Urban Europe and NSFC

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

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UNCNET

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

D2/2: Final concept of urban nitrogen flows including uncertainty considerations

Due date of deliverable: **01/04/2020** Actual submission date: **04/08/2020**

Start Date of Project: **01/04/2019** Duration: **35 months**
Organization name of co-chairs for this deliverable: **IIASA, CAS**

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1. Executive Summary

Building on results from WP3, on ammonia emissions, WP4, on N inputs and irrigation, WP5, on urban agriculture and WP6, on waste, with the draft concept for urban N flows, that has previously been developed in WP2, a final concept for urban N flows was developed as well as a concept for data exchange between the different models involved in UNCNET. The backbone structure, that was set up using the STAN software (developed by Vienna University of Technology) was extended accordingly. This development was complimented with a detailed analysis of the type of data needed for each model and the data transferred between the models. Additionally, a concept to include uncertainties, as required by STAN, was developed to enable

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), others are more implicit (identifying appropriate system boundaries and comparable data sources; representing trade across such boundaries; developing strategies to represent changes that are more prevalent in dynamic urban situations than for a whole country). The central model structure will need to be organized to meet these challenges. Hence, this report describes the final version of a structure to be tested on the challenges. The structure is complimented with a concept on the linkage between existing models and data sets, sufficiently rigid to force datasets from different cities (in different world regions) into comparability, while still being flexible enough to learn from experience and allow improvements. As collected data is commonly accompanied by uncertainty, a concept for handling data uncertainty in a way that can be implemented in the central modelling structure of STAN is needed and provided in this report.

3. Activities:

Interaction with STAN developers (Oliver Cencic, Vienna University of Technology)

Expansion of the STAN model to include subsystems for urban agriculture

Development of a concept for data requirements and data transfer between the models

Uncertainty consideration

4. Results:

A complete flow model has been established in its final version – see attachment

A concept for data transfer has been developed – see attachment

A concept for uncertainty consideration has been established – see attachment

5. Milestones achieved:

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6. Deviations and reasons:

Delay due to Corona crisis

7. Publications:

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8. Meetings:

Kick-off meeting at PKU
CAS – IIASA bilateral meeting at CAS

Teleconferences

9. List of Documents/Annexes:

Annex:

A final nitrogen flow model to describe urban situations

A concept for data transfer

A concept for uncertainty considerations

REFERENCES

ANNEX

Final Nitrogen Flow Model to describe urban situations

Building on prior results from WP2 and results from WP5, a final concept for urban nitrogen flows was developed and implemented in STAN, the stock and flow model developed at the Technical University Vienna (Figure 1). This concept includes a detailed consideration of N flows within urban agriculture as well as into and from urban agriculture, characterized by its two main pools, urban animals and urban plants (Figure 2 and Figure 3). A detailed description of the stocks and flows included in urban agriculture can be found in D5.1.

The implementation of the subsystems of urban agriculture into STAN, enables the extraction of Excel Tables containing a detailed list of flows and stocks to which data needs to be collected. These Excel tables are not only essential for data collection but are a central piece of the development of the concept for data exchange between the different models involved.

