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

D7/2: Final urban nitrogen budget

Due date of deliverable: **28/02/2022**

Actual submission date: **15/07/2022**

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

Duration: **35 months + 6 months**

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

Authors: Katrin Kaltenegger, Samuel Guéret, Wilfried Winiwarter

1. Executive Summary

Building on results from WP2 on the final concept of Urban N flows and the deliverable D7/1 dealing with conceptual N budgets, the final Urban Nitrogen Budgets (UNBs) of Vienna core and surrounding areas were determined.

The structure of the deliverable is as follows. First, we present a pool-by-pool methodology including detailed assumptions behind the data collected and computations used to estimate N flows. Second, we discuss the main results of Vienna core and surrounding UNBs. The material flow analysis software STAN is used to present the main qualitative results and differences between the two test areas. A quantitative assessment summarizing the main findings following relevant indicators was eventually developed from the results. Additionally, we included an annex documenting the various assumptions underlying each of the N flows considered in the final UNB. The successful implementation of the method for Vienna serves as a blueprint for its use in the other test areas of UNCNET.

2. Objectives:

The UNCNET project has been established to meet several challenges associated with urban nitrogen flows. Some of these challenges are explicit (linking different environmental spheres and problem areas via a common denominator, which in this case is reactive nitrogen; optimizing flows via circular economy approaches), and others are more implicit (identifying appropriate system boundaries and comparable data sources; representing trade across such boundaries; developing strategies to find solutions that are more prevalent in dynamic urban situations than for a whole country). Building on the final version of the central model structure (WP2) and the conceptual N Budgets (D7/1), this report presents the final Urban Nitrogen Budgets for the Vienna core and surrounding areas. This includes both a comprehensive methodological framework describing data collection and N flows estimation together with the summary of main findings for both test areas.

3. Activities:

- Development of a methodological framework describing data collection and N flows estimation.
- Expansion of the STAN model to include complete Urban N Budgets for both test areas.
- Development of documentation compiling assumptions underlying each of the N flows.

4. Results:

- A complete methodological framework describing data collection and N flows estimation has been established.
- A flow model for the complete Urban N budgets of Vienna core and surrounding areas has been developed using the STAN software.
- A document compiling assumptions underlying each of the N flows has been drafted.

5. Milestones achieved:

---

6. Deviations and reasons:

Delay due to Corona crisis.

7. Publications:

---

8. Meetings:

---

9. List of Documents/Annexes:

Annex I: Urban Nitrogen Budget Vienna and Vienna Surrounding Area 2015 - Methodological Framework

Annex II: UNCNET – Brief description of flows and pools

10. Bibliography

ANNEX I

Urban Nitrogen Budget for Vienna and for Vienna Surrounding Area 2015: Methodological Framework

Urban Nitrogen Budget Vienna and Vienna Surrounding Area 2015: Methodological Framework

The following text describes the calculation of Nitrogen (N) flows of the N budget for the city of Vienna and its surrounding area for the base year 2015. The surrounding area includes the NUTS3 divisions "Wien Umland - Nordteil" and "Wien Umland - Südteil" (Statistik Austria, 2014).

Urban Plants

Synthetic Fertilizer Application

To calculate fertilizer application for Vienna and its surrounding area, first data on crop type distribution was taken from Statistik Austria, taking separate statistics for fruit, grain, vegetables etc and compiling them to one file showing harvested areas and production for the year 2015 (Statistik Austria 2020d; 2020e; 2020f). As such data was only available for the whole province of Lower Austria, the subset of the Vienna surrounding area could not be separated. To make such a separation, statistical data from "Agrarstrukturerhebung 2010" (Statistik Austria, 2020c) was used as auxiliary because it offered data on harvested areas at a higher provincial resolution. However, this data did only offer a coarse differentiation between crops (oleaginous, grain, protein, roots, etc.). Hence, a list was created where all crop types from the statistics in 2015 were assigned to a crop category from the statistics from 2010. From this data, area fractions of total area for lower Austria were assigned to each district in lower Austria. These fractions were then used to calculate harvested areas for 2015 for each of the districts included in the Vienna surrounding area by multiplying them with the values for harvested area for each crop type for lower Austria in 2015. A Python program was written to perform this procedure.

To distribute synthetic fertilizer accordingly, crop-type specific data on synthetic fertilizer use from BMLFUW (2013) was taken. As these crop types or categories were not the same as in the "Agrarstrukturerhebung 2010", another list was compiled where all crops were assigned a respective category. Using this list, synthetic fertilizer application per year and crop was calculated. However, this crop-specific fertilizer data was given as crop-specific N needed to achieve average yield. To arrive at the total amount of mineral fertilizer use, the same factors used for the calculation for Vienna and its surrounding area were used to calculate synthetic fertilizer application for whole Austria. Other biological N fertilizers (such as manure N, compost or sewage sludge) used in Austria were taken from the CRF table (used for national reporting under the UNFCCC – UNFCCC (2020)) and subtracted from the synthetic fertilizer amount calculated before. A factor adjusting the result of this calculation to the mineral fertilizer use as reported in the CRF table (with a share going to private use subtracted) was calculated and applied to the respective calculations for Vienna and its surrounding area.

Share of urea in synthetic fertilizer and NH_3 volatilization rates for urea and non-urea shares as well as volatilization rates for N_2O were taken from GAINS (IIASA AIR, 2018c; 2018d; 2018e) to calculate losses.

Egle et al. (2014), based on personal information from venders, postulated that between 1% and 3% of total synthetic fertilizer application in Austria is used for private purposes. We hence adopted a share of 2% of synthetic fertilizer to be spread on urban greens. As urban greens include larger areas than only gardens, this amount can be assumed to be a lower boundary. To arrive at the final amount of synthetic fertilizer used for urban greens in Vienna and its surrounding area, the share of total synthetic fertilizer application in Austria going to urban greens was divided by the area of urban greens in whole Austria (taken from Umweltbundesamt, 2015) to calculate fertilizer use per area. This was then multiplied with the respective areas for Vienna and its surrounding area (Umweltbundesamt, 2015). For Vienna, no synthetic fertilizer was applied to urban greens because an officer of the city of Vienna stated that for the public gardens of Vienna only organic fertilizers are used.

Breaking this down to the regional level, around 18% of total mineral fertilizer used in Austria is applied to agricultural land in Vienna and its surrounding area while the agricultural area share of these regions only comprises 10% of total Austrian agricultural area. Since roots & tubers, vegetables & wheat need the most fertilizer per area and have a rather big area share in the cultivated areas (VIE & VIE+), it seems plausible that the fertilizer consumption share is higher than the area share.

Table 1 Synthetic fertilizer application per hectare and area shares of Vienna and its surrounding area (VIEVIE+) in Austrian agricultural land (for comparison: VIEVIE+ cover 5.5% of the total area of Austria)

	Fertilizer Application [kg/ha]	Area Share [haVIEVIE+/ haAUT]	IFA Fertilizer Application Europe [kg/ha]
Fruits	34.83	0.06	82.53
Residuals	36.25	0.13	78.71
Wheat	120.00	0.26	115.80
Oth Cereals	95.18	0.11	80.70
Maize	114.15	0.09	107.09
Grass	103.59	0.02	138.41
Soybean	30.00	0.14	2.51
Oth Oilseeds	81.67	0.17	67.60
RootsTuber	121.74	0.30	84.13
Sugar Crops	100.00	0.25	
Vegetables	122.27	0.50	170.79

Biological N Fixation

To calculate biological N fixation (BNF), the crop distribution described in section “Synthetic Fertilizer Application” was used and multiplied with an area and crop type specific BNF factor taken from BMLFUW (2013) and from Kremer (2013) for fodder crops as no information was available. For this procedure, every crop was assigned a crop type category as needed for the BNF factors to fit BMLFUW (2013) crop types. When compared with other BNF factors such as Herridge et al. (2008) and data from the EUROSTAT handbook (Kremer, 2013), but also Austrian data before and after the year 2013, BNF factors differ quite substantially. Highest discrepancies were found between the BMUB (2019) data and all other datasets which is why the year 2013 was chosen rather than the year 2019. BNF for soybeans and clover was adjusted to crop rotations and therefore reduced from 2010 to 2013, which then fits better to the data shown in Herridge et al. (2008) and Kremer (2013). Data for grass also differs between the sources, however, asymbiotic BNF in grass is highly uncertain and depends on the leguminous crop and grass mix (Keuter et al., 2014; Soussanna & Tallec, 2010). Better grassland data will most probably be available for the next Austrian N budget according to BMUB (2019).

Table 2 Comparison of BNF values between Herridge et al. (2008), Statistik Austria (2010), BMLFUW (2013), BMUB (2019) and Kremer (2013)

Crop Type	Nfix Herridge [kg/ha]	Nfix Statistik Austria 2010 [kg/ha]	Nfix BMLFUW 2013 [kg/ha]	Nfix BMUB 2019 [kg/ha]	Kremer (2013)
Other Crops	3.00	4.00			
Peas	86.00	127.00	127.00	17.00	24-125
Broadbeans	111.00	127.00	127.00	33.00	24-125
Beans	23.00	127.00	127.00	17.00	24-125
Leguminous Crops	41.00	127.00	127.00	17.00	55-500
Soybeans	160.00	130.00	65.00	35.00	20-135
Clover	150.00	224.33	153.00	24.00	
Grass	80.00	4.00	50.50		5-153
Fodder	100.00	4.00			10-190

N harvest

For the N harvest calculation, the crop distribution described in section “Synthetic Fertilizer Application” was used and multiplied with crop-specific N content taken from BMUB (2019). Crop production was taken from Statistik Austria (2020d; 2020e; 2020f). To match data on harvested areas, only production data for which information on harvested area was available was included.

The N content was given as percentage of crop production BMUB (2019), however this data differed from N content data previously published by Statistik Austria (2010). As it was stated in BMUB (2019) that N content data was derived from previous data and judged by experts, it was decided to select the most recent data. Depending on the crop type, this can lead to differences when compared to other sources e.g. Lassaletta et al. (2014) and Winiwarter & EPNB (2016) as shown in Table 3. Highest discrepancies are shown for grass, fruit and oilcrops. As it is not clearly stated in Statistik Austria (2010) whether the N contents of grass relate to fresh weight or dry matter, assuming it is the latter could explain discrepancies. The values given by Winiwarter & EPNB (2016) refer to fresh weight with an average moisture content of about 80% (Eurostat, 2020). Grass data from Statistik Austria (2010), on the other hand, is given with a moisture content of 12% (personal information/pdf description of surveys). This discrepancy in weight and N content could indicate that the N content from Statistik Austria (2010) was adjusted to fit the Statistik Austria harvest data.

Table 3 Comparison of total N harvest between the use of N content factors from Lassaletta et al. (2014), Statistik Austria (2010) and UMUB (2019)

	N harv UMUB 2019 [kg/kg]	N harv Statistik Austria 2010 [kg/kg]	N harv Lassaletta [kg/kg]
Vegetables	0.0027	0.0017	0.0026
Residuals	0.0101	0.0090	0.0089
RootsTuber	0.0028	0.0031	0.0023
Fruits	0.0019	0.0017	0.0007
Wheat	0.0212	0.0202	0.0195
Oth Cereals	0.0168	0.0166	0.0174
Maize	0.0076	0.0085	0.0075
Grass	0.0157	0.0212	0.0094
Soybean	0.0590	0.0480	0.0608
Oth Oilseeds	0.0393	0.0307	0.0261
Sugar Crops	0.0018	0.0018	0.0021

Horticulture

Data on type of horticulture and area per district was available from Statistik Austria (2021g). Information on mineral fertilizer application, BNF and N content were taken from Statistik Austria (2010) while N volatilization was calculated using factors from IIASA AIR (2018c; 2018d; 2018e). N leaching was calculated using factors provided by Eder et al. (2015). However, further research on soil microbe activity in horticulture, especially areas under glass and foil, will be needed to enhance N calculations. BNF will most likely be highly reduced due to high N availability. Leaching depends on the foundation of the glasshouse. An important aspect to be mentioned is that horticultural areas (except for vegetables which are included in the production statistics as well) are given as physical area as opposed to harvested area. This might influence the results as multi-cropping is excluded. Information on trade of horticultural goods was only available for Vienna and Lower Austria. Additionally, it was confirmed by employees of Statistik Austria that it is likely that these products are imported to the headquarters in Vienna but are then distributed throughout Vienna. As these factors made a proper allocation impossible, it was decided to leave out this flow in the final model.

Personal information was received from the city of Vienna on flowers etc being traded from horticultural holdings to urban greens (park areas owned by the city). No such information was available for the Vienna surrounding area.

Urban Greens

Information on urban greens (including information on usage e.g. park, leisure facility, forest, garden plot) was available from Umweltbundesamt (2015). As data was only available for the total of Lower Austria, the area share was used to arrive at the final number for the Vienna surrounding area.

Estimates on mineral fertilizer and compost application on urban greens were taken from Winiwarter & EPNB (2016) and the STAN model. It was assumed that 55% of the compost gained from waste treatment is used on urban greens corresponding to the sum of shares of compost used in gardens (20%) and as substrate for landscaping (35%) (Egle et al., 2014). Additionally, there is home composting of about 177 kg per person per year in Austria (BMNT, 2017) which was accounted for in a flow from households to urban greens, subtracting volatilization taken from the waste model. Clippings and other waste from these areas can be found in the waste statistics from the respective region. Leaching was again calculated using factors provided by Eder et al. (2015) for grassland.

