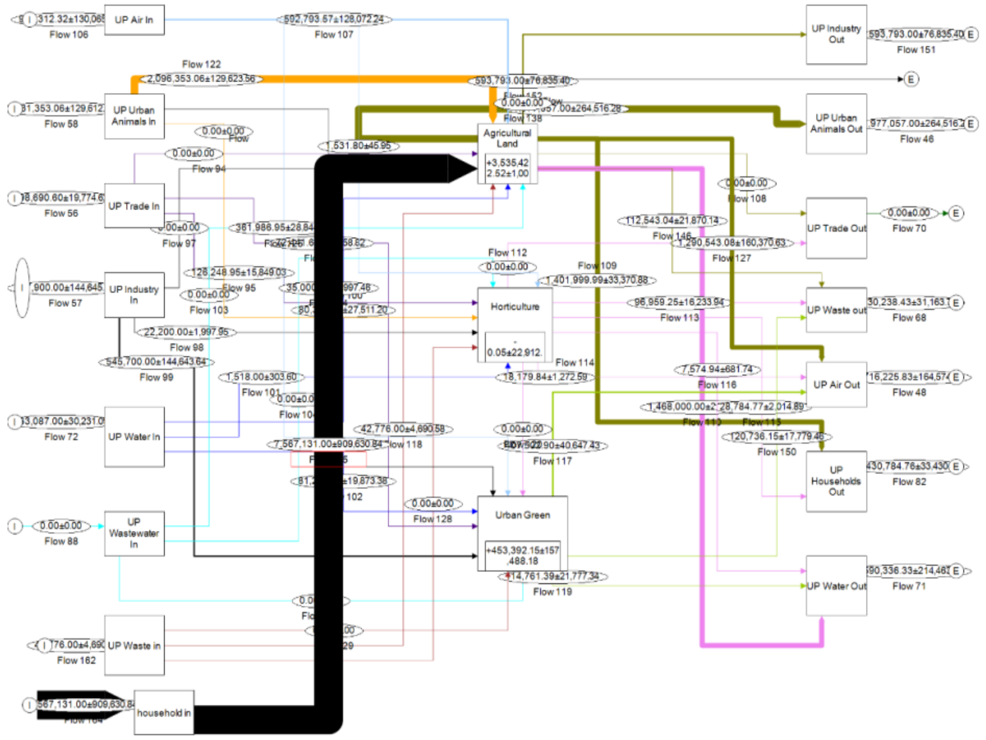
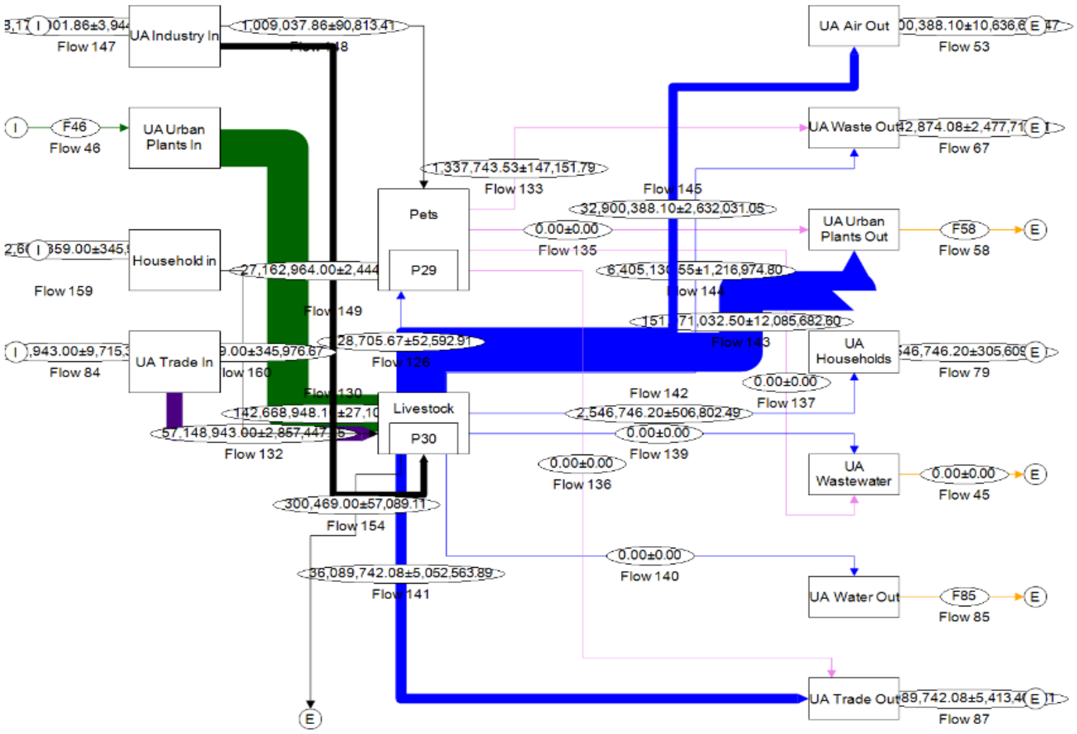


Fig 1. Agricultural N flows in Shijiazhuang city. a, Nitrogen cycling in urban animal pool which includes pets and livestock. b, Nitrogen cycling in urban plant pool which includes agricultural land, horticulture and urban green. The arrow width represents the N flow magnitude. Colors represent the direction of N flows (same colors represent N flows from same sub-pools).

a.



