Urban Europe and NSFC

Europe – China joint call on Sustainable Urbanisation in the Context of Economic Transformation and Climate Change: Sustainable and Liveable Cities and Urban Areas

Funded by
NCN (Poland), project UMO-2018/29 / Z / ST10 / 02986
NSFC (China), project 71961137011
FFG (Austria), project 870234

UNCNET

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

D7/3: Report on comparison between cities and alternative nitrogen flows

Due date of deliverable: **31/05/2022**

Actual submission date: **31/08/2022**

Start Date of Project: **01/04/2019**

Duration: **35 months + 6 months**

Organisation name of co-chairs for this deliverable: **IIASA, UZG**

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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

Urban as well as peri-urban areas are sites of reactive nitrogen (Nr) transformation. Nr enters these areas as food, products, fuel, fertilizers, or livestock. These inputs are then transformed to products (e.g. food produced from fertilization or meat from imported livestock) that are either consumed within the city or exported as well as directly or subsequently turned to waste or emissions to water or air (including non-reactive N_2). However, it is possible to recycle Nr waste (=unintended by-products such as manure, sewage sludge or compost). Depending on the test areas, different patterns of these flows and transformations can be observed.

A distinct difference in the patterns of Nr flows through the test areas can be observed between the core (urban) and surrounding (peri-urban) region in all cities (Vienna, Zielona Góra, Beijing and Shijiazhuang). In the core area, the biggest share of Nr entering the area is emitted to the atmosphere, mostly in the form of N_2 from wastewater treatment but also as NO_x from combustion processes. In the surrounding areas of the European cities, most Nr is either exported as goods (agricultural goods like food or feed) or stays within the area as stock which can mostly be found in the agricultural sector (e.g. due to excessive fertilizer use). In the Chinese surrounding areas, Nr is not exported as product or only to a negligible extent. The largest share of Nr remains within the test areas as stock in agricultural soils due to excessive fertilization (N input to soils is up to 10 times that of the European test areas). However, these general patterns can also vary depending on the test area's local production and consumption patterns. In Zielona Góra, for example, Nr export in product is also high in the core area due to a local wood factory.

Investigating these patterns allowed us to not only find differences and similarities but also to identify potential challenges and potentials. With most of Nr being 'wasted' in core areas due to its conversion to N_2, making use of wastewater and especially sewage sludge poses a potential for Nr recycling. In Vienna, for example, composting sewage sludge would provide enough Nr to substitute the total use of mineral fertilizer in Vienna, with 2/3 of the compost still remaining available for export. But also enhancing waste management is an option: recycling the organic fractions in residual waste could replace synthetic fertilizer use (which is low) in Vienna. In the Shijiazhuang core area, available data indicate that human excreta is recycled to agricultural land directly. As no sanitary problems are reported (that might be expected to be connected with such practices) further indirect confirmation is still needed. Yet, clearly, human metabolic Nr constitutes the most prominent potential for recycling due to the very large amounts. Case studies in China in general demonstrate large amounts of Nr remaining in the soils, also from mineral fertilizers, which calls for a focus to be directed towards more sustainable N management.

In conclusion, a detailed comparison between the flows of all test areas confirmed distinct patterns between the core and surrounding area, showed how regional structural differences impact the flows, and allowed us to find challenges and potentials linked to Nr accumulation.

2. Objectives:

The objective of this deliverable was to compare all urban N budgets in detail, highlight similarities or differences between the test areas and identify points of improvement for Nr management (e.g. potentials for Nr recycling).

3. Activities:

- Development of indicators that facilitate comparison
- Comparison of all urban N budgets per pool
- Identification of challenges and potentials
- All of the above required extensive communication between the partners (e.g. Zoom calls)

4. Results:

An elaborate report describing the differences of flows between the test areas per pool

5. Milestones achieved:

M4 - Successful coupling of N budgets and impact modelling

6. Deviations and reasons:

Delay due to Corona crisis.

7. Publications:

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8. Meetings:

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9. List of Documents/Annexes:

Annex I: Urban Nitrogen Budgets: A Comparison

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ANNEX I

Urban Nitrogen Budgets: A Comparison

Introduction and context

The UNCNET project establishes and quantifies flows of reactive nitrogen compounds through individual pools of a society and its environment on an urban scale. Specifically, four cities have been selected as test areas, Vienna (Austria), Zielona Góra (Poland), and Beijing and Shijiazhuang (China). For each of these case studies, the core city (urban area) and the peri-urban (surrounding) area are assessed and investigated separately. This report takes advantage of the approach and modelling technique specifically developed within UNCNET and applies the methodology to the four cities, separately for urban and peri-urban area. Visualization takes advantage of flow implementation in the STAN model for material flows developed by TU Vienna.

Flows through the urban & peri-urban area – characterization

Looking at the core area of Zielona Góra, the first pattern to be investigated, one notices is that the biggest N flows are linked to the household pool (from trade to industry to households, and then from households to wastewater to waste – see Figure 1). This pattern can also be seen when looking at Vienna, Shijiazhuang and Beijing core areas. In the respective surroundings of all test areas, however, largest flows are centered around industry, urban animals and urban plants as agriculture plays a larger role.

According to these characteristics some of the central parameters can be derived from the flow data. The surrounding areas generally show higher self-sufficiency in terms of protein, i.e. agricultural production of protein is in the same range as human consumption in these areas, while in the core city human consumption is much larger and protein has to be imported. However, as livestock does not play a big role in either of the European test areas, self-sufficiency of livestock protein remains on a low level in both surrounding as well as core areas (Table 1). Due to a higher share in grass and certain cereal products, Vienna as well as its surrounding exceed the need for feed with their production thus becoming an exporter of livestock feed.

In Shijiazhuang, self-sufficiency is lower in the core area compared to the surrounding, but it is on a higher level for both plant and livestock protein than in European cities, reaching 59% and 41% respectively.

Core areas generally can be seen as a place of consumption. Most imported Nr is consumed and subsequently emitted to the atmosphere, either as unreactive N_2 or as NO_X. The export of products is often also lower in the core areas (Table 1, Table 2). Only 1% of imported Nr is being exported as product in Vienna core area. This increases to 57% in the surrounding area, mostly due to industrial production (mostly feed, fuel and resins). However, export of Nr from the test areas is also dependent on industrial production. In Zielona Góra already 31% of imported Nr are exported as products due to wood industry being situated in the core area. In Zielona Góra surrounding, exported Nr in products increases to 46% of imported Nr due to the export of agricultural products. In Shijiazhuang core, 42% of N inflows are being exported, while in its surrounding only 4% are being exported as agricultural products (meat and crops). The high export in the core area is due to a high level of industrial production of products high in Nr such as fibres, wood fiberboard, furniture, tableware, and textiles. In Beijing, no export of Nr as product takes place in the core as well as the surrounding area because population density is high and local production is lower compared to Shijiazhuang and only used to cover local demand.