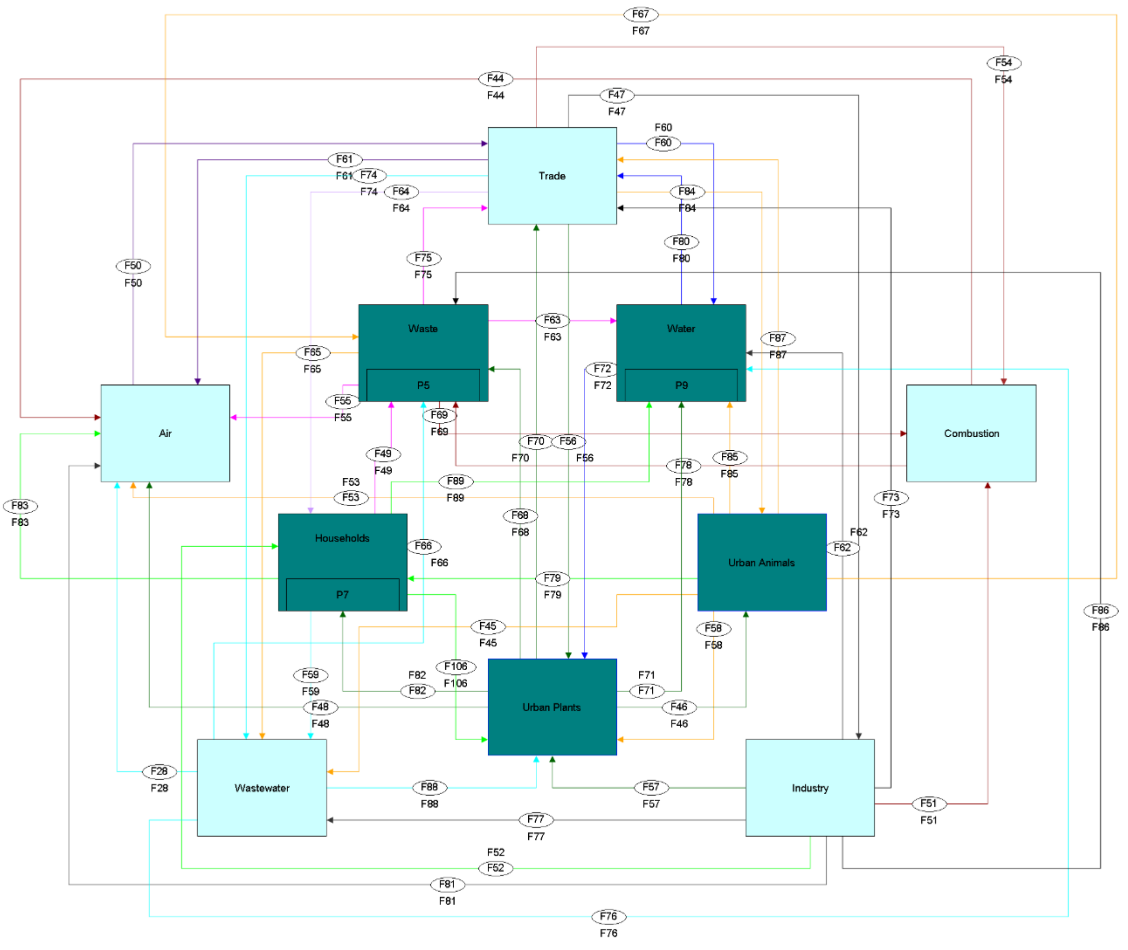

Figure 1 Final Concept of Urban Nitrogen Flows as implemented in STAN

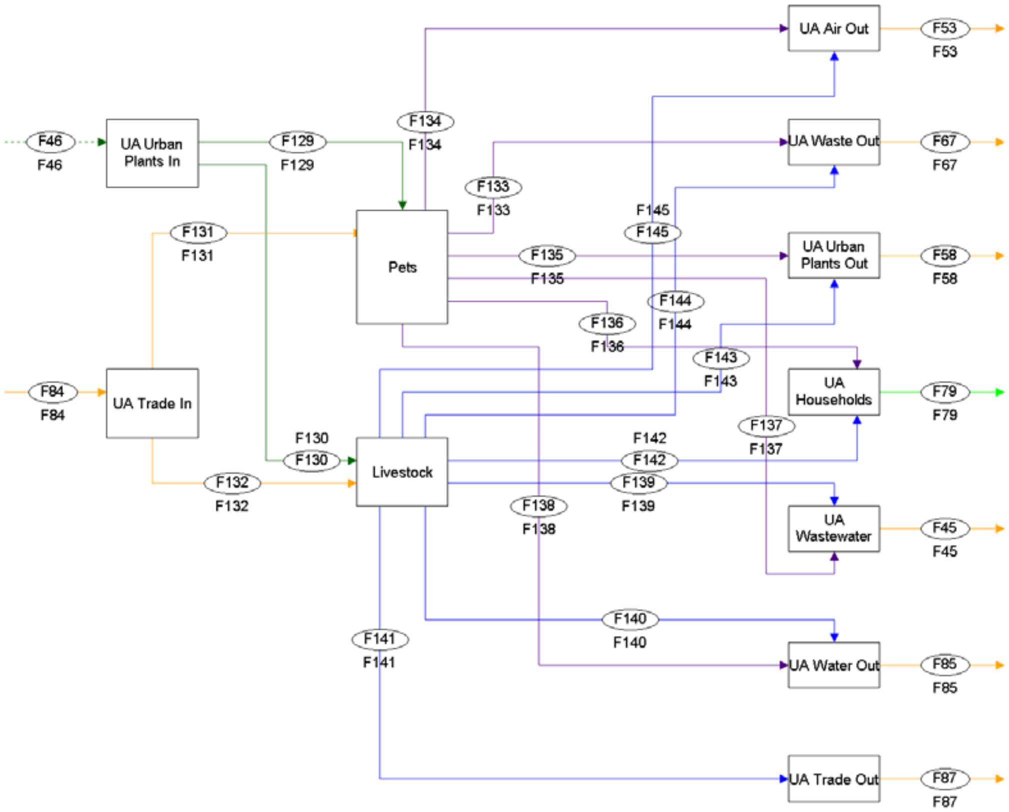

Figure 2 Stock and Flows considered in the subsystem 'Urban Animals'

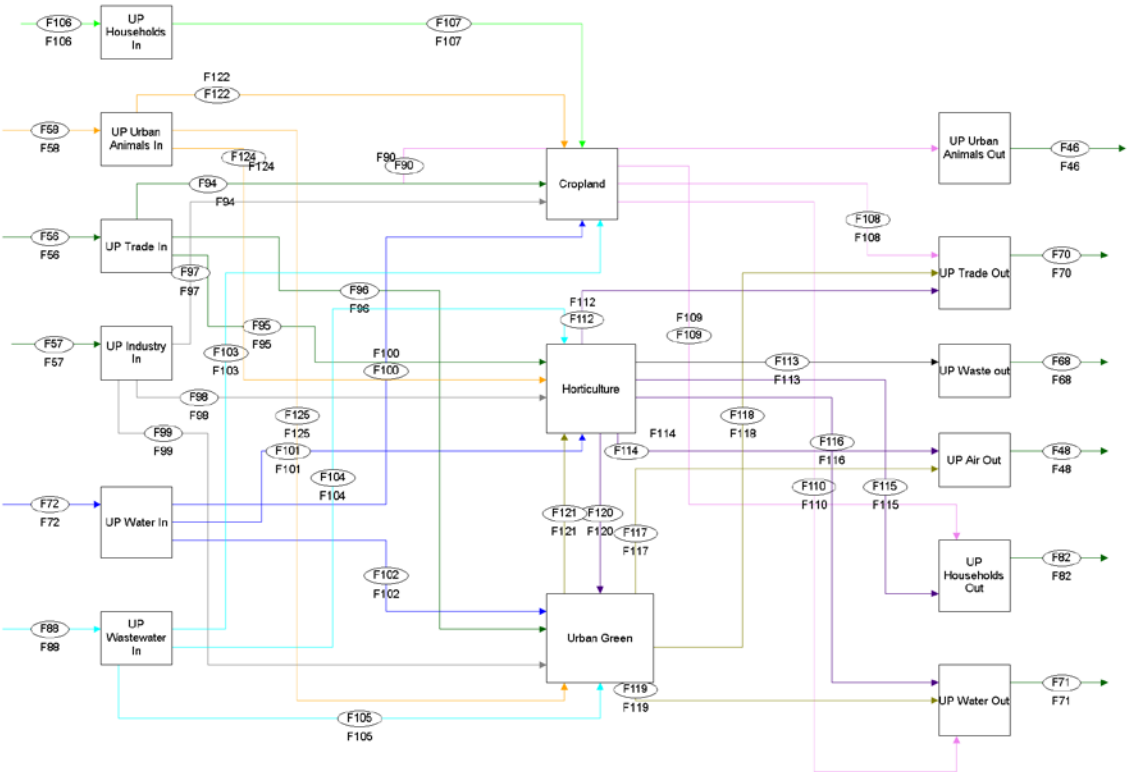

Figure 3 Stock and Flows considered in the subsystem 'Urban Plants'

Concept for Data Exchange

Several models will be involved in the calculation of urban N budgets. Therefore, a concept for data exchange between these models is needed. As STAN will be used for the final N budget calculation, it is the center piece of the data exchange. Depending on the other models' requirements data will be transported to or from STAN. Figure 4 gives an overview of the models involved and the type of data transferred between them.