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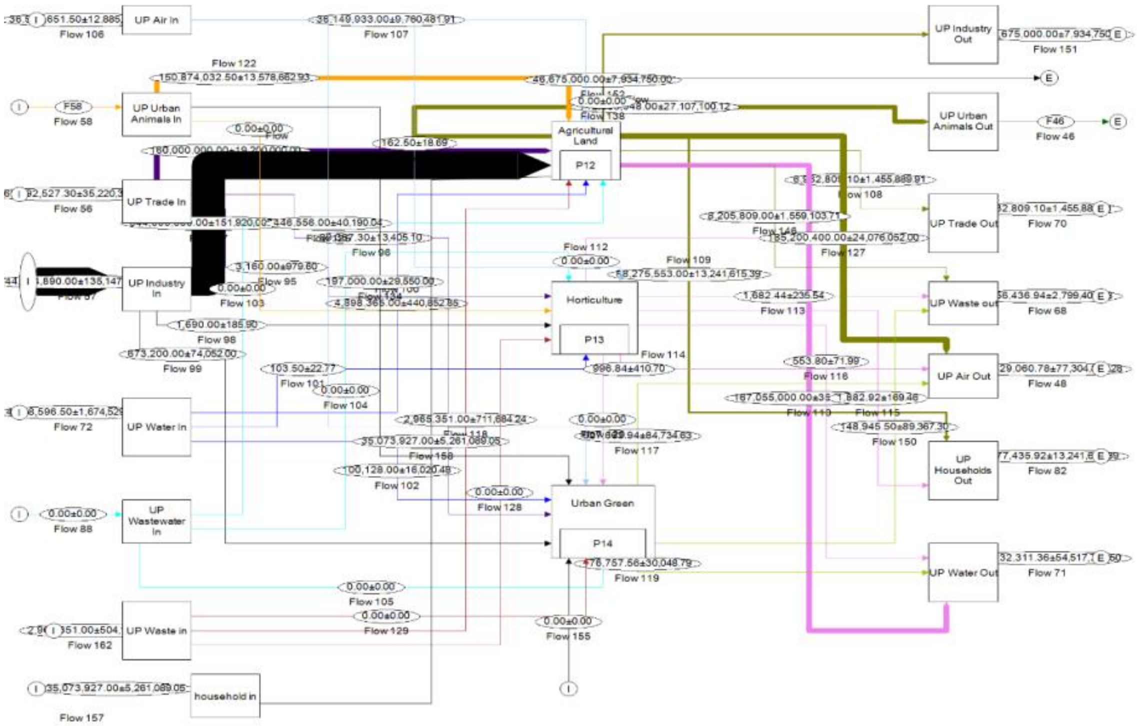


Fig 2. Agricultural N flows in Shijiazhuang surrounding areas. a, Nitrogen cycling in urban animal pool which includes pets and livestock. b, Nitrogen cycling in urban plant pool which includes agricultural land, horticulture and urban green. The arrow width represents the N flow magnitude. Colors represent the direction of N flows (same colors represent N flows from same sub-pools).

The total N outputs are 5.9 Gg N in the agricultural land pool, among which about 33% is discharged into the environment, and 33% is returned to livestock pool as fodder. For urban green, 19% of total Nr output is lost as waste. After decoration in horticulture pool, most of ornamental plants end up to the waste sub-pool. This flow from horticulture to waste is the dominating output, which accounts for 64% of total Nr outputs. In the city centre, the share of manure returned to fields is higher than in the surrounding area. Returning livestock manure to fields is the dominating output of animal husbandry, which accounts for 73% of total Nr output. Further 17% of total output is discharged to air, potentially becoming a pollution hazard.

For cat excretion in city area (pet pool), we assume half is removed as cat litter, while the other half is lost to urban green land. However, dogs' excretion in city area is assumed to be entirely lost to urban green land. As a result of Nr inputs and outputs in the urban plant pool, the Nr accumulations are 1.75 Gg N. Agricultural land and urban green sub-pools contribute to the successive accumulation. The agricultural land sub-pools contributed most of total accumulation.