Irrigation

To calculate N amount distributed on agricultural lands via irrigation, we used the extent of irrigated area and crop type specific irrigation rates from Österr. Bundesministerium für Land- und Forstwirtschaft (2011). For Lower Austria partially also county specific information was available. For extrapolating data originally derived for 2009 to the year 2015, we assumed area shares of irrigation remained constant for specific crop types. Crop type specific area was available from Statistik Austria (as used to calculate mineral fertilizer, BNF, N harvest). As the crop specific data from Statistik Austria is harvested areas while we may expect the irrigated areas being physical areas, potential errors may be introduced. We assume that this procedure still leads to more accurate results than not accounting for the temporal change.

To arrive at the total amount of N spread on agricultural areas, additional information on nitrate (NO_3) and ammonium (NH_4) content of groundwater was taken from Umweltbundesamt (n.d.). We only included groundwater as Dötzl & Peyr (2018) stated that, especially in Lower Austria, ground water is the main source for irrigation. Due to groundwater bodies stretching out under several municipalities, a map provided by Land Niederösterreich (2018) was compared with the map of waterbodies provided by Umweltbundesamt (n.d.) to assign each municipality in the Vienna surrounding area to a groundwater body. As several groundwater bodies can be found below Vienna, an estimate on the water bodies most likely used for irrigation of agricultural land was done using data from "Stadt Wien" which identified the Eastern districts of Vienna as key players in agriculture (Stadt Wien, n.d.). It was estimated that half of the water taken for the irrigation of agricultural area in Vienna was taken from Marchfeld DUJ and the other half from Südl. Wiener Becken DUJ. Accordingly, the average of the NO_3 and NH_4 content of these two sources was taken. Ammonia and nitrate contents then were converted to total Nitrogen using the respective conversion factors.

The only irrigated non-agricultural area according to Österr. Bundesministerium für Land- und Forstwirtschaft (2011), is turf located in Lower Austria. As the exact location of turf is unknown, even distribution over the area was assumed and the share of the Vienna surrounding area was used to indicate the share of turf.

N Deposition

Data on N deposition was taken from EMEP using a 0.1-degree resolution (Norwegian Meteorological Institute, n.d.). This dataset showed yearly N deposition in kg per m^2. To arrive at total N deposition in Vienna and the Vienna surrounding area, this data was multiplied by the area of the respective grid cell and the respective shares per grid cell of agricultural area, horticultural area and urban green in total area of Vienna and its surrounding area, which were obtained by intersection using a GIS.

Urban Animals

Manure N Excretion and Application

Livestock numbers are taken from Statistik Austria (Statistik Austria, 2020a; 2020b). This represents livestock population at a reference date (1st of April). First livestock numbers from the "Agrarstrukturerhebung 2010" were downloaded as these were available at a higher provincial resolution, allowing the division of livestock numbers for lower Austria into "Wien Umland" and "rest" and assigning each district a share of livestock in the total lower Austrian livestock (Statistik Austria, 2020a). This share was then used to update the livestock numbers to the year 2016 (Statistik Austria, 2020b). This year was chosen, as for 2015 the subdivision of cattle into milk cows and other and the subdivision of chicken into laying hens and other was not available. This subdivision was needed for the correct assignment of manure N excretion rates, needed for the next step in the procedure. Excretion rates were taken from GAINS v.4 for Austria (http://gains.iiasa.ac.at/gains4/) (Amann et al., 2011; IIASA AIR, 2018a). The effect of milk yield on N excretion of milk cows in Austria was taken into account (IIASA AIR, 2018b). Shares for N excreted in liquid, solid and pasture management were taken from the Common Reporting Format (CRF) tables and are values representing livestock management for whole Austria (UNFCCC, 2020). It was assumed that all manure excreted in pasture management was applied to pastures (grassland). Liquid and solid manure management was assumed to exclude N excretion outdoors. Manure excreted in other management systems or brought to other uses (composting, digesters, other) were also taken from the CRF tables.

Emission factors specific for livestock category and control strategy were calculated from GAINS emission factors (NH_3 and N_2O) per management stage (housing, storage, application) (IIASA AIR, 2018a; 2018c). These factors were divided into volatilization from housing and storage (flow allocated to urban livestock) and application (flow allocated to urban agricultural land). Volatilization rates are manure management system specific with different factors for liquid and solid manure management. Volatilization rates for manure N excreted on pastures were also taken from GAINS. The share of manure N applied to cropland and grassland was taken from Liu et al. (2010).

Calculations were checked for plausibility comparing N excretion and application as stated in the Austrian CRF tables (UNFCCC, 2020) with calculations for whole Austria using the same methodology and factors used for Vienna and its surrounding area. Excretion is lower in the CRF tables which can be explained by lower animal numbers and slightly different N excretion rates in these tables. The amount of manure applied to grassland is very similar which can be explained by taking the values for livestock management systems for our calculations from the CRF tables. Our results for manure N applied to cropland and grassland is lower than the numbers presented in the CRF table which could be explained by a different approach of the volatilization calculations. In our calculations, volatilization during application is subtracted from the amount of manure applied to cropland and grassland to arrive at total N on cropland or grassland, while in the CRF tables, the value shown as manure N applied to soils is assumed to still include the amount of N that is volatilized during application, leading to higher results.

Grazing and Fodder

N intake was calculated using the 2019 refinement of the IPCC national GHG inventory guidelines (Chapter 10, Volume 4, Equation 10.31) (IPCC, 2019). We rearranged the equation used to calculate N excretion to obtain the amount of N intake per animal:

$$N_{intake\ (T)} = \frac{N_{ex_{(T)}}}{1 - N_{retention\_frac(T)}} \quad (1)$$

$N_{ex(T)}$ … annual N excretion rates on grassland of animal of species/category T, kg N animal^{-1} yr^{-1}
$N_{intake(T)}$ … annual N intake per head of animal of species/category T, kg N animal-1 yr-1
$N_{retention(T)}$… fraction of daily N intake that is retained by animal of species/category T

$N_{retention(T)}$ was taken from IPCC (2019) Table 10.20, 10A.1-10A.4 and combined with shares of livestock in a specific growth stage of animal type in herd from the same tables.

To calculate the N amount grazed, Nex in Equation 1 was exchanged for Nex outdoors only. This amount was then subtracted from total N intake to calculate the amount of N needed to be taken in with fodder. For comparison, data from Statistik Austria (2019) on fodder use in Austria was downloaded. The share of fodder used for Vienna and its surrounding area in total fodder use in Austria was then compared to the share of livestock held in Vienna and its surrounding area in total livestock held in Austria and both shares were about 2%.

Pets

Information on pet numbers (cats and dogs) per household in Vienna and Lower Austria in 2014/2015 was taken from Statistik Austria (2014/2015). This data had to be complemented with information on households in 2015 to arrive at total pets (Statistik Austria, 2021f). To distinguish the municipalities in the Vienna surrounding area from those in Lower Austria, information on households per municipality was taken from Hemetsberger (2014) and complemented with data from Land Niederösterreich (2021) for municipalities missing from Hemetsberger (2014). Then, shares of the households in each municipality of the Vienna surrounding area in the total households of Lower Austria were calculated to receive an estimate of households in the Vienna surrounding area for the year 2015. Using this data, total cats and dogs in the respective area were calculated.

Data in N in feed, N excretion and N volatilization was taken from Winiwarter & EPNB (2016). For stray cats and dogs, no information was available with an exception for cats in Vienna.

For Vienna, a detailed list on dog excrements in residual waste was available from Egle et al. (2017). It was assumed that in Vienna, all N excretion by pets goes to waste while in the surrounding area all N excreted is located on urban greens.

Household/ Urban Livestock/ Urban Plants

Livestock and Crop Product Consumption

To calculate meat from livestock numbers, the number of slaughters per livestock type from the year 2015 were taken from Statistik Austria (2021c) and multiplied by the livestock specific slaughter weight for the year 2015 from Neumann (2018). As slaughters per year were only available on a provincial level, the share of livestock found in the Vienna surrounding area in Lower Austria was used on the slaughters that took place in Lower Austria. Slaughter weight for chicken was calculated from the poultry default weight taken from the IPCC guidelines (IPCC, 2019) and the slaughter ratio for poultry was taken from Wikipedia (Wikipedia, 2020). To calculate the amount of N in meat, livestock-specific N contents were taken from Winiwarter & EPNB (2016).

Milk yield was taken from Statistik Austria (2021d) and multiplied with the number of milk cows found per region. To get the total amount of N from milk production, the N content for milk was taken from Winiwarter & EPNB (2016) and multiplied with the total amount of produced milk. For egg production no information on egg yield was available. To calculate the number of eggs produced per laying hen, data on eggs produced in 2016 was taken from Statistik Austria (2021b) and divided by the total amount of laying hens in Austria in 2016. This ratio was then multiplied with the number of laying hens per region. The division of chicken into laying hens and other chicken was only available for the year 2016 and not 2015. N content for eggs was again taken from Winiwarter & EPNB (2016).
Comparing data on slaughtered livestock with living livestock, the number of imported livestock was derived from the difference (Weight of living livestock – live weight of slaughtered livestock).

A check was done to see whether meat production calculated from slaughters adds up to meat production as stated in Statistik Austria (2021b), taking into account the shares of slaughters attributed to Vienna and Lower Austria. The results were within 10%. The same was done for milk production, where differences were also found to be within 10%. As cow milk accounts for over 99% of milk produced in Austria, goat and sheep milk was not considered.

Additional to meat, Ertl et al. (2016) also provided an estimate of offal (liver, tongue etc.) and blood used as food. They provided information on the percentage of offal or blood of live weight per livestock category as well as the respective protein content. To arrive at total N, these factors were multiplied with live weight per livestock type and number of slaughters and divided by 6.25 for protein to N conversion.

Information on losses from livestock product production was compiled from several sources. Losses from milk production were available from Statistik Austria (2021b) while data from Ertl et al. (2016) was used to calculate losses during processing as well as the share of bones and the share of carcasses used as pet food. Slaughter waste was assumed to be the difference of live weight and the carcass added to losses during processing taken from Ertl et al. (2016) plus the bones and a share of blood (Ertl et al. (2016) Information on the processing of slaughter waste was taken from BMNT (2018) and added to the STAN model for waste.

Data on crop and livestock product consumption per capita (differentiating between different meat products (beef, mutton, etc.) and milk, cheese, eggs etc. and different crops (fruit, vegetables, cereal crops etc.)) were available for Austria from Statistik Austria (2021b). Additionally, this also included data on total production and losses as well as total amounts imported, exported to industry, seeds and further processing. As this data was only available for Austria as a whole and not per capita, total loss etc data for Austria was converted to shares of production (e.g. 3% of production quantity of wheat is lost). These shares were then applied to the municipality-specific production.

Although available in this format, we decided against calculating imported and exported goods for Vienna and its surrounding area this way because we feared a strong bias as both areas have a very small share of livestock compared to the whole of Austria which could indicate a greater need for import of livestock products than the Austrian average.

Checks were made for meat production in Vienna and its surrounding area. As only 0.01% of Austrian livestock are held in Vienna and 1.2% in the Vienna surrounding area, meat production is accordingly low. Consequently, meat production is far from meeting meat consumption and manure N application plays a minor role in crop production. A check was made to see whether the slaughters taken from Statistik Austria (2021b) are similar to the slaughters calculated. This was done by applying shares of Vienna and its surrounding area in slaughters to the Austrian slaughters from Statistik Austria (2021b). Although these values are different for sheep and horses, they are very similar in total & especially for cattle and pigs.

An additional check for food consumption was made by comparing the data calculated from Statistik Austria (2021b) combined with Winiwarter & EPNB (2016) N contents with the FAOSTAT food balance sheets for Austria (FAOSATA, 2021). Converting the protein consumption found in the food balance sheets to N gives a per capita N consumption of 6.25 kg per year, which is quite similar to our calculation of 6.13 kg per year.

Wastewater

Wastewater effluent was calculated from the N in food consumption (minus food waste) per region taken from Statistik Austria (2021b) combined with N contents taken from Winiwarter & EPNB (2016) and IPCC (2019) (Eq. 2). First total N in wastewater before treatment was calculated (TN_{DOM_j}) using Eq. 1 taken from IPCC (2019). The food waste losses are taken from Winiwarter & EPNB (2016) and constitute about 12% of total food consumption which is below the average 27% of food waste stated for Vienna (Pladerer et al., 2016). According to FAO (2011) (the original source used by Winiwarter & EPNB, 2016), food waste only includes the wasted fraction of edible food which would only include parts of the fractions found in organic waste (excluding peel etc) and could explain the discrepancy. This could also explain a higher level of wastewater input calculated using the methodology described above when compared to data taken from ebswien (n.d.) for the year 2020.

$$TN_{DOM\_j} = N_{FOOD} * F_{CON} * F_{NON-CON} * N_{HH} * F_{IND-COM} \qquad (2)$$

TN_{DOM_j}… N (from household) in wastewater (kg N) per region
N_{FOOD}… N in food (kg N) per region
F_{CON} … factor for N consumed – in our calculations this factor is replaced by subtracting N in food waste from consumed N
$F_{NON-CON}$ … factor for N in non-consumed protein disposed in sewer system – default for Europe: 1.09 – CRF:0 for AUT
N_{HH} … additional N from household products added to wastewater - default for Europe: 1.08
$F_{IND-COM}$.... factor for co-discharge of industrial N in sewer system – default: 1.25 – CRF: 0.3

$$N_{effluent} = \sum\left[(TN_{DOM\_j} * T_j) * (1 - N_{REM,j})\right] \qquad (3)$$

T_j… degree of utilization of treatment system j in inventory year – Taken from Oftner et al. (2020): 1 for Vienna and 0.951 for Vienna surrounding area
$N_{REM,j}$ … fraction of total wastewater nitrogen removed during wastewater treatment per treatment type j.