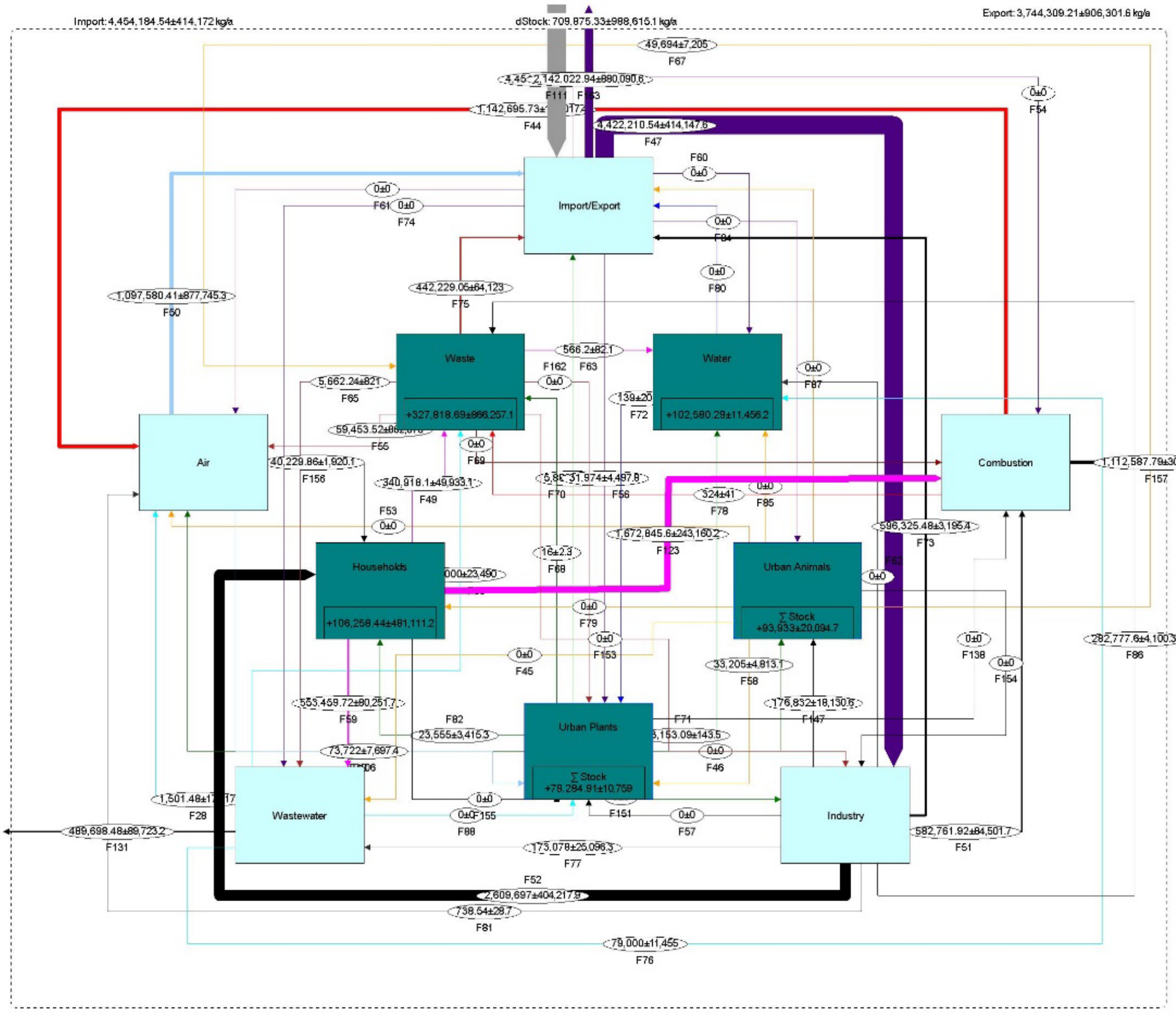

Figure 1 STAN flow model of the N budget for Zielona Góra core area

Flows to air in core areas primarily come from the combustion pool (Table 1 and Table 2). In the surrounding areas, flows to air primarily originate from agricultural land and livestock with Vienna surrounding being the only exception where combustion remains the primary source. Emissions to air per hectare are higher in all core areas when compared to their surroundings. In all surrounding areas, except for Vienna surrounding, N deposition per hectare exceeds N emission per hectare (Table 1, Table 2).

The biggest share of emissions to water in core areas can be assigned to wastewater treatment while in surrounding areas emissions primarily originate from agricultural land. Only in Shijiazhuang core area, where agricultural activity plays a big role as well, emissions from agricultural land are almost as high as emissions from wastewater treatment.

Nr recycling is defined as the intentional re-use of Nr coming from a pool within the system (e.g. manure Nr from the livestock pool used on agricultural land, waste recycling such as re-use of composted organic waste on agricultural land, re-use of sewage sludge on agricultural land etc). Only 4% of Nr is recycled in Vienna (mostly waste) and no Nr is recycled in Zielona Góra. In the surrounding areas recycling remains low in Vienna with only 6% but increases to 24% in Zielona Góra surrounding (manure). In Beijing and its surrounding, the recycling rate is similarly low as in Vienna, with 5% and 7%. However, in both Chinese test areas, human manure plays a big role in recycling, with human excreta being collected and directly applied to agricultural land constituting the biggest share of recycled Nr in the core area (55%) and manure N application constituting the biggest share in the surrounding area (67%) of Beijing. In Shijiazhuang, Nr recycling in the core area is the highest with over 30% of Nr input being recycled. Also in this test area, direct application of human excreta on agricultural land makes up the biggest share of Nr recycling (64%). In the surrounding area, 18% of inflowing Nr is being recycled, most of it being manure Nr (77%).

Table 1 Parameters & Indicators to describe urban N budget in Vienna and Zielona Góra

	Vienna	Vienna Surrounding	Zielona Gora	Zielona Gora Surrounding
General				
In [kgN]	19,339,227.17	58,199,522.22	1,914,082.52	1,028,181.90
Per area [kgN/ha]	466	139	328	47
Per person [kgN/cap]	11	89	16	52
Out [kgN]	4,070,165	45,797,759	1,432,926	637,427
Per area [kgN/ha]	98	109	246	29
Per person [kgN/cap]	2	70	12	32
Air (% of import)	20%	1%	6%	0%
N2 - sink (% of import)	57%	20%	28%	4%
Products Out (% of import)	1%	57%	31%	46%
Waste Out (% of import)	1%	0%	12%	12%
dStock (% of import)	22%	21%	23%	38%
Plant Stock (% of import)	3%	3%	4%	26%
Animals Stock (% of import)	2%	1%	5%	6%
Household Stock (% of import)	2%	4%	2%	4%
Waste Stock (% of import)	1%	0%	7%	0%
Industry Stock (% of import)				
Water (% of import)	15%	13%	4%	2%
Recycling (% of import)	4%	6%	0%	24%
Agri-Food Chain				
Self-sufficiency Plant Food	3%	317%	6%	74%
Self-sufficiency Livestock Products	0%	38%	0%	63%
Self-sufficiency Feed	728%	276%	0%	49%
NUE on agricultural land	55%	68%	70%	80%
N surplus [kgN/ha]	62	46	26	23
Emission and Deposition				
N deposition per hectare [kgN/ha]	17	13	16	17
Emission per person [kgN/cap]	2	51	2	1
Emission per hectare [kgN/ha]	110	16	35	1
Emission Shares				
From livestock to air	0%	6%	0%	23%
From agricultural land	1%	21%	1%	58%
From combustion	89%	52%	67%	15%
From waste	8%	11%	29%	0%
From wastewater	1%	0%	1%	0%
From urban greens	1%	10%	3%	5%
From horticulture	0%	0%	0%	0%

Table 2 Parameters & Indicators to describe urban N budget in Shijiazhuang and Beijing

	Shijiazhuang	Shijiazhuang surrounding	Beijing	Beijing surrounding
General				
In [kgN]	23,857,053	1,145,480,661	150,100,311.72	308,539,380.10
Per area [kgN/ha]	589	811	1,083	201
Per person [kgN/cap]	18	162	18	59
Out [kgN]	16,222,869	253,714,827	31,235,020	91,064,559
Per area [kgN/ha]	401	180	225	59
Per person [kgN/cap]	12	36	4	18
Air (% of import)	10%	18%	12%	21%
N2 - sink (% of import)	18%	3%	47%	25%
Products Out (% of import)	42%	4%	0%	0%
Waste Out (% of import)	5%	0%	0%	0%
dStock (% of import)	25%	75%	42%	54%
Plant Stock (% of import)	8%	52%	3%	33%
Animals Stock (% of import)	0%	0%	0%	0%
Household Stock (% of import)	1%	5%	25%	7%
Waste Stock (% of import)	0%	0%	0%	0%
Industry Stock (% of import)		4%		
Water (% of import)	16%	15%	14%	14%
Recycling (% of import)	24%	17%	5%	7%
Agri-Food Chain				
Self-sufficiency Plant Food	59%	69%	9%	66%
Self-sufficiency Livestock Products	41%	84%	0%	65%
Self-sufficiency Feed	48%	88%	0%	49%
NUE on agricultural land	46%	19%	49%	82%
N surplus [kgN/ha]	191	961	62	20
Emission and Deposition				
N deposition per hectare [kgN/ha]	37	37	21	45
Emission per person [kgN/cap]	2	4	2	4
Emission per hectare [kgN/ha]	80	18	132	14
Emission Shares				
From livestock to air	11%	14%	0%	16%
From agricultural land	9%	76%	6%	58%
From combustion	65%	6%	66%	13%
From waste	1%	4%	8%	1%
From wastewater	4%	0%	5%	0%
From urban greens	10%	0%	5%	7%
From horticulture	0%	0%	9%	5%

This difference in Nr pattern between the core area and the surrounding can also be found when looking at imported Nr in more detail, with food import to households being higher in the core area and fertilizer imports to agricultural land having a high share of imported Nr in the surrounding. In Vienna, 55% of imported Nr can be found in food and 41% in non-food products directed to households. In the surrounding area, 39% of Nr import is fertilizer, while 24% of Nr import is directed to industry for fuel production (basically the result of a large oil refinery being located in the Vienna surrounding area). In Zielona Góra core area, 51% of imported Nr can be found in fuels – mostly used for industrial production, only 21% of Nr import is found in food. In the surrounding area of Zielona Góra, the majority of imported Nr can be found in fuels (mainly used for residential heating) as well, while 29% of imported Nr can be found in fertilizers (Figure 2).