The total Nr input in the agricultural land pool in the surrounding areas of Shijiazhuang is 1136 Gg N. The dominating anthropogenic inputs included fertilizer and animal manure, which account for 72% and 13%, respectively (see Fig. 2). Total Nr input in urban green and horticultural sub-pools are less than in agricultural land: they amount to 1.5 Gg N and 0.005 Gg N respectively. For the urban green sub-pool, fertilizer and deposition are dominating inputs, which account for 45% and 30%, respectively. Also, the surrounding areas of Shijiazhuang barely have horticulture, hence most of horticultural products have to be imported from other areas. This imported N is the dominating input in the horticulture pool, accounting for 61% of total Nr input. The total Nr input of livestock pool is 229 Gg N, among which the flow from urban plant to livestock (fodder production from agricultural land) and the imported fodder N amount to 62% and 24% of total Nr input, respectively. For the pet pool, the major share of N input comes from pet food. 25% of total pet food comes from households residuals in the surrounding areas.

The total N outputs are 640 Gg N in the agricultural land pool, and approximately 54% is Nr that is discharged into the environment. The major reason is that the level of N management in the surrounding areas is lower than in the city area. 22% of total agricultural land output is returned to livestock pool as fodder. For urban green, 65% of total Nr output is discharged to air, which includes N_2O and NH_3. The households to wastewater and agricultural land flows are the dominating outputs of the households pool, which account together for 85% of total Nr outputs. The livestock manure returned to fields is the dominating output of the livestock sub-pool, accounting for 65% of total Nr output. Additionally, the discharge to air due to NH_3 and N_2O volatilization (14% of total Nr output) may potentially lead to serious atmospheric problems.

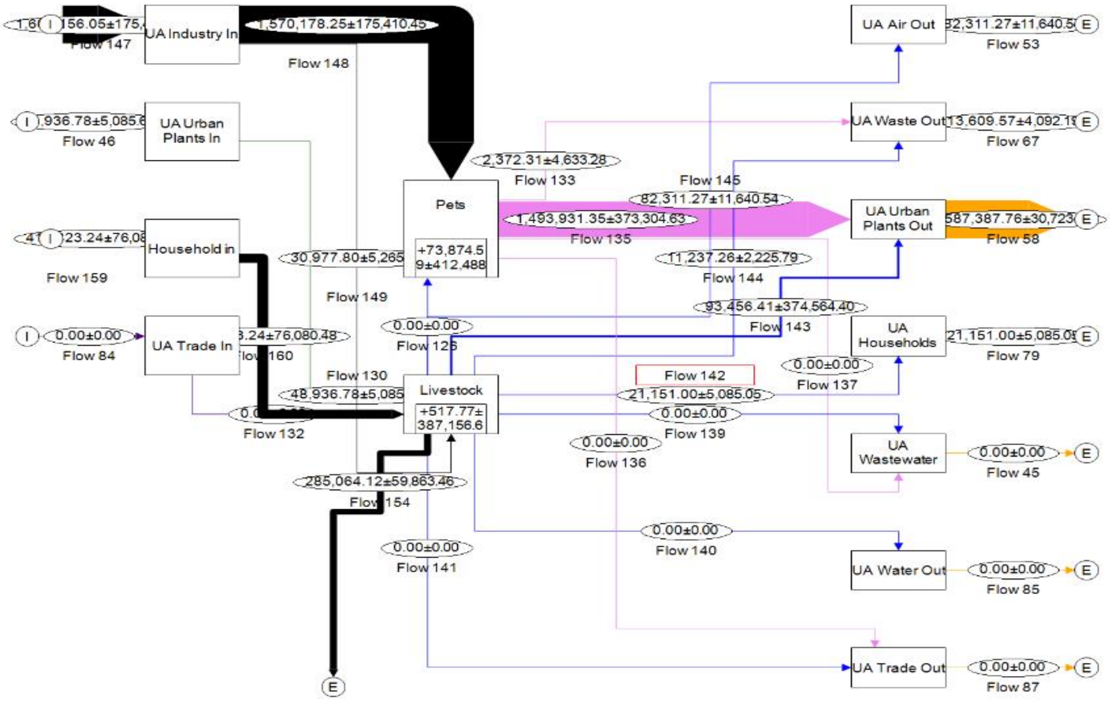
For pet excretion in surrounding areas, we assume all excretion is treated as waste (Gu et al. 2015). As a result of Nr inputs and outputs in the urban plant pool, the Nr accumulations are 617 Gg. Accumulation occurs both in agricultural land and urban green sub-pools, but agricultural land contributed to 99% of the total accumulation.

Beijing

The total Nr input to the agricultural land pool in Beijing city centre is 4.9 Gg N, the anthropogenic dominating inputs included household, mineral fertilizer imports and atmospheric deposition, which account for 73%, 13% and 11%, respectively (Fig. 3). Total Nr input in urban green is 2.9 Gg N, which is less than in agricultural land. Because Beijing uses lots of flowers to decorate streets and squares, the total Nr input to horticultural land has a similar value as for agricultural land, amounting to 4.8 Gg N. Because Beijing city barely plants horticultural products, most of ornamental plants are not produced locally and need to be imported from outside the city borders. Hence N import is the dominating input in the horticulture pool, accounting for 87% of total Nr input (4.1Gg). The total Nr input of the livestock pool is 0.5 Gg N, and the Nr flow from household to livestock (kitchen residues recovered from households as animal feed) amounted to 84% of total Nr input. The flow from agricultural land to livestock (harvested crops used as feed) amounted to 10% of total Nr input. For the pet pool, all N input comes from pet food.

