

SUPPLEMENTARY DATA

1. Swiss phosphorus system 2015 – detailed results

Table S1: Swiss P system 2015. All values in tons of P (t P), including uncertainty values (+/-).

Process output	Process input	Flow name	P flow (t)		
	animal husbandry	fodder net imp.	6'222	+/-	691
		animal-based food net imp.	501	+/-	56
	cultivation	mineral fertilizer imp.	4'229	+/-	127
		plant-based food net imp.	2'108	+/-	173
	chemical industry	chemicals net imp.	360	+/-	180
		cleaning products net imp.	1'234	+/-	392
	households & business	precipitation settlements	23	+/-	8
	waterbodies	diffuse inputs non-agricultural	2'135	+/-	365
		sum imports	16'812		
animal husbandry		animals net exp.	4	+/-	0
cultivation		wood & paper net exp.	69	+/-	11
waste management		fly ash exp.	134	+/-	8
		animal by-products exp.	2'418	+/-	397
		sewage sludge exp.	106	+/-	21
waterbodies		outflow abroad	1'779	+/-	247
		sum exports	4'506		
animal husbandry	cultivation	farmyard manure	23'353	+/-	2'497
	households & business	animal-based food	4'883	+/-	297
	waste management	animal by-products	3'651	+/-	393
	waterbodies	leachate excrements	20	+/-	10
cultivation	animal husbandry	plant-based fodder	25'187	+/-	2'501
	households & business	mineral fertilizer gardens	172	+/-	23
		plant-based food	3'751	+/-	227
		wood & paper	320	+/-	60
	waste management	plant-based waste	225	+/-	31
	waterbodies	diffuse inputs agricultural	1'136	+/-	168
chemical industry	households & business	cleaning products	1'140	+/-	37
	waste management	wastewater industry	453	+/-	348
households & business	cultivation	waste paper	66	+/-	6
	waste management	wastewater H&B	6'456	+/-	335
		municipal solid waste	2'780	+/-	265
		green waste	1'151	+/-	58
waste management	cultivation	sewage sludge in agriculture	0	+/-	0
		digestate & compost	1'237	+/-	50
	households & business	digestate & compost gardens	198	+/-	10
	waterbodies	effluent WWTP	934	+/-	174
Stock changes					
animal husbandry			0	+/-	0

cultivation	133	+/-	885
households & business	34	+/-	41
waste management	9'690	+/-	781
waterbodies	2'446	+/-	389

Table S2: Swiss P system 2015, sub-system *animal husbandry*. All values in tons of P (t P), including uncertainty values (+/-).

Process output	Process input	Flow name	P flow (t)		
	animal production	fodder net imp.	6'222	+/-	691
	trade animals	animals net imp.	0	+/-	0
	trade animal-based food	animal-based food net imp.	501	+/-	56
cultivation	animal production	plant-based fodder	25'187	+/-	2'501
trade animals		animals net exp.	4	+/-	0
animal production	animal husbandry	farmyard manure	23'353	+/-	2'497
trade animal-based food	households & business	animal-based food	4'883	+/-	297
processing animal-based food	waste management	animal by-products	3'651	+/-	393
animal production	waterbodies	leachate excrements	20	+/-	10
animal production	trade animals	animals exp.	52	+/-	4
	processing animal-based food	animals for slaughter	4'839	+/-	411
		milk & eggs	3'277	+/-	318
trade animals	animal production	animals imp.	48	+/-	4
processing animal-based food		liquid fodder	84	+/-	21
	trade animal-based food	domestic animal-based food	4'381	+/-	298
No stocks					

Table S3: Swiss P system 2015, sub-system *cultivation*. All values in tons of P (t P), including uncertainty values (+/-).