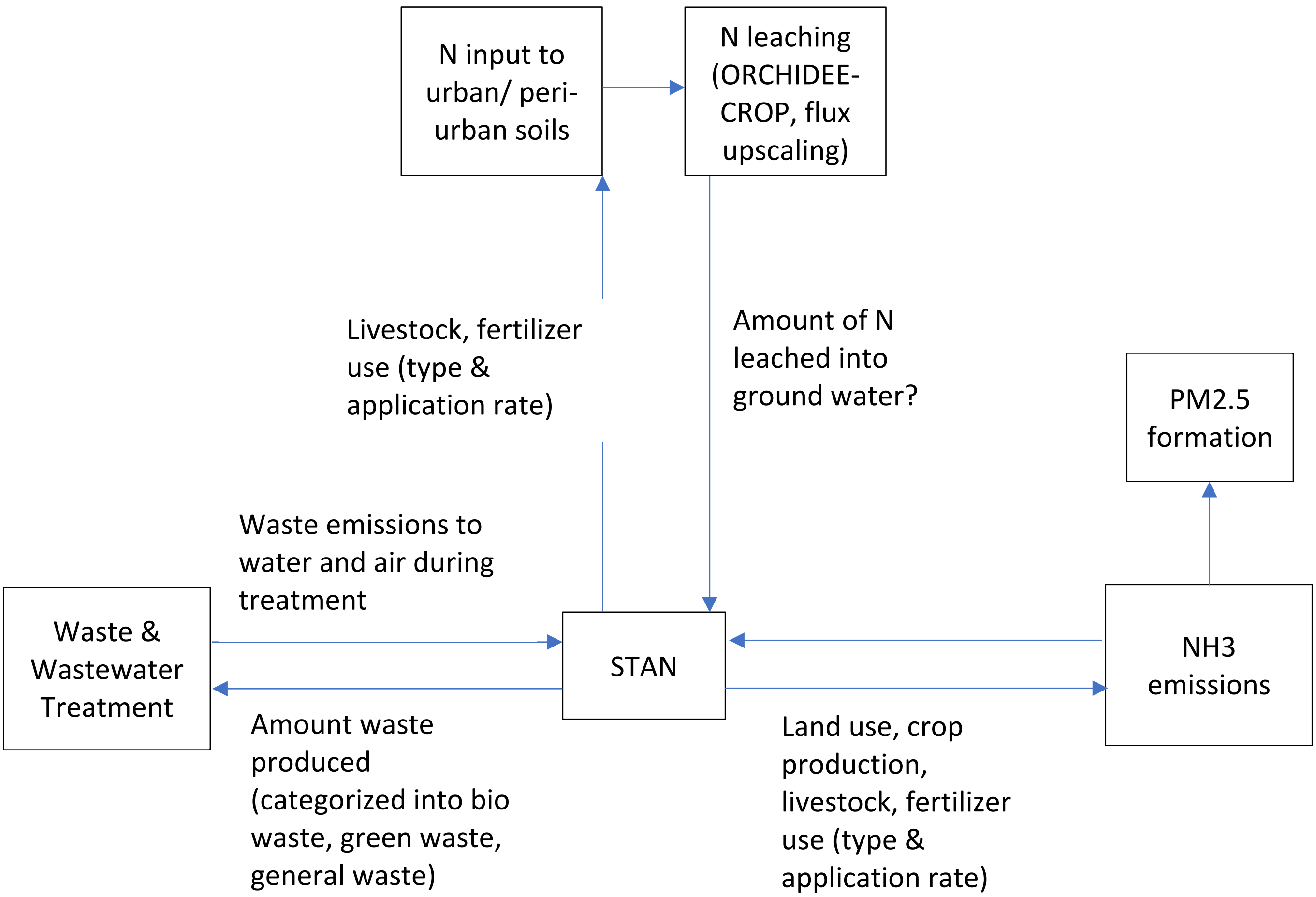

Figure 4 Data transfer between different models

Table 1-4 show details on the data used by each model. The first column indicates which data is needed by each model to arrive at the final results. The second column states the source that has been used so far. This source can also be another model. Data for which this column remains empty needs to be collected. Column three states the extent of the data which can be either global or limited to a city or region. In the latter case, global data or city specific data needs to be collected additionally. The fourth column states the years covered by each model while the fifth column indicates the resolution in which the data is available or required. Data available in higher resolution and greater extent can be aggregated to fit each city's extent using shape files which have previously been provided by each research team from the respective city. The seventh column gives information on other models to which data, either required for or calculated by each model, can be exported.

These tables will be central to the data collection as well as the data exchange. When all data noted down in these tables is available, it will be imported into STAN and urban N budgets for Beijing, Vienna, Zielona Góra and Shijiazhuang will be calculated.

Table 1 Data used in the NH3 model

	data available for all cities					
NH3 atmospheric model - Lin Zhang						
item	**source**	**extent**	**years covered**	**resolution**	**extra info**	**exported to**
Land use	MODIS	global	2005-2012	500 m		STAN
crops	Earthstat	global	2000	5'	18 crop types used (M3)	STAN
fertilizer type	IFA	global		countries/regions		STAN
fertilizer use	NBSC	China	2005-2016	province		STAN
pH						
CEC						
temperature	GEOS-FP	global		0.25deg x 0.3125deg		
wind	GEOS-FP	global		0.25deg x 0.3125deg		
livestock	GLW	global	2010	5'		STAN
livestock calibration	NBSC	China	2005-2016	province		
NH3 emission from non-agricultural activities	Kang et al. (2016)	China	2005-2012	1000m		

	data available for all cities					
NH3 atmospheric model - Lin Zhang						
item	**source**	**extent**	**years covered**	**resolution**	**extra info**	**exported to**
Land use	MODIS	global	2005-2012	500 m		STAN
crops	Earthstat	global	2000	5'	18 crop types used (M3)	STAN
fertilizer type	IFA	global		countries/regions		STAN
fertilizer use	NBSC	China	2005-2016	province		STAN
pH						
CEC						
temperature	GEOS-FP	global		0.25deg x 0.3125deg		
wind	GEOS-FP	global		0.25deg x 0.3125deg		
livestock	GLW	global	2010	5'		STAN
livestock calibration	NBSC	China	2005-2016	province		
NH3 emission from non-agricultural activities	Kang et al. (2016)	China	2005-2012	1000m		

Table 2 Data used in the N input and irrigation model

N inputs & irrigation model / leaching - Feng Zhou						
item	**source**	**extent**	**years covered**	**resolution**	**extra info**	**exported to**
water use	2nd National Water Resou	China	1965-2000	prefectures		STAN
water use	Water Ressources Bulleti	China	2001-2013	31 provinces		STAN
irrigated area per crop	statistical year book	China		31 provinces		STAN
irrigated areas	HYDE	global	-2017	5'		STAN
fertilizer use	several national surveys	China	county	~2900 counties	9 crop types	STAN
manure N applied to CL	Eubolism model	China	county			STAN
N deposition	LMDZ-OR-INCA	global		1.27deg x 2.5deg	validated only for chinese dat	STAN
agriculture management practice (e.g. tillage, cropping systems, application rate)		urban & suburban area	1995-2030 - base year 2015			
land use area (cropland horticulture etc)		urban & suburban area	1995-2030 - base year 2015			