Pathways for N removal include transfer to sludge and nitrification–denitrification with concomitant N loss to the atmosphere. - default for tertiary treatment (ebswien (n.d.) 2020 /tertiary): 0.822

A value of 438 g N/cap/yr for wastewater effluent after secondary biological treatment was proposed by the team working on UNCNET WP 6 (Monika Suchowska-Kisielewicz, personal information). The results from calculations with this value are quite different to the results when calculating wastewater effluent according to the IPCC guidelines. While the latter results in 2.5 kt N for Vienna, the former results in 0.8 kt N. During a stakeholder workshop information was received from ebswien that about 2.2 kt N are found in the wastewater effluent, fitting better to the results following IPCC guidelines.

Checking with the Austrian report on wastewater from 2020 (Oftner et al., 2020), N in wastewater in Vienna (12 kt N) and its surrounding area is similar to the share calculated from total N in wastewater in Austria in 2018 (50 kt N) using a population share of 0.22 for Vienna (11 kt N).

For sewage sludge, an N content of 3.5% for dry matter sewage sludge was given in Oliva et al. (2009) for wastewater treatment plants with a capacity over 150000 people (assumed suitable for Vienna) while an N content of 3.2% was given for a capacity between 2000 and 50000 people (assumed suitable for Vienna surrounding area). This was combined with data on dry matter of sewage sludge in Vienna in 2014 from BMLFUW (2015b). N_2O emissions were calculated from total N in wastewater using a factor of 0.0039 taken from BLFUW (2015) and from wastewater effluent using a factor of 0.005 taken from IPCC (2019). N_2 emissions were then calculated as the difference between N in wastewater and N in effluent, N_2O emissions and N in sewage sludge. However, uncertainty for N_2O emissions is extremely high as IPCC (2019) gives a range of 0.000016-0.045 for the emission factor.

Waste

For the waste calculation in Vienna, data from the 2015 annual report by the MA 48[1] was used (MA 48, 2015). This data included information on waste types and amounts collected. Each waste entry was assigned a source (industry, household, urban greens etc) according to its type (e.g. hospital waste to industry).

Data on waste dry matter content and N content was taken from D6/1 and Brunner et al. (2016). Using transfer coefficients for different waste treatment types from Brunner et al. (2016), a waste flow model was created using STAN (https://www.stan2web.net/).

Compost produced from organic waste in Vienna is distributed to the inhabitants and also used on agricultural land owned by the city. In our calculations it is assumed that half of the compost is distributed on agricultural fields and half of the compost is distributed on urban greens (private gardens).

Waste in the Vienna surrounding area is managed by different waste management associations. These are responsible for different districts, some in the Vienna surrounding area, some in lower Austria. Therefore, it was necessary to divide the waste amounts reported by each association between the Vienna surrounding area and lower Austria. This was done using population data per municipality from Statistik Austria as auxiliary data and calculating shares of population in the Vienna surrounding area per waste management association.

The report Land Niederösterreich (2015) included information on waste type and amount per waste management association. This was then combined with waste flow information taken from Neubauer et al. (2019) to derive the respective waste amount per treatment type. Using the information from D6/1 and N contents and transfer coefficients from Brunner et al. (2016), a separate waste flow model for the Vienna surrounding area was created using STAN (https://www.stan2web.net/).

While in Vienna, most N can be found looking at the flow of residual household waste as well as wastewater (sludge), composting plays a bigger role in the Vienna surrounding area. Sewage sludge from wastewater treatment is much lower in the Vienna surrounding area because most of it is treated differently (e.g. humification) (BMLFUW, 2015).

When comparing the N flows in waste in Vienna to a study by Lampert et al. (1996), flows are comparable but rather low for our results. Total waste amounts have increased and so has the N flow related to them. However, Lampert et al. (1996) use a higher N content for waste (almost twice as high). This could be explained by the fact that we explicitly account for moisture in waste, which lowers the N contents taken from D6/1 and Brunner et al. (2016). Brunner et al. (2016) specifically states that the N content he proposes refer to dry matter. Assuming that the waste amount given by MA 48 is not given as fresh weight, dry matter content needs to be

[1] MA 48 is the department for waste management of the city administration of Vienna

applied to arrive at the final N content. As can be seen in Table 4, the N contents in our study is lower for separate waste collection because in this category about 2/3 of the waste is composed of scrap (glass, paper, metal etc) which has a rather low N content. In Lampert et al. (1996), about 15% of the separate waste collection is residual waste to which the authors assign a rather high N content of 0.007.

Table 4 N content comparison

Waste type	N content Lampert et al. (1996)	N content of this study
Residual	0.007	0.005
Separate waste collection	0.008	0.004

Trade

To calculate trade flows, first an approach to downscale Austrian statistics was taken. However, due to a lack of data and the problem that headquarters situated in Vienna import goods and distribute it throughout Austria with no further information on this intranational trade, this approach was switched to a balance approach based on supplying enough goods to meet the demand in goods of the population calculated beforehand.

Combustion

To calculate flows from industry to combustion, encompassing different types of fuels (gasoline, coal, oil etc), the energy balance per county from Statistik Austria was consulted (Statistik Austria, 2021a). From this statistic, type and amount of fuel consumed in the energy sector was added to type and amount of fuel for final consumption and multiplied with the respective N content. Information on N content was primarily taken from Winiwarter & EPNB (2016) and Bach et al. (2019) and complemented with other sources where necessary. As the energy balance was only available for the total of Lower Austria and not the Vienna surrounding area, proxies had to be used to calculate the respective shares. Final energy consumption was divided into energy consumption in agriculture, households, transport (ship, airplane, train, cars etc.) and industry. These shares where then multiplied with the respective shares of households, agricultural holdings and industry in the Vienna surrounding area in Lower Austria.

As can be seen in Figure 1, when compared with N emissions from combustion, N consumption (=fuels) by the different sectors is usually lower in Vienna while it can exceed N emissions in the surrounding area. This is especially true for the energy and household sector. This could be explained by the NO_x emissions being primarily driven by the high-temperature combustion process itself (from ambient air N_2) as opposed to the N content of the respective fuel. Therefore, N consumption through fuels can be higher than N emissions when fuels with a high N content are used. This is the case in lower Austria, where the biggest share (71%) of non-electric energy consumption in households stems from fuelwood with an N content of 0.2% while only 53% of non-electric energy consumption in Vienna stems from fuelwood and 32% from gasoil with an N content of 0.1%. In industry, the high N input through fuels in the Vienna surrounding area comes from coke which has an N content of 12.5% being about 30 times higher than the average N content of other fuels and coal which has an N content of 1.2%. In Vienna, mostly wood is used, with an N content of 0.2%.

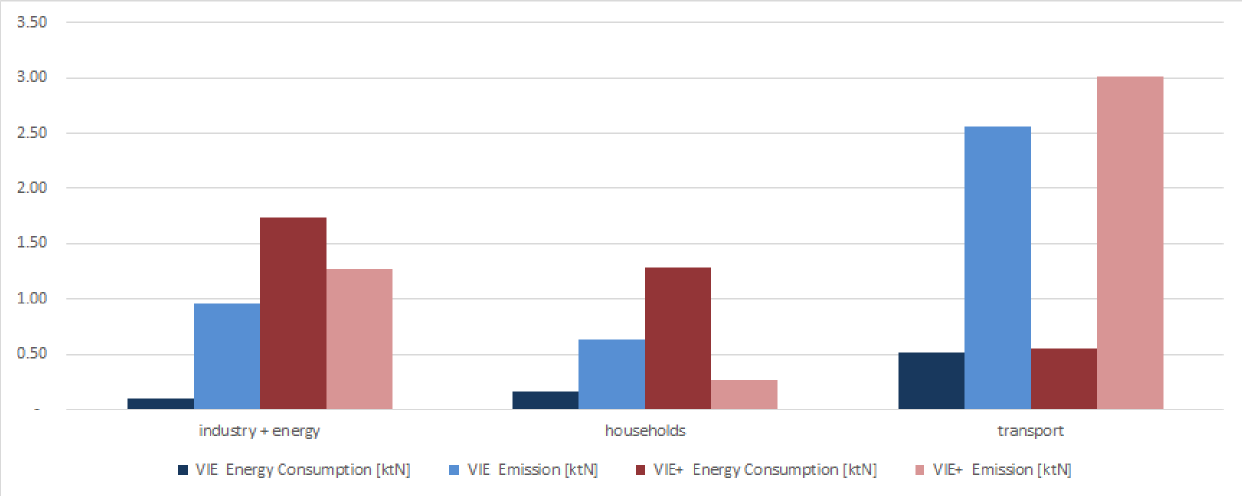

Figure 1 – Comparison of the N energy consumption (fuels) and N emissions from combustion for the industry, households and transports sectors and for Vienna and its surrounding area.

Air

For N emissions to air, we received data from the emission register (Emissionskataster) from MA 22 in Vienna and Land Niederösterreich for the Vienna surrounding area (personal communication) covering the flow from combustion to air. Due to a difference in reporting format, data on the N flow from industry to air was available for Vienna but not for its surrounding area.

Urban N Budget – Main Results

STAN Model – Qualitative assessment

The data compiled as described above was then implemented in the STAN model, hence yielding a stock-and-flow overview of the urban N budgets of Vienna and its surrounding area. The main results are summarized for both test areas below.

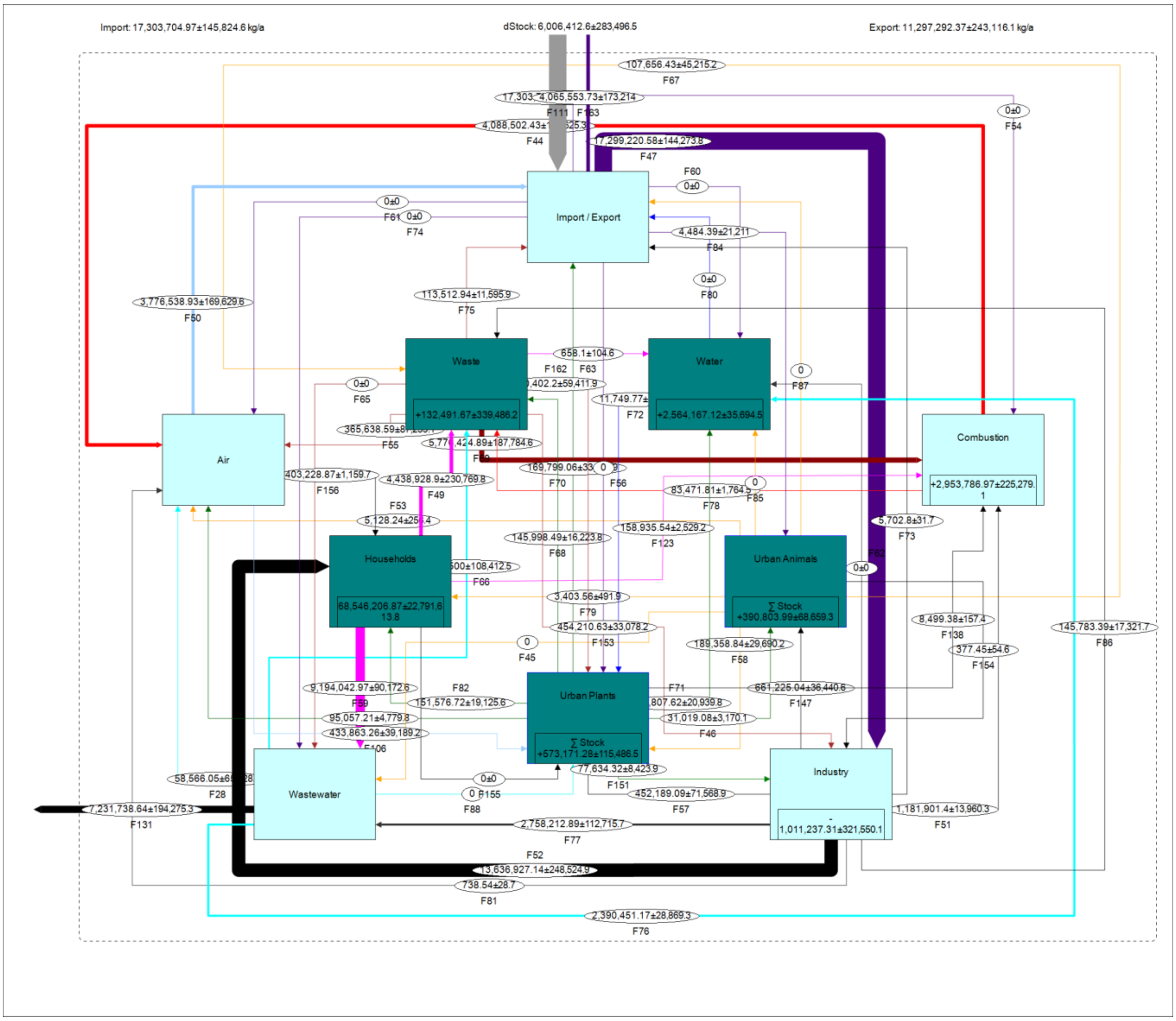

Figure 2 – Urban Nitrogen Budget for Vienna core area in 2015.

The Figure 2 displays the global UNB for Vienna core area in 2015. In that graphical representation of the N flows using a Sankey style, the arrow widths represent the relative magnitudes of the flows.

As seen in Figure 2, the biggest N flows for Vienna are related to the industry, households, and import/export pools. The initial large N import to the import/export pool flows to industry and households to further cascade into the wastewater, waste, combustion, and air pools in smaller amounts. This highlights the relative importance of households and human consumption in the overall budget of Vienna core area.

We note that agriculture does not play a big role here, as production capacity is very low especially when put into relation to the number of inhabitants.

A total of 5 pools that are the waste, water, households, urban plants, and urban animal ones contain stock changes.

