The Phos4You partnership

April 2021

Sewage sludge ashes for P-recovery purposes in The Netherlands

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RECOVER

Phosphorus

From sewage sludge ashes

MONITOR

Sewage sludge ashes

Quality

IDENTIFY

Potentials

In the Netherlands

This report was prepared by the partners HVC and SNB of the Phos4You project, funded through INTERREG VB North-West Europe programme (2014-2021).

Sewage sludge ashes for P-recovery purposes in The Netherlands

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1. Introduction to sewage sludge management

1.1 The Netherlands

The Dutch water authorities possess two sludge incineration facilities in which about 700.000 tons of wet sludge is incinerated. The other approximately 700.000 tons of wet sludge are separated dried and co-incinerated in waste to energy plant or composted and co-incinerated either in The Netherland or in surrounding countries. HVC and SNB are the owners and operators of the 2 incinerations plants in Dordrecht (province of Zuid Holland) and Moerdijk (province of Brabant) since the early 1990's.

Since the "BOOM-besluit" in year 1998 (https://wetten.overheid.nl/BWBR0009360/2006-01-010) it became impossible in The Netherlands to spread sewage sludge on agricultural land. At that time mainly heavy metals like copper and zinc were the limiting factors for this. Nowadays the concerns about micro plastics and organic contaminants play a relevant role in emphasizing that sewage sludge contains a lot of pollutants. In the LAP3 (Dutch National Waste plan) it is stated that sewage sludge needs to be thermally treated. Other treatment is possible if proven at least equivalent (in term of eliminating contaminants) to thermal treatment.

HVC sewage sludge mono-incinerator is currently in operation for more than 25 years, while that of SNB is approaching the same age. These 25 years of state of the art incineration has delivered the Dutch water and sludge sector a lot of experience and insight in the changing qualities of sludge and sludge incineration ashes.

1.2 The incineration process

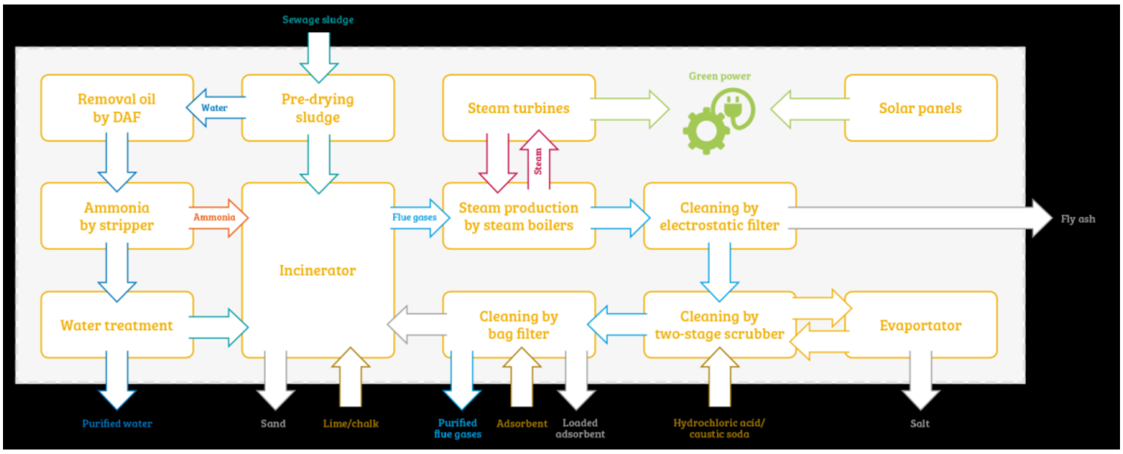

Figure 1: The sludge incineration process (source: SNB).

The main difference between the HVC and SNB process influencing the quality of the ashes, is the dosing of $CaCO_3$ in the furnaces of SNB, aiming to reduce Sulfur in the flue gasses and reducing the capital investment of the scrubbers (which can be smaller). Approximately 25% of the ash of SNB consist of $CaCO_3$ and $CaSO_4$. Assuming this all origins from direct Sulfur abatement the ashes are diluted with a factor of approximately 1,35.

SNB possesses an own treatment installation for the condensate from the drying process. In the treatment process, ammonia is recovered and is being used in the denox installation of the incinerator. After stripping the waste water is treated in a biological waste water treatment plant reducing COD and nitrogen. HVC discharges the condensate, currently without pre-treatment, to the neighboring WWTP.

As with increasing sludge digestion on the WWTP's of the water authorities, it appears that a slightly higher N content in the sludge is produced. Moreover this N is probably more available as NH_3 as it is more removed in the sludge dryers . As a consequence the $N_{kjeldahl}$ contents in the condensate from the drying step is rising significantly. In 2020 HVC did a small test to separate digested an undigested sludge and incinerate it in separate lines.

COD and N_{kj} values in the condensate from the different lines is clearly distinguished:

Measurement in condensate	unit	Undigested sewage sludge	Digested sewage sludge
pH		8,5	9,5
COD	mg/l	7000	3800
Nkj	mg/l	1000	4800

Table 1: Condensate concentrations (source: own tests by HVC)

Additional increase of digested sludge will lead to a higher risk on NO_x or NH_3 air emissions and increase of N in the drying condensate will need an increase of the N removal capacity of the receiving biological waste water treatment.

Further research is therefore done in other to find the technical possibilities for N-recovery at the HVC and SNB-plant and the most optimal configuration in cooperation with the water authorities.

2. Quality of sewage sludge

2.1 Sewage sludge quality HVC

The average yearly sewage sludge quality supplied in the last 10 years to the incineration plants of HVC and SNB is given in the tables. Variation in copper, zinc and lead is seen and they all approach or surpass the thresholds of the Meststoffenbesluit (Dutch Fertiliser Regulation). Also the mentioned increase of nitrogen content is clearly seen in the figures of SNB (no data on N available of HVC).

	ds	org. stof	Cu	Cr	Zn	Pb	Cd	Ni	Hg	As	Sb	Mo	pH
	%	%	concentratie in mg/kg droge stof										--
1992: cijfers uit 2e MER	19,6	63	460	40	1.230	265	3,6	25	2,4	11	--	--	--
1994	20,0	61	470	35	1.200	285	2,9	29	2,0	12	--	--	--
1996	21,9	59	340	47	800	145	2,3	27	1,6	10	4,1	6,1	--
1998	22,7	60	370	32	910	170	1,9	29	1,4	13	2,0	7,0	7,5
2000	22,4	64	380	33	940	170	< 1,8	< 31	< 1,4	< 12	< 3,2	< 8	7,3
2002	22,5	64	365	30	940	160	< 1,7	< 28	< 1,2	< 13	< 9,7	< 14	7,3
2004	22,9	65,6	370	33	980	155	< 1,7	< 28	< 1,2	< 12	< 4	< 11	6,9
2006	22,6	65,3	350	30	880	130	< 1,4	23	< 0,9	< 12	< 4	< 9	7,1
2008	21,8	67,7	350	28	905	130	< 1,1	23	< 0,8	< 14	< 3	< 8	7,1
2010	22,0	68,6	370	35	1.005	150	< 1,2	27	< 0,8	< 13	< 4	< 9	7,0
2012	22,0	69,1	365	39	970	130	< 1,2	29	< 0,7	15	< 4	< 9	7,3
2014	22,2	69,5	400	44	970	120	< 1,1	25	< 0,7	15	< 4	10	7,4
2016	21,9	70,7	380	40	970	125	1,1	26	0,6	16,2	4	10	7,3
2017	21,7	72,1	380	31	930	100	0,9	22	0,6	14,3	4	10	7,3
2018	21,7	72,2	380	33	940	100	0,9	22	0,6	15,4	4	9	7,3
2019 naar SVI	21,9	72,7	380	38	930	90	0,9	23	0,5	13,5	4	10	7,4
2020 naar SVI	22,2	71,9	375	33	960	96	0,9	23	0,5	15	3	10	7,5
Uitvoeringsbesluit Meststoffenwet	--	--	75	75	300	100	1,25	30	0,75	15	--	--	--

Table 2: Sludge composition HVC (source: Milieujaarverslag HVC, 2020)