Table 3 Data used for waste and wastewater calculations

Waste						
item	**source**	**extent**	**years covered**	**resolution**	**extra info**	**exported to**
Material Recovery Facility		city (urban vs peri-urban)	1995-2030 - base year 2015	divided into urban/peri-urban		
Anaerobic digestion		city (urban vs peri-urban)	1995-2030 - base year 2015	divided into urban/peri-urban		
landfilling		city (urban vs peri-urban)	1995-2030 - base year 2015	divided into urban/peri-urban		
composting green waste						
check degree of utilisation & processes in city		city (urban vs peri-urban)	1995-2030 - base year 2015	divided into urban/peri-urban	is composition assumed to be the same everywhere	
garden waste (mass & composition(&DOM, %DM, etc needed)	STAN (horticulture, urban	city (urban vs peri-urban)	1995-2030 - base year 2015	divided into urban/peri-urban	all data on waste will be collected to fit STAN pools	
composting bio waste						
check degree of utilisation & processes in city		city (urban vs peri-urban)	1995-2030 - base year 2015	divided into urban/peri-urban		
biowaste (mass & composition)	STAN (households)	city (urban vs peri-urban)	1995-2030 - base year 2015	divided into urban/peri-urban		
composting sewage sludge						
check degree of utilisation & processes in city		city (urban vs peri-urban)	1995-2030 - base year 2015	divided into urban/peri-urban		
sewage sludge (mass & composition)	wastewater component	city (urban vs peri-urban)	1995-2030 - base year 2015	divided into urban/peri-urban		
mechanical-biological treatment biostabilization						
check degree of utilisation & processes in city		city (urban vs peri-urban)	1995-2030 - base year 2015	divided into urban/peri-urban	mostly mixed municipal waste	
waste (mass & composition)	STAN (households)	city (urban vs peri-urban)	1995-2030 - base year 2015	divided into urban/peri-urban		
mechanical-biological treatment biodrying						
check degree of utilisation & processes in city	mostly mixed municipal w	city (urban vs peri-urban)	1995-2030 - base year 2015	divided into urban/peri-urban		
waste (mass & composition)	STAN	city (urban vs peri-urban)	1995-2030 - base year 2015	divided into urban/peri-urban		
fermentation						
check degree of utilisation & processes in city		city (urban vs peri-urban)	1995-2030 - base year 2015	divided into urban/peri-urban	mostly mixed municipal waste	
waste (mass & composition)	STAN	city (urban vs peri-urban)	1995-2030 - base year 2015	divided into urban/peri-urban		
waste incineration						
check degree of utilisation & processes in city		city (urban vs peri-urban)	1995-2030 - base year 2015	divided into urban/peri-urban		
waste (mass)	STAN	city (urban vs peri-urban)	1995-2030 - base year 2015	divided into urban/peri-urban		
combustion technology		city (urban vs peri-urban)	1995-2030 - base year 2015	divided into urban/peri-urban		
Wastewater						
population		city (urban vs peri-urban)	1995-2030 - base year 2015	gridded? 5'		STAN
country specific protein supply	Food Balance Sheets of F/	city (urban vs peri-urban)	1995-2030 - base year 2015			STAN
check treatment systems & degree of utilisation		city (urban vs peri-urban)	1995-2030 - base year 2015		treatment systems: no treatment, primary (mechani	