Process output	Process input	Flow name	P flow (t)		
	plant production	mineral fertilizer imp.	4'229	+/-	127
	trade plant-based food	plant-based food net imp.	2'108	+/-	173
animal husbandry	plant production	farmyard manure	23'353	+/-	2'497
households & business	paper production	waste paper	66	+/-	6
waste management	plant production	sewage sludge in agriculture	0	+/-	0
		digestate & compost	1'237	+/-	50
trade wood & paper		wood & paper net exp.	69	+/-	11
plant production	animal husbandry	plant-based fodder	25'187	+/-	2'501
	households & business	mineral fertilizer gardens	172	+/-	23
processing plant-based food		plant-based food	3'751	+/-	227
processing wood		wooden goods	78	+/-	33

		fuel wood	160	+/-	21
paper production		paper	81	+/-	6
processing p-b food	waste management	plant-based waste	225	+/-	31
plant production	waterbodies	diffuse inputs agriculture	1'136	+/-	168
plant production	processing plant-based food	domestic plant-based food	1'869	+/-	190
trade plant-based food		plant-based food imp.	2'679	+/-	177
processing p-b food	trade plant-based food	plant-based food exp.	571	+/-	63
forestry	processing wood	timber	323	+/-	36
trade wood & paper		wood imp.	119	+/-	18
trade wood & paper	paper production	paper & -raw materials imp.	88	+/-	14
processing wood	trade wood & paper	wood exp.	151	+/-	19
	paper production	paper raw materials	53	+/-	9
paper production	trade wood & paper	paper & -raw materials exp.	125	+/-	14
Stock changes					
plant production			456	+/-	848
forestry			-323	+/-	36

Table S4: Swiss P system 2015, sub-system *chemical industry*. All values in tons of P (t P), including uncertainty values (+/-).

Process output	Process input	Flow name	P flow (t)		
	trade chemicals	chemicals net imp.	360	+/-	180
	trade cleaning products	cleaning products net imp.	1'234	+/-	392
production chem. goods	households & business	cleaning products	1'140	+/-	37
	waste management	wastewater industry	453	+/-	348
production chem. goods	production chem. goods	chemicals exp.	0	+/-	0
	trade cleaning products	cleaning products exp.	100	+/-	50
trade chemicals	production chem. goods	chemicals imp.	360	+/-	180
trade cleaning products		cleaning products imp.	1'331	+/-	364
No stocks					

Table S5: Swiss P system 2015, sub-system *households & business*. All values in tons of P (t P), including uncertainty values (+/-).

Process output	Process input	Flow name	P flow (t)		
	sewer system	precipitation settlements	23	+/-	8
animal husbandry	settlement & households	animal-based food	4'882	+/-	297
cultivation	gardens	mineral fertilizer gardens	172	+/-	23
	settlement & households	plant-based food	3'751	+/-	227
		wooden goods	78	+/-	33

	fuel generation from wood	fuel wood	160	+/-	21
	paper consumption	paper	81	+/-	6
chemical industry	sewer system	cleaning products	1'140	+/-	37
waste management	gardens	digestate & compost gardens	198	+/-	10
paper consumption	cultivation	waste paper	66	+/-	6
sewer system	waste management	wastewater H&B	6'456	+/-	335
settlement & households		municipal solid waste	2'780	+/-	265
		green waste	1'151	+/-	58
settlement & households	gardens	food waste garden composting	27	+/-	14
	sewer system	faeces	1'877	+/-	254
		urine	3'386	+/-	350
		food waste wastewater	29	+/-	15
paper consumption	settlement & households	waste paper in MSW	15	+/-	2
fuel generation from wood		wood ash in MSW	108	+/-	44
	gardens	wood ash in gardens	52	+/-	41
gardens	settlement & households	garden waste external	415	+/-	38
Stock changes					
gardens			34	+/-	41

Table S6: Swiss P system 2015, sub-system *waste management*. All values in tons of P (t P), including uncertainty values (+/-).

Process output	Process input	Flow name	P flow (t)		
animal husbandry	triage animal by-products	animal by-products	3'651	+/-	393
cultivation	triage biogenic waste	plant-based waste	225	+/-	31
chemical industry	sewerage	wastewater industry	453	+/-	348
households & business	sewerage	wastewater H&B	6'456	+/-	335
	MSWI	municipal solid waste	2'780	+/-	265
	triage biogenic waste	green waste	1'151	+/-	58
triage animal by-products		animal by-products exp.	2'418	+/-	397
WWTP	cultivation	sewage sludge in agriculture	0	+/-	0
sales and distribution compost & digestate		compost & digestate	1'237	+/-	50
	households & business	compost & digestate gardens	198	+/-	38
WWTP		sewage sludge exp.	106	+/-	21
	waterbodies	effluent WWTP	934	+/-	174
landfill Type C		fly ash exp.	134	+/-	8
composting	sales and distribution compost & digestate	compost	689	+/-	60
fermentation		digestate	520	+/-	68