The total N outputs are 2.3Gg N in the agricultural land sub-pool, among which about 46% and 48% is Nr losses to water and air (N_2O，NH_3), respectively. Additionally, 2% of total agricultural land output is returned to the livestock pool as fodder. For the urban green sub-pool, 73% of total Nr output are losses to air. The atmospheric emissions and waste are the dominating outputs in the horticulture pool, accounting for 37% and 27% of total Nr outputs, respectively. Furthermore, the flow from horticulture to households and losses to water account for 25% and 11% of total Nr output, respectively. For the livestock sub-pool, the flow from livestock to industry is the dominating output, accounting for 58% of total N output. For the pet pool, we assume that half of the excretion from cats in the core city area is transferred to waste while the other half is lost to urban greens. On the other hand, dogs' excretion in the core city area is assumed to be integrally excreted to urban greens. As a result of Nr inputs and outputs in the urban plant pool, the Nr accumulations amount to 6.4 Gg N. Both agricultural land and urban green areas contribute to the accumulation, with the agricultural land sub-pools accumulating 75% and urban green sub-pools 22% of the total accumulation.

a.



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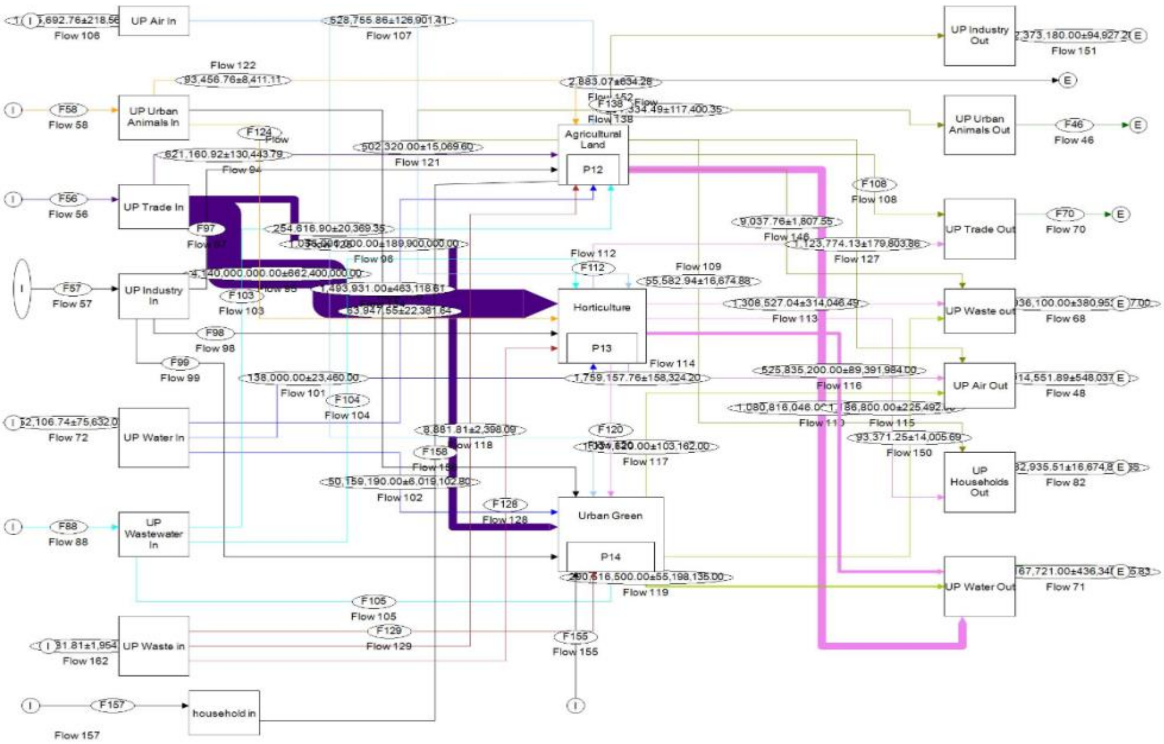
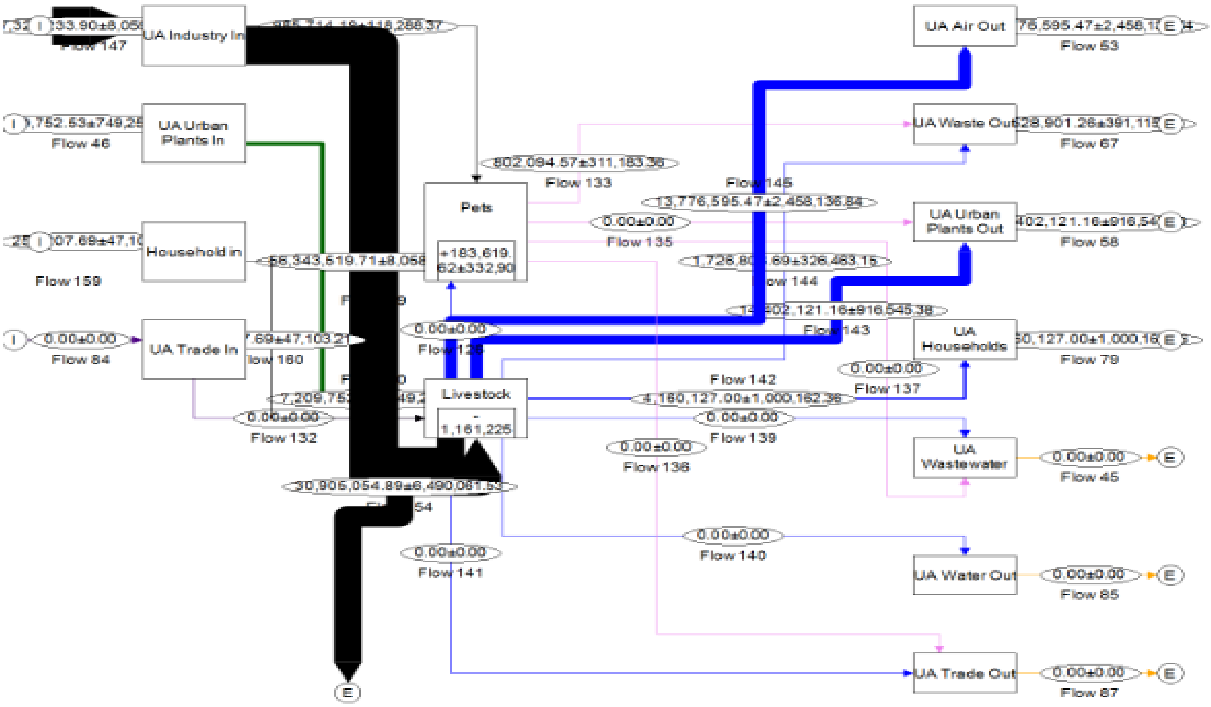