Table 4 Data used in STAN

STAN							
item	**source / imported from**	**extent**	**years covered**	**resolution**	**extra info**	**exported to**	**STAN Flows**
urban animals							
urban livestock distribution							
spatial distribution, livestock systems	input/irrigation model?	city (urban vs peri-urban)	1995-2030 - base year 2015	divide between urban & peri-urban			
amount of manure N to cropland, horticulture and urban greens	input/irrigation model	city (urban vs peri-urban)	1995-2030 - base year 2015	divide between urban & peri-urban	trade between urban/peri-urb	input/ irrigation mode	F122, F124, F
urine flushed into wastewater in urban livestock system			1995-2030 - base year 2015		livestock system dependent (a	waste model	F139, F45
manure N leached	leaching model		1995-2030 - base year 2015				F140, F85
export of urban livestock products (meat, milk, eggs etc)		city (urban vs peri-urban)	1995-2030 - base year 2015	divide between urban & peri-urban	trade between urban/peri-urban area?		F141, F87
urban livestock products consumed in households		city (urban vs peri-urban)	1995-2030 - base year 2015	divide between urban & peri-urban	trade between urban/peri-urban area? - probably pe		F142, F79
disposed of manure, feed, carcasses etc in waste			1995-2030 - base year 2015		livestock system dependent (a	waste model	F144, F67
N volatilization from livestock manure	NH3 model		1995-2030 - base year 2015		livestock system dependent (also resolution & exte		F145, F53
pets							
amount of pets and spatial distribution - urban, peri-urban		city (urban vs peri-urban)	1995-2030 - base year 2015	divide between urban & peri-urban			
N volatilization from pet manure	NH3 model		1995-2030 - base year 2015				F134, F53
manure N excreted in urban greens (parks and gardens)	input/irrigation model?	city (urban vs peri-urban)	1995-2030 - base year 2015		pet specific N excretion rate?, spatial resolution de		F135, F58
pet manure N run-off to wastewater		city (urban vs peri-urban)	1995-2030 - base year 2015	divide between urban & peri-urban			F137, F45
Amount of N from pets to households (manure)			1995-2030 - base year 2015				F136, F79
Amount of N from pets to water (manure leaching)	leaching model		1995-2030 - base year 2015				F138, F85
Amount of N from pets to waste (manure N from pets (collected manure N on walks disposed of in public waste bins)			1995-2030 - base year 2015			waste model	F133, F67
water							
amount and N content of water	leaching model?	city (urban vs peri-urban)	1995-2030 - base year 2015	divide between urban & peri-urban			
water useage shares for cropland, horticulture, urban greens	input/irrigation model	city (urban vs peri-urban)	1995-2030 - base year 2015	divide between urban & peri-urban			F100, F101, F
export of N in water e.g. from urban to suburban area		city (urban vs peri-urban)	1995-2030 - base year 2015				F80
waste water							
amount and N content of waste water	waste model?	city (urban vs peri-urban)	1995-2030 - base year 2015	divide between urban & peri-urban			
waste water useage shares for cropland, horticulture, urban greens	input/irrigation model	city (urban vs peri-urban)	1995-2030 - base year 2015	divide between urban & peri-urban		input/irrigation mode	F103, F104, F
N emissions from wastewater	waste model	city (urban vs peri-urban)	1995-2030 - base year 2015	divide between urban & peri-urban			F28
sludge to waste (N content)	waste model		1995-2030 - base year 2015		waste model internal flow depends on waste and w		F66
share of treated wastewater to water	waste model		1995-2030 - base year 2015	divide between urban & peri-urban	dependent on distribution of wastewater treatment		F76
urban plants							
land use data (spatial distribution of horticulture, urban green, cropland) for disaggregation of data available as shape file	NH3 model	city (urban vs peri-urban)	1995-2030 - base year 2015	5' (peri-urban & urban)			
horticulture							
type and N content of flowers grown			1995-2030 - base year 2015		extent & resolution depends on land use data/ is derived from lan		
amount of flowers exported (traded)			1995-2030 - base year 2015		trade between urban & peri-urban region, extent &		F112, F70
amount of flowers etc in horticulture to waste			1995-2030 - base year 2015		extent & resolution depends o	waste model	F113, F68
amount of flowers etc to households (flowers indoors/on balcony - not in garden)			1995-2030 - base year 2015		trade between urban & peri-urban region, extent &		F115, F82
share of flowers etc to urban greens (flowers in parks, private gardens)			1995-2030 - base year 2015		trade between urban & peri-urban region, extent &		F120
N volatilization	NH3 model		1995-2030 - base year 2015		extent & resolution depends on land use data/ is de		F114, F48
N leaching	leaching model		1995-2030 - base year 2015		extent & resolution depends on land use data/ is de		F116, F71
cropland							
type and N content of crops			1995-2030 - base year 2015		extent & resolution depends on land use data/ is derived from lan		
amount of crops exported			1995-2030 - base year 2015		extent & resolution depends on land use data/ is de		F108, F70
amount of crop N to urban livestock			1995-2030 - base year 2015		extent & resolution depends on land use data/ is de		F90, F130, F4
amount of crop N to pets							F90, F129, F4
N leaching	leaching model	city (urban vs peri-urban)	1995-2030 - base year 2015		extent & resolution depends on land use data/ is de		F110, F70
amount of crops to household as food			1995-2030 - base year 2015		trade between urban & peri-urban region		F109, F82
N volatilization	NH3 model	city (urban vs peri-urban)	1995-2030 - base year 2015	divide between urban & peri-urban	extent & resolution depends on land use data/ is derived from lan		
urban greens							
type and N content of urban greens			1995-2030 - base year 2015		extent & resolution depends on land use data/ is derived from lan		
N volatilization	NH3 model	city (urban vs peri-urban)	1995-2030 - base year 2015	divide between urban & peri-urban	extent & resolution depends on land use data/ is de		F117, F48
N leaching	leaching model	city (urban vs peri-urban)	1995-2030 - base year 2015	divide between urban & peri-urban	extent & resolution depends on land use data/ is de		F119, F70
Amount of N from urban green to trade			1995-2030 - base year 2015				F118, F70
Amount of N from urban green to horticulture (green manure)			1995-2030 - base year 2015				F121
Amount of N from gardens etc to waste (garden waste)							
Industry							
type and location of industry in urban vs peri-urban areas		city (urban vs peri-urban)	1995-2030 - base year 2015	divide between urban & peri-urban			
amount of industrial production to households, trade and urban plants (seeds, fertilizer, textiles etc - depending on industry)	fertilizer from input/irrigation model?		1995-2030 - base year 2015		trade between urban & peri-u	fertilizer data to inpu	F52, F73, F97,
N emissions from industry			1995-2030 - base year 2015		extent & resolution depends on industry location da		F81
industrial waste (composition)			1995-2030 - base year 2015		extent & resolution depends o	waste model	F86
Amount of N from industry to combustion (heating, etc)			1995-2030 - base year 2015				F51
Amount of N from industry to water (cooling water? Leaks?)			1995-2030 - base year 2015				F62
Amount of N from industry to wastewater	IPCC guidelines Table 6.11		1995-2030 - base year 2015				F77

Trade							
trade statistics for cities - broken down from country statistics, per capita?			1995-2030 - base year 2015	divide between urban & peri-urban			
amount of traded goods going to industry, households, combustion, urban plants and urban animals (seeds, fertilizers, textiles, food, nitrogen enriched fuel, feed)		city (urban vs peri-urban)	1995-2030 - base year 2015	divide between urban & peri-urban			F131, F132, F
Amount of N from trade to wastewater (e.g. waste water treated within boundaries coming from outside)		city (urban vs peri-urban)	1995-2030 - base year 2015			waste model	F74
Amount of N from trade to air (emissions from outside boundaries e.g. suburbs)			1995-2030 - base year 2015				F61
Amount of N from trade to water (N transported from outside to water inside boundaries)			1995-2030 - base year 2015				F60
Combustion							
location of combustion		city (urban vs peri-urban)		divide between urban & peri-urban			
N emissions from combustion to air (from industry trade and waste)		city (urban vs peri-urban)	1995-2030 - base year 2015	divide between urban & peri-urban			F44
Amount of N from combustion to waste (e.g Ash)			1995-2030 - base year 2015				F78
Air							
flow from air to urban plants - N deposition	NH3 model		1995-2030 - base year 2015		extent & resolution depends on land use data/ is derived from la		
Amount of N from air to trade (export of emissions)			1995-2030 - base year 2015				F50
Household							
spatial distribution of households - people per household?		city (urban vs peri-urban)		divide between urban & peri-urban			
any kind of waste - composition of waste (share of residual, organic, plastic, textiles??) needed			1995-2030 - base year 2015			waste model	F49
human excreta - population, country specific protein supply (IPCC/FAO Food Balance sheet)			1995-2030 - base year 2015		people per household needed	waste model	F59
N emissions (household-air) from heating/ cooking with gas or petroleum			1995-2030 - base year 2015				F83
Amount of N from households to urban plants (Fertilizer, compost)			1995-2030 - base year 2015				F106, F107
Waste							
location of & type of waste treatment plants		city (urban vs peri-urban)		divide between urban & peri-urban			
N emissions from waste	waste model		1995-2030 - base year 2015				F55
N leaching from waste	waste model		1995-2030 - base year 2015			leaching model?	F63
N (waste to wastewater) from dewatering in MBT eg	waste model		1995-2030 - base year 2015				F65
waste incineration	waste model		1995-2030 - base year 2015				F69
amount of waste traded (type of waste, N content)			1995-2030 - base year 2015				F75