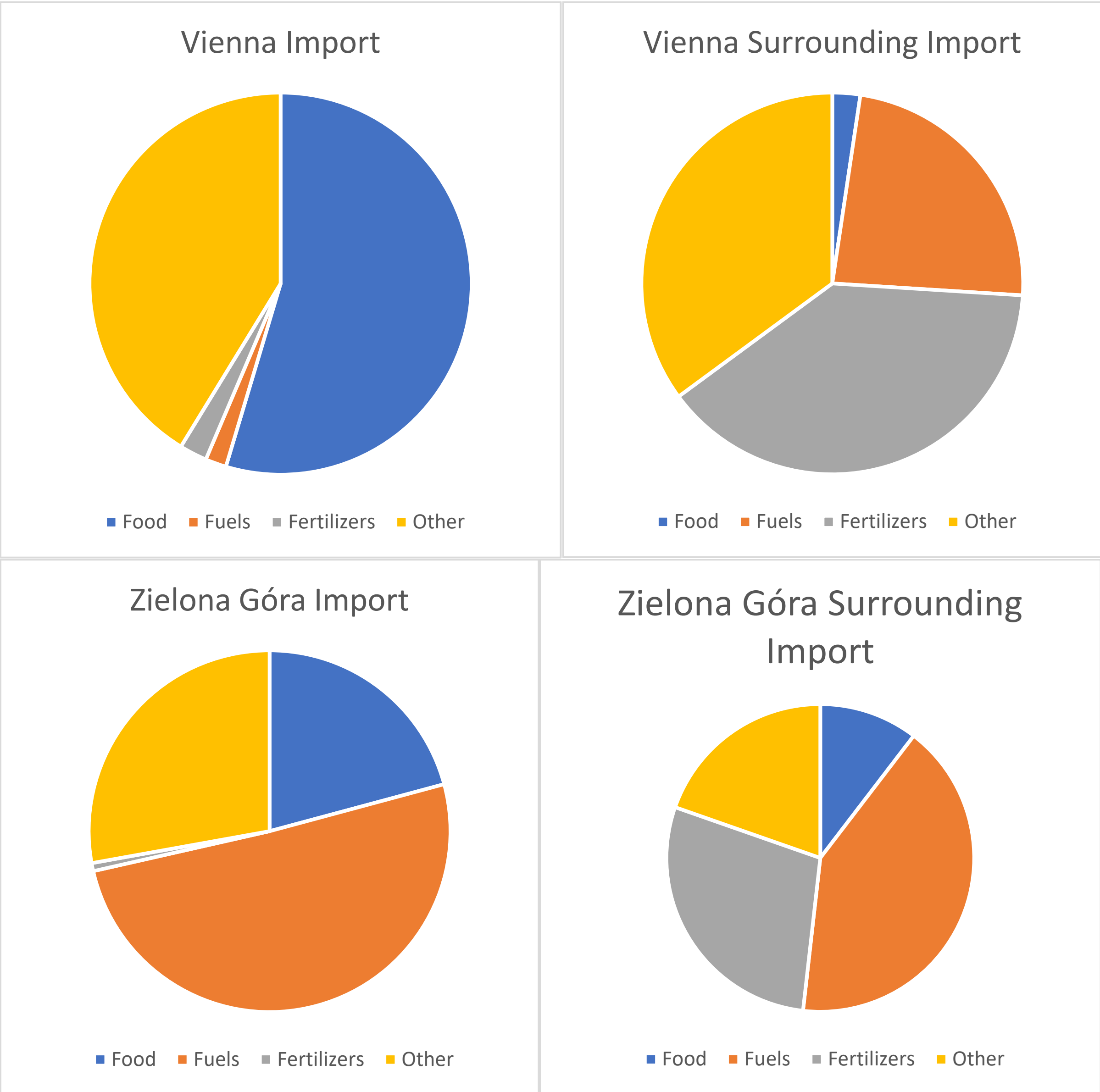

Figure 2 Share of goods categories in imported Nr for different test areas

Detailed Comparison

For a more detailed comparison between all test areas, each of the 10 pools and the corresponding flows will be discussed in detailed throughout this section. In addition to the four test areas (Vienna, Zielona Góra, Beijng and Shijiazhuang, for each of which core area and surrounding have been assessed separately), an N budget based on limited data was developed for the region “Klagenfurt-Villach” in southern Austria (with the intention to support the stakeholder process in this area). That budget only encompasses the flows around urban animals and plants, households, waste, wastewater, water and air. The respective flows will be considered in this more detailed comparison; however, as this additional budget does not extend to all pools, this region cannot be considered in the overall comparison.

Regions also strongly differ in size (Table 3). In order to allow for comparison, we always refer to normalized figures (flows per capita or flows per area).

Table 3 Basic statistical parameters for the respective test areas

	Vienna	Vienna Surrounding	Zielona Gora	Zielona Gora Surrounding	Shijiazhuang	Shijiazhuang Surrounding	Beijing	Beijing Surrounding
Population [1000 heads]	1,828	654	111	28	1,309	7,074	8,401	5,201
Area [1000 ha]	41	420	6	22	41	1,413	139	1,536
Population density [head/ha]	*44*	*2*	*19*	*1*	*32*	*5*	*61*	*3*
Livestock [LSU]	368	56,159	-	2,503	61,867	6,299,022	7,992	1,795,848
Livestock density [LSU/1000 ha]	*9*	*134*	-	*114*	*1,528*	*4,459*	*58*	*1,169*
Agricultural land [1000 ha]	6	211	1	7	16	980	16	198
Agricultural land share [ha/ha]	*13%*	*50%*	*9%*	*31%*	*40%*	*69%*	*11%*	*13%*

Livestock

Comparing livestock data from the Polish test areas to the Austrian test areas shows that analyzing differences may pose some difficulties. Values for N intake, excretion and volatilization differ quite substantially between Zielona Góra surrounding and Vienna & Klagenfurt-Villach. N intake is generally higher for cattle and pigs in Zielona Góra surrounding, leading to higher N excretion rates. In Zielona Góra surrounding, N excretion of all livestock except for poultry is higher than N excretion in Vienna and its surrounding (see Table 5). However, volatilization rates in Zielona Góra surrounding are lower for all livestock categories leading to rather low N volatilization from livestock altogether.

However, apart from methodological differences, livestock composition influences the flows the most. Volatilization is highest in Vienna core, as horses make up more than two thirds of livestock in this region. Horses have a high N excretion rate, and their manure is then subject to rather high volatilization rates. In the Vienna surrounding area, mostly pigs are being kept whose N excretion rate is low (9 kgN/head) even when coverted to livestock units (LSU) compared to cattle (49 kgN/head) or horses (48 kgN/head). Therefore relatively lower amounts of manure N per LSU are being transferred to the urban plants pool, and the volatilization remains smaller compared to Vienna core or Klagenfurt-Villach. As the majority of LSU in Zielona Góra surrounding is composed of cattle whose N intake and N excretion is high, manure N transfer to the urban plants pool is the highest of all test areas. However, volatilization rates are assumed lower than rates used for the Austrian test areas, so N volatilization in Zielona Góra surrounding remains lower than in Vienna core area. As the Austrian test areas are self-sufficient in feed provision, feed from industry is only used in Zielona Góra surrounding and the Chinese test areas.

In Shijiazhuang, N intake is lower due to a large share of pigs and poultry in total livestock. The same is true for Beijing. In both Chinese surrounding test areas, the share of poultry in total livestock is close to 50%. This also leads to lower N volatilization as N excretion of poultry is lower.