Composition sludge received by SNB															
	Dry matter	organic matter	As	Cd	Cr	Cu	Pb	Ni	Zn	Hg	S	Cl	EOX	PAK	N-Kj
	%sludge cake	% dm	mg/kg dm												g/kg dm
2021	22,3	69,4	9,1	1,2	42	426	81	27	1.241	0,4	10.748	2.741	10,3	4,2	60,7
2020	22,7	69,2	8,0	1,2	44	418	80	26	1.077	0,4	12.245	2.564	10,1	3,8	57,9
2019	22,3	68,3	9,7	1,2	48	419	91	28	1.135	0,5	12.517	2.667	11,2	4,9	57,9
2018	23,2	69,2	8,7	1,1	45	375	76	28	934	0,5	10.966	1.816	12,9	5,5	56,6
2017	23,1	70,0	8,3	1,0	47	356	78	28	890	0,5	10.356	2.592	12,7	4,1	56,1
2016	24,0	67,2	8,6	1,2	76	382	93	31	995	0,6	11.570	1.462	11,6	5,0	54,5
2015	23,1	67,9	8,3	1,1	68	421	95	30	994	0,6	10.106	1.443	10,7	4,8	56,2
2014	23,5	66,3	8,7	1,1	57	437	110	35	949	0,7	9.542	1.672	12,2	4,9	54,9
2013	23,7	66,2	9,0	1,2	56	467	120	38	993	0,7	9.493	1.314	16,2	4,7	56,3
2012	23,6	66,5	7,7	1,3	48	471	113	30	1.136	0,7	11.692	958	22,6	6,0	52,7
2011	23,3	65,5	8,4	1,4	45	479	112	30	1.042	0,7	10.596	1.035	14,2	7,7	52,4
2010	23,4	65,1	8,4	1,9	49	500	122	29	1.084	0,8	10.768	850	10,6	7,9	52,2
2009	23,4	64,9	8,4	1,3	48	466	119	26	1.000	0,9	9.963	649	15,6	6,1	49,4
2008	23,3	63,2	9,9	1,7	51	482	126	33	1.064	1,3	10.287	799	18,6	6,3	49,5
2007	23,3	62,5	9,2	1,5	49	495	124	29	1.055	0,8	10.234	1.043	17,9	13,1	43,6
2006	23,6	62,2	9,0	1,5	62	479	122	30	1.054	1,1	10.945	1.226	18,0	11,0	43,8
2005	23,2	61,5	9,5	1,6	63	479	121	37	1.123	1,0	10.744	1.778	15,9	10,0	50,1
2004	23,0	62,1	6,9	1,3	54	433	106	33	1.001	0,9	12.083				46,3

Table 3: Sludge composition SNB (source: Milieujaarverslag SNB, 2020)

Looking deeper into the historic data over the past 25 years, the following trends can be identified:

- A reduction of cadmium, lead and mercury in sewage sludge
- After 1996 no specific reduction is seen with regard to copper and zinc.
- A steady increase in organic matter content, despite more digestion of sewage sludge at the WWTPs.

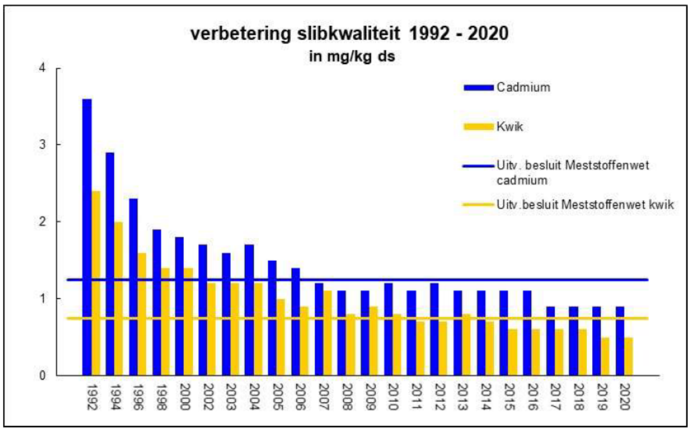

Figure 2: Reduction of Cd and Hg in sludge HVC (source: Milieujaarverslag HVC, 2020).

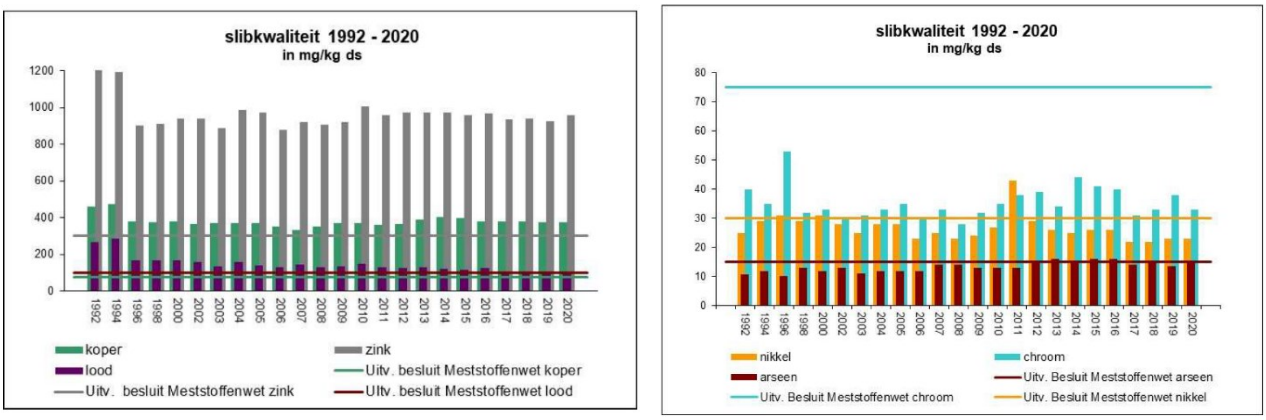

Figure 3: Heavy metals in sludge HVC (source: Milieujaarverslag HVC, 2020)

Concerning nickel and chrome no significant decrease could be distinguished, while for arsenic a slight increase is seen. This might have to do with arsenic in groundwater in the western parts (delta area) of The Netherlands.

The strong increase of chloride which can be seen in the sludge of SNB in the last 4 years is caused by a switch of large sludge supplying clients.

3. Sewage sludge ashes

3.1 General overview

The project made it possible to assess all the available ash-data of HVC and SNB from 2009/2010 until 2020/2021. Weekly mixed samples and analyses are available from 2010 for phosphorus in the ashes, while other elements are usually analyzed on a monthly basis. The raw data is given in the appendix I.

	Dewatered sludge to incinerator										SVI-ashes					
year	Ton sewage sludge to incinerator		ton dry matter incinerated		% ds		% os		P2O5/inorganic sludge		ton Sewage sludge ash after incineration		P2O5 (g/kg ds)		ton P2O5 total produced	
	HVC	SNB	HVC	SNB	HVC	SNB	HVC	SNB	HVC	SNB	HVC	SNB	HVC	SNB	HVC	SNB
2011	350.000	418.320	77.000	97.608	22,0	23,3	68,2	65,5	24%	22%	21.575	36.164	268	206	5.758	7.420
2012	369.300	436.455	81.200	102.922	22,0	23,6	69,1	66,4	26%	20%	23.182	36.953	282	188	6.498	6.888
2013	363.900	433.476	81.200	102.791	22,3	23,7	68,8	66,2	25%	21%	22.862	36.359	274	197	6.239	7.136
2014	360.100	408.395	79.600	95.905	22,2	23,5	69,5	66,3	24%	22%	22.642	35.000	258	202	5.832	7.018
2015	367.700	448.284	80.900	103.772	22,0	23,1	70,8	67,9	25%	22%	22.080	36.136	267	200	5.886	7.191
2016	362.900	409.735	79.300	98.459	21,9	24,0	70,8	67,2	24%	21%	21.782	35.461	255	192	5.513	6.754
2017	378.500	411.163	82.100	94.851	21,7	23,1	72,1	70,0	25%	22%	21.116	31.955	270	200	5.678	6.354
2018	370.700	419.157	80.400	97.155	21,7	23,2	72,2	69,2	25%	21%	20.809	32.269	272	198	5.630	6.362
2019	339.400	434.771	74.200	97.713	21,9	22,5	72,7	68,3	25%	24%	19.196	34.014	264	220	4.978	7.452
2020	345.400	417.075	76.800	94.503	22,2	22,7	71,9	69,2	24%	24%	20.050	33.812	265	209	5.235	6.989

Table 4: Sludge and SSA HVC and SNB (source: Milieujaarverslag HVC and Milieujaarverslag SNB, 2020)

HVC incinerated about 360.000 tons of dewatered sludge on a yearly basis in the SVI (Slibverbrandingsinstallatie, Sewage sludge incineration plant), while SNB incinerated about 420.000 tons. The amount of ashes from the sludge in HVC and SNB is decreasing slightly with approximately 10% over the last 10 years. This is explained by the fact that the organic content in the sludge is slightly rising, despite an increase of digestion and biogas production at the WWTP's of the water authorities.