Concept for Uncertainty Consideration

The integration of uncertainties is an important element of quality assurance as it helps to estimate the influence of imperfect information on the calculated quantities (EPNB 2011). This is also reflected in the STAN model used for the urban N budget calculations as for every quantity its standard uncertainty should be included. The standard uncertainty, also called standard error, is an estimate of the distance between the sample mean and the population mean and is calculated by dividing the standard deviation, the degree to which data in the sample differs from the sample mean, by the sample size (1). With the help of standard uncertainties, the STAN model is able to calculate connected unknown quantities and their uncertainties through error propagation.

$$s_x = \frac{s}{\sqrt{n}} \tag{1}$$

s_x… standard uncertainty (standard error)
s… standard deviation
n… sample size

However, STAN only allows for standard errors of normal distributions due to the procedure for calculating error propagation being based on the weighted least square approach (IWR, 2012).
As it is suspected that the data collected for calculating urban N budgets will not always follow a normal distribution, a closer look was taken at common distributions as well as possible approximations of such distributions with a normal distribution to make the collected data compatible with STAN requirements.

Uniform Distribution

Data estimates originating from expert opinions often show a uniform distribution as the experts give a best estimate of an upper boundary (a) and a lower boundary (b) between which every outcome is equally likely (Figure 1). From these boundaries, the expected value and variance can be calculated ((2) and (3)) and used for the approximation with a normal distribution. The standard error (s) is calculated using the calculated standard deviation (3) as shown in (1).

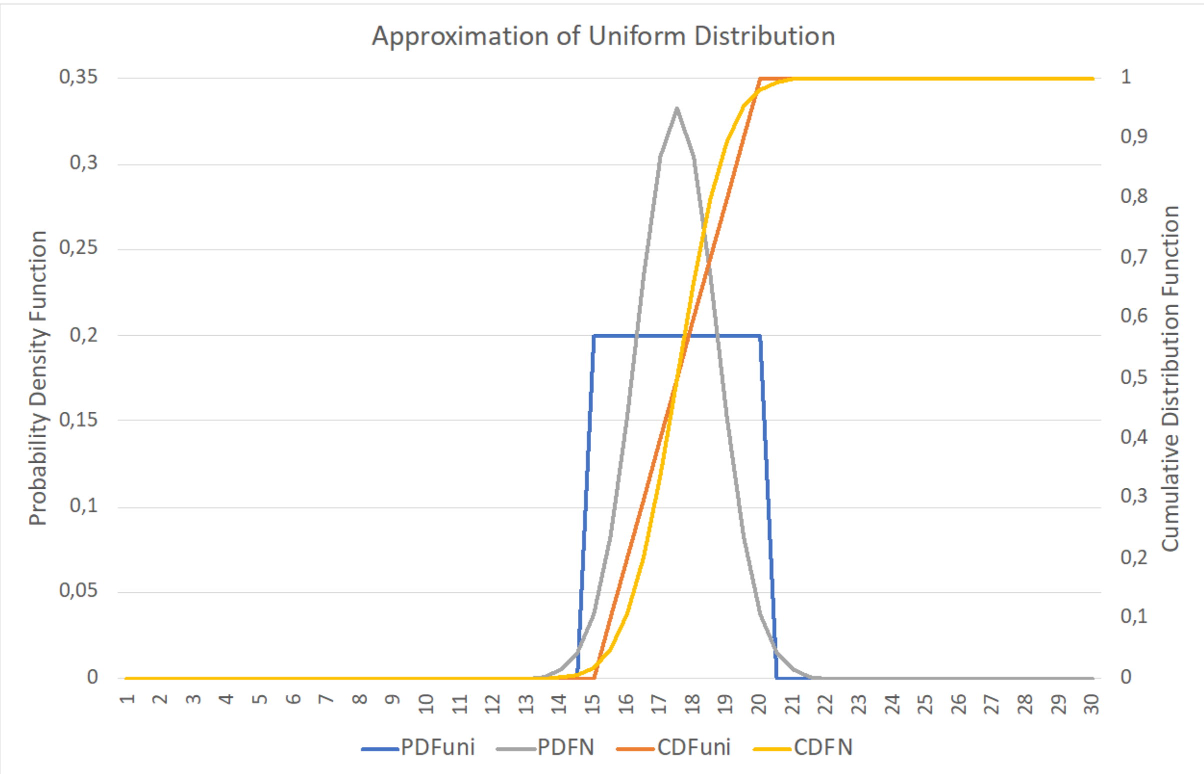

Figure 5 Uniform Distribution, PDF - probability density function, CDF - cumulative distribution function, uni – uniform distribution, N – normal distribution

$$m = \frac{a+b}{2} \tag{2}$$

$$s = \frac{b-a}{\sqrt{12}} \tag{3}$$

m… expected value/mean
s… standard deviation
a… lower boundary
b… upper boundary

Triangular Distribution

Variations of the uniform distribution are triangular distributions, where an additional value is given to the boundary values, indicating the most likely outcome (mode). This additional value can either be central to the boundaries (Figure 6) or shifted to one of the sides (7). Formulas (4) to (7) show the calculation of the mean and standard deviation needed for the approximation with a normal distribution.