Table 4 N flows to and from urban livestock

	Vienna		Vienna Surrounding		Klagenfurt-Villach		Zielona Gora	Zielona Gora Surrounding
	kgN/LSU	kgN/head	kgN/LSU	kgN/head	kgN/LSU	kgN/head	kgN/LSU	kgN/head
Feed from industry to livestock	0			0	-	-	97	4
Feed from agricultural land to livestock	85	20	63	7	72	12	92	3
Import to livestock	12	3	2	0	-	-	0	0
Household to livestock	0	0	0	0	-	-		
Livestock (product) export	0	0	0	0	-	-	48	2
Livestock to households	17	4	7	1	5	1	17	1
Manure N to agricultural land	51	12	38	4	55	9	100	4
Livestock to waste	9	2	4	1	4	1	0	0
Volatilization	14	3	9	1	10	2	11	0
Livestock to industry	1	0	5	1	23	4	0	0

	Beijing		Beijing Surrounding		Shijiazhuang		Shijiazhuang Surrounding	
	kgN/LSU	kgN/head	kgN/LSU	kgN/head	kgN/LSU	kgN/head	kgN/LSU	kgN/head
Feed from industry to livestock	4	0	32	1	8	0	4	0
Feed from agricultural land to livestock	6	1	4	0	32	4	23	4
Import to livestock	0	0	0	0	2	0	9	2
Household to livestock	52	5	0	0	1	0	0	0
Livestock (product) export	0	0	0	0	0	0	6	1
Livestock to households	3	0	2	0	3	0	0	0
Manure N to agricultural land	12	1	8	0	31	4	24	5
Livestock to waste	1	0	1	0	1	0	1	0
Volatilization	10	1	7	0	7	1	5	1
Livestock to industry	36	4	17	1	0	0	0	0

Due to the market structure in Zielona Góra, a share of livestock products is exported although the local demand cannot be met. For the Austrian test areas, no detailed data is available, so it is assumed that all livestock products are consumed locally to meet demand. This assumption was taken as no detailed information on in- and export on this geographical level was available. The situation is similar when looking at feed, for which it is assumed that only locally harvested produce is consumed by livestock in the Austrian test areas. As self-sufficiency for feed exceeds 100% all over Austria, no additional feed has to be imported, and exceedance is assumed to be exported.

In the Chinese test areas, livestock products are only exported in Shijiazhuang. The inflow from households to livestock, representing food residues used as feed, is a special case in all Chinese test areas. This flow is especially high in Beijing core area, making up more than 80% of feed.

Table 5 N excretion and NH3 volatilization for Vienna (VIE) and Zielona Góra (ZG). Values are the same for the core and the surrounding areas.

	N excretion		NH3 volatilization	
	VIE	ZG	VIE	ZG
	kgN/head	*kgN/head*	*kgN/head*	*kgN/head*
Cattle	49.33	58.06	7.70	4.54
Pigs	9.03	33.11	1.94	2.51
Poultry	0.73	0.63	0.18	0.20
Horse	47.90		11.66	

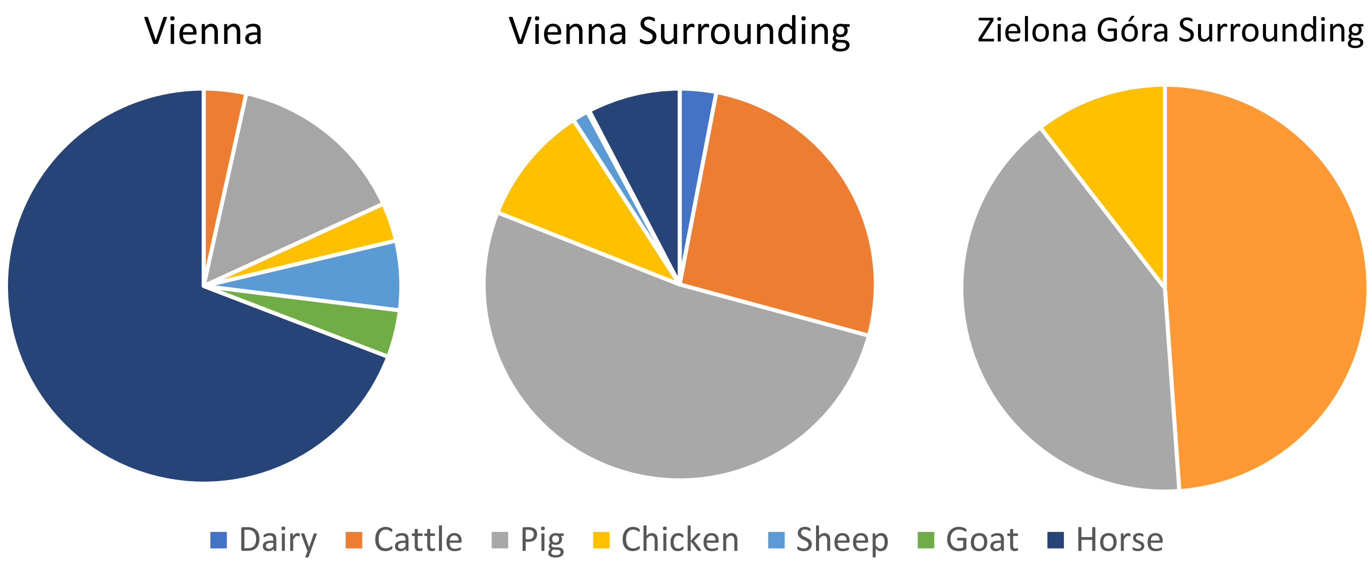

Figure 3 Livestock shares in test areas (LSU) - Vienna core and surrounding, and Zielona Góra surrounding

Agricultural land

Even in the vicinity of large conurbations, the agriculture pool is a very relevant element to the nitrogen cycle. In this analysis, detailed and separate views of input, output and environmental impacts are provided.

Input

Nitrogen deposition and BNF is quite high in the Vienna surrounding area when compared to the other European test areas. While N deposition was calculated from NO_2 concentration measurements on several sites across Poland from 1992 to 2020, N deposition for Vienna and its surrounding area were taken from spatially explicit EMEP data (Norwegian Meteorological Institute, n.d.).

As the nitrate content in the groundwater bodies below agricultural areas in Vienna and its surrounding are mostly above 45 mg/l, N is transported to the agricultural soils through irrigation. As irrigation is not high in these areas, N contained in irrigation water is negligible as N input to agricultural land, compared to other N inputs. No irrigation takes place in the Polish test areas.

Only in Vienna surrounding and Klagenfurt-Villach, sewage sludge is recycled to agricultural lands whereas in the Polish test areas all waste and sewage sludge is either exported for recycling or landfilled. In the Vienna core area, all sewage sludge is burnt.

Due to a difference in allocation, synthetic fertilizer application comes from import for Polish test areas and from industry for Austrian test areas. All European test areas solely import fertilizers, they do not produce fertilizers locally. Synthetic fertilizer application in the European test areas is generally slightly higher in Austria, except for Klagenfurt-Villach. The amount of synthetic fertilizer application in the Austrian test areas is driven by crop types. As Wheat, Maize, Other Cereals and Grass compose the largest share of harvested areas the Vienna surrounding area, synthetic fertilizer application is the highest (see Figure 4).

In Beijing core, we can observe the impact of a specificity of the Chinese test areas: the use of human manure on agricultural fields. Blackwater is collected from households separately and transported directly to agricultural land. In the Beijing core area, N input from human excreta has the highest share with over 70% of total N input, followed by Shijiazhuang core with over 50%. In the surroundings of Chinese test areas, it plays a smaller role with 1%-3% of total N input for Beijing and Shijiazhuang respectively. In Shijiazhuang surrounding, a fertilizer plant exists, which supplies most of the fertilizer needed in this area. Generally, total N input per area to agricultural land in the Chinese test areas is up to 9 times higher than in the European test areas, with N application in the surrounding areas exceeding application in the core.

Output

While in Zielona Góra core area 80% of the harvest from agricultural land is used in the households, around 60% of the harvest is exported in its surrounding area, with the second biggest share (36%) being used for livestock. In Vienna, its surrounding as well as Klagenfurt-Villach, a large share of harvest is exported which on the one hand has to do with the crop types grown (grass and grain crops of which up to 66% is used as feed) as well as assumptions on export (feed exceeding the livestock demand will be exported). In Shijiazhuang and Beijing core and surrounding, most N harvest is used as livestock feed (>50%), closely followed by household consumption (>31%). Amongst the Chinese test areas, only Shijiazhuang surrounding exports N harvest outside the test area boundaries (2% of N harvest).