Based on the sludge material treated by the incinerators and the produced amounts of ashes and phosphate in ashes, differences are obvious between the HVC and the SNB flows:

- Ash ratio to sludge at SNB is higher, due to the higher inorganic content of the sludge (higher water content and a lower organic content) and due to the addition of calcium carbonate in the incineration process. As a consequence the P_2O_5 % in ash of HVC is higher.
- The percentage of P_2O_5 in supplied sludge to SNB varies more compared to HVC, which is probably caused by the incineration of a larger amount of sludge obtained via European Tenders by SNB leading to a larger number of clients. HVC is mainly treating sludge from their own shareholders.

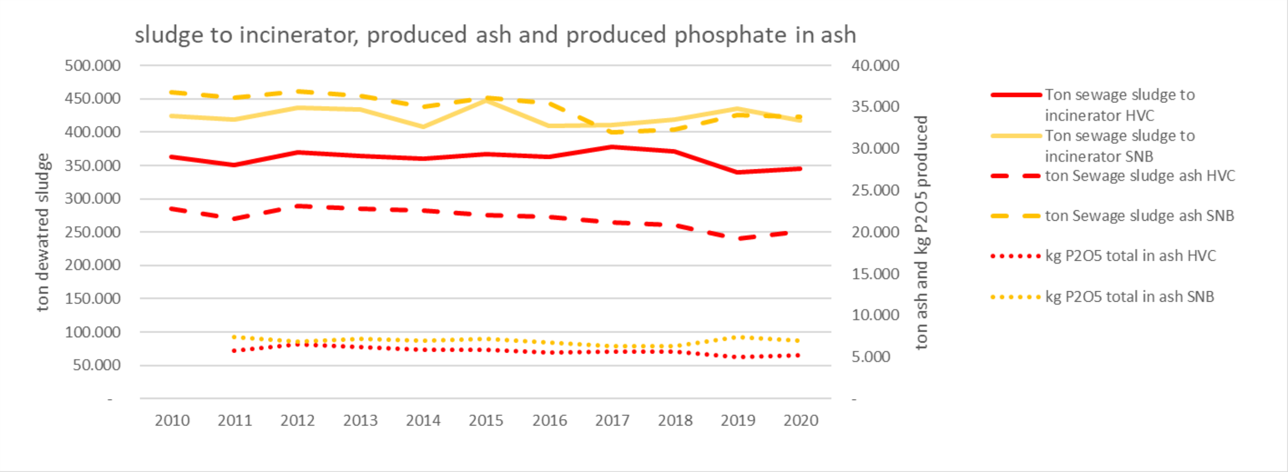

Figure 4: Ton input and output at HVC and SNB (source: Milieujaarverslag HVC and milieujaarverslag SNB, 2020).

3.2 Detailed trends in ashes

The data of sewage sludge ashes of HVC and SNB are for the first time combined in one dataset to make it possible to compare the ash composition in an structured and visual attractive way.

The follow data is assessed:

1. Phosphate (weekly and annual trend)
2. Arsenic (weekly and annual trend)
3. Cadmium per ton of P_2O_5 (weekly and annual trend)
4. Calcium per ton of P_2O_5 (annual trend)
5. Aluminum per ton of P_2O_5 (annual trend)
6. Iron per ton of P_2O_5 (annual trend)

The other elements in the ashes (dry matter, organic matter, Cr, Cu, Ni, Pb, Zn, Mo, K and S) are given in the appendix II.

HVC and SNB have been monitoring the ash quality since the start of their installations. The amount of analyses and the frequency has changed. SNB started monitoring the ash quality on a weekly basis in 2017 with the start of Phos4You. Before 2017 the ash quality was monitored on a monthly base. HVC has already been monitoring the ash quality on a weekly bases before. Data from 2009 on has been used in this this report.

The parameters are very important to monitor on a high frequency basis, as they are relevant in the optimization settings in the technology and processes of phosphorus recovery.

Most of the heavy metals remain in the residue after acid leaching. This residue has to be disposed, but the higher the heavy metal concentration the higher the risks of toxicity which increases the challenges for safe disposal or reuse. Some slight concentration will end of the raw phosphoric acid as recovered product, which will have to purified by nano-filtration to get rid of the final pollutants and to reach the technical or merchant grade quality.

Iron and aluminum are available in sludge and in ashes as caused, partly, by the use of Fe and Al-containing coagulants for P-removal in waste water. The chemical leaching process during P-recovery form ashes needs to be settled in such a way that the optimum is achieved in the removal and/or recovery of iron and aluminum salts, or example via an ion-exchange process.

Calcium plays a role in the formation of gypsum in case a sulphuric acid is used in the P-recovery process.

3.2.1 Phosphate

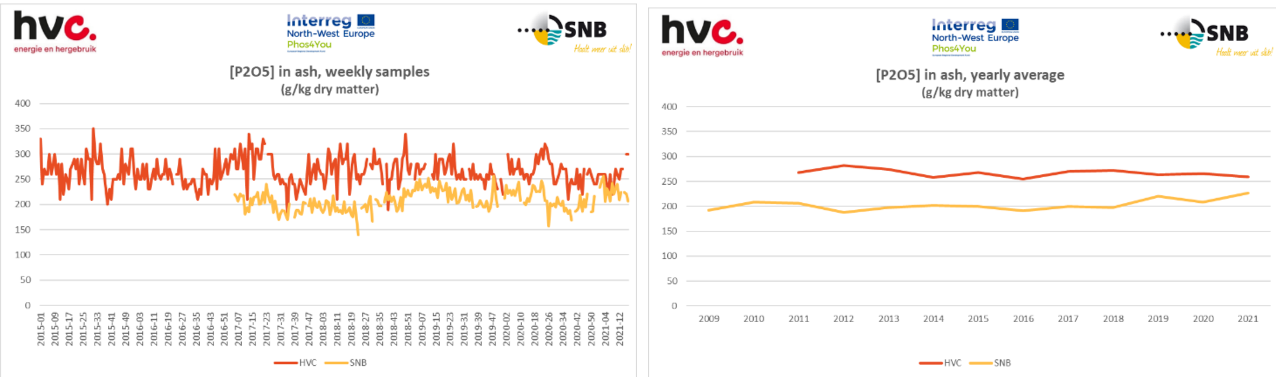

Figure 5: Phosphate in ash (source: own illustration based on weekly sampling program)

Phosphorus content varies between the ashes of HVC and SNB, mainly due to addition of Ca in the incineration process of SNB. As a consequence the ashes of SNB are a bit more ‘diluted’.

3.2.2 Arsenic

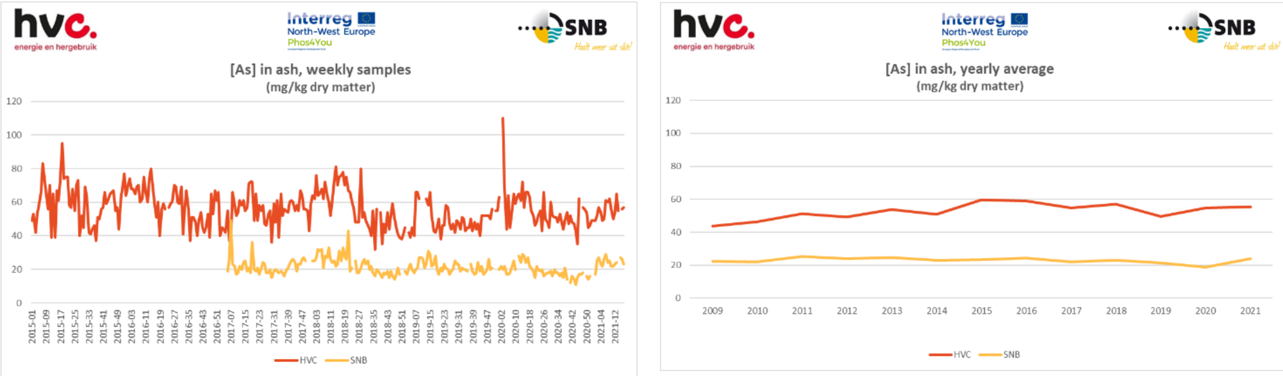

Figure 6: Arsenic in ash (source: own illustration based on weekly sampling program)

Arsenic in ashes might be caused by groundwater effects in sewers.