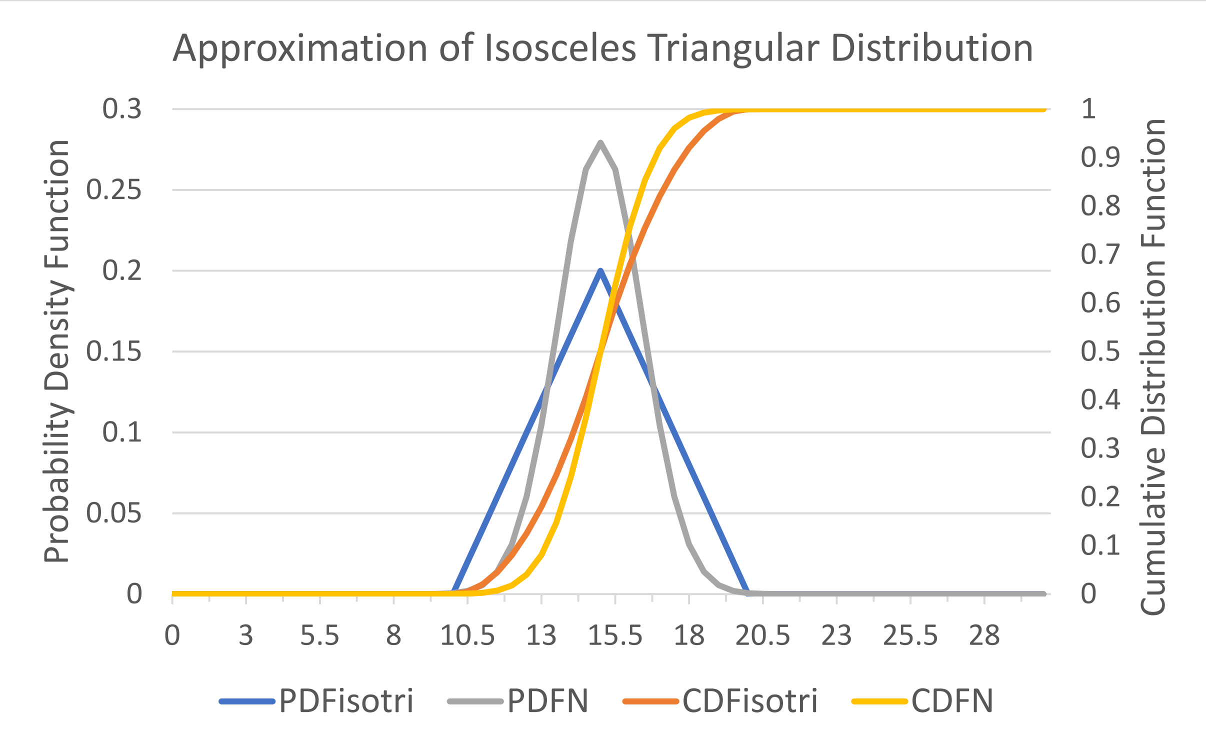

Figure 6 Isolescenes triangular Distribution, PDF - probability density function, CDF - cumulative distribution function, tri – isolescenes triangular distribution, N – normal distribution

$$m = \frac{a+b}{2} \quad (4)$$

$$s = \frac{b-a}{\sqrt{24}} \quad (5)$$

m… expected value/mean
s… standard deviation
a… lower boundary

b… upper boundary

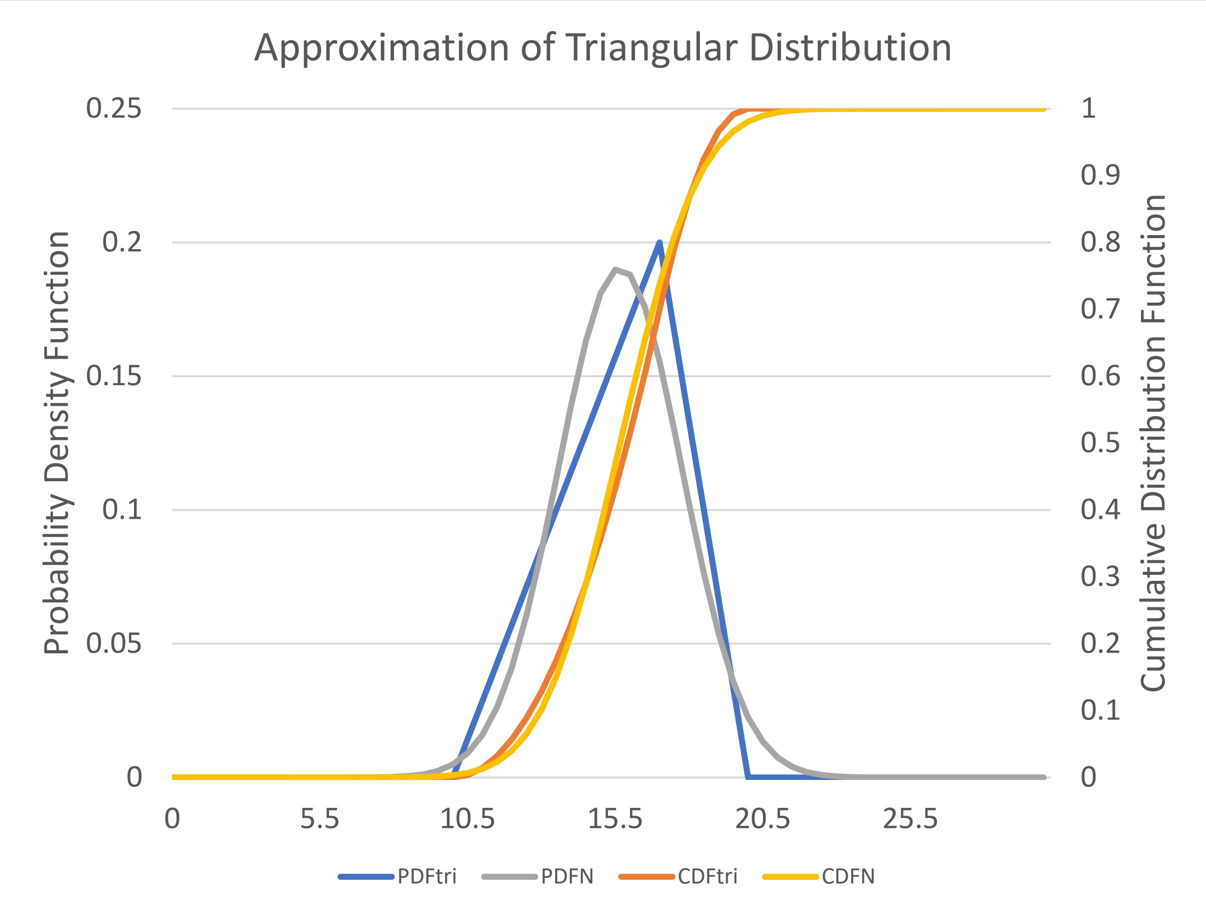

Figure 7 Triangular Distribution, PDF - probability density function, CDF - cumulative distribution function, tri - triangular distribution, N – normal distribution

$$m = \frac{a+b+c}{3} \tag{6}$$

$$s = \sqrt{\frac{a^2+b^2+c^2-ab-ac-bc}{18}} \tag{7}$$

m… expected value/mean
s… standard deviation
a… lower boundary
b… upper boundary
c… mode (value that appears most often)

All formulas for the uniform and triangular distributions were taken from (Kacker and Lawrence, 2007).