In Austria, crop production for industry also plays a rather large role. 25% of wheat production and 38% of maize production are being industrially processed. As wheat is the dominant crop cultivated in Vienna and its surrounding area (30%, 38% of harvested area), and maize makes up 13% of harvested area in the Vienna surrounding area, shares of harvest going to industry are rather high in Vienna and even higher in its surrounding area. In Shijiazhuang, shares of harvested crops processed in industry are similar to the shares in Vienna and its surrounding. However, no crop harvest is processed by industry in the Polish test areas and only a negligible amount is processed by industry in Beijing.

Table 6 Flows to and from the pool "agricultural land"

	Vienna	**Vienna Surrounding**	**Klagenfurt-Villach**	**Zielona Gora**	**Zielona Gora Surrounding**	**Shijiazhuang**	**Shijiazhuang Surrounding**	**Beijing**	**Beijing Surrounding**
	kgN/ha	kgN/ha	kgN/ha	kgN/ha	kgN/ha	kgN/ha	kgN/ha	kgN/ha	kgN/ha
Irrigation	0.8	0.6	0.0	0.0	0.0	5.0	5.0	4.1	5.1
Wastewater to agricultural land		0.8	1.1	0.0	0.0	0.0		0.0	0.0
N deposition	14.0	24.9	15.0	15.8	15.8	36.9	36.9	34.0	53.3
Waste to agricultural land (e.g. compost)	28.4	1.9	6.4	0.0	0.0	2.7	3.0	0.6	7.1
Manure N to agricultural land	3.4	10.0	48.1		38.3	120.1	154.2		
Fertilizer application	69.6	105.4	34.5	0.0	0.0	45.5	861.5	0.0	0.0
Imported fertilizer application				68.7	61.7	0.0	163.3	39.9	821.4
Household to agricultural land (human excreta)	0.0	0.0				235.6	35.8		
Exported crops	30.5	46.8	33.0	11.8	52.5	0.0	7.1	0.0	0.0
Crops to households	23.8	8.7	5.6	47.1	6.6	87.3	90.1	3.6	17.2
N leaching and run-off	23.7	31.0	11.3	45.7	23.1	91.4	170.5	69.4	198.8
N volatilization	8.2	9.1	11.5	3.2	8.0	21.8	187.6	72.2	234.3
Agricultural land to waste	1.2	1.3	0.4	0.0	0.0	7.0	8.4	0.6	7.4
Crops to industry	14.0	24.9	13.8	0.0	0.0	37.0	47.6	0.2	2.4
Feed	5.7	16.6	62.8	0.0	33.7	123.1	145.6	3.1	36.4
Fuel for agricultural machinery	1.5	0.2				0.0			

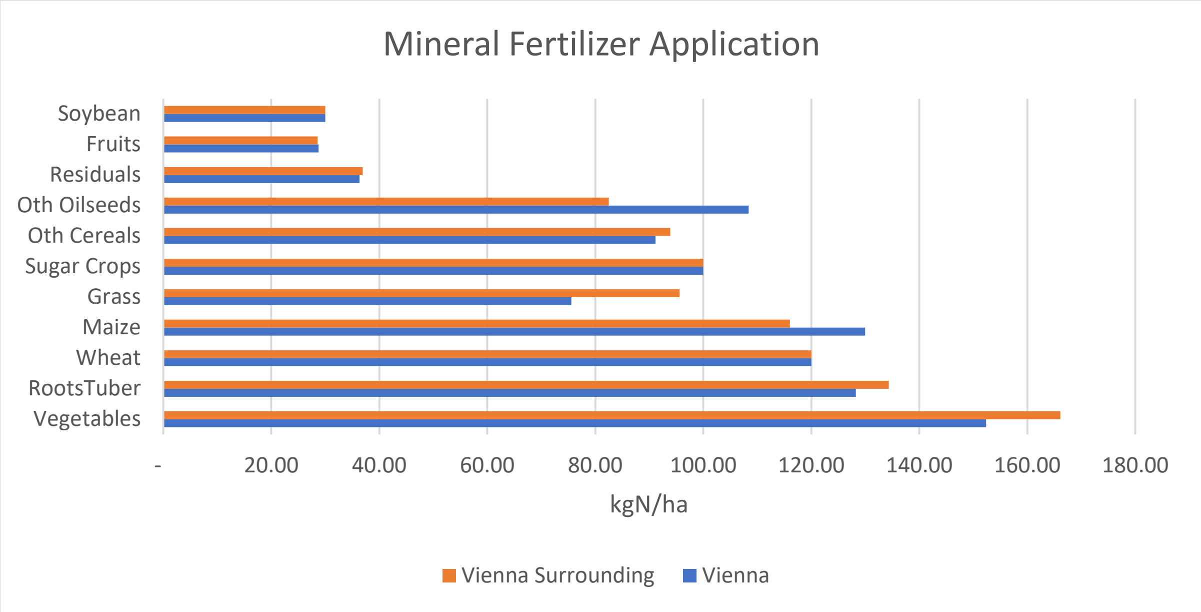

Figure 4 Mineral Fertilizer Application per crop type (kg/ha) for Vienna core and surrounding