Fig 3. Agricultural N flows in Beijing city. a, Nitrogen cycling in urban animal pool which includes pets and livestock. b, Nitrogen cycling in urban plant pool which includes agricultural land, horticulture and urban green. The arrow width represents the N flow magnitude. Colors represent the direction of N flows (same colors represent N flows from same sub-pools).

a.



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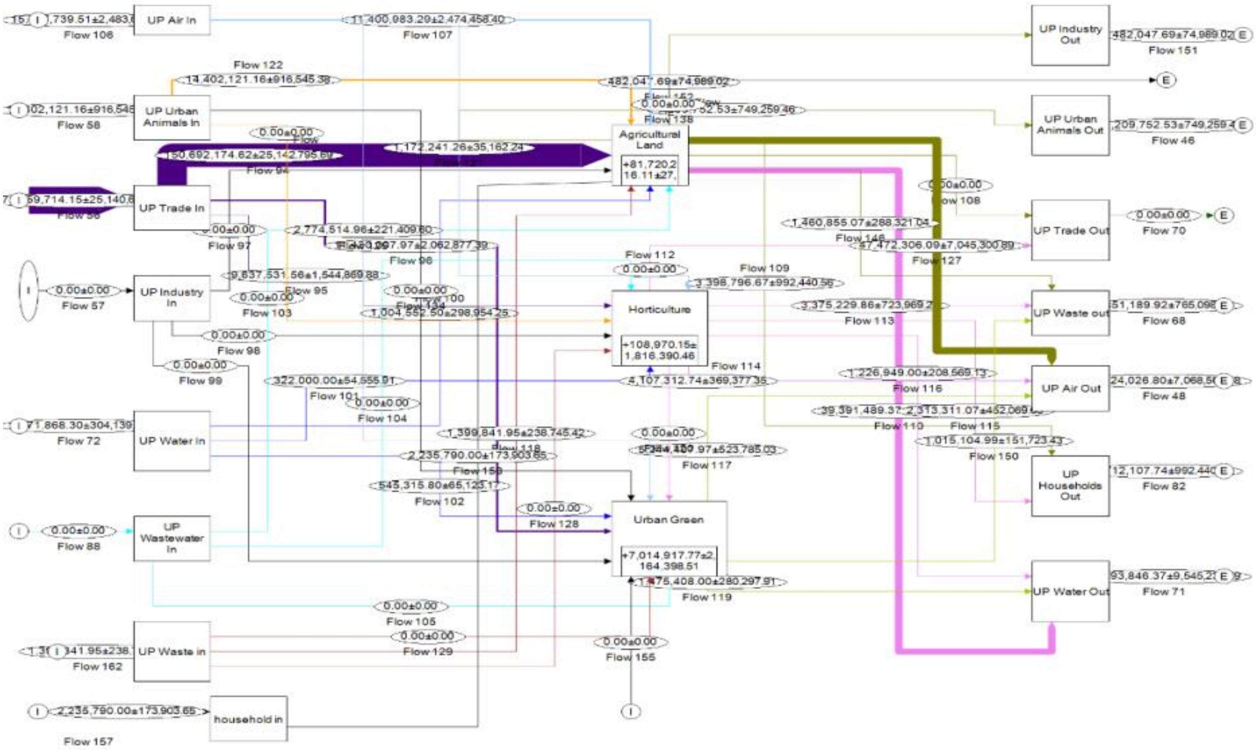