3.2.3 Cadmium

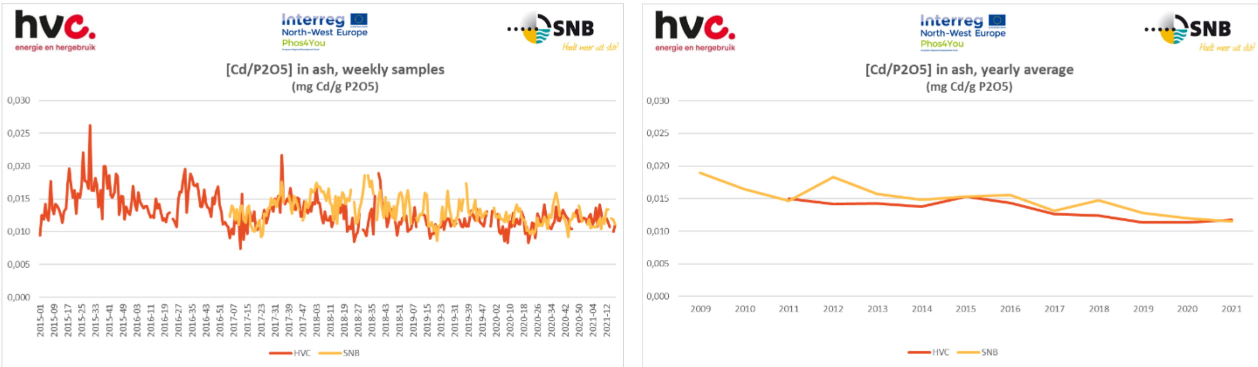

Figure 7: Cadmium in ash (source: own illustration based on weekly sampling program)

Cadmium levels are slowly reducing, maybe due to less effects of industrial influences to sewage sludge.

3.2.4 Calcium

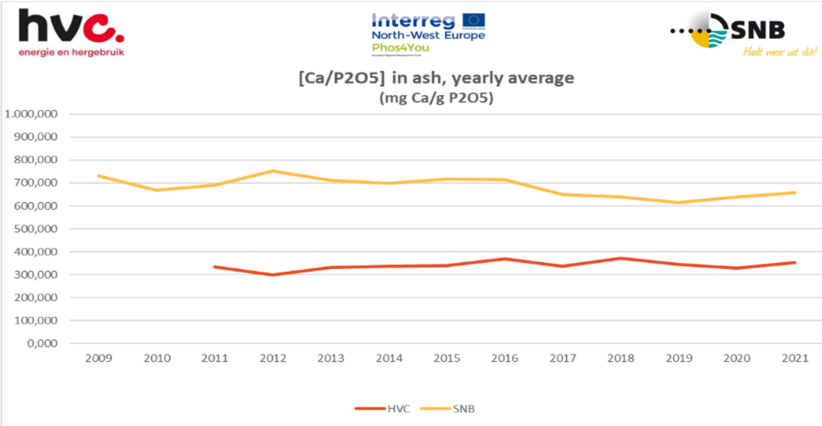

Figure 8: Calcium in ash (source: own illustration based on weekly sampling program)

Lime is added into the incineration process of SNB.

3.2.5 Aluminum

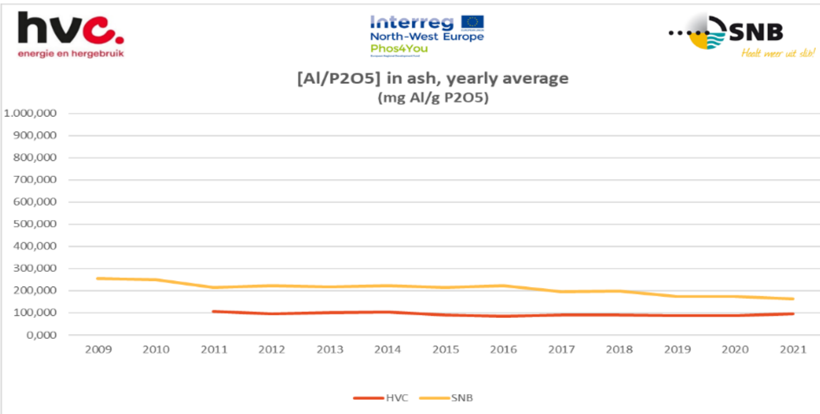

Figure 9: Aluminum in ash (source: own illustration based on weekly sampling program)

The Al/P ratio is important to monitor in relation to the coagulant use at WWTP's and for further P-recovery from ashes.

3.2.6 Iron

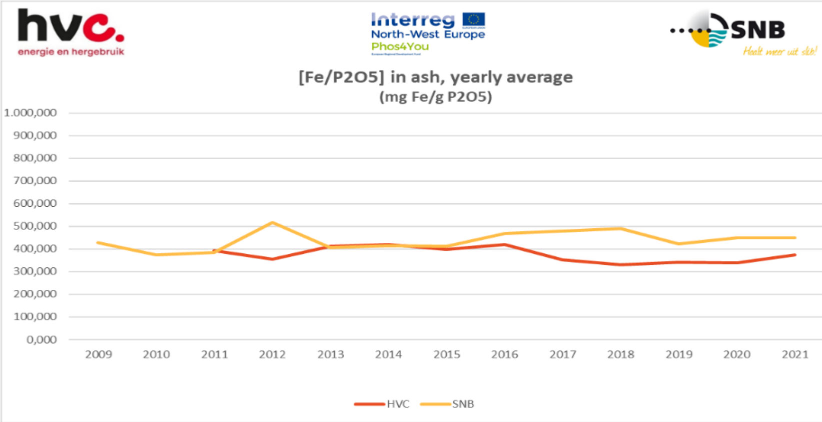

Figure 10: Iron in ash (source: own illustration based on weekly sampling program)

4. SSA: waste or end-of-waste and its implications

It has been topic of discussion to what extend end of waste for sewage sludge fly ash for P-recovery purposes is useful or valuable. Until now, within Europe's stakeholders on P-recovery and the use in final products, more and more discourse took place on end-of-waste on fly ashes and on end products.

For the purpose of recycling the P contained into the SSA, the SSA can be delivered to external companies either as a "waste" or as a "product". When delivered as a "waste", the SSA need to comply to the transport rules for waste. Also, the factory receiving the SSA needs to obtain a specific permit allowing it to manage waste. In the factory, the SSA remain waste until the final product is CE-marked (in case of integration of the SSA into a fertilising product).

To have the SSA delivered as a "product", the SSA first need to obtain the "end-of-waste status". The transport rules for waste do not apply anymore; a REACH registration of the SSA is necessary.

If SSA with end-of-waste status might enhance its monetary value, ease its transportation and acceptation at receiving factory, SSA as waste might better guarantee its traceability until its integration into products.

Also considerations with regard to the quality of the products in which P-recyclates are used, the market demand, and responsibility or the actors in the value chain need to be taken into account.

In the Netherlands, to check the possibilities on end of waste, by-product or resource, companies are enabled to conduct an web-test. The status with regard to end of waste was also tested for the HVC and SNB sewage sludge ashes. This was done via the website: https://www.afvalcirculair.nl/onderwerpen/afval/toetsing-afval/webtoets-afval/

In a next step, an assessment was done by Rijkswaterstaat on the SNB and HVC ashes for the specific phosphate recovery route to Ecophos in 2019/early 2020. This stopped due to the bankruptcy of Ecophos in early 2020.

The procedure is schematically depicted in the block scheme below.