The overall N_2-related sink of the budget is constituted of 2 major contributions. The first one is associated with the denitrification step of wastewater treatment plants, while the second contributor are combustion-related processes where N_2 is formed from fuel N, in part as a consequence of air pollution abatement (NO_x reduction). These contributions should be considered when discussing potential pathways to support the development of a circular economy.

On top of its stock change related to N deposition, we also note that the household pool encompasses a stock four times as large as the total N import in the budget, but which remains largely uncertain (standard uncertainty as large as a third of the stock magnitude). This stock would mostly encompass interior furniture (89%), as well as food (1%) or textiles (1%) to a much smaller extent.

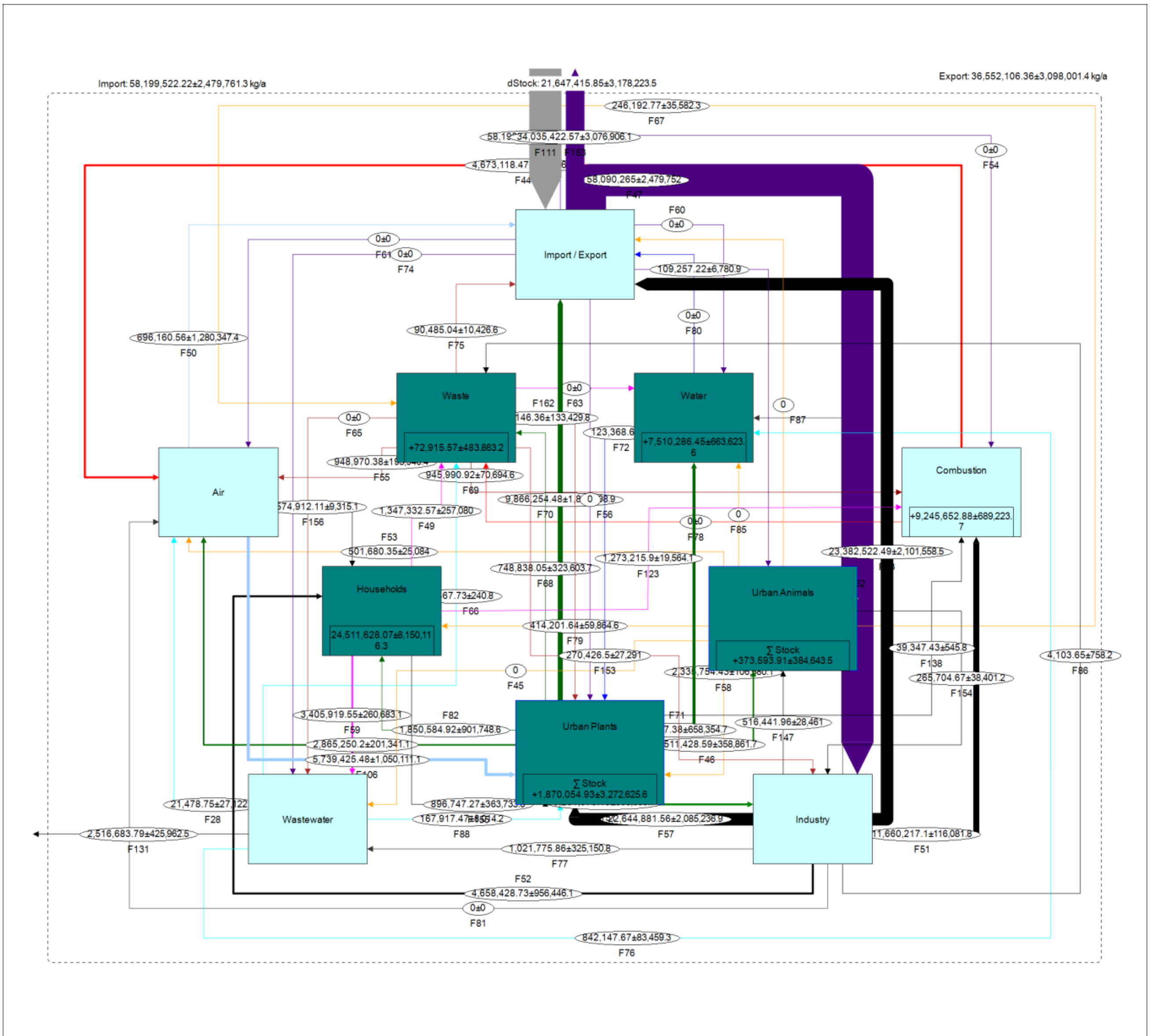

Figure 3 - Urban Nitrogen Budget for Vienna surrounding area in 2015.

The above Figure 3Figure 2 displays the global UNB for Vienna surrounding area in 2015. Unlike the situation of the core area, the largest flows are in this case revolving around the import/export, industry, and urban plants pools. The initial large N import to the import/export pool flows to industry to further cascade down into the urban plants and urban animal pools and then feed back to the import/export one. In that regard, the agro-food chain is a more prominent pathway in the surrounding area than in the core area owing to the larger role played by agriculture in the surroundings. The combustion pathway, on the other hand, remains as relevant as in the core, with the notable driver of fossil fuel consumption in the industry and transport sectors.

Regarding stock changes, similar conclusions to those drawn for the core area are observed, with the largest of them being associated with the water pool. The household stock remains as uncertain as in the core area but is about 10 times smaller relative to the total N import.

We also note that the quantity of exported N (relative to total imported N) is larger than in the core area, with major contributions coming from the urban plants (agricultural products) and industry (process-related products) pools. Indeed, as population density in the surroundings (and therefore also consumption) is lower as compared to production, more export is taking place than in the core area. Specific pattern differences in import and export in both test areas are further discussed in the next section dealing with the quantitative assessment of UNBs.

Quantitative assessment

Table 5 Table 1below presents a quantitative overview of the main indicators of the overall budget, and the Agri-food and Combustion chains for both test areas.

Table 5 – Summary Table for the overall budget, Agri-food chain, and Combustion chain for both test areas following relevant indicators.

	Vienna	Vienna Surrounding
General		
In [ktN]	18	58
Per area [kgN/ha]	442	138
Per person [kgN/cap]	10	88
Out [ktN]	11	36
Per area [kgN/ha]	273	86
Per person [kgN/cap]	6	55
Products Out [share of total inflows]	1%	58%
Agricultural products [share of Products Out]	97%	30%
Industrial products [share of Products Out]	3%	70%
Total stock change [share of total inflows]	22%	21%
Urban Plants Δ stock [share of Total Δ stock]	3%	3%
Urban Animals Δ stock [share of Total Δ stock]	2%	1%
Household Δ stock [share of Total Δ stock]	2%	4%
Waste Δ stock [share of Total Δ stock]	1%	0%
Water Δ stock [share of Total Δ stock]	14%	13%
Household stock [share of total inflows]	374%	42%
Air [share of total inflows]	21%	1%
Waste Out [share of total inflows]	1%	0%
Recycling rate [share of total inflows]	5%	10%
Manure [share of recycling rate]	2%	61%
Compost [share of recycling rate]	43%	26%
Sewage sludge [share of recycling rate]	NA	5%
Recycled industrial waste [share of recycling rate]	55%	8%
N2 – sink [share of total inflows]	56%	20%
Wastewater [share of total N2 sink]	71%	20%
Combustion [share of total N2 sink]	29%	80%
Agri-Food Chain		
Self-sufficiency Plant Food [Production/consumption]	3%	317%

Self-sufficiency Livestock Products [Production/consumption]	0%	38%
Self-sufficiency Feed [Production/consumption]	728%	276%
NUE on agricultural land	58%	72%
N surplus [kgN/ha]	55	38
Combustion Chain		
Emission per person [kgN/cap]	3	51
Emission per hectare [kgN/ha]	111	16
N deposition per hectare [kgN/ha]	17	13

As seen in Table 5, several budget indicators show large differences across both study areas. First, we note that the surrounding area exports much more (industrial and agricultural) N products relative to total inflows than the core area (58% of inflows versus 1% respectively). While agricultural products dominate export shares in the core area (97%), the situation is more balanced in the surrounding with an emphasis on industrial products (70%). Looking specifically into the Agri-food chain shows that the surrounding area is also self-sufficient in terms of plant protein, unlike the core area. Neither of the areas will however reach self-sufficiency of animal protein owing to the small role livestock is playing in that regard. This consequently explains the self-sufficiency reached by both areas regarding animal feed protein.

Furthermore, we observe higher shares relative to total inflows of atmospheric emissions transported outside the system's boundaries in the core area than in the surroundings (21% versus 1%). This is explained by two main trends. On the one hand, the core area exhibits a larger population density and stronger consumption patterns than the surrounding, with most imported Nr being consumed and subsequently emitted to the atmosphere, either as unreactive N_2 (16% of total inflows) or as (mostly) NO_X (21% of total inflows). On the other hand, a large share of this atmospheric emission is deposited on crop- and grasslands in the surrounding area owing to its greater surface.

The following Table 6 further indicates the emission share of each inflowing pool to the air pool relative to total atmospheric emissions together with the relative share of each pollutant within each of these pools.

Table 6 – Atmospheric emission shares relative to total emissions and Nr pollutant share relative to pool emission share per each pool connecting inflows to the air pool for Vienna core and surrounding areas.

	Vienna core				**Vienna surrounding**			
	Emission share	NH_3 share	N_2O share	NO_X (incl NO_2) share	Emission share	NH_3 share	N_2O share	NO_X (incl NO_2) share
From livestock	0%	96%	4%		4%	96%	4%	
From agricultural land	1%	49%	16%	12%	22%	61%	15%	17%
From combustion	88%	2%	0%	98%	53%	6%	3%	91%
From waste	8%				11%			
From wastewater	1%		100%				100%	
From urban greens	1%	92%	8%		11%	80%	20%	
From horticulture	0.06%	74%	26%		0.01%	74%	26%	

As seen in Table 6, most of the atmospheric emissions of Vienna core area (88%) are NO_X emissions coming from the combustion pool. These are directly related to human consumption of fuels (heating, traffic, …) and industrial production. The emission source apportionment is more diversified in Vienna surrounding area with a.o. much larger NH_3 volatilization from manure and fertilizer use amounting to about 22% of the total emissions.

The recycling rate of the budget is a relevant indicator to compare the extent to which Nr is reintegrated into the budget between test areas. For both test areas, recycling rates are relatively low and amount to 5 and 10% of total inflows for the core and surrounding areas respectively. Regarding the source apportionment of the recycling flows, manure reapplied on agricultural land is the dominating pathway in the surrounding area (61% of total recycled Nr) owing to the large presence of agriculture. The situation is different in the core area where the total recycled Nr is almost entirely constituted of the application of compost on urban greens and agricultural land (43%) and recycled industrial waste (55%).

As already argued, it is helpful to consider total emissions of unreactive N_2 when devising potential pathways to reintegrate Nr into the budget and support the development of a circular economy. In that regard, we note that the magnitude of N_2-related sinks relative to total inflows as well as shares from wastewater & combustion widely varies across the test areas. In the core area, those emissions amount to 56% of total inflows among which 71% are due to denitrification steps in wastewater treatment plants. The relative importance of unreactive emissions is reduced in the surrounding area (20% of total inflows) with this time combustion processes being responsible for 80% of them. Such difference in trends between both areas can be explained by the much larger population density in the core area directly driving wastewater-related emissions.

Mitigation pathways and potentials

Various mitigation pathways and potentials are currently being investigated in preparation for the upcoming stakeholder meeting and final recommendations to be addressed.

First, pathways directly mitigating emissions are considered. These may encompass end-of-pipe technologies such as combustion exhaust cleaning and nitrification inhibitors in wastewater treatment plants, or rather demand-side driven reduction pathways. In the latter case, approaches currently scrutinized include change toward plant-based diets and traffic reduction through incentivization of alternative means of transport.

Furthermore, we look at Nr recycling potentials in the budget. On the one hand, we quantify the Nr potential of routes comprising the current recycling rate of both test areas. These include a.o. manure, sewage sludge, and compost reapplied on agricultural land or urban greens, and recycled industrial waste. On the other hand, new routes aiming to enhance the recycling rate, such as textile or waste residue recycling, are investigated. In that regard, we specifically suggest making use of the expertise of all UNCNET teams to consider and assess synergistic approaches.

Eventually, the results of this final Urban Nitrogen Budget will serve as a basis for formulating integrated narratives for relevant partners participating in the upcoming stakeholder meeting. Specifically, we recommend exploiting the various environmental indicators of this deliverable to devise approaches associated with planetary boundaries and Sustainable Development Goals.

Bibliography

Amann, M., Bertok, I., Borken-Kleefeld, J., Cofala, J., Heyes, C., Höglund-Isaksson, L., Klimont, Z., Nguyen, B., Posch, M., Rafaj, P., Sandler, R., Schöpp, W., Wagner, F., & Winiwarter, W. (2011). Cost-effective control of air quality and greenhouse gases in Europe: Modeling and policy applications. *Environmental Modelling and Software*, *26*(12), 1489–1501. https://doi.org/10.1016/j.envsoft.2011.07.012

Bach, M. et al. (2019). *Reaktive Stickstoffflüsse in Deutschland 2010-2014 (DESTINO Bericht 2)*. Report.

Bundesministerium für Nachhaltigkeit und Tourismus (BMNT). (2017). *Bundesabfallwirtschaftsplan 2017 - Teil 1*.

Bundesministerium für Nachhaltigkeit und Tourismus (BMNT). (2018). *DIE BESTANDSAUFNAHME DER ABFALLWIRTSCHAFT IN ÖSTERREICH - STATUSBERICHT 2018*.

Bundesministerium für Land- und Forstwirtschaft Umwelt und Wasserwirtschaft [BMLFUW]. (2013). *Stickstoffbilanzen Berechnung auf GWK-Ebene*. 1–31.