MSWI	landfill Type D	press water	226	+/-	32
		MSWI sludge	3'301	+/-	272
		MSWI fly ash acid wash	307	+/-	18
sewerage	landfill Type C	MSWI fly ash solidified	117	+/-	7
	WWTP	raw sewage	6'909	+/-	375
WWTP	MSWI	sewage sludge in MSWI	1'078	+/-	178
	SS-MI	sewage sludge in SS-MI	3'219	+/-	284
SS-MI	cement plant	sewage sludge in cement plant	1'571	+/-	264
	landfill Type D	SS-MI sludge	2'882	+/-	249
	landfill Type C	SS-MI fly ash	338	+/-	122
trriage animal by-products	cement plant	animal by-products in cement plant	1'175	+/-	170
	fermentation	animal by-products in fermentation	58	+/-	30
trriage biogenic waste	composting	biogenic waste composting	689	+/-	60
	fermentation	biogenic waste fermentation	688	+/-	59
Stock changes					
landfill Type D			6'489	+/-	345
landfill Type C			454	+/-	123
cement plant			2'745	+/-	313

Table S7: Swiss P system 2015, sub-system *waterbodies*. All values in tons of P (t P), including uncertainty values (+/-).

Process output	Process input	Flow name	P flow (t)		
animal husbandry	running waters	diffuse inputs non-agricultural	2'135	+/-	365
		leachate excrements	20	+/-	10
		diffuse inputs agricultural	1'136	+/-	168
cultivation		effluent WWTP	934	+/-	174
waste management		outflow abroad	1'779	+/-	247
running waters		inflow lakes	2'790	+/-	388
running waters	lakes	outflow lakes	344	+/-	69
Stock changes					
lakes			2'446	+/-	389