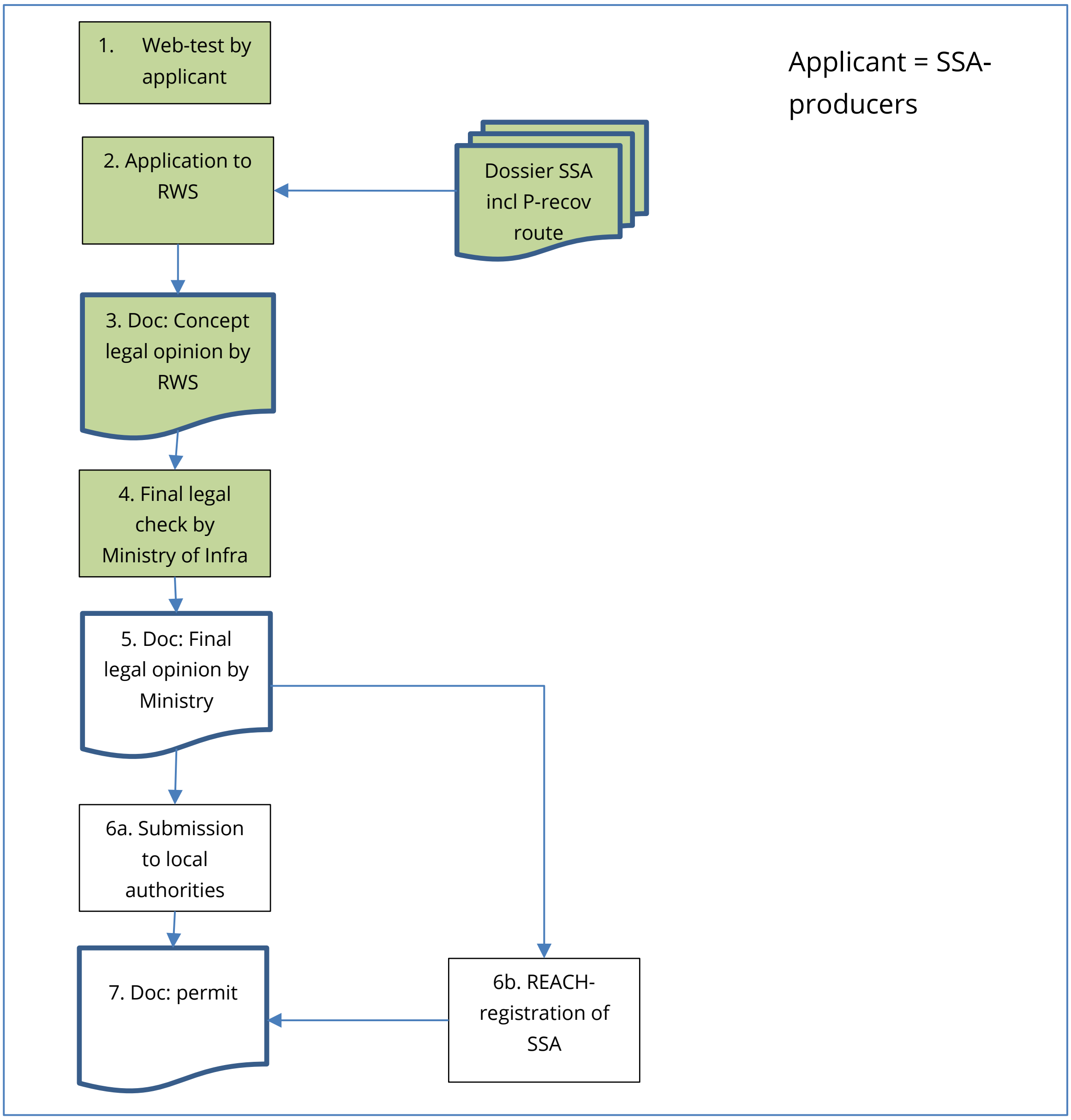

Figure 11: Procedure end of waste

After obtaining the final legal opinion from the Ministry (step 5) by the applicant (the SSA producer), it is up to the applicant to submit the dossier to the local permitting authorities to get the final permits. However, a REACH-registration will be needed once SSA has no waste status anymore. The REACH –processes is time consuming and expected to be costly. Until now, HVC and SNB have gone through the process until step 4. After step 5 is finished, depending on the specific situation, an evaluation would hopefully point out the advantages and disadvantages to proceed to the next step. This, however, would only be interesting in case a larger consortium could be formed and shared commitment of major stakeholders is present.

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Appendices

Appendix I: Sewage sludge ash analyses

Concentrations in ash
HVC & SNB

	Dry matter		Org. matter		Cd				Cr			
	%		%		mg/kg dry matter		mg Cd/g P2O5		mg/kg dry matter		mg Cr/g P2O5	
Yearly average	HVC	SNB	HVC	SNB	HVC	SNB	HVC	SNB	HVC	SNB	HVC	SNB
2009	99,8		0,2		3,6	3,6		0,019	95	116		0,61
2010	99,3		0,3		3,7	3,4		0,016	105	113		0,54
2011	99,6		0,5		4,0	3,0	0,015	0,015	124	94	0,46	0,46
2012	99,3		0,5		4,0	3,4	0,014	0,018	117	99	0,41	0,53
2013	99,7		0,6		3,9	3,1	0,014	0,016	120	139	0,44	0,70
2014	99,7		0,3		3,6	3,0	0,014	0,015	144	158	0,56	0,78
2015	99,7		0,2		4,1	3,1	0,015	0,015	142	177	0,53	0,88
2016	99,4		0,3		3,6	3,0	0,014	0,016	121	202	0,47	1,05
2017	99,5		0,3	1,8	3,4	2,6	0,013	0,013	108	135	0,40	0,68
2018	99,5	99,6	0,3	1,5	3,4	2,9	0,012	0,015	110	132	0,41	0,66
2019	98,3	99,6	0,3	1,5	3,0	2,8	0,011	0,013	130	124	0,49	0,56
2020	98,5	99,1	0,2	1,6	3,0	2,5	0,011	0,012	109	109	0,41	0,52
2021	99,8	99,1	0,2	2,0	3,0	2,6	0,012	0,012	126	106	0,49	0,47

	Cu				Ni				Pb			
	mg/kg dry matter		mg Cu/g P2O5		mg/kg dry matter		mg Ni/g P2O5		mg/kg dry matter		mg Pb/g P2O5	
Yearly average	HVC	SNB	HVC	SNB	HVC	SNB	HVC	SNB	HVC	SNB	HVC	SNB
2009	1.063	1.075		5,6	76	65		0,34	424	282		1,47
2010	1.045	1.131		5,4	84	67		0,32	455	280		1,34
2011	1.118	1.362	4,2	6,6	142	63	0,53	0,31	434	263	1,62	1,27
2012	1.087	984	3,9	5,2	91	62	0,32	0,33	421	281	1,49	1,50
2013	1.188	1.083	4,3	5,5	83	89	0,30	0,45	420	317	1,53	1,60
2014	1.205	1.092	4,7	5,4	88	91	0,34	0,45	413	301	1,60	1,49
2015	1.290	1.027	4,8	5,1	92	79	0,34	0,39	441	254	1,65	1,27
2016	1.210	949	4,8	5,0	84	79	0,33	0,41	434	247	1,71	1,29
2017	1.358	883	5,0	4,4	85	76	0,32	0,38	393	221	1,45	1,11
2018	1.301	946	4,8	4,8	85	76	0,31	0,38	364	208	1,34	1,05
2019	1.310	1.019	5,0	4,6	88	70	0,34	0,32	354	211	1,34	0,96
2020	1.310	929	4,9	4,5	84	61	0,32	0,29	361	187	1,36	0,90
2021	1.206	961	4,7	4,2	82	66	0,32	0,29	314	188	1,21	0,83

	Zn				As			
	mg/kg dry matter		mg Zn/g P2O5		mg/kg dry matter		mg As/g P2O5	
Yearly average	HVC	SNB	HVC	SNB	HVC	SNB	HVC	SNB
2009	2.898	2.217		11,6	44	22		0,12
2010	2.919	2.350		11,3	46	22		0,10
2011	3.027	2.225	11,3	10,8	51	25	0,19	0,12
2012	2.992	2.717	10,6	14,5	49	24	0,17	0,13
2013	3.188	2.550	11,6	12,9	54	25	0,20	0,12
2014	3.208	2.475	12,4	12,3	51	23	0,20	0,11
2015	3.611	2.650	13,5	13,2	60	23	0,22	0,12
2016	3.359	2.542	13,2	13,3	59	24	0,23	0,13
2017	3.529	2.444	13,1	12,2	55	22	0,20	0,11
2018	3.396	2.529	12,5	12,8	57	23	0,21	0,12
2019	3.413	2.708	12,9	12,3	49	21	0,19	0,10
2020	3.500	2.446	13,2	11,7	55	19	0,21	0,09
2021	3.531	2.744	13,6	12,1	55	24	0,21	0,11