BMLFUW. (2015). *Die Bestandsaufnahme Der Abfallwirtschaft in Österreich Statusbericht 2015*. 99.

BMLFUW. (2015b). *ReLaKO – Reduktionspotential bei den Lachgas-Emissionen aus Kläranlagen durch Optimierung des Betriebes.*

BMLFUW. (2017). *Richtlinie für die sachgerechte Düngung im Ackerbau und Grünland, Anleitung zur Interpretation von Bodenuntersuchungsergebnissen in der Landwirtschaft, 7. Auflage*.

Bundesministerium für Umwelt, Naturschutz, B. und R. (BMUB). (2019). *Umwelt Bundesamt*. http://www.umweltbundesamt.de/themen/wirtschaft-konsum

Brunner, P. H., Allesch, A., Färber, B., Getzner, M., Grüblinger, G., Huber-Humer, M., & Jandric, A. (2015). *Benchmarking for the Austrian waste management*. *November*, 365.

Dötzl, M., & Peyr, S. (2018). *Agrarstrukturerhebung 2016. Betriebsstruktur. Schnellbericht 1.17*. 195. http://www.statistik-austria.at/web_de/statistiken/wirtschaft/land_und_forstwirtschaft/agrarstruktur_flaechen_ertraege/betriebsstruktur/index.html

ebswien (n.d.). Kläranlage. https://www.ebswien.at/klaeranlage/. Accessed 2021-06-23.

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

Egle, L., Zoboli, O., Thaler, S., Rechberger, H., & Zessner, M. (2014). The Austrian P budget as a basis for resource optimization. Resources, Conservation and Recycling, 83, 152–162. https://doi.org/10.1016/j.resconrec.2013.09.009

Egle, L., Rolland, C. and Broukal, S. (2017). Strategische Umweltprüfung zum Wiener Abfallwirtschaftsplan: Wr. AWP= 2019-2024 und zum Wiener Abfallvermeidungsprogramm: Wr. AVP= 2019-2024, Anhang I Ist-Zustand der Wiener Abfallwirtschaft 2017 (Langfassung)

Ertl, P., Steinwidder, A., Schönauer, M., Krimberger, K., Knaus, W., & Zollitsch, W. (2016). Net food production of different Livestock: A national analysis for Austria including relative occupation of different land categories. *Bodenkultur*, *67*(2), 91–103. https://doi.org/10.1515/boku-2016-0009

Eurostat. (2020). *Annual crop statistics: Handbook 2020 Edition*. https://ec.europa.eu/eurostat/cache/metadata/Annexes/apro_cp_esms_an1.pdf

Food and Agricultural Organization of the United Nations [FAO]. (2001). Food Balance Sheets – A handbook, Annex I Food Composition Tables. http://www.fao.org/3/X9892E/X9892e05.htm#P8217_125315.

FAO. (2011). Global food losses and food waste – Extent, causes and prevention. Rome

Food and Agricultural Organization of the United Nations Statistical Database [FAOSTAT]. (2021). New Food Balances. http://www.fao.org/faostat/en/#data/FBS. Accessed 2021-03-12.

Hemetsberger, M. (2014). Registerzählung 2011, Arbeitsstättenzählung 2011 Gebäude- und Wohnungszählung 2011 Ergebnisse für Niederösterreich. Statistik. Wien: Land Niederösterreich.

Herridge, D. F., Peoples, M. B., & Boddey, R. M. (2008). Global inputs of biological nitrogen fixation in agricultural systems. *Plant and Soil*, *311*(1–2), 1–18. https://doi.org/10.1007/s11104-008-9668-3

International Institute for Applied Systems Analysis [IIASA] AIR Group (2018a). Emission factors for livestock by stage. GAINS ver. 4. IIASA. http://gains.iiasa.ac.at/gains4/. Accessed 2020-10-12.

IIASA AIR Group (2018b). Milk yield of dairy cows. GAINS ver. 4. IIASA. http://gains.iiasa. ac.at/gains4/. Accessed 2019-04-30.

IIASA AIR Group (2018c). Emission factors - All sources (select N2O). GAINS ver. 4. IIASA. http://gains.iiasa.ac.at/gains4/. Accessed 2020-10-12.

IIASA AIR Group (2018d). NH3 emission factors for agricultural activities and industrial processes. GAINS ver. 4. IIASA. http://gains.iiasa.ac.at/gains4/. Accessed 2020-10-12.

IIASA AIR Group (2018e). Mineral nitrogen fertilizer consumption. GAINS ver. 4. IIASA. http://gains.iiasa.ac.at/gains4/. Accessed 2020-10-12.

IPCC (2019). 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Task Force on National GHG Inventories (Technical Support Unit, Institute for Global Environmental Strategies Kamiyamaguchi Hayama) (Kanagawa JAPAN) 5

Keuter, A., Veldkamp, E., & Corre, M. D. (2014). Asymbiotic biological nitrogen fixation in a temperate grassland as affected by management practices. *Soil Biology and Biochemistry*, *70*, 38–46. https://doi.org/10.1016/j.soilbio.2013.12.009

Kremer, A. M. (2013). Methodology and Handbook Eurostat / OECD Nutrient Budgets, version 1.02. 1–112.

Land Niederösterreich. (2016). Abfallwirtschaft Niederösterreich. Daten 2015. Bericht. St. Pölten, Land Niederösterreich.

Land Niederösterreich. (2018). Niederösterreich Landesübersicht (A1). https://www.noe.gv.at/noe/Karten-Geoinformationen/DownloadGeodatenKarten.html. Accessed: 2021-04-12.

Land Niederösterreich. (2021). Bezirke und Gemeinden. https://noe.gv.at/noe/index.html. Accessed: 2021-04-12.

Lassaletta, L., Billen, G., Grizzetti, B., Anglade, J., & Garnier, J. (2014). 50 year trends in nitrogen use efficiency of world cropping systems: The relationship between yield and nitrogen input to cropland. *Environmental Research Letters*, *9*(10). https://doi.org/10.1088/1748-9326/9/10/105011

Liu, J., You, L., Amini, M., Obersteiner, M., Herrero, M., Zehnder, A. J. B., & Yang, H. (2010). A high-resolution assessment on global nitrogen flows in cropland. *Proceedings of the National Academy of Sciences of the United States of America*, *107*(17), 8035–8040. https://doi.org/10.1073/pnas.0913658107

MA 48 (2015). Jahresbericht 2015. Bericht. Wien: MA 48.

Neubauer, M., Karigl, B., Kleemann, F. & Tesar, M. (2019). Fortschreibung des Niederösterreichischen LAWP 2016, Detailauswertung aus EDM. REP-0673. Wien: Umweltbundesamt.

Neumann, F. (2018). *Lebend- & Schlachtgewichte Jahresergebnis 2017. Schnellbericht 1.8.* Wien: Statistik Austria.

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.

Oftner, M., Lenz, K., & Zieritz, I. (2020). *Kommunales Abwasser – Österreichischer Bericht 2020*. Wien: Bundesministerium Landwirtschaft, Regionen und Tourismus.

Oliva, J., Bernhardt,A., Reisinger, H., Domenig, M. & Krammer, H.-J. (2009). Klärschlamm-Materialien zur Abfallwirtschaft. Bericht, REP-0221. Klagenfurt, Wien: Umweltbundesamt.

Österr. Bundesministerium für Land- und Forstwirtschaft (2011). Evaluierung des Programms LE07-13 „Abschätzung der bedürftigen landwirtschaftlichen Flächen sowie Integration der Daten in die INVEKOS-Datenbank". 29

Soussana, J. F., & Tallec, T. (2010). Can we understand and predict the regulation of biological N2 fixation in grassland ecosystems? *Nutrient Cycling in Agroecosystems*, *88*(2), 197–213. https://doi.org/10.1007/s10705-009-9335-y

Stadt Wien (n.d.). Landwirtschaft – Statistik. https://www.wien.gv.at/statistik/wirtschaft/landwirtschaft/. Accessed 2021-04-09.

Statistik Austria (2010). *Regionale Nährstoffbilanzen in Österreich für NUTS 3-Gebiete Eurostat Grant 2008/ Thema 4.07 Endbericht Juni 2010*. 1–66.

Statistik Austria (2014). NUTS 3 mit Gemeinden, Flächen und Bevölkerung. http://www.statistik.at/web_de/static/nuts_3_mit_gemeinden_flaechen_und_bevoelkerung_024562.pdf. Accessed 2020-09-01.

Statistik Austria (2014/2015). Themenblatt Haustiere – Konsumerhebung 2014/2015. https://www.statistik.at/web_de/statistiken/menschen_und_gesellschaft/soziales/ausstattung_privater_haushalte/index.html. Accessed 2020-10-01.

Statistik Austria (2019). Futtermittelbilanz. http://www.statistik.at/web_de/statistiken/wirtschaft/land_und_forstwirtschaft/preise_bilanzen/futtermittelbilanzen/index.html. Accessed 2021-01-20.

Statistik Austria (2020a). Agrarstrukturerhebung 2010 Viehbestand. https://www.statistik.at/web_de/statistiken/wirtschaft/land_und_forstwirtschaft/viehbestand_tierische_erzeugung/viehbestand/index.html. Accessed 2020-10-05.

Statistik Austria (2020b). Agrarstrukturerhebung 2016 Viehbestand. https://www.statistik.at/web_de/statistiken/wirtschaft/land_und_forstwirtschaft/viehbestand_tierische_erzeugung/viehbestand/index.html. Accessed 2020-10-05.

Statistik Austria (2020c). Agrarstrukturerhebung 2010 Bodennutzung. https://www.statistik.at/web_de/statistiken/wirtschaft/land_und_forstwirtschaft/agrarstruktur_flaechen_ertraege/bodennutzung/index.html. Accessed 2020-10-09.

Statistik Austria (2020d). Obstproduktion ab 1975. https://www.statistik.at/web_de/statistiken/wirtschaft/land_und_forstwirtschaft/agrarstruktur_flaechen_ertraege/obst/index.html. Accessed 2020-10-09.

Statistik Austria (2020e). Gemüseproduktion ab 1995. https://statcube.at/statistik.at/ext/statcube/jsf/dataCatalogueExplorer.xhtml. Accessed 2020-10-09.

Statistik Austria (2020f). Feldfruchtproduktion ab 1970. https://www.statistik.at/web_de/statistiken/wirtschaft/land_und_forstwirtschaft/agrarstruktur_flaechen_ertraege/feldfruechte/index.html. Accessed 2020-10-09.

Statistik Austria (2020g). Betriebsstruktur: Land- und forstwirtschaftliche Betriebe und Kulturflächen 1995/1999/2010. https://statistik.at/web_de/statistiken/wirtschaft/land_und_forstwirtschaft/agrarstruktur_flaechen_ertraege/betriebsstruktur/index.html. Accessed 2021-04-09.

Statistik Austria (2021a). Energy balances for Laender as of 1988. https://statcube.at/statistik.at/ext/statcube/jsf/tableView/tableView.xhtml. Accessed 2021-05-02.

Statistik Austria (2021b). Versorgungsbilanz. https://www.statistik.at/web_de/statistiken/wirtschaft/land_und_forstwirtschaft/preise_bilanzen/versorgungsbilanzen/index.html. Accessed 2021-03-30.

Statistik Austria (2021c). Untersuchte Schlachtungen 2011 bis 2020. https://www.statistik.at/web_de/statistiken/wirtschaft/land_und_forstwirtschaft/viehbestand_tierische_erzeugung/schlachtungen/index.html. Accessed 2021-03-30.

Statistik Austria (2021d). Milch. https://www.statistik.at/web_de/statistiken/wirtschaft/land_und_forstwirtschaft/viehbestand_tierische_erzeugung/milch/index.html. Accessed 2021-03-25.

Statistik Austria (2021e). Regional data by federal provinces and 2digits CN (Q) https://www.statistik.at/web_en/statistics/Economy/foreign_trade/regional_data_by_federal_states/index.html. Accessed 2021-05-31.

Statistik Austria (2021f). Haushalte, Familien und Lebensformen. https://www.statistik.at/web_de/statistiken/menschen_und_gesellschaft/bevoelkerung/haushalte_familien_lebensformen/index.html. Accessed 2020-05-31.

Statistik Austria (2021g). Gartenbauerhebung ab 1982 (Betriebe, Flächen). https://www.statistik.at/web_en/statistics/Economy/agriculture_and_forestry/index.html. Accessed 2020-05-31.

Umweltbundesamt. (n.d.). H2O Fachdatenbank - Qualitätsdatenabfrage Öffentlich. https://wasser.umweltbundesamt.at/h2odb/fivestep/abfrageQdPublic.xhtml. Accessed: 2021-04-05.

Umweltbundesamt. (2015). Flächeninanspruchnahme in Österreich 2015, Regionalinformation der Grundstücksdatenbank (Bundesamt für Eich- und Vermessungswesen) https://www.umweltbundesamt.at/umweltthemen/boden/flaecheninanspruchnahme. Accessed: 2021-06-05.

UNFCCC (2020). Austria. 2020 Common Reporting Format (CRF) Table. https://unfccc.int/documents/226190. Accessed 2020-10-23.

Pladerer, C., Bernhofer, G., Kalleitner-Huber, M., & Hietler, P. (2016). Lagebericht zu Lebensmittelabfällen und - verlusten in Österreich. WWF Österreich, 1–33.

Wikipedia (2020). Schlachtgewicht. https://de.wikipedia.org/wiki/Schlachtgewicht. Accessed 2020-11-05.