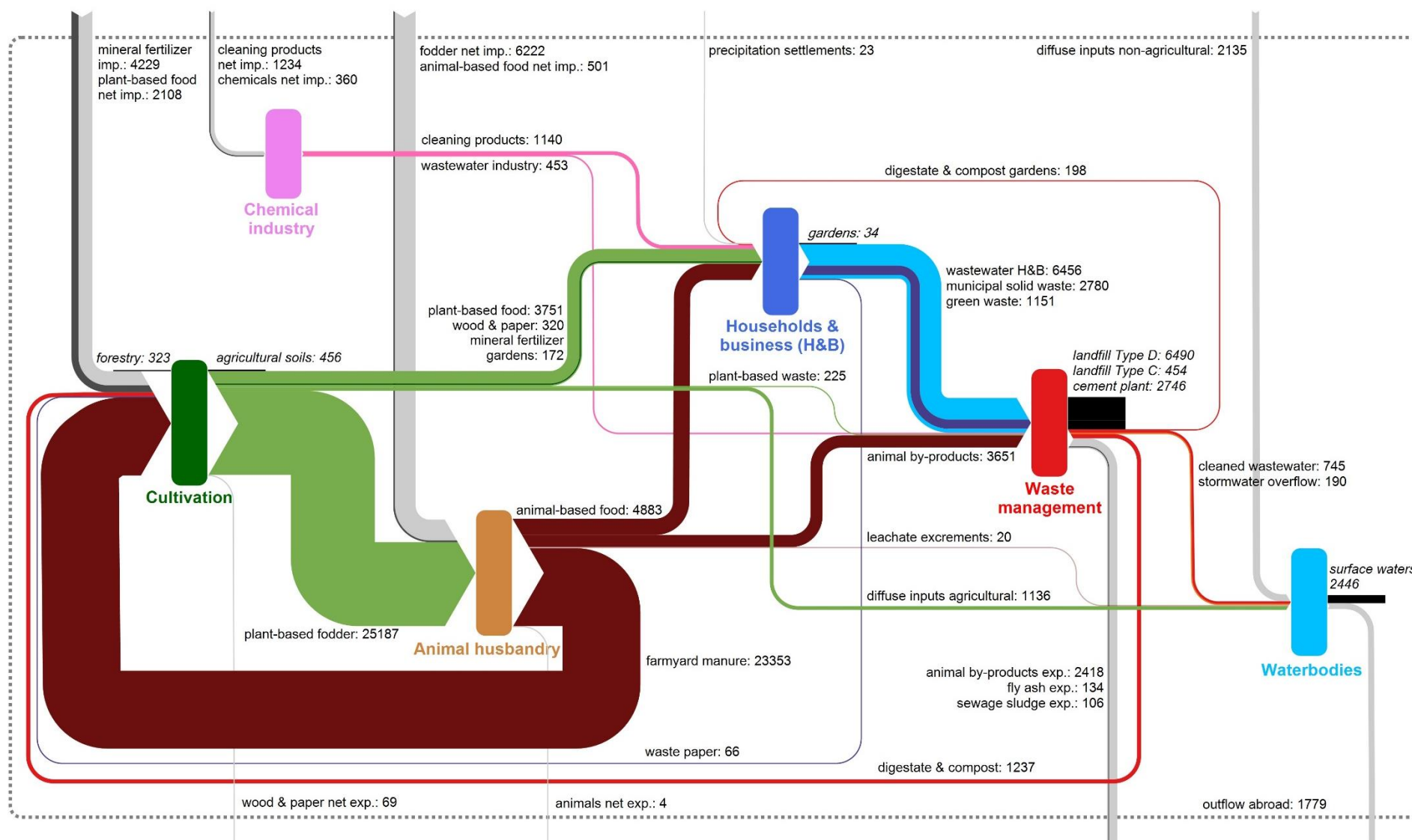


Figure S1: Swiss P system 2015. All values are in t P (stocks in *italics*).

2. Data sources

Table S8: Data sources of all P flows calculated in this study. In the column “data source” it is distinguished between: (G) flow of goods, (cP) P concentration and (P) P flow.

Flow name		flow of goods (1000t)			P concentration (g/kg)			P flow (t)			Data source
Imports											
	fodder net imp.				5.31	+/-	0.53	6'241	+/-	698	(P) Agristat 2016 (cP) own calculations, weighted avg.
	animal-based food net imp.							507	+/-	57	(P) Agristat 2016, own calculations
	mineral fertilizer imp.							4'229	+/-	127	(P) Agristat 2016, own calculations
	plant-based food net imp.							2'146	+/-	240	(P) Agristat 2016, own calculations
	chemicals net imp.										no input value in model, calculation through mass balance
	cleaning products net imp.										no input value in model, calculation through mass balance
	precipitation settlements	573'000	+/-	286'500	4E-5	+/-	4E-5	23	+/-	8	according to Binder et al. 2009
	diffuse inputs non-agricultural							2'224	+/-	445	(P) Hürdler, Prasuhn & Spiess 2015
Exports											
	animals net exp.							4	+/-	0.4	(P) Agristat 2016, own calculations
	wood & paper net exp.	1'103	+/-	165	0.06	+/-	0.01				according to Binder et al. 2009
	fly ash exp.	29	+/-	3	6.48	+/-	0.19				(G) FOEN 2017a (cP) according to Binder et al. 2009
	animal by-products exp.	156	+/-	31	15.03	+/-	3.01	2'290	+/-	572	(G) Centravo 2017 (cP) own calculations, weighted avg.
	sewage sludge exp.	6	+/-	0	27.22	+/-	5.00				(G) own assumption (cP) according to Binder et al. 2009, verified through values of Zurich (WWEA) and Valais (T. Pralong)
	outflow abroad				4E-5	+/-	4E-5	1'748	+/-	262	(P) FOEN 2015