Concentrations in ash
HVC & SNB

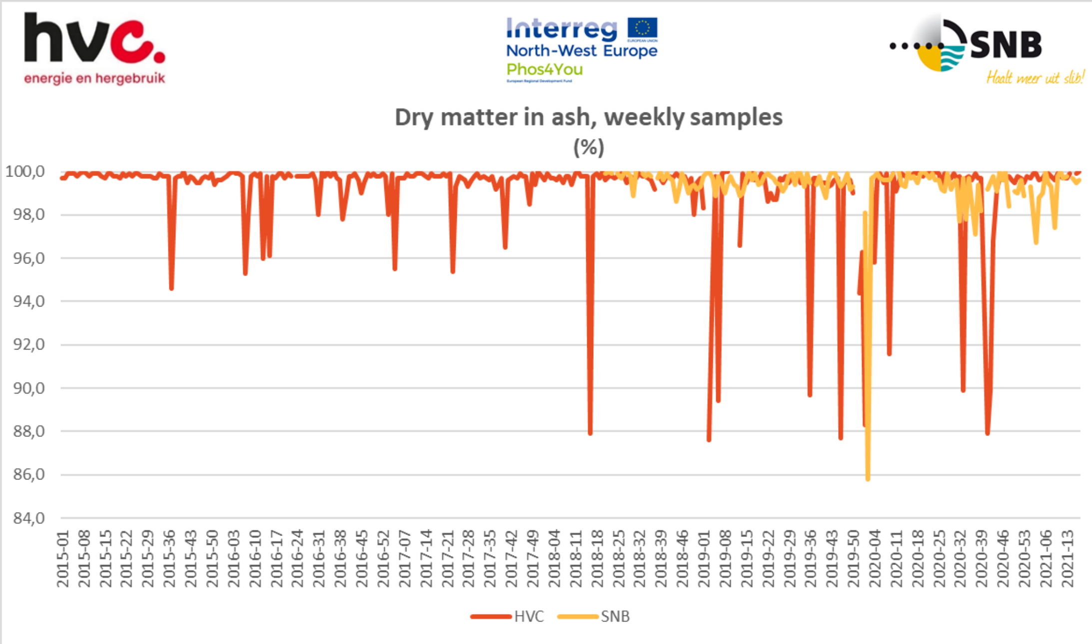
n.d. = not detectable.

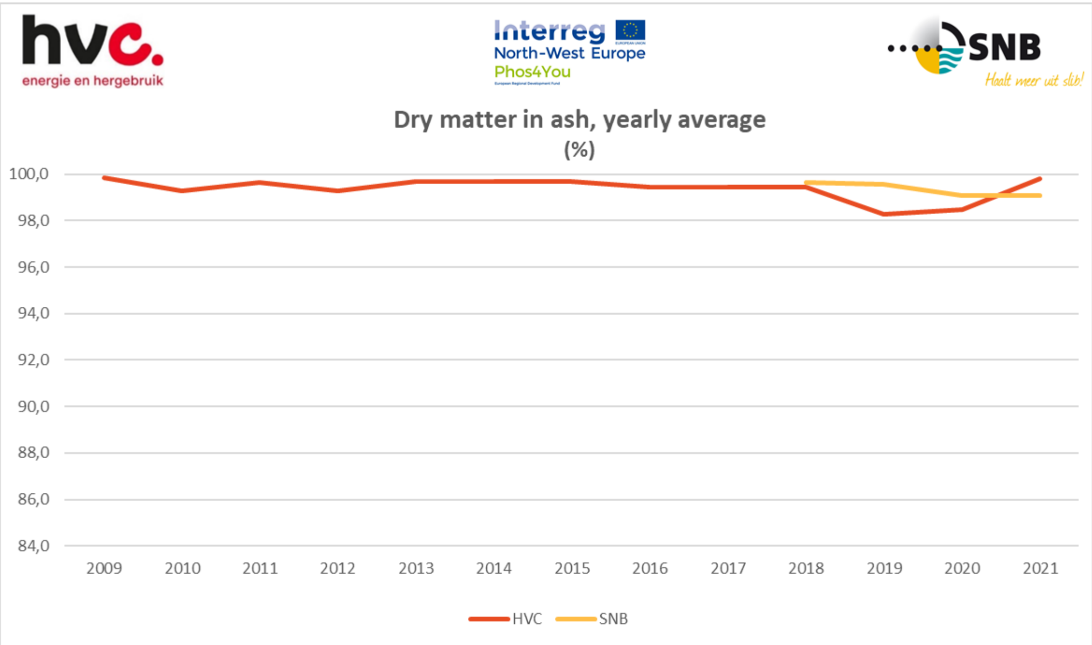
	Mo				Al				Ca			
	mg/kg dry matter		mg Mo/g P2O5		mg/kg dry matter		mg Al/g P2O5		mg/kg dry matter		mg Ca/g P2O5	
Yearly average	HVC	SNB	HVC	SNB	HVC	SNB	HVC	SNB	HVC	SNB	HVC	SNB
2009	29	24		0,13		49.158		256		140.083		730
2010	29	27		0,13		51.975		249		139.250		668
2011	33	28	0,12	0,14	28.702	44.350	107	215	89.489	142.500	334	690
2012	31	29	0,11	0,15	27.064	41.917	96	224	84.319	141.083	299	752
2013	33	31	0,12	0,16	27.420	42.950	100	218	91.040	140.833	333	713
2014	33	27	0,13	0,13	27.091	45.025	105	223	87.091	140.917	337	699
2015	36	30	0,13	0,15	24.364	42.992	91	215	90.636	143.583	339	717
2016	36	25	0,14	0,13	21.475	42.617	84	222	93.667	137.000	368	715
2017	39	26	0,15	0,13	24.400	39.180	90	196	90.800	129.778	336	649
2018	38	25	0,14	0,13	24.733	38.988	91	197	100.867	126.551	371	639
2019	38	26	0,14	0,12	23.400	38.259	89	174	90.700	135.004	344	614
2020	35	24	0,13	0,12	23.083	36.224	87	174	86.833	133.140	328	638
2021	34	23	0,13	0,10	24.500	37.025	95	163	91.500	149.063	354	658

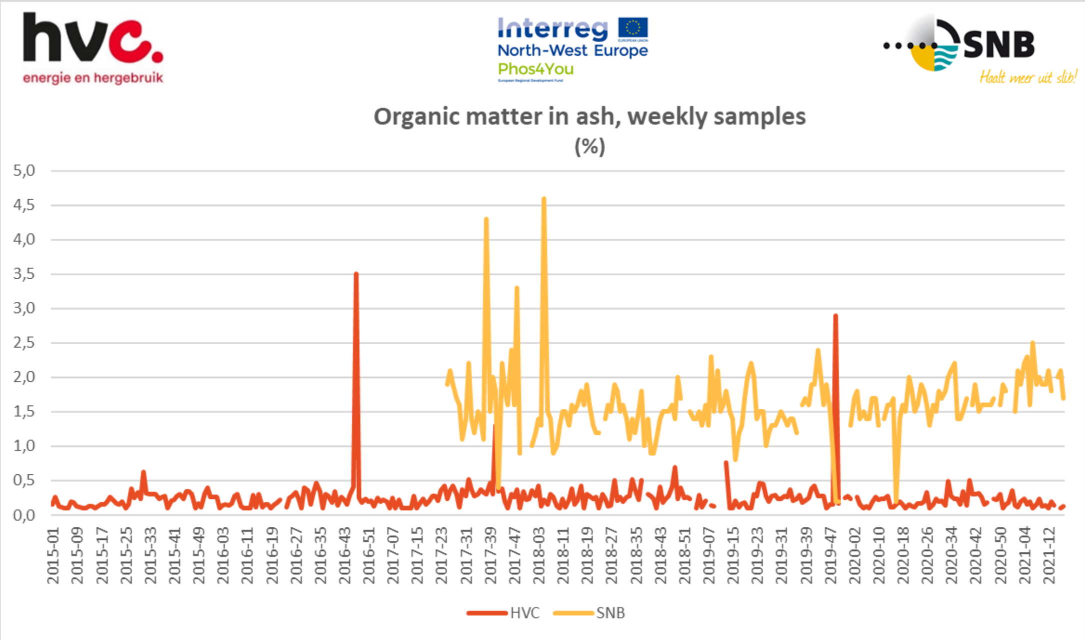
	Fe				K				P2O5	
	mg/kg dry matter		mg Fe/g P2O5		mg/kg dry matter		mg K/g P2O5		g/kg dry matter	
Yearly average	HVC	SNB	HVC	SNB	HVC	SNB	HVC	SNB	HVC	SNB
2009		82.300		429						192
2010		78.033		374						209
2011	105.085	79.267	392	384	19.146		71		268	206
2012	100.404	97.050	356	518	18.334		65		282	188
2013	112.840	79.983	412	405	18.379		67		274	197
2014	108.545	83.342	420	413	16.273		63		258	202
2015	106.818	82.550	399	412	17.909		67		267	200
2016	106.583	89.692	419	468	18.250	13.500	72	70	255	192
2017	95.143	95.693	352	478	20.400	13.650	75	68	270	200
2018	90.000	96.912	331	490	18.733	13.427	69	68	272	198
2019	90.000	92.694	341	421	18.700	12.088	71	55	264	220
2020	90.000	93.982	339	451	19.067	11.406	72	55	265	209
2021	96.750	101.556	374	448	18.500	13.838	71	61	259	227