Winiwarter, W. & Expert Panel on Nitrogen Budgets [EPNB] (2016). *Detailed Annexes to ECE / EB . AIR / 119 – "Guidance document on national nitrogen budgets "*. http://www.clrtap-tfrn.org/sites/clrtap-tfrn.org/files/documents/EPNB_new/EPNB_annex_20210302_public.pdf

ANNEX II

UNCNET –
Brief description of flows and pools

UNCNET

Brief description of flows and pools

Version 2.0: April 2022

Samuel Guéret, Katrin Kaltenegger
Pollution Management Group
International Institute for Applied Systems Analysis (IIASA), Schlossplatz 1, 2361 Laxenburg, Austria

OVERVIEW

In this document we summarize the various assumptions underlying the N flows being quantified between environmental compartments. As of April 2022, a total of 74 flows being exchanged in 13 environmental pools are accounted for in the STAN model.

The document is structured as follows: The Section **Pools** details each of the pools/pools used in the UNCNET project as well as each of their corresponding inflows and outflows.
The current state of the network topology of Vienna and Vienna surrounding area's Urban Nitrogen Budgets (UNBs) for the base year 2015 is shown as a compact table matrix in the following Figure 4. The abbreviations of the various pools are defined in the Figure's caption.

to

from	AIR	WW	WAT	WAS	HH	AGL	HOR	URG	LIV	PET	IND	COM	IMX	OUT
AIR	0	0	0	0	F156	F107	F121	F125	0	0	0	0	F50	0
WW	F28	0	F76	F66	0	F103	0	0	0	0	0	0	0	0
WAT	0	0	0	0	0	F100	F101	F102	0	0	0	0	F80	0
WAS	F55	F65	F63	0	0	F118	0	F129	0	0	F153	F69	F75	0
HH	0	F59	0	F49	0	0	0	F155	0	0	0	F123	0	0
AGL	F127	0	F110	F146	F109	0	0	0	F130	0	F152	F138	F108	0
HOR	F114	0	F116	F113	F115	0	0	F120	0	0	0	0	F112	0
URG	F117	0	F119	F150	0	0	0	0	0	0	0	0	0	0
LIV	F145	F139	0	F144	F142	F143	0	0	0	0	F154	0	F141	0
PET	0	F137	0	F133	0	0	0	F135	0	0	0	0	F136	0
IND	F81	F77	F62	F86	F52	F97	F98	F99	F149	F148	0	F51	F73	0
COM	F44	0	0	F78	0	0	0	0	0	0	0	0	0	0
IMX	F61	F74	F60	0	0	0	F95	0	F132	0	F47	F54	0	F163
OUT	0	0	0	0	0	0	0	0	0	0	0	0	F111	0

Figure 4 - UNB Topology matrix of the Vienna surrounding area for the base year 2015 indicating the flows (flow numbers refer to detailed explanation given in Appendix A). Rows represent the originating pools and columns the recipient ones. AIR = Air; WW = Wastewater; WAT = Water; WAS = Waste; HH = Households; AGL = Agricultural land; HOR = Horticulture; URG = Urban green; LIV = Livestock; PET = Pets; IND = Industry; COM = Combustion; IMX = Import/Export; OUT = Outside boundaries

POOLS

URBAN PLANTS: This pool contains three pools: agricultural land, horticulture and urban green. Agricultural land encompasses cropland and grassland. Urban green includes public parks, private gardens, backyards, forests and green belts. Horticulture includes horticultural areas according to the individual national definitions. In Vienna, horticulture includes areas used for flower cultivation but also areas where fruit/vegetables are grown in horticultural holdings.

POOL AGRICULTURAL LAND

Inflows

Inflow connections to the agricultural land pool currently include those from the AIR, WASTEWATER, WATER, WASTE, LIVESTOCK and INDUSTRY pools:

- **FLOW 107: AIR TO AGRICULTURAL LAND:** This flow accounts for wet and dry N deposition on agricultural land. It also includes the amount of N fixed from the air by organisms (BNF – biological N fixation)
- **FLOW 103: WASTEWATER TO AGRICULTURAL LAND:** This flow includes N in wastewater used for crop- and grassland irrigation.
- **FLOW 100: WATER TO AGRICULTURAL LAND:** This flow includes N in irrigation water used for crop- and grasslands.
- **FLOW 118: WASTE TO AGRICULTURAL LAND:** This flow encompasses N application from compost to crop-and grasslands. The assumption taken for Vienna and its surrounding area is that half of the available compost is going to the urban green pool and the other half in the agricultural land pool.
- **FLOW 143: LIVESTOCK TO AGRICULTURAL LAND:** This flow encompasses manure N application to cropland and grassland from manure managed indoors as well as manure N excreted by grazing animals on grassland.
- **FLOW 97: INDUSTRY TO AGRICULTURAL LAND:** This flow accounts for N contained in industrially manufactured or distributed fertilizers used on crop- and grasslands.

Outflows

Outflow connections from the agricultural land pool currently include those towards the AIR, WATER, WASTE, HOUSEHOLDS, LIVESTOCK, INDUSTRY, COMBUSTION and IMPORT/EXPORT pools:

- **FLOW 127: AGRICULTURAL LAND TO AIR:** This flow includes NH3 and N2O volatilization from manure N applied to agricultural land (cropland- and grassland) and manure N excreted by grazing animals as well as volatilization from fertilizer application (taking urea and non-urea shares of fertilizers into account).
- **FLOW 110: AGRICULTURAL LAND TO WATER:** This flow includes N leaching and runoff water from total N input to agricultural lands (synthetic fertilizer, manure N).
- **FLOW 146: AGRICULTURAL LAND TO WASTE:** This flow includes N losses on field at harvest as well as during transport and packaging.
- **FLOW 109: AGRICULTURAL LAND TO HOUSEHOLDS:** This flow includes N in harvested crops used as food for households. For Vienna, the computed flow represents the total amount of harvested crops used as food. For Vienna surrounding area, the computed flow only represents what is being consumed in the test area by the households as more is produced in practice.
- **FLOW 130: AGRICULTURAL LAND TO LIVESTOCK:** This flow includes N in harvested crops that are used as feed as well as N intake from grazing animals.
- **FLOW 152: AGRICULTURAL LAND TO INDUSTRY:** This flow includes N in harvested crops either processed or used in industry.
- **FLOW 138: AGRICULTURAL LAND TO COMBUSTION:** This flow includes N in fuel used to operate agricultural machinery. This flow does not include N generated by the burning of agricultural waste.

- **FLOW 108: AGRICULTURAL LAND TO IMPORT/EXPORT:** This flow includes N in harvested crops and fodder that are exported outside the system boundaries

POOL HORTICULTURE

Inflows

Inflow connections to the horticulture pool currently include those from the AIR, WATER, INDUSTRY and IMPORT/EXPORT pools:

- **FLOW 121: AIR TO HORTICULTURE:** This flow accounts for N deposition and BNF on the horticulture pool, thereby only taking into account outdoor areas.
- **FLOW 101: WATER TO HORTICULTURE:** This flow includes N in irrigation water used for horticultural land.
- **FLOW 98: INDUSTRY TO HORTICULTURE:** This flow accounts for N contained in industrial fertilizers used on horticultural land.
- **FLOW 95: IMPORT/EXPORT TO HORTICULTURE:** This flow accounts for N contained in flowers that are imported from outside the system boundaries.

Outflows

Outflow connections from the horticulture pool currently include those towards the urban green pool and the AIR, WATER, WASTE, HOUSEHOLDS, URBAN GREEN and IMPORT/EXPORT pools:

- **FLOW 114: HORTICULTURE TO AIR**: This flow includes N volatilization (N2O & NH3) from synthetic fertilizer application.
- **FLOW 116: HORTICULTURE TO WATER:** This flow includes N leaching and runoff water from total N input to outdoor horticultural lands.
- **FLOW 113: HORTICULTURE TO WASTE:** This flow includes N in flowers or horticultural fruits/vegetables that are lost at harvest.
- **FLOW 115: HORTICULTURE TO HOUSEHOLDS:** This flow includes N in flowers or horticultural fruits/vegetables that are directly sold to households.
- **FLOW 120: HORTICULTURE TO URBAN GREEN:** This flow includes N in flowers going to urban greens (e.g. parks).
- **FLOW 112: HORTICULTURE TO IMPORT/EXPORT:** This flow encompasses N in flowers & horticultural fruits/vegetables that are exported.

POOL URBAN GREEN

Inflows

Inflow connections to the urban green pool currently include those from the horticulture pool and the AIR, WATER, WASTE, HOUSEHOLDS, HORTICULTURE, PETS and INDUSTRY pools:

- **FLOW 125: AIR TO URBAN GREEN:** This flow accounts for wet and dry N deposition and BNF on urban greens.
- **FLOW 102: WATER TO URBAN GREEN:** This flow includes N in irrigation water used for urban greens.
- **FLOW 129: WASTE TO URBAN GREEN:** This flow includes N in compost spread on urban greens (e.g in private gardens). The assumption taken for Vienna and its surrounding area is that half of the available compost is going to the urban green pool and the other half in the agricultural land pool.
- **FLOW 155: HOUSEHOLDS TO URBAN GREEN:** This flow represents N contained in household compost ending in urban greens (mostly private gardens).

- **FLOW 120: HORTICULTURE TO URBAN GREEN:** This flow includes N in flowers or horticultural fruits/vegetables going to urban greens (e.g. parks).

- **FLOW 135: PETS TO URBAN GREEN:** This flow includes manure N from pets deposited on urban greens. The assumption currently taken is that a fraction of cat and dog manure in urban areas is going to waste and a fraction to urban greens (for Vienna this can be derived from waste statistic) but all manure in peri-urban areas is going to urban greens.

- **FLOW 99: INDUSTRY TO URBAN GREEN:** This flow accounts for N contained in industrial fertilizers used on urban greens.

Outflows

Outflow connections from the urban green pool currently include those towards the AIR, WATER, WASTE, and IMPORT/EXPORT pools:

- **FLOW 117: URBAN GREEN TO AIR:** This flow includes N volatilization (N2O & NH3) from synthetic fertilizer application (differentiation between urea and non-urea ones is made due to difference in emission factors), pet manure and compost.

- **FLOW 119: URBAN GREEN TO WATER**: This flow includes N leaching and runoff water from parks and gardens using all N input as basis (synthetic fertilizer and compost, pet manure).

- **FLOW 150: URBAN GREEN TO WASTE**: This flow includes N from green clippings.

URBAN ANIMALS: This pool contains two pools: pets and livestock. Pets encompass cats, dogs and other pets. Livestock includes dairy cattle, chicken, sheep, pigs etc. Horses are currently categorized under livestock.

POOL PETS

Inflows

Inflow connections to the pets pool currently include those from the INDUSTRY pool:

- **FLOW 148: INDUSTRY TO PETS:** This flow includes N in pet food coming from the industry. For Vienna and its surrounding area, the computed numbers represent the total amount that is needed as feed for the pets. For Vienna, the entire computed amount of N is imported from outside the study area (hence transferred from the import/export pool) while for Vienna surrounding area, only part of N in pet food is imported.

Outflows

Outflow connections from the pets pool currently include those towards the WASTEWATER, WASTE, URBAN GREEN, and IMPORT/EXPORT pools:

- **FLOW 137: PETS TO WASTEWATER:** This flow includes N excreted outdoors on the streets and thus not on urban greens that eventually results in run-off.

- **FLOW 133: PETS TO WASTE:** This flow includes N excretion from pets assumed to be collected and binned. The assumption currently taken is that a fraction of cat and dog manure in urban areas is going to waste and a fraction to urban greens (for Vienna this can be derived from waste statistic) but all manure in peri-urban areas is going to urban greens.

- **FLOW 135: PETS TO URBAN GREEN:** This flow includes manure N from pets deposited on urban greens. The assumption currently taken is that a fraction of cat and dog manure in urban areas is going to waste and a fraction to urban greens (for Vienna this can be derived from waste statistic) but all manure in peri-urban areas is going to urban greens.

- **FLOW 136: PETS TO IMPORT/EXPORT:** This flow includes N from pets that are exported outside the system boundaries.

POOL LIVESTOCK

Inflows

Inflow connections to the livestock pool currently include those from the AGRICULTURAL LAND, INDUSTRY, and IMPORT/EXPORT pools:

- **FLOW 130: AGRICULTURAL LAND TO LIVESTOCK:** This flow includes N in harvested crops that are used as feed as well as N intake from grazing animals.
- **FLOW 149: INDUSTRY TO LIVESTOCK:** This flow encompasses feed. In Vienna & its surrounding, it is assumed that no feed needs to be imported because feed demand can be met with local production. No detailed production/trade statistic was available.
- **FLOW 132: IMPORT/EXPORT TO LIVESTOCK:** This flow includes N in imported living livestock and livestock products. For Vienna and its surrounding area, the assumption taken is that the imported living livestock should at least match the slaughtered livestock minus the livestock already present. Also, another assumption taken is that all fodder is produced locally because no detailed statistics on the city/region level are available.

Outflows

Outflow connections from the livestock pool currently include those towards the AIR, WASTEWATER, WASTE, HOUSEHOLDS, AGRICULTURAL LAND, INDUSTRY, and IMPORT/EXPORT pools:

- **FLOW 145: LIVESTOCK TO AIR:** This flow includes N volatilization (NH3 and N2O) from livestock and manure management indoors. This flow does not include N volatilization from manure excreted outdoors, which is included in the flow FLOW 127 AGRICULTURAL LAND TO AIR.
- **FLOW 139: LIVESTOCK TO WASTEWATER:** This flow includes N contained in livestock excrements that are washed away into wastewater when stables are flushed.
- **FLOW 144: LIVESTOCK TO WASTE:** This flow includes N contained in slaughterhouse waste in Vienna and its surrounding

  but could also encompass in other regions manure N that is going to waste.
- **FLOW 142: LIVESTOCK TO HOUSEHOLDS:** This flow includes N contained in livestock products (meat, eggs, milk, fancy meat etc.) consumed by the inhabitants of the respective region. For Vienna and its surrounding it is derived from food demand of population (average food intake).
- **FLOW 143: LIVESTOCK TO AGRICULTURAL LAND:** This flow includes manure N application to cropland and grassland from manure managed indoors as well as manure N excreted by grazing animals on grassland
- **FLOW 154: LIVESTOCK TO INDUSTRY:** This flow includes N contained in livestock products (pet food, milk, eggs, etc) directed to the processing industry.
- **FLOW 141: LIVESTOCK TO IMPORT/EXPORT:** This flow includes N from living animals that are exported outside the system boundaries. Processed livestock products would pass through the industry pool before going to export/import.