Fig 4. Agricultural N flows in Beijing surrounding areas. a, Nitrogen cycling in urban animal pool which includes pets and livestock. b, Nitrogen cycling in urban plant pool which includes agricultural land, horticulture and urban green. The arrow width represents the N flow magnitude. Colors represent the direction of N flows (same colors represent N flows from same sub-pools).

Because Beijing surrounding areas have larger agricultural land than the urban areas, application of mineral fertilizer is the major N input. The total Nr input in agricultural land pool in Beijing surrounding areas is 192 Gg N. The dominating anthropogenic inputs include imported mineral fertilizer and animal manure, which account for 85% and 7%, respectively (Fig. 4). Total Nr input in urban green and horticultural sub-pools are much smaller than in the agricultural land sub-pool, amounting to 14.7 Gg N and 11.2 Gg N of the total Nr input, respectively. For the urban green sub-pool, imported fertilizer and deposition are dominating inputs, which account for 78% and 19%, respectively. As for Beijing core area, the surrounding areas also need large quantities of horticultural crops to decorate streets and squares. Because Beijing surrounding areas barely plant horticultural crops, most of them need to be imported from other areas. Hence the imported N constitutes about 87% of total Nr input (9.7Gg N). The total Nr input of livestock pool is 64.1 Gg N, from which imported fodder comprises 88%. For the pet pool, all N input comes from pet food.

The total N outputs are 99 Gg N in the agricultural land pool, from which 87% are Nr losses to the environment. The major reason is that the level of N management in the surrounding areas is lower than in the city area. 7% of total agricultural land output returns to livestock pool as fodder. For the urban green sub-pool, 68% of total Nr output is discharged to air, which is the dominating output. For the horticulture sub-pool, waste output and atmospheric emissions are the dominating outputs which account for 37% and 30% of total Nr output, respectively. The flow from livestock to industry is the dominating output of the livestock sub-pool and accounts for 48% of total Nr output. The flows from livestock to air and livestock to agricultural land (i.e., manure N) have similar magnitudes, accounting for 19% and 22% of total N output, respectively. For the pet pool, we assume that all excretion is treated as waste. As a result of Nr inputs and outputs in the urban plant pool, the Nr accumulations are 101 Gg N. Agricultural land and urban green sub-pools both contribute to 92% and 8% of the total accumulation, respectively.

Nitrogen and the Sustainable Development Goals

Developing agricultural N budgets offers opportunities to extract meaningful indicators from such a dataset. The UN Sustainable Development Goals (SDGs) require multiple such indicators to be developed from readily available data (see e.g. Schmidt-Traub et al., 2017). Hence, we establish relationships between data derived in the nitrogen budget and the SDGs.

To perform a quantitative analysis, we need to identify SDGs for which threshold values are available. Using the online databases for the Sustainable Development Report (SDR) 2022 and European Sustainable Development Report (ESDR) 2021 (Lafortune et al. 2021; Sachs et al. 2022), as well as references from the literature (Zhang et al. 2015, 2021; Winiwarter et al. 2020), we identified 8 nitrogen indicators for which thresholds have been quantified: Sustainable Nitrogen Management Index (SNMI), Nitrogen Use Efficiency (NUE), N surplus, NH_3 emissions from agriculture, NO_3^- concentration in groundwater, Recycling rate, Production-based N emissions, and N_2O emissions from agriculture. On the basis of the above literature, each of the 8 N indicators was connected to one of the 17 SDGs at a time, following a single-goal mapping framework (Table 1).

Table 1. Single-goal mapping between N indicators and Sustainable Development Goals.

N Indicator	SDG
SNMI	2
NUE	2
N Surplus	2
NH_3 emissions from agriculture	3
[NO_3^-] in groundwater	6
Recycling rate	12
Production-based N emissions	12
N_2O emissions from agriculture	13

To enable cross-comparison among indicators and to identify priorities for improvement in a city's performance, we designed a methodology for score calculation following the framework adopted in the latest Sustainable Development Report (Sachs et al., 2022). The score of each indicator provides an overview of the sustainability performance of each city. For some of the selected indicators, (E)SDR online databases (Lafortune et al., 2021; Sachs et al., 2022) provide an optimum and a lower boundary value. We understand the actual value of each indicator being in between, and define the score between 0 (lower bound) and 100 (optimum) as the linear value (in %) the actual indicator takes according to equation (1):

$$Score_i = 100 * \frac{Raw_i - min_i}{max_i - min_i} \tag{1}$$

Where Raw_i is the value of the indicator, min_i the value of the lower threshold limit (lower bound), and max_i the value of the ideal situation (optimum) for the i'th indicator using threshold values for each indicator as shown in Table 2.