Lognormal Distribution

Another common distribution is the lognormal distribution, which means that the distribution of data is skewed but its logarithm is normally distributed. This distribution can, for example, be observed when only positive values are allowed (Figure 4). Formulas (8) and (9) show the calculation of the mean and standard deviation needed for the approximation with a normal distribution.

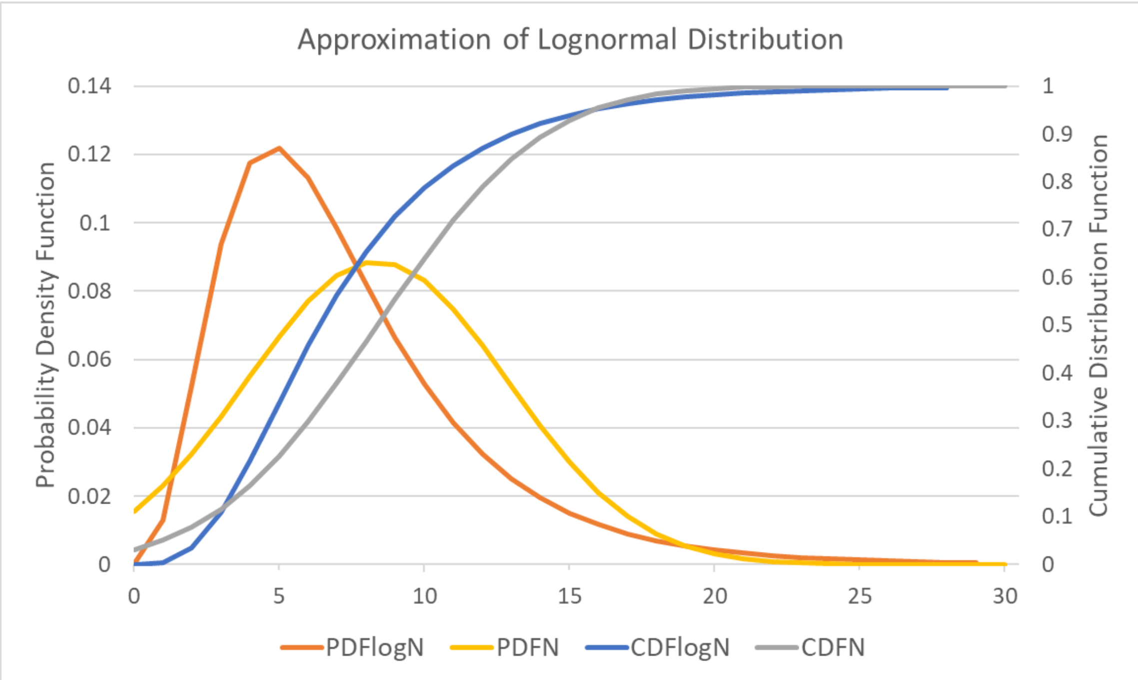

Figure 8 Lognormal Distribution, PDF - probability density function, CDF - cumulative distribution function, logN – lognormal distribution, N – normal distribution

$$m = \log\left(\frac{E[X]^2}{\sqrt{Var[X]+E[X]^2}}\right) \tag{8}$$

$$s = \sqrt{\log\left(\frac{Var[X]}{E[X]^2}+1\right)} \tag{9}$$

m… expected value/mean
s… standard deviation
E[X]… expected value/mean of lognormal function
Var[X]… variance of lognormal function ($Var[X]=s^2$)

Using the transformations of the most common distributions described above, we expect to be able to calculate the required normally distributed standard error for the collected data in order to make best use of features such as error propagation and calculation of unknown quantities available in STAN.

Covariance and Correlation

Another requirement for the calculation of error propagation, supporting the data reconciliation tool in STAN, is the independence of input data. The combination of dependent data can lead to an underestimation of the overall uncertainty (Winiwarter & Rypdal, 2001; Winiwater & Muik, 2010).To test the relation between separate flows going into one pool, Spearman's Rank Correlation Hypothesis Testing will be applied to check their correlation in case more datapoints are available for each flow. Spearman is chosen as it is a non-parametric measure for correlation using a monotonic function to assess relationships between input data rather than expecting a purely linear relationship (Dytham, 2011).

$$r_s = 1 - \frac{6\sum D^2}{n(n^2-1)} \qquad (10)$$

D^2 … rank difference
n … number of data pairs

Once the Spearman correlation coefficient has been calculated, hypothesis testing can be used to check whether the Nullhypothesis of no correlation ($r_s = 0$) is rejected using a predefined significance level (α). This check can be done either using Spearman's rho table to find the corresponding r_s for the significance level chosen or by calculating t according to (11) and comparing it to critical t of the chosen significance level taken from a table or calculated.

$$t = \frac{r_s}{\sqrt{\frac{1-{r_s}^2}{n-2}}} \qquad (11)$$

Sensitivity Analysis

The Spearman coefficient can also be used to get information of each inflow's contribution to the total outflow using Monte Carlo simulation (Winiwater & Rypdal, 2001).

References

Dytham, C. 2011. Choosing and Using Statistics: A Biologist's Guide (3rd ed). Wiley Publishing.

Expert Panel on Nitrogen Budgets. *Draft Guidance document on Nitrogen Budgets*. UNECE?? https://www.unece.org/fileadmin/DAM/env/documents/2011/eb/wg5/WGSR49/Informal%20docs/20_N_budget_guidelines_wgsr-49.pdf

Institute for Water Quality and Resource Management (IWR) TU Wien. (2012). *Manual for STAN 2.6 – Material Flow Analysis – Data Uncertainty*. http://www.stan2web.net/NetHelp/default.htm?turl=HTMLDocuments%2FContentManual.htm.

Kacker, R. N., & Lawrence, J. F. (2007). Trapezoidal and triangular distributions for Type B evaluation of standard uncertainty. *Metrologia*, *44*(2), 117–127. https://doi.org/10.1088/0026-1394/44/2/003

Pfeifer, D. (n.d). *Lognormalverteilung*. https://www.solvency-ii-kompakt.de/content/lognormalverteilung

Winiwarter, W., and Muik, B. (2010). Statistical dependence in input data of national greenhouse gas inventories: Effects on the overall inventory uncertainty. *Climatic Change*, *103*(1–2), 19–36. https://doi.org/10.1007/s10584-010-9921-7

Winiwarter, W., and Rypdal, K. (2001). Assessing the uncertainty associated with national greenhouse gas emission inventories: a case study for Austria. *Atmospheric Environment*, *35*(32), 5425–5440. https://doi.org/10.1016/S1352-2310(01)00171-6