(cP) NADUF, average 2012-2015

System flows total system											
farmyard manure							22'890	+/-	3'434		(P) Agristat 2016, calculation by Agroscope Reckenholz-Tänikon (ART)
animal-based food	2'695	+/-	135	1.92	+/-	0.19	5'188	+/-	580		(G,P) Agristat 2016 (cP) own calculations, weighted avg.
animal by-products	282	+/-	56	12.47	+/-	2.49	3'515	+/-	778		(G,P) Centravo 2017 (cP) own calculations, weighted avg.
leachate excrements							20	+/-	10		according to Binder et al. 2009
plant-based fodder				3.35	+/-	0.33	25'681	+/-	3'546		(P) Agristat 2016 (cP) own calculations, weighted avg. (new values by E. Spiess)
mineral fertilizer gardens							180	+/-	24		according to Binder et al. 2009
plant-based food	4'279	+/-	214	0.96	+/-	0.10	4'089	+/-	457		(P) Agristat 2016 (cP) own calculations, weighted avg.
wood & paper	5'370	+/-	951	0.06	+/-	0.01					according to Binder et al. 2009
plant-based waste	260	+/-	26	0.87	+/-	0.09					(G) Mandaliev & Schleiss 2016 (cP) according to Binder et al. 2009
diffuse inputs agricultural							1'149	+/-	172		(P) Hürdler, Prasuhn & Spiess 2015
cleaning products							1'143	+/-	37		according to Binder et al. 2009, adaption to population growth
wastewater industry							850	+/-	425		according to Binder et al. 2009
waste paper	1'059	+/-	21	0.06	+/-	0.01					according to Binder et al. 2009
wastewater H&B											no input value in model, calculation through mass balance
municipal solid waste	2'850	+/-	143	0.67	+/-	0.11					(G) FOEN 2017a (cP) Morf 2006
green waste	996	+/-	50	1.13	+/-	0.11					(G) Mandaliev & Schleiss 2016 (cP) according to Binder et al. 2009
sewage sludge in agriculture	0	+/-	0				0	+/-	0		-

digestate & compost							1'220	+/-	61	(P) share based on Mandaliev & Schleiss 2016, calculation based on preceding flows
digestate & compost gardens							199	+/-	10	(P) share based on Mandaliev & Schleiss 2016, calculation based on preceding flows
effluent WWTP							896	+/-	179	(P) Hürdler, Prasuhn & Spiess 2015; stormwater overflow based on REZGUS
System flows <i>animal husbandry</i>										
animals exp.							52	+/-	6	(P) Agristat 2016, own calculations
animals for slaughter	672	+/-	20	6.64	+/-	0.66	4'996	+/-	522	(G,P) Agristat 2016, based on slaughter weight (cP) own calculations, weighted avg.
milk & eggs	3'576	+/-	107	0.94	+/-	0.09	3'347	+/-	349	(G,P) Agristat 2016 (cP) own calculations, weighted avg.
animals imp.							48	+/-	5	(P) Agristat 2016, own calculations
liquid fodder	28	+/-	7	2.96	+/-	0.74	84	+/-	21	(G,P) Centravo 2017 (cP) own calculations, weighted avg.
domestic animal-based food	2'857	+/-	143	1.64	+/-	0.16	4'694	+/-	525	(G,P) Agristat 2016 (cP) own calculations, weighted avg.
System flows <i>cultivation</i>										
domestic plant-based food	1'887	+/-	94	1.02	+/-	0.10	1'916	+/-	214	(G,P) Agristat 2016 (cP) own calculations, weighted avg.
plant-based food imp.	3'087	+/-	154	0.88	+/-	0.09	2'715	+/-	304	(G,P) Agristat 2016 (cP) own calculations, weighted avg.
plant-based food exp.	587	+/-	29	0.97	+/-	0.10	569	+/-	64	(G,P) Agristat 2016 (cP) own calculations, weighted avg.
timber	5'515	+/-	827	0.06	+/-	0.01				according to Binder et al. 2009
wood imp.	1'352	+/-	203	0.08	+/-	0.01				according to Binder et al. 2009