For the remaining N indicators for which lower bound and optimum values are not available as such, available low ("red") and high ("green") thresholds from the literature are collected assuming that they correspond to scores of 33 and 67 respectively (i.e., one-third and two-third of the 0-100 score scale). In this case, the score is calculated similarly to Equation (1), but linearizing this time between the "red" and "green" thresholds:

$$Score_i = 33 + 33 * \frac{Raw_i - Red_i}{Green_i - Red_i} \tag{2}$$

where Red_i is the value of the lower red threshold, and $Green_i$ the value of the higher green threshold for the i'th indicator. In both cases the score values Raw_i are set to 0 and 100 when they are lower than 0 or higher than 100, respectively.

Like the SDG Dashboards, we follow a “traffic light” color scheme (green, yellow, orange, and red) providing a visual representation of each city’s performance. The two options of calculating SDG scores from available thresholds on environmental N indicators are illustrated in Figure 5.

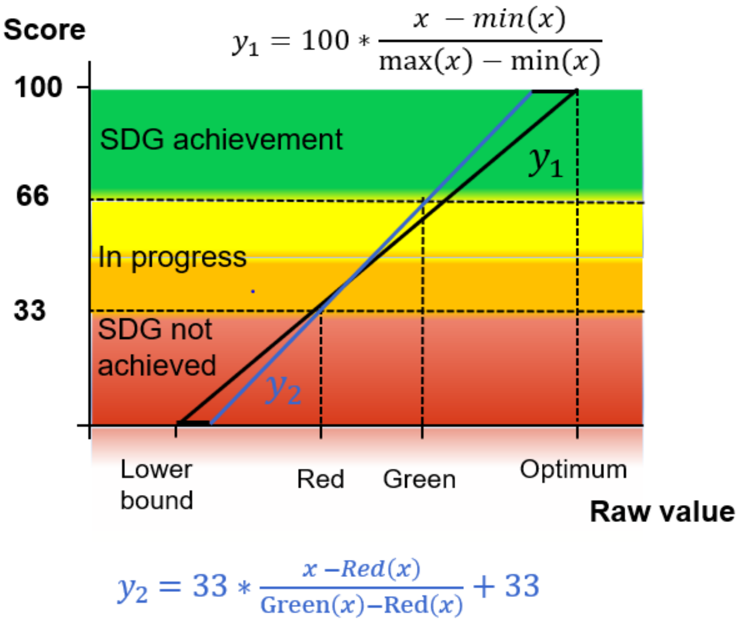

Fig.5. SDG Score calculation methodology following a traffic light color scheme. Lines y_1 and y_2 correspond to a linearization between lower bound and optimum (Sachs et al. 2022), and between Red and Green (Zhang et al. 2021) thresholds values respectively.

The lower bound, red, green, and optimum threshold values are summarized for each selected N indicator in the following Table 2:

Table 2: Green and red thresholds of the N indicators. In a traffic light system, values between the green and optimum thresholds would be shown positively, in green, and values between the red and lower bound thresholds problematic, in red.

Indicator	Unit	Lower bound	Red threshold	Green threshold	Optimum	Reference
SNMI		1.2	0.7	0.3	0	Sachs et al. 2022
NUE	%		0.68	0.42		Zhang et al. 2015
Nitrogen surplus	kg N/ha	200	100	50	10	Lafortune et al. 2021
NH_3 emission from agriculture	kg NH_3/ha	60	45	20	8	Lafortune et al. 2021
[NO_3^-] in groundwater	mg NO_3^-/L	60	50	25	10	Lafortune et al. 2021
Recycling rate	%		7	20		Winiwarter et al. 2020
Production-based N emissions	kg N/cap	30	20	10	2	Lafortune et al. 2021
N_2O emissions from agriculture	ton CO_2eq/ha		0.51	0.41		Zhang et al. 2021 + GAINS model

Based on the above framework, we designed an Urban SDG Index aggregating the various scores of the respective N indicators into a single number, ranging from 0 to 100. The index was calculated as the average of the score of the respective SDGs, considering an equal weighing for each goal. For the score goals calculated on the basis of several N indicators (i.e., SDG 2 and SDG 12), an equal weighing for each N indicator was similarly assumed.