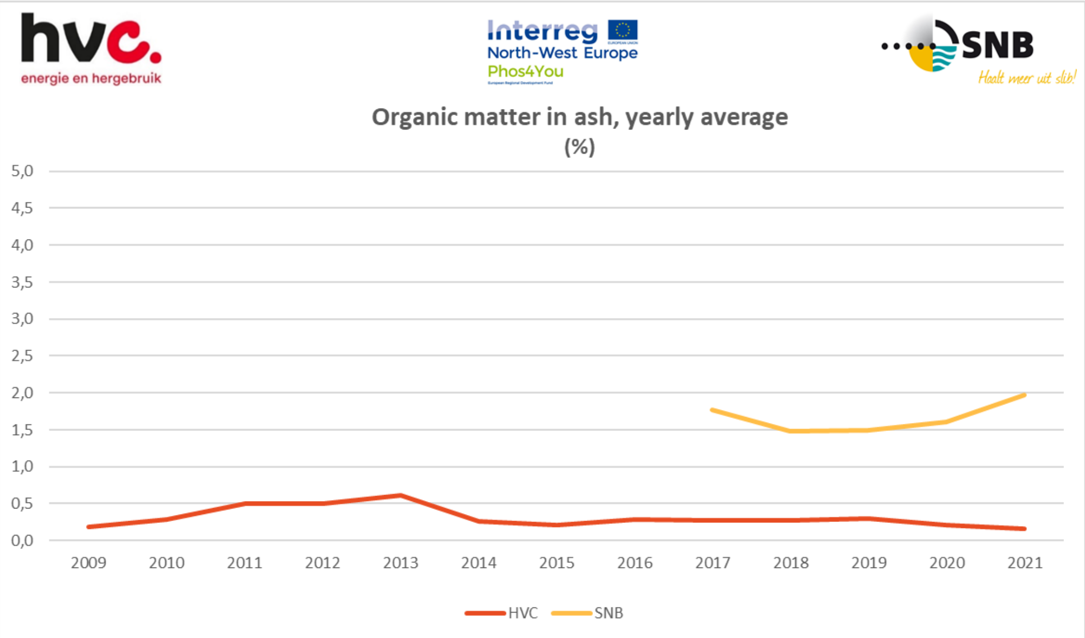
	S				TE-PCDD/F-NATO/CCMS	
	g/kg dry matter		g S/g P2O5		ng TEQ/kg dry matter	
Yearly average	HVC	SNB	HVC	SNB	HVC	SNB
2009		18,7		0,097		
2010		18,5		0,089		
2011	3,5	18,1	0,013	0,088		
2012	3,4	17,6	0,012	0,094	n.d.	
2013	4,3	20,4	0,016	0,103	n.d.	
2014	3,6	17,3	0,014	0,086	0,15	0,51
2015	4,2	17,0	0,016	0,085	n.d.	1,68
2016	4,2	17,0	0,017	0,089	0,87	0,81
2017	4,0	15,0	0,015	0,075	n.d.	0,85
2018	4,4	13,9	0,016	0,070	n.d.	0,68
2019	4,4	15,6	0,017	0,071	0,02	0,38
2020	3,3	15,5	0,012	0,074	n.d.	0,36
2021	3,4	17,1	0,013	0,075	n.d.	0,74