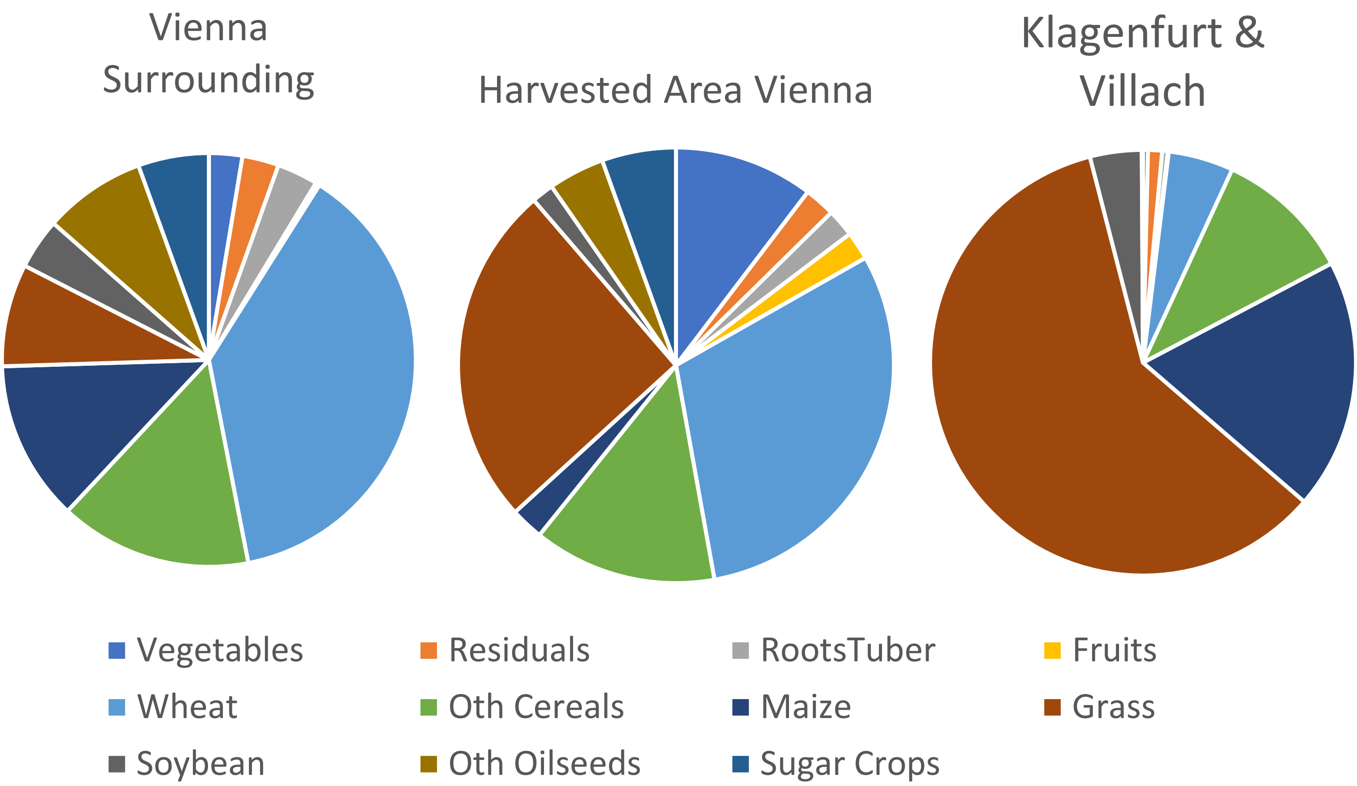

Figure 5 Harvested Area per crop type (ha) in the Austrian test areas

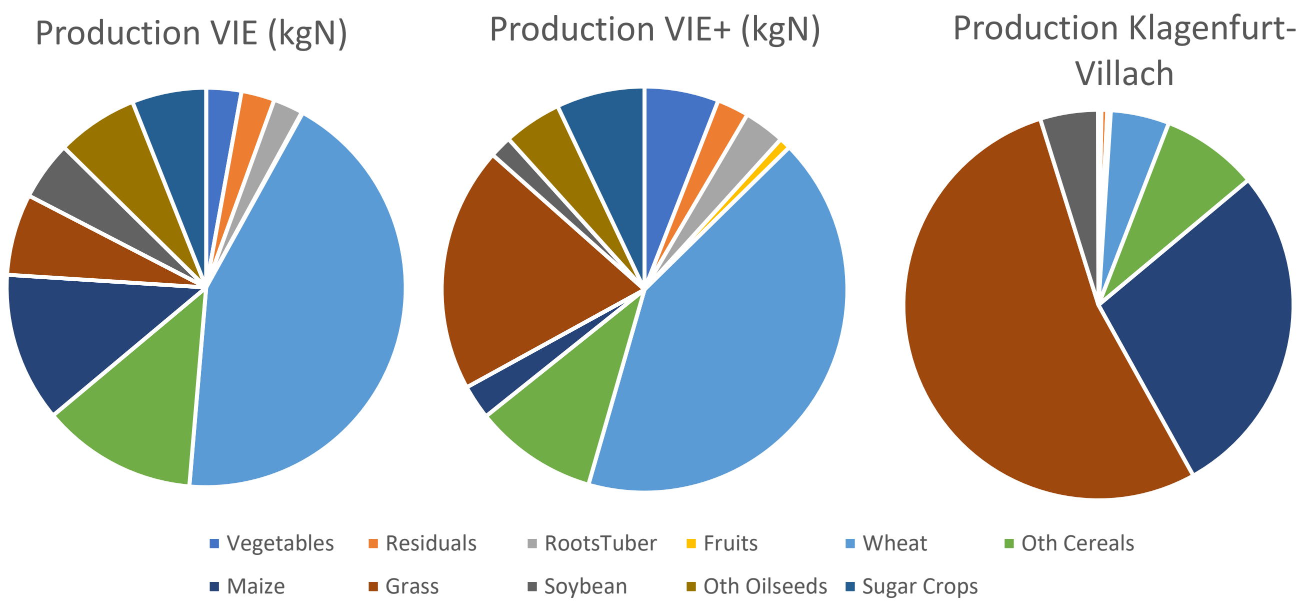

Figure 6 Production per crop type (kgN) in the Austrian test areas

Emissions to water and air

Leaching is higher in Vienna and its surrounding area than in Klagenfurt-Villach, which can be explained by the cultivated crop types and their recommended fertilization. In Vienna and its surrounding, higher shares of fertilizer use are assigned to wheat and maize which also have the highest share of harvested area, leading to high Nr input and subsequently higher leaching. However, leaching also depends on the soil type and the amount of fertilizer applied to it, which was assumed to be different for cropland (CL) and grassland (GL) area, with cropland showing a higher leaching rate (see Equation (1) below taken from Eder et al. (2015)). Subsequently, total leaching is highest not only in areas where crops with high Nr fertilizer needs are grown but also where most fertilizer is spread on cropland, not grassland, namely the Vienna surrounding area, where 90% of fertilizer is spread on cropland, followed by Vienna (80%) and the Klagenfurt-Villach region (50%). High N leaching in the Vienna core and surrounding area is reflected in nitrate groundwater level surpassing the threshold of 45 µg/m3 in some water bodies (BMLFUW, n.d.). In the Chinese test areas, leaching and runoff is highest with up to 198 kg/ha in Beijing surrounding because of the particularly high N input. However, due to the fact that groundwater can be found at a higher depth in the Chinese areas, leaching effects are not yet reflected in NO_3 levels in groundwater. However, it can be seen that Nr accumulates to a large extent in Shijiazhuang surrounding (N surplus of 961 kgN/ha – see Table 2), potentially leading to future problems (Zhou et al., 2016).

Volatilization rate per hectare in agricultural lands is similar between Zielona Góra surrounding and Vienna and its surrounding (see Table 6). The Villach-Klagenfurt area shows, however, a higher rate compared to other test areas. NH_3 Volatilization is generally higher than N_2O volatilization and, as it is calculated for the Austrian regions, differs between types of fertilizer used (highest rate for manure N (N_{man}), then urea fertilizer, then sewage sludge (N_{ww}) and compost (N_w) followed by other mineral N fertilizers – see Equation (2). All emission factors were taken from the GAINS model (IIASA AIR Group, 2018) and a more detailed description of the calculations is available in D7/2. As livestock density (LSU/agric area) is highest in the Klagenfurt-Villach area, and more than 4 times the density of livestock in the Vienna surrounding area, manure N also constitutes the highest share of N input to soils (see Figure 7) leading to high volatilization rates. Due to excessive N input and high shares of urea in synthetic fertilizers in the Chinese test areas, N volatilization per hectare is higher than in all other test areas.

$N_{leach} = 0.227*(N_w+N_{ww}+N_{synCL}+N_{manCL}) + 0.027*(N_{synGL}+N_{manGL})$ (1)

$N_{vol} = EF_{Nm}*N_{man}+EF_{N2O}*(N_{syn}+N_{ww}+N_w)+S_U* EF_{NH3u}*N_{syn}+(1-S_U)*EF_{NH3nu}*N_{syn}+EF_{NH3w}*N_w+ EF_{NH3ww}*N_{ww}$ (2)

N_{leach} … leached Nr
N_w … Nr input from waste (as compost)
N_{ww} … Nr input from wastewater (as sewage sludge)
N_{synCL} … Nr in synthetic fertilizers used on cropland
N_{manCL} … manure Nr used on cropland
N_{synGL} … Nr in synthetic fertilizers used on grassland
N_{manGL} … manure Nr used on grassland
N_{vol} … Nr volatilization
N_{man} … manure Nr
N_{syn} … Nr in synthetic fertilizers
EF_{N2O} … N2O emission factor 0.01273, source: GAINS
EF_{NH3u} … NH3 emission factor (urea) 0.158, source: GAINS
EF_{NH3nu} … NH3 emission factor (non-urea) 0.024, source: GAINS
EF_{NH3w} … NH3 emission factor (compost application) 0.024, source: GAINS
EF_{NH3ww}… NH3 emission factor (sewage sludge application) 0.050, source: GAINS
EF_{Nm} … NH3 and N2O emission factor (manure application) 0.376, source: GAINS
S_U … urea share in synthetic fertilizer: 0.09, source: GAINS

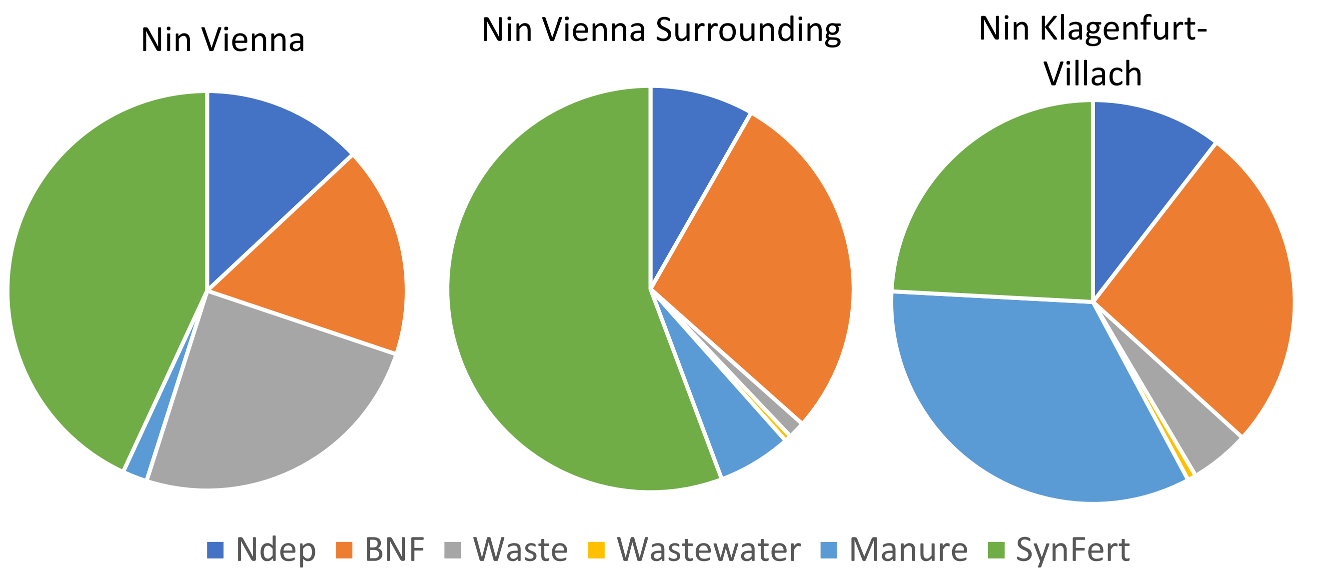

Figure 7 N input (Nin) to Austrian agricultural land

<u>Horticulture & Urban Greens</u>

The biggest share of harvest from horticulture in Zielona Góra and its surrounding is directed to urban greens whereas most of N harvest in the Austrian and Chinese test areas is going to households. In China, mostly flowers for the decoration of households but also streets are grown which are disposed of soon after their use.