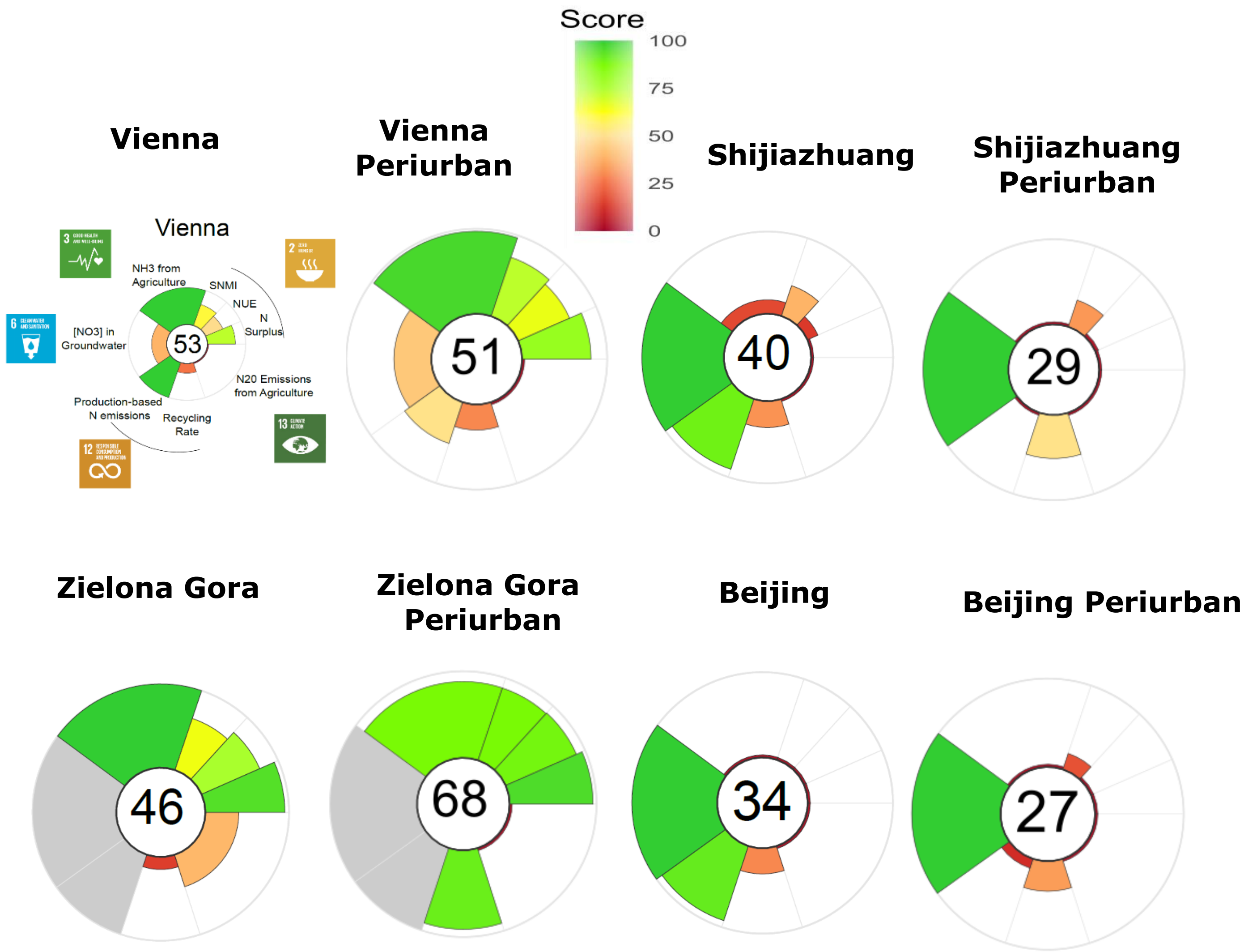

Figure 6. Urban SDG Index to benchmark achievements of SDG's for all of the UNCNET test areas, using a traffic light approach. Same width is provided for each SDG, thus narrower pies are shown where an SDG is characterized by more than one goal.

Fig. 6 provides a comparison of all of the UNCNET test areas for their performance regarding the SDG's, based on this indicator approach and also includes the European sites of Vienna and Zielona Góra. The comparison indicates sustainability challenges in several aspects for the Chinese test areas that are much less relevant for the European cities, even though also in Europe the improvement of NUE and N surplus remains still to be solved also for urban areas.

5. Milestones achieved:

While none of the defined UNCNET milestones are affected, this report describes the following achievements:

(1) The urban agricultural N flows in Shijiazhuang and Beijing have been compiled.

(2) The relationship between urban agricultural N flows and urban sustainable development goals has been developed.

(3) New indicators and score calculation methods have been explored.

6. Deviations and reasons:

Delays caused by COVID-19.

7. Publications:

Bai, Z., Fan, X., Jin, X., Zhao, Z., Wu, Y., Oenema, O., ... & Ma, L. (2022). Relocate 10 billion livestock to reduce harmful nitrogen pollution exposure for 90% of China's population. *Nature Food*, *3*(2), 152-160.

8. Meetings:

Multiple on-line discussion meetings with partners

9. List of Documents/Annexes:

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Zhang, X., Davidson, E. A., Mauzerall, D. L., Searchinger, T. D., Dumas, P., & Shen, Y. (2015). Managing nitrogen for sustainable development. Nature, 528(7580), 51-59.

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