Appendix II: Elements in ash






hvc.
energie en hergebruik
Interreg North-West Europe Phos4You
SNB
Haalt meer uit slib!
Organic matter in ash, weekly samples
(%)
5,0
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
2015-01
2015-09
2015-17
2015-25
2015-33
2015-41
2015-49
2016-03
2016-11
2016-19
2016-27
2016-35
2016-43
2016-51
2017-07
2017-15
2017-23
2017-31
2017-39
2017-47
2018-03
2018-11
2018-19
2018-27
2018-35
2018-43
2018-51
2019-07
2019-15
2019-23
2019-31
2019-39
2019-47
2020-02
2020-10
2020-18
2020-26
2020-34
2020-42
2020-50
2021-04
2021-12
HVC
SNB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energie en hergebruik
Interreg North-West Europe Phos4You
SNB
Haalt meer uit slib!
Organic matter in ash, yearly average
(%)
5,0
4,5
4,0
3,5
3,0
2,5
2,0
1,5
1,0
0,5
0,0
2009
2010
2011
2012
2013
2014
2015
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2017
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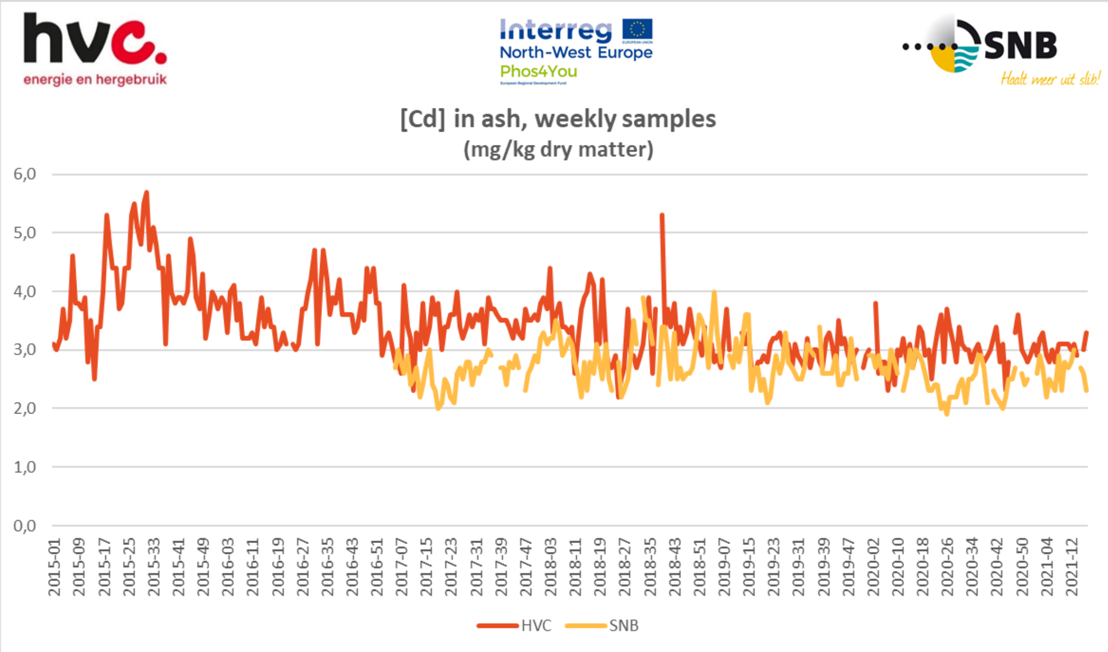
2019
2020
2021
HVC
SNB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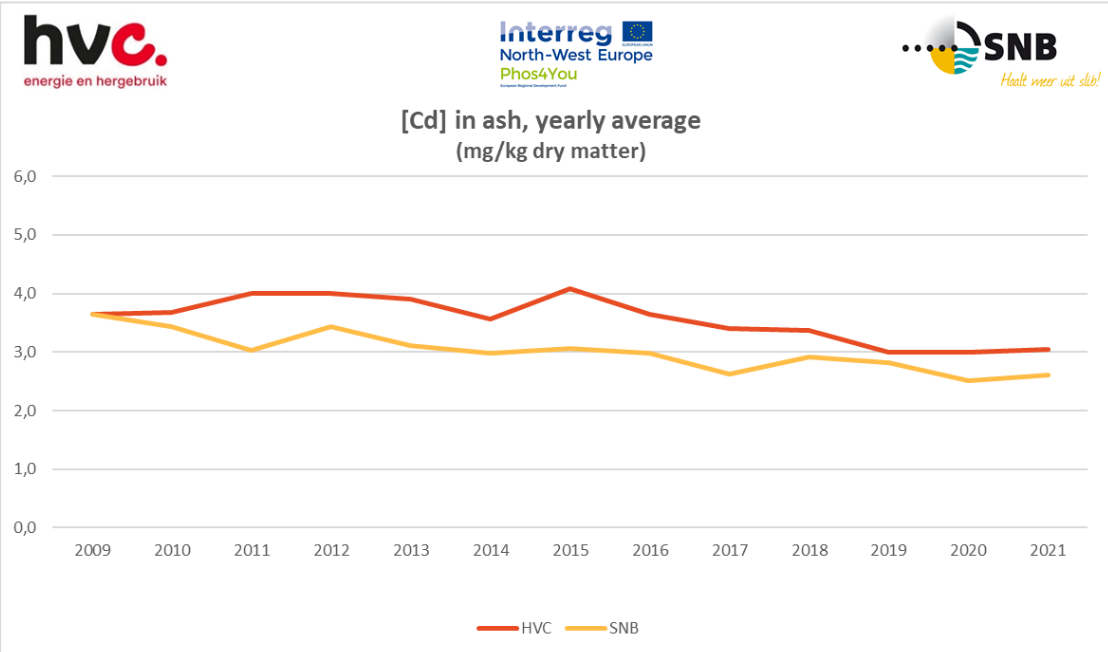
energie en hergebruik
Interreg North-West Europe Phos4You
SNB
Haalt meer uit slib!
[Cd] in ash, weekly samples
(mg/kg dry matter)
6,0
5,0
4,0
3,0
2,0
1,0
0,0
HVC
SNB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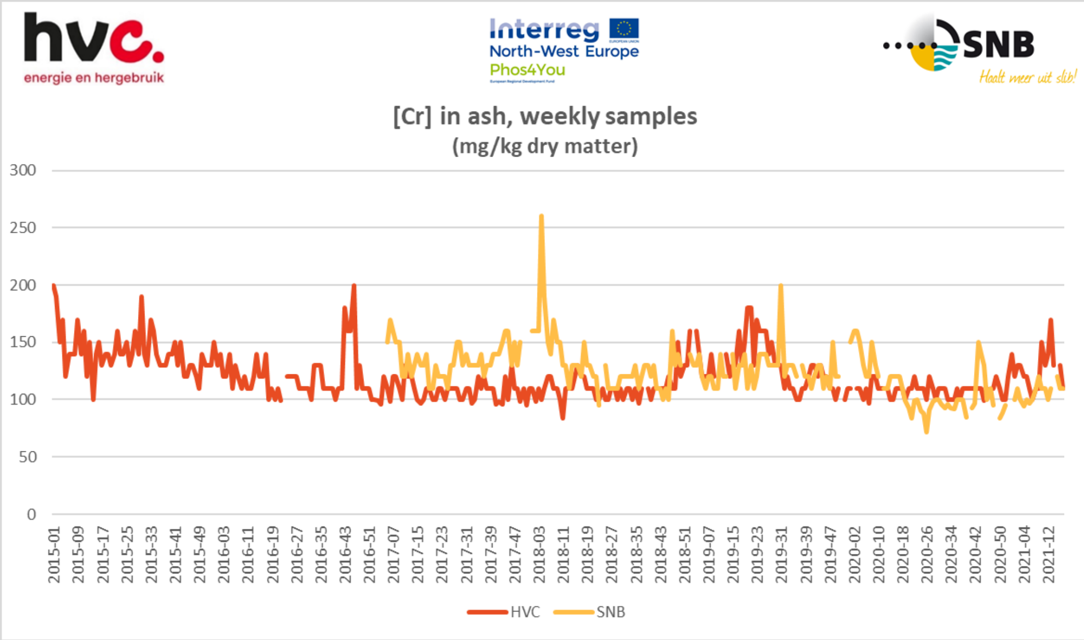
energie en hergebruik
Interreg North-West Europe Phos4You
SNB
Haalt meer uit slib!
[Cd] in ash, yearly average
(mg/kg dry matter)
6,0
5,0
4,0
3,0
2,0
1,0
0,0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
HVC
SNB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energie en hergebruik
Interreg
North-West Europe
Phos4You
SNB
Haalt meer uit slib!
[Cr] in ash, weekly samples
(mg/kg dry matter)
300
250
200
150
100
50
0
2015-01
2015-09
2015-17
2015-25
2015-33
2015-41
2015-49
2016-03
2016-11
2016-19
2016-27
2016-35
2016-43
2016-51
2017-07
2017-15
2017-23
2017-31
2017-39
2017-47
2018-03
2018-11
2018-19
2018-27
2018-35
2018-43
2018-51
2019-07
2019-15
2019-23
2019-31
2019-39
2019-47
2020-02
2020-10
2020-18
2020-26
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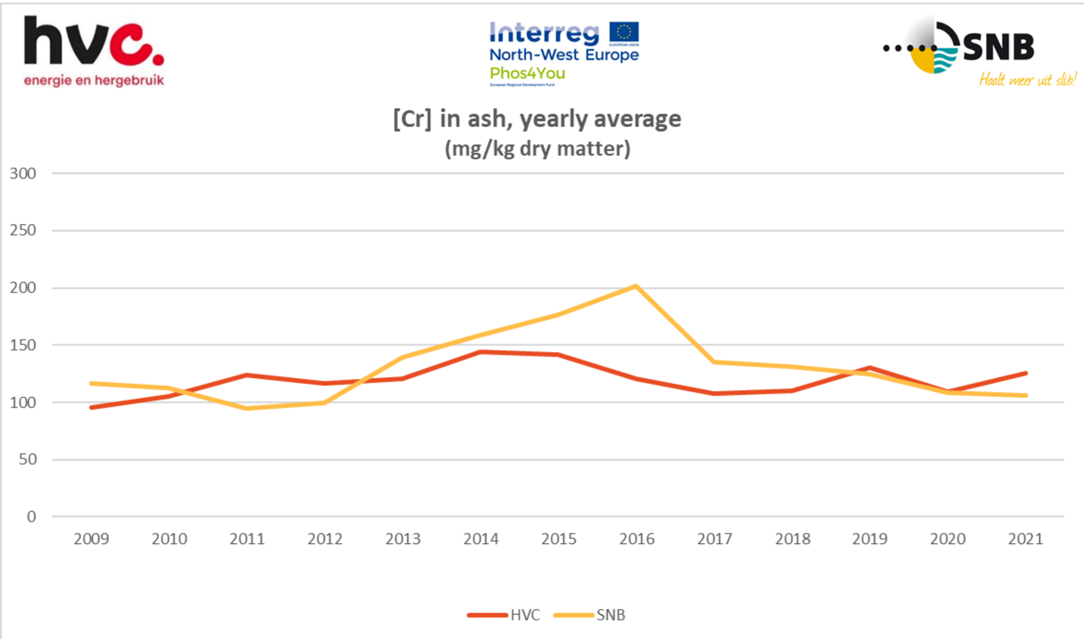
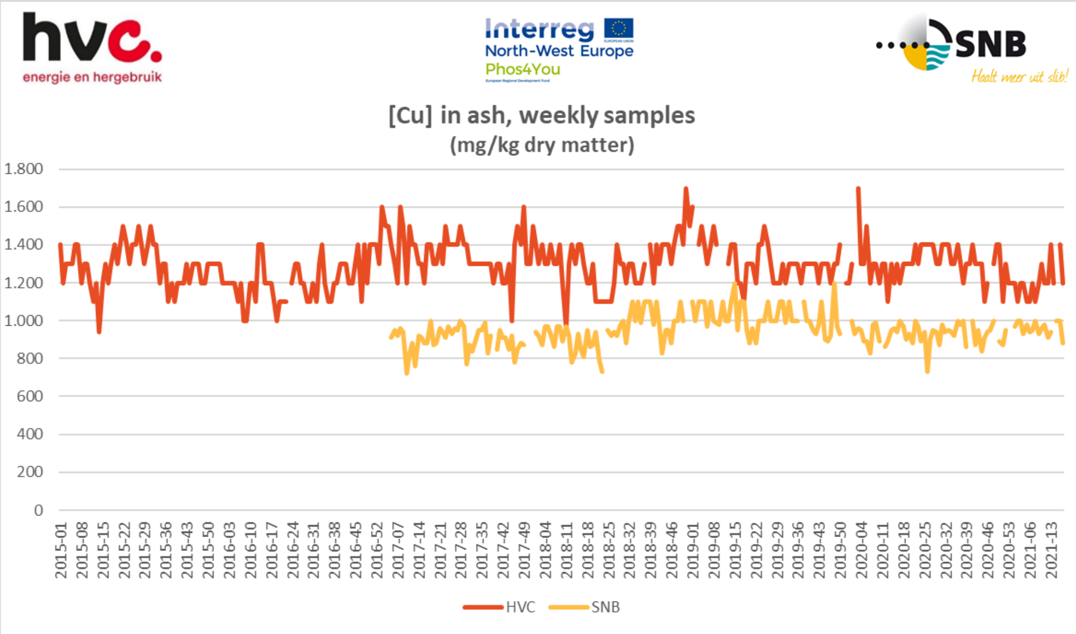