Because this is difficult to account for, waste from the streets is accounted for under the flow “horticulture to waste” making this flow one of the highest outflows of the horticulture pool (27%).

Due to different crop types being cultivated in horticultural holdings, synthetic fertilizer application varies between the Austrian test areas. In Klagenfurt-Villach and Vienna surrounding, mostly trees and flowers are grown which require less than half as much fertilizer as vegetables (130 kg/ha), which takes up more than 70% of harvested horticultural area in Vienna core. Fertilization in Zielona Góra and its surrounding, where mostly strawberries are grown, is the same as for all agricultural crops (61 kg/ha). In the Chinese test areas N input (89% synthetic fertilizer) is very high (300 kg/ha) making emissions to air and water again the highest of all test areas.

Synthetic fertilizer use on urban greens is very low compared to the fertilization of horticultural areas with less than 1 kgN/ha in the Zielona Góra test areas and around 10 kgN/ha in Vienna surrounding and Klagenfurt-Villach while it reaches up to 152 kgN/ha in Beijing core and 68 kgN/ha in Shijiazhuang. In Vienna core, no synthetic fertilizer is used. Largest N inputs to urban greens in the Vienna surrounding area and Klagenfurt-Villach are from home composting which is not a common practice in the Polish and Chinese test areas. Nr inputs from pets as well as N deposition also play a bigger role with 20% to 50% in some test areas. While Nr input from pet manure in the European test areas and Shijiazhuang does not exceed 22 kg/ha, it is assumed to exceed 200 kgN/ha in the Beijing core area due to high population density and comparably small urban green areas (around 5%).

Pets

Although outnumbering livestock in the European test areas (Vienna and Zielona Góra), their contribution to the overall budget is rather small compared to other flows. In urban areas, the addition of pet manure to urban greens can exceed the addition of livestock manure to agricultural land. The dominant type of pet kept in each test area impacts the amount of Nr directed to urban greens or waste respectively. In the Chinese test areas, where dogs are prominent (>70%), the flows are bigger than in the European test areas where, except for Zielona Góra core, cats are prevalent.

Wastewater

In general, data on wastewater between Vienna core and surrounding, Klagenfurt-Villach and Zielona Góra core (no wastewater treatment takes place in its surrounding) is well comparable as tertiary treatment is prevalent in all these test regions. Nr from households to wastewater is approximately 5 kg/cap in the Austrian test regions and around 4 kg/cap in Zielona Góra core. The wastewater treatment plant in Zielona Góra core is, according to records, around 10% more efficient than the Austrian treatment plants, removing around 90% of Nr from the wastewater.

In Shijiazhuang surrounding, more than 80% of the wastewater comes from industry due to high industrial production and due to the direct use of human excreta on agricultural land which reduces the amount of wastewater collected for treatment.

No sewage sludge is used on agricultural land in Zielona Góra and Vienna core but 4% of total N input to the wastewater treatment is used in agriculture in Vienna surrounding and 1% is used in the Klagenfurt & Villach area. This translates to 16% of sewage sludge being used in agriculture in Vienna surrounding and only 3% in Klagenfurt & Villach. However, in Klagenfurt & Villach, 49% of sewage sludge are being composted supposedly being then used in agriculture or as fertilizers on urban greens. Generally, these percentages are still quite low compared to EU average of sludge used in agriculture (25% -calculated using EUROSTAT data) with countries like Ireland reporting that 80% of their sewage sludge is applied to agricultural soils (EUROSTAT, 2018).

As no indirect N_2O emissions from wastewater are considered in Zielona Góra, the amount of emissions from wastewater per person is slightly lower. However, largest export from the wastewater pool in all test areas remains N_2, followed by Nr in wastewater effluent directed to water.

Waste

Waste streams are quite different depending on the waste composition and the waste treatment in the respective test areas. As can be seen in Figure 8, residual waste constitutes the largest fraction of waste in Vienna, while in the surrounding area, scrap and biowaste also play a big role. In Zielona Góra, the largest fraction of waste is scrap.

The flow from households to waste treatment is highest in Zielona Góra, closely followed by Vienna, its surrounding area, and Klagenfurt-Villach with a difference of over 1 kgN/head. This could be explained by the largest fraction of residual waste (37 % of total mass) in Vienna being organic, which, in the surrounding area, would maybe more likely be subject to home composting which constitutes a flow of around 1 kg/capita in the Vienna surrounding area and Klagenfurt-Villach.

Depending on the waste composition and the treatment, emissions to air and water/wastewater differ between the test areas. In regions where the share of biowaste and green waste is rather high and composting is a common practice (e.g. Vienna surrounding), emissions to air are high (>99% of emissions to air are from composting). As wastewater is mostly composted in Klagenfurt-Villach (Table 7), emissions to air are approximately 20% of all flows from the waste pool. While emissions to air are 6% of all flows from waste in Zielona Góra, they make up 8% in Vienna and 30% in the surrounding area.

In Zielona Góra core, the biggest share of waste (60%) is exported and being treated outside the city borders. As waste in Zielona Góra is being treated in a MBA before being landfilled, emissions to water occur. However, they remain rather small with only 0.01 kgN/cap. All waste is being exported for treatment in Zielona Góra surrounding.