HOUSEHOLDS: This pool represents the households of the inhabitants of the respective study area and contains a stock that represents the N content of all products stored within the households (e.g. clothes, furniture, etc).

Inflows

Inflow connections to the households pool currently include those from the AIR, AGRICULTURAL LAND, HORTICULTURE, LIVESTOCK and INDUSTRY pools:

- **FLOW 156: AIR TO HOUSEHOLD:** This flow accounts for N deposition on urban (built-up) areas.
- **FLOW 109: AGRICULTURAL LAND TO HOUSEHOLDS:** This flow includes N in harvested crops used as food for households. For Vienna, the computed flow represents the total amount of harvested crops used as food. For Vienna surrounding area, the computed flow only represents what is being consumed in the test area by the households as more is produced in practice.
- **FLOW 115: HORTICULTURE TO HOUSEHOLDS:** This flow includes N in flowers or horticultural fruits/vegetables that are assumed to go to households. For Vienna, a fraction going to urban greens is subtracted.
- **FLOW 142: LIVESTOCK TO HOUSEHOLDS:** This flow includes N contained in livestock products (meat, eggs, milk, fancy meat etc.) consumed by the inhabitants of the respective region. For Vienna and its surrounding it is derived from food demand of population (average food intake).
- **FLOW 52: INDUSTRY TO HOUSEHOLD:** This flow accounts for N contained in industrial products going to households. These industrial products also include commercial ones, such as those found in small retailers or supermarkets. For Vienna and its surrounding this flow was calculated from balancing input with output, taking into account food demand. If available, more detailed statistics on household consumption are a better option.

Outflows

Outflow connections from the households pool currently include those towards the WASTEWATER, WASTE, URBAN GREEN and COMBUSTION pools:

- **FLOW 59: HOUSEHOLD TO WASTEWATER:** This flow accounts for N discharged by the population (e.g. excretion, household chemicals) into domestic wastewater.
- **FLOW 49: HOUSEHOLD TO WASTE:** This flow accounts for N related to residential waste only. All kinds of waste are taken into account. Hence, the waste composition is needed to properly assess the overall quantity of transported nitrogen.
- **FLOW 155: HOUSEHOLDS TO URBAN GREEN:** This flow represents N contained in household compost ending in urban greens (mostly private gardens).
- **FLOW 123: HOUSEHOLDS TO COMBUSTION:** This flow encompasses all N (NOx, NO2, NH3 and N2O) in fuels used by the residential sector (e.g. fuel wood, petrol, diesel, biofuels).

WASTE: This pool represents the waste treatment plants in the respective study area and contains a stock that represents N in waste stored in landfills (including landfills for building materials or other specific material).

Inflows

Inflow connections to the waste pool currently include those from the WASTEWATER, HOUSEHOLD, AGRICULTURAL LAND, HORTICULTURE, URBAN GREEN, LIVESTOCK, PETS, INDUSTRY, and COMBUSTION pools:

- **FLOW 66: WASTEWATER TO WASTE**: This flow represents N in sewage sludge that is treated in waste treatment plants.
- **FLOW 49: HOUSEHOLD TO WASTE:** This flow accounts for N related to residential waste only. All kinds of waste are taken into account which means the waste composition is needed to properly assess the overall quantity of transported nitrogen.
- **FLOW 146: AGRICULTURAL LAND TO WASTE:** This flow includes N losses on field at harvest as well as during transport and packaging.
- **FLOW 113: HORTICULTURE TO WASTE:** This flow includes N in flowers or horticultural fruits/vegetables that are lost at harvest.
- **FLOW 150: URBAN GREEN TO WASTE**: This flow includes N from green clippings.

- **FLOW 144: LIVESTOCK TO WASTE:** This flow includes N contained in slaughterhouse waste but could also encompass manure N that is going to waste.
- **FLOW 133: PETS TO WASTE:** This flow includes N excretion from pets assumed to be collected and binned. The assumption currently taken is that a fraction of cat and dog manure in urban areas is going to waste and a fraction to urban greens (for Vienna this can be derived from waste statistic) but all manure in peri-urban areas is going to urban greens.
- **FLOW 86: INDUSTRY TO WASTE:** This flow accounts for N contained in industrial waste.
- **FLOW 78: COMBUSTION TO WASTE**: This flow represents N contained in burning residues that are being disposed of in waste treatment plants.

Outflows

Outflow connections from the waste pool currently include those towards the AIR, WASTEWATER, WATER, AGRICULTURAL LAND, URBAN GREEN, INDUSTRY, COMBUSTION, and IMPORT/EXPORT pools:

- **FLOW 55: WASTE TO AIR:** This flow accounts for atmospheric N emissions (NH3 and N2O volatilization) which are mostly coming from composting (and to landfill and pet manure to a smaller extent).
- **FLOW 65: WASTE TO WASTEWATER**: This flow represents N contained in run-off or processing flows from waste treatment facilities ending into centralized wastewater treatment plants (e.g. dewatering process from Mechanical Biological Treatment (MBT) or run-off from composting).
- **FLOW 63: WASTE TO WATER**: This flow accounts for N leached from waste treatment facilities using chemical-physical treatments.
- **FLOW 118: WASTE TO AGRICULTURAL LAND:** This flow encompasses N application from compost to crop-and grasslands. The assumption taken for Vienna and its surrounding area is that half of the available compost is going to the urban green pool and the other half in the agricultural land pool.
- **FLOW 129: WASTE TO URBAN GREEN:** This flow includes N in compost spread on urban greens (e.g in private gardens). The assumption taken for Vienna and its surrounding area is that half of the available compost is going to the urban green pool and the other half in the agricultural land pool.
- **FLOW 153: WASTE TO INDUSTRY**: This flow accounts for the N in waste that is re-used in industry.
- **FLOW 69: WASTE TO COMBUSTION**: This flow represents the N contained in waste being incinerated.
- **FLOW 75: WASTE TO IMPORT/EXPORT**: This flow represents N contained in exported waste.

WATER: This pool contains a stock that represents N in waterbodies like lakes, groundwater or rivers coming from e.g. leaching and run-off which are subject to 'indirect' emissions.

Inflows

Inflow connections to the water pool currently include those from the WASTEWATER, WASTE, AGRICULTURAL LAND, HORTICULTURE, URBAN GREEN, INDUSTRY, and IMPORT/EXPORT pools:

- **FLOW 76: WASTEWATER TO WATER**: This flow represents N contained in the outflow of wastewater treatment plants (effluent) into waterways. The flow has been computed using the revised IPCC guidelines from 2019 regarding the N2O emissions from domestic wastewater.
- **FLOW 63: WASTE TO WATER**: This flow accounts for N leached from waste treatment facilities using chemical-physical treatments.
- **FLOW 110: AGRICULTURAL LAND TO WATER:** This flow includes N leaching and runoff water from total N input to agricultural lands (synthetic fertilizer, manure N).
- **FLOW 116: HORTICULTURE TO WATER:** This flow includes N leaching and runoff water from total N input to outdoor horticultural lands.

- **FLOW 119: URBAN GREEN TO WATER**: This flow includes N leaching and runoff water from parks and gardens using all N input as basis (synthetic fertilizer and compost, pet manure).
- **FLOW 62: INDUSTRY TO WATER**: This flow accounts for N-related leakage and runoff losses from industrial and commercial activities.

- **FLOW 60: IMPORT/EXPORT TO WATER:** This flow represents N contained in water coming into the study area from outside the system boundaries for the respective urban or peri-urban area (e.g. via rivers).

Outflows

Outflow connections from the water pool currently include those towards the AGRICULTURAL LAND, HORTICULTURE, URBAN GREEN, and IMPORT/EXPORT pools:

- **FLOW 100: WATER TO AGRICULTURAL LAND:** This flow includes N in irrigation water used for crop- and grasslands.
- **FLOW 101: WATER TO HORTICULTURE:** This flow includes N in irrigation water used for horticultural land.
- **FLOW 102: WATER TO URBAN GREEN:** This flow includes N in irrigation water used for urban greens.
- **FLOW 80: WATER TO IMPORT/EXPORT:** This flow accounts for N contained in water carried away from the system's boundaries for the respective urban or peri-urban area (e.g. via rivers).

INDUSTRY: This pool encompasses all industrial processes (chemical, food processing, energy production, etc) taking place in the respective study area.

Inflows

Inflow connections to the industry pool currently include those from the WASTE, AGRICULTURAL LAND, LIVESTOCK, and IMPORT/EXPORT pool:

- **FLOW 153: WASTE TO INDUSTRY**: This flow accounts for the N in waste that is re-used in industry.
- **FLOW 152: AGRICULTURAL LAND TO INDUSTRY:** This flow includes N in harvested crops either processed or used in industry.
- **FLOW 154: LIVESTOCK TO INDUSTRY:** This flow includes N contained in livestock products (pet food, milk, eggs, etc) directed to the processing industry.
- **FLOW 47: IMPORT/EXPORT TO INDUSTRY:** This flow accounts for N contained in goods imported from outside the study area and serving as materials for the processing activities of a given industry.

Outflows

Outflow connections from the industry pool currently include those towards the AIR, WASTEWATER, WATER, WASTE, HOUSEHOLD, AGRICULTURAL LAND, HORTICULTURE, URBAN GREEN, LIVESTOCK, PETS, COMBUSTION, and IMPORT/EXPORT pools:

- **FLOW 81: INDUSTRY TO AIR:** This flow accounts for the N-related industrial atmospheric emissions.
- **FLOW 77: INDUSTRY TO WASTEWATER**: This flow represents N contained in industrial wastewater.
- **FLOW 62: INDUSTRY TO WATER**: This flow accounts for N-related leakage and runoff losses from industrial and commercial activities.
- **FLOW 86: INDUSTRY TO WASTE:** This flow accounts for N contained in industrial waste.
- **FLOW 52: INDUSTRY TO HOUSEHOLD:** This flow accounts for N contained in industrial products going to households. These industrial products also include commercial ones, such as those found in small retailers or supermarkets. For Vienna and its surrounding this flow was calculated from balancing input with output, taking into account food demand. If available, more detailed statistics on household consumption would be a better option.

- **FLOW 97: INDUSTRY TO AGRICULTURAL LAND:** This flow accounts for N contained in industrial fertilizers used on crop- and grasslands.

- **FLOW 98: INDUSTRY TO HORTICULTURE:** This flow accounts for N contained in industrially manufactured or distributed fertilizers used on horticultural land.

- **FLOW 99: INDUSTRY TO URBAN GREEN:** This flow accounts for N contained in industrially manufactured or distributed fertilizers used on urban greens.

- **FLOW 149: INDUSTRY TO LIVESTOCK:** This flow encompasses feed. In Vienna & its surrounding, it is assumed that no feed needs to be imported because feed demand can be met with local production. No detailed production/trade statistic was available.

- **FLOW 148: INDUSTRY TO PETS:** This flow includes N in pet food coming from the industry. For Vienna and its surrounding area, the computed numbers represent the total amount that is needed as feed for the pets.

- **FLOW 51: INDUSTRY TO COMBUSTION:** This flow accounts for N in fuels used for industrial combustion (boilers, power plant, ovens, etc).

- **FLOW 73: INDUSTRY TO IMPORT/EXPORT**: This flow accounts for N contained in exported industrial goods (anything from textiles to agricultural products).

COMBUSTION: This pool encompasses all combustion processes within the respective study area (energy production, traffic, heating, etc.).

Inflows

Inflow connections to the combustion pool currently include those from the WASTE, HOUSEHOLDS, AGRICULTURAL LAND, INDUSTRY, and IMPORT/EXPORT pools:

- **FLOW 69: WASTE TO COMBUSTION**: This flow represents the N contained in waste being incinerated.
- **FLOW 123: HOUSEHOLDS TO COMBUSTION:** This flow encompasses all N (NOx, NO2, NH3 and N2O) in fuels used by the residential sector (e.g. fuel wood, petrol, diesel, biofuels).

- **FLOW 138: AGRICULTURAL LAND TO COMBUSTION:** This flow includes N in fuel used to operate agricultural machinery. This flow does not include N generated by the burning of agricultural waste.

- **FLOW 51: INDUSTRY TO COMBUSTION:** This flow accounts for N in fuels used for industrial combustion (boilers, power plant, ovens, etc).

- **FLOW 54: IMPORT/EXPORT TO COMBUSTION:** This flow accounts for N contained in goods imported from outside the study area and serving as fuel for any combustion activity, such as the import of fuels.

Outflows

Outflow connections from the combustion pool currently include the one towards the AIR and WASTE pools:

- **FLOW 44: COMBUSTION TO AIR:** This flow includes all N (N2O, NOx, NO2, NH3) emitted to the atmosphere from combustion for heating or energy purposes (from residential, agricultural & industrial sector as well as transport).

- **FLOW 78: COMBUSTION TO WASTE**: This flow represents N contained in burning residues that are being disposed of in waste treatment plants.

AIR: This pool represents the atmospheric environment and is mostly seen as a reservoir pool. Nitrogen compounds are collected, transported and deposited in and from this pool. Conversions between compounds are not considered (see Draft Guidance document on N budgets).