paper & -raw materials imp.	1'787	+/-	268	0.06	+/-	0.01	according to Binder et al. 2009
wood exp.	2'530	+/-	379	0.06	+/-	0.01	according to Binder et al. 2009
paper raw materials	1'004	+/-	151	0.06	+/-	0.01	according to Binder et al. 2009
paper & -raw materials exp.	1'712	+/-	257	0.06	+/-	0.01	according to Binder et al. 2009
System flows <i>chemical industry</i>							
chemicals exp.					0	+/-	0 (P) not verified
cleaning products exp.					100	+/-	50 according to Binder et al. 2009, uncertainty increased to 50%
chemicals imp.					360	+/-	180 according to Binder et al. 2009, uncertainty increased to 50%
cleaning products imp.							no input value in model, calculation through mass balance
System flows <i>households & business (H&B)</i>							
food waste garden composting					29	+/-	15 according to Binder et al. 2009, adaption to population growth
faeces					1'842	+/-	276 according to Binder et al. 2009, adaption to population growth
urine					3'275	+/-	491 according to Binder et al. 2009, adaption to population growth
food waste wastewater					29	+/-	15 according to Binder et al. 2009, adaption to population growth
waste paper in MSW	248	+/-	5	0.06	+/-	0.01	(G) FOEN 2017a
wood ash in MSW	17	+/-	4	10.00	+/-	5.00	(cP) according to Binder et al. 2009
wood ash in gardens	13	+/-	3	10.00	+/-	5.00	according to Binder et al. 2009
garden waste external	353	+/-	17	1.13	+/-	0.11	(G) Mandaliev & Schleiss 2016
							(cP) according to Binder et al. 2009
System flows <i>waste management</i>							
compost				3.30	+/-	1.40	no input value in model, calculation through mass balance

digestate	132	+/-	13	3.90	+/-	1.80			according to Binder et al. 2009
press water	38	+/-	4	6.00	+/-	0.60			according to Binder et al. 2009
MSWI sludge	746	+/-	37	4.88	+/-	0.52			(G) FOEN 2017a (cP) Morf 2006
MSWI fly ash acid wash	48	+/-	2	6.48	+/-	0.19			(G) FOEN 2017a (cP) Morf 2006
MSWI fly ash solidified	18	+/-	1	6.48	+/-	0.19			(G) FOEN 2017a (cP) Morf 2006
raw sewage	1'818'648	+/-	181'865	5E-3	+/-	4E-3			(G) own calculations based on data by Max Maurer 2017 (cP) data by Max Maurer 2017 (G) FOEN 2017c, WWEA 2017 (cP) according to Binder et al. 2009, verified through values of Zurich (WWEA) and Valais (T. Pralong)
sewage sludge in MSWI	34	+/-	2	27.00	+/-	5.00			
sewage sludge in MI	104	+/-	5	27.00	+/-	5.00			(G) FOEN 2017c, WWEA 2017 (cP) according to Binder et al. 2009, verified through values of Zurich (WWEA) and Valais (T. Pralong)
sewage sludge in cement plant	51	+/-	3	27.00	+/-	5.00			(G) FOEN 2017c, WWEA 2017, Cemsuisse 2016 (annual report) (cP) according to Binder et al. 2009, verified through values of Zurich (WWEA) and Valais (T. Pralong)
SS-MI sludge	43	+/-	2	63.50	+/-	6.35			(G) adaption according to WWEA 2017 (cP) according to S. Nanzer
SS-MI fly ash				6.48	+/-	0.19			no input value in model, calculation through mass balance
animal by-products in cement plant	36	+/-	9	32.50	+/-	8.13	1'163	+/-	174 (G,P) Centravo 2017 (cP) own calculations, weighted avg.

animal by-products in fermentation	16	+/-	8	4.00	+/-	2.00	63	+/-	31	(G,P) Centravo 2017, own assumption (cP) own calculations, weighted avg.
biogenic waste composting	628	+/-	31	1.10	+/-	0.09				(G) Mandaliev & Schleiss 2016 (cP) according to W. Obrist
biogenic waste fermentation	628	+/-	31	1.10	+/-	0.09				(G) Mandaliev & Schleiss 2016 (cP) according to W. Obrist
System flows <i>waterbodies</i>										
inflow lakes							2'663	+/-	533	(P) Hürdler, Prasuhn & Spiess 2015
outflow lakes							346	+/-	69	(P) Hürdler, Prasuhn & Spiess 2015

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