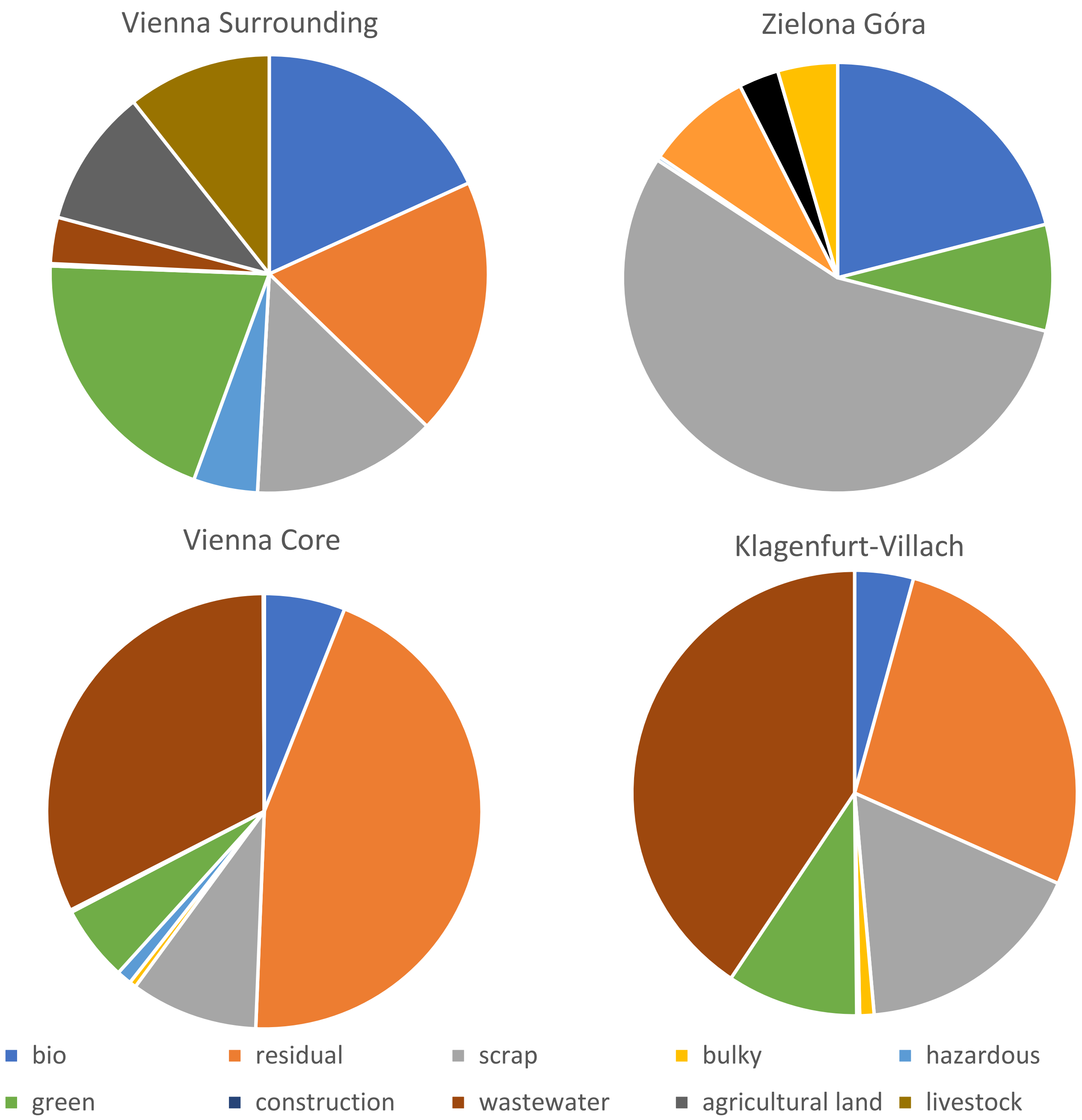

Figure 8 Waste composition for the European test areas

Table 7 Waste treatment in the Austrian test areas

Vienna Waste Treatment							
	combustion	other treatment	landfill	composting	biogas	recycling	CPO
residual	100%						
construction		97%	3%				
bio	0%			88%	11%		
scrap	84%	16%					
green				100%			
problematic material		9%				91%	0%
wastewater	100%						
agricultural land	1%			98%	1%		
urban livestock	34%	20%		2%	32%		

Klagenfurt & Villach Waste Treatment							
	combustion	other treatment	landfill	composting	biogas	recycling	CPO
residual	94%			5%		1%	
construction							
bio				100%			
scrap	20%					80%	
green				100%			
problematic material		100%					
wastewater	42%		2%	49%			
agricultural land	1%			98%	1%		
urban livestock	34%	20%		2%	32%		

Vienna Surrounding Waste Treatment							
	combustion	other treatment	landfill	composting	biogas	recycling	CPO
residual	79%	1%	3%			1%	16%
construction	1%		8%			91%	
bio	1%			98%	1%		
scrap	10%					90%	
green	1%			98%	1%		
problematic material	28%		10%			62%	
wastewater	9%		2%	88%			
agricultural land	1%			98%	1%		
urban livestock	34%	20%		2%	32%		

Challenges and Potentials

As was shown in the section describing “Agricultural land”, leaching can lead to heightened NO_3^- levels in groundwater, as observed in Vienna surrounding, posing a threat to human health (WHO, 2011; Feichtinger, 2013). Nr accumulation in the soils, as observed in all Chinese test areas, can disrupt the soil balance. It can lead to higher Nr emissions, and soil acidification (Velthof et al., 2011). Improved Nr management methods (see UNCNET deliverables D3/3 and D4/3) could improve these situations (Hansen et al., 2017). A combination of reduction strategies (reduced N feeding of livestock, improved housing, storage and field application of manure, optimized synthetic fertilizer application, deep fertilization and the addition of urease inhibitors to synthetic fertilizer) for example, was found to have the highest impact on NH_3 emissions and PM2.5 formation, particularly in summer (see D3/3 for more detail).

Although facing some challenges with Nr accumulation in soils, the Chinese test areas are already recycling a larger share of Nr due to the use of human excreta on agricultural land and the use of food residues as livestock feed.

In Vienna, all sewage sludge is being burnt, with current discussions on making use of this resource focusing only on Phosphorus, neglecting Nr recycling. The re-use of sewage sludge, which makes up over 30% of total waste could be seen as a potential to reduce emissions from synthetic fertilizer production when used as a substitute. It is estimated that around one ton of CO_2 is produced for every ton of NH_3 that is produced using Haber-Bosch powered by natural gas as it is common practice in 90% of western European countries (UBA, n.d.). For Vienna this would result in a reduction potential of 1-2kt CO_2 based on the assumption that 88% of sewage sludge are composted and around 50% of this compost can be used on agricultural fields (mimicking the current situation in the Vienna surrounding area). It would also be enough to substitute the total use of mineral fertilizer in Vienna with 2/3 of the compost then still available for export. However, this substitution would also increase ammonia emissions (see Equation 2).

Another reduction potential is the fraction of organic waste (37% of total mass in Vienna and 12% in the Vienna surrounding) in residual waste. If this fraction would be separated and composted, it could replace all synthetic fertilizer use in Vienna. However, as this fraction is small in the Vienna surrounding area and agricultural production is large, only 0.2% of synthetic fertilizer N could be replaced by recycling organic waste to agricultural land.

In Zielona Góra, waste is not properly separated before collection, leading to a large share of organic waste in residual waste that could potentially be recycled.

Bibliography

BMLFUW (n.d.). H2O Fachdatenbank – Grundwasserkörperabfrage. H2O Fachdatenbank - Grundwasserkörperabfrage (umweltbundesamt.at). Accessed 2021-11-01.

Eder, A., Blöschl, G., Feichtinger, F., Herndl, M., Klammler, G., Hösch, J., Erhart, E., & Strauss, P. (2015). Indirect nitrogen losses of managed soils contributing to greenhouse emissions of agricultural areas in Austria: results from lysimeter studies. Nutrient Cycling in Agroecosystems, 101(3), 351–364. https://doi.org/10.1007/s10705-015-9682-9

EUROSTAT (2018). Water statistics. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Water_statistics#Wastewater_treatment_and_disposal. Accessed 2022-08-03.

Feichtinger, F. (2013). Nitrat im Grundwasser. 4. Umweltökologisches Symposium 2014, 25–30. http://www.umwelt.sg.ch/home/Themen/wasser/grundwasser/Messergebnisse/nitrat.html. Accessed 2022-08-03

Hansen, B., Thorling, L., Schullehner, J., Termansen, M. & Dalgaard, T. (2017). Groundwater nitrate response to sustainable nitrogen management. Sci Rep 7, 8566. https://doi.org/10.1038/s41598-017-07147-2

IIASA AIR Group (2018). Emission factors. GAINS ver. 4. IIASA. http://gains.iiasa.ac.at/models/gains_models4.html. Accessed 2020-10-12.

Norwegian Meteorological Institute. (n.d.) Earlier reported EMEP MSC-W modelled air concentrations and depositions. https://www.emep.int/mscw/mscw_ydata.html. Accessed: 2021-04-12.

UBA (Umweltbundesamt) (n.d). Prozessdetails: Chem-AnorgAmmoniak-DE-2020. https://www.probas.umweltbundesamt.de/php/prozessdetails.php?id=%7B79A3BA36-8F46-48C1-B379-0D3ABA48F561%7D. Accessed 2022-08-03

Velthof, G., Barot, S., Bloem, J., Butterbach-Bahl, K., de Vries, W., Kros, J., Lavelle, P., Olesen, J.E., Oenema, O. (2011). Nitrogen as a threat to European soil quality. Chapter 21 in: Mark A. Sutton, Clare M. Howard, Jan Willem Erisman, Gilles Billen, Albert Bleeker, Peringe Grennfelt, Hans van Grinsven and Bruna Grizzetti (eds.), The European Nitrogen Assessment, ed., pp. 495-510. Published by Cambridge University Press.

WHO (2011). Guidelines for drinking water quality – 4th ed. http://apps.who.int/iris/bitstream/handle/10665/44584/9789241548151_eng.pdf;jsessionid=606210FBF97F193DC1581FFA26A0EC55?sequence=1. Accessed 2022-08-03

Zhou, J., Gu, B., Schlesinger, W. H., & Ju, X. (2016). Significant accumulation of nitrate in Chinese semi-humid croplands. *Scientific Reports*, *6*, 1–8. https://doi.org/10.1038/srep25088