Inflows

Inflow connections to the air pool currently include those from WASTEWATER, WASTE, AGRICULTURAL LAND, HORTICULTURE, URBAN GREEN, LIVESTOCK, INDUSTRY, COMBUSTION, and IMPORT/EXPORT pools:

- **FLOW 131: WASTEWATER TO AIR:** This flow accounts for N related to direct and indirect N2O emissions from Wastewater Treatment Plants (WWTPs) that occur during the transport and treatment of the wastewater. The flow has been computed using the revised IPCC guidelines from 2019 regarding the N2O emissions from wastewater.
- **FLOW 55: WASTE TO AIR:** This flow accounts for atmospheric N emissions (NH3 and N2O volatilization) which are mostly coming from composting (and to landfill to a smaller extent).
- **FLOW 127: AGRICULTURAL LAND TO AIR:** This flow includes NH3 and N2O volatilization from manure N applied to agricultural land (cropland- and grassland) and manure N excreted by grazing animals as well as volatilization from fertilizer application (taking urea and non-urea shares of fertilizers into account).
- **FLOW 114: HORTICULTURE TO AIR**: This flow includes N volatilization (N2O & NH3) from synthetic fertilizer application.
- **FLOW 117: URBAN GREEN TO AIR:** This flow includes N volatilization (N2O & NH3) from synthetic fertilizer application (differentiation between urea and non-urea ones is made due to difference in emission factors), pet manure and compost.
- **FLOW 145: LIVESTOCK TO AIR:** This flow includes N volatilization (NH3 and N2O) from livestock and manure management indoors. This flow does not include N volatilization from manure excreted outdoors, which is included in the flow FLOW 127 AGRICULTURAL LAND TO AIR.
- **FLOW 81: INDUSTRY TO AIR:** This flow accounts for the N-related industrial atmospheric emissions not undergoing any combustion.
- **FLOW 44: COMBUSTION TO AIR:** This flow includes all N (N2O, NOx, NO2, NH3) emitted to the atmosphere from combustion for heating or energy purposes.
- **FLOW 61: IMPORT/EXPORT TO AIR**: This flow accounts for N-related atmospheric emissions (NH3, N2O, NOx) in the study area whose source is located outside the system boundaries.

Outflows

Outflow connections from the air pool currently include those towards the HOUSEHOLD, AGRICULTURAL LAND, HORTICULTURE, URBAN GREEN, and IMPORT/EXPORT pools:

- **FLOW 156: AIR TO HOUSEHOLD:** This flow accounts for N deposition on urban (built-up) areas.
- **FLOW 107: AIR TO AGRICULTURAL LAND:** This flow accounts for wet and dry N deposition on agricultural land. It also includes the amount of N fixed from the air by organisms (BNF – biological N fixation)
- **FLOW 121: AIR TO HORTICULTURE:** This flow accounts for N deposition and BNF on the horticulture pool, thereby only taking into account outdoor areas.
- **FLOW 125: AIR TO URBAN GREEN:** This flow accounts for wet and dry N deposition and BNF on urban greens.
- **FLOW 50: AIR TO IMPORT/EXPORT:** This flow accounts for N emissions (NH3, N2O, NOx) which are emitted within the study area but transported across the system boundaries through atmospheric circulation.

IMPORT/EXPORT: This pool represents the N in all flows transported into and out of the system boundaries.

Inflows

Inflow connections to the air pool currently include those from the AIR, WATER, WASTE, AGRICULTURAL LAND, HORTICULTURE, LIVESTOCK, PETS, and INDUSTRY pools and from outside the system boundaries:

- **FLOW 50: AIR TO IMPORT/EXPORT:** This flow accounts for N emissions (NH3, N2O, NOx) which are emitted within the study area but transported across the system boundaries through atmospheric circulation.
- **FLOW 80: WATER TO IMPORT/EXPORT:** This flow accounts for N contained in water carried away from the system's boundaries for the respective urban or peri-urban area (e.g. via rivers).
- **FLOW 75: WASTE TO IMPORT/EXPORT**: This flow represents N contained in exported waste, which mostly consists of recycled paper.
- **FLOW 108: AGRICULTURAL LAND TO IMPORT/EXPORT:** This flow includes N in harvested crops that are exported outside the system boundaries.
- **FLOW 112: HORTICULTURE TO IMPORT/EXPORT:** This flow encompasses N in flowers & horticultural fruits/vegetables that are exported.
- **FLOW 141: LIVESTOCK TO IMPORT/EXPORT:** This flow includes N from living animals that are exported outside the system boundaries. Processed livestock products would pass through the industry pool before going to export/import.
- **FLOW 136: PETS TO IMPORT/EXPORT:** This flow includes N from pets that are exported outside the system boundaries.
- **FLOW 73: INDUSTRY TO IMPORT/EXPORT**: This flow accounts for N contained in exported industrial goods (anything from textiles to agricultural products).
- **FLOW 111: OUTSIDE THE SYSTEM BOUNDARIES TO IMPORT/EXPORT:** This flow represents the sum of all N contained in imported goods (food, feed, textiles, etc) but also the N contained in air, water and wastewater that is entering the system from outside (sources located outside the system boundaries) as well as imported waste and combustion material.

  Sum of the various flows F61: IMPORT/EXPORT TO AIR, F74: IMPORT/EXPORT TO WASTEWATER, F60: IMPORT/EXPORT TO WATER, F95: IMPORT/EXPORT TO HORTICULTURE, F132: IMPORT/EXPORT TO LIVESTOCK, F47: IMPORT/EXPORT TO INDUSTRY, F163: IMPORT/EXPORT TO OUTSIDE THE SYSTEM BOUNDARIES. Refer to these sub-flows for more details.

Outflows

Outflow connections from the air pool currently include towards the AIR, WASTEWATER, WATER, HORTICULTURE, LIVESTOCK, INDUSTRY, and COMBUSTION pools and towards outside the system boundaries:

- **FLOW 61: IMPORT/EXPORT TO AIR**: This flow accounts for N-related atmospheric transmission (NH3, N2O, NOx - whose source is located outside the system boundaries).
- **FLOW 74: IMPORT/EXPORT TO WASTEWATER**: This flow accounts for N contained in the wastewater coming within the study area from outside the system's boundaries.
- **FLOW 60: IMPORT/EXPORT TO WATER:** This flow represents N contained in water coming into the study area from outside the system boundaries for the respective urban or peri-urban area (e.g. via rivers)
- **FLOW 95: IMPORT/EXPORT TO HORTICULTURE:** This flow accounts for N contained in flowers that are imported from outside the system boundaries.

- **FLOW 132: IMPORT/EXPORT TO LIVESTOCK:** This flow includes N in imported feed as well as imported living livestock and livestock products. For Vienna and its surrounding area, the assumption taken is that the imported living livestock should at least match the slaughtered livestock minus the livestock already present.
- **FLOW 47: IMPORT/EXPORT TO INDUSTRY:** This flow accounts for N contained in goods imported from outside the study area and serving as materials for the processing activities of a given industry.
- **FLOW 54: IMPORT/EXPORT TO COMBUSTION:** This flow accounts for N contained in goods imported from outside the study area and serving as fuel for any combustion activity, such as the import of fuels.
- **FLOW 163: IMPORT/EXPORT TO OUTSIDE THE SYSTEM BOUNDARIES:** This flow represents the sum of all N contained in exported goods (food, feed, textiles, etc) but also the N contained in air, water and wastewater that is leaving the system (sources located inside the system boundaries) as well as exported waste and combustion materials.

  Sum of the flows F50: AIR TO IMPORT/EXPORT, F80: WATER TO IMPORT/EXPORT, F75: WASTE TO IMPORT/EXPORT, F108: AGRICULTURAL LAND TO IMPORT/EXPORT, F112: HORTICULTURE TO IMPORT/EXPORT, F136: PETS TO IMPORT/EXPORT, F141: LIVESTOCK TO IMPORT/EXPORT, F73: INDUSTRY TO IMPORT/EXPORT, F111: OUTSIDE THE SYSTEM BOUNDARIES TO IMPORT/EXPORT. Refer to these sub-flows for more details.

WASTEWATER: This pool represents the wastewater treatment (industrial and domestic) in the respective area.

Inflows

Inflow connections to the wastewater pool currently include those from the WASTE, HOUSEHOLDS, LIVESTOCK, PETS, INDUSTRY, and IMPORT/EXPORT pools:

- **FLOW 65: WASTE TO WASTEWATER**: This flow accounts for N contained in run-off or processing flows from waste treatment facilities ending into centralized wastewater treatment plants (e.g. dewatering process from Mechanical Biological Treatment (BMT)).
- **FLOW 59: HOUSEHOLD TO WASTEWATER:** This flow accounts for N discharged by the population (e.g. excretion, household chemicals) into domestic wastewater.
- **FLOW 139: LIVESTOCK TO WASTEWATER:** This flow includes N contained in livestock excrements that are washed away into wastewater when stables are flushed.
- **FLOW 137: PETS TO WASTEWATER:** This flow includes N excreted outdoors on the streets and thus not on urban greens that eventually results in run-off.
- **FLOW 77: INDUSTRY TO WASTEWATER**: This flow represents N contained in industrial wastewater.
- **FLOW 74: IMPORT/EXPORT TO WASTEWATER**: This flow accounts for N contained in the wastewater coming within the study area from outside the system's boundaries.

Outflows

Outflow connections from the wastewater pool currently include those towards the AIR, WATER, WASTE, and AGRICULTURAL LAND pools:

- **FLOW 28: WASTEWATER TO AIR:** This flow accounts for N related to direct domestic N2O atmospheric emissions from Wastewater Treatment Plants (WWTPs) that occur during the transport and treatment of the wastewater. The flow has been computed using the revised IPCC guidelines from 2019 regarding the N2O emissions from domestic wastewater
- **FLOW 76: WASTEWATER TO WATER**: This flow represents N contained in the outflow of wastewater treatment plants (wastewater effluent) ending in waterways. The flow has been computed using the revised IPCC guidelines from 2019 regarding the N2O emissions from domestic wastewater.
- **FLOW 66: WASTEWATER TO WASTE**: This flow represents N in sewage sludge that is treated in waste treatment plants.

- **FLOW 103: WASTEWATER TO AGRICULTURAL LAND:** This flow includes N in wastewater used for crop- and grassland irrigation.

POTENTIAL FLOWS

- **FLOW 104: WASTEWATER TO HORTICULTURE:** This flow includes N in wastewater used for horticultural irrigation.
- **FLOW 105: WASTEWATER TO URBAN GREEN:** This flow includes N in wastewater used for urban green irrigation.
- **FLOW 128: WASTE TO HORTICULTURE:** This flow includes N in compost or residues from biogas production from waste used as fertilizer in horticulture.

REMOVED FLOWS

- **FLOW 124: URBAN ANIMALS TO HORTICULTURE:** This flow was set zero for Vienna and its surrounding area as no information was found and it was assumed highly unlikely that manure N will be used in horticulture.
- **FLOW 47: PETS TO AIR:** This flow includes N volatilization (only NH3) from pet manure excretion. This flow is now included in the flow waste to air & urban greens to air respectively.
- **FLOW 136: PETS TO IMPORT/EXPORT:** This flow includes N in pets that are being exported across the boundaries of the study area.
- **FLOW 137: PETS TO WASTEWATER:** This flow includes N excreted outdoors on the streets and thus not on urban greens that eventually results in run-off.
- **FLOW 138: PETS TO WATER:** The flow from pets to water does most likely not exist as pet manure is deposited on urban greens. This would rather indicate a flow from urban greens to water that includes nitrogen from pet manure (run-off).
- **FLOW 140: LIVESTOCK TO WATER:** This flow does most likely not exist. It could refer to leaching or run-off of manure N to close by water bodies but in this case the flow would rather go from agricultural land to water.
- **FLOW 139: LIVESTOCK TO WASTEWATER:** This flow includes N contained in livestock excrements that are washed away into wastewater when stables are flushed.
- **FLOW 126: LIVESTOCK TO PETS:** This flow includes N in imported pet food. Imported pets could also be included but data availability is questionable
- **FLOW 83: HOUSEHOLD TO AIR:** This flow accounts for the N-based atmospheric emissions generated in the residential sector
- **FLOW 89: HOUSEHOLDS TO WATER:** This flow does most likely not exist: N leaching from the private gardens should in theory be allocated to the flow URBAN PLANTS TO WATER, whereas the rest of households' water consumption (e.g. domestic wastewater) should be allocated to the flow HOUSEHOLDS TO WASTEWATER.
- **FLOW 62: INDUSTRY TO WATER**: This flow accounts for N-related leakage and runoff losses from industrial and commercial activities.
- **FLOW 94: IMPORT/EXPORT TO AGRICULTURAL LAND:** This flow accounts for N contained in imported fertilizer and seeds (if such information is available) from outside the study area. This flow is nevertheless still used in Zielona Gora and its New District as all N fertilizer is imported there.

- **FLOW 96: IMPORT/EXPORT TO URBAN GREEN**: This flow only accounts for N contained in imported fertilizers as it is assumed that flowers planted on urban greens come from the horticulture pool. Imported flowers are allocated into the horticulture pool and then transported to the urban green pool.
- **FLOW 66: IMPORT/EXPORT TO PETS:** This flow includes N in imported pet food. Imported pets could also be included but data availability is questionable.
- **FLOW 64: IMPORT/EXPORT TO HOUSEHOLDS**: This flow accounts for N contained in goods imported from outside the study area that are used by the respective population. Everything goes through the industry pool now.
- **FLOW 54: IMPORT/EXPORT TO COMBUSTION:** This flow accounts for N contained in goods imported from outside the study area and serving as raw materials for any combustion activity, such as the import of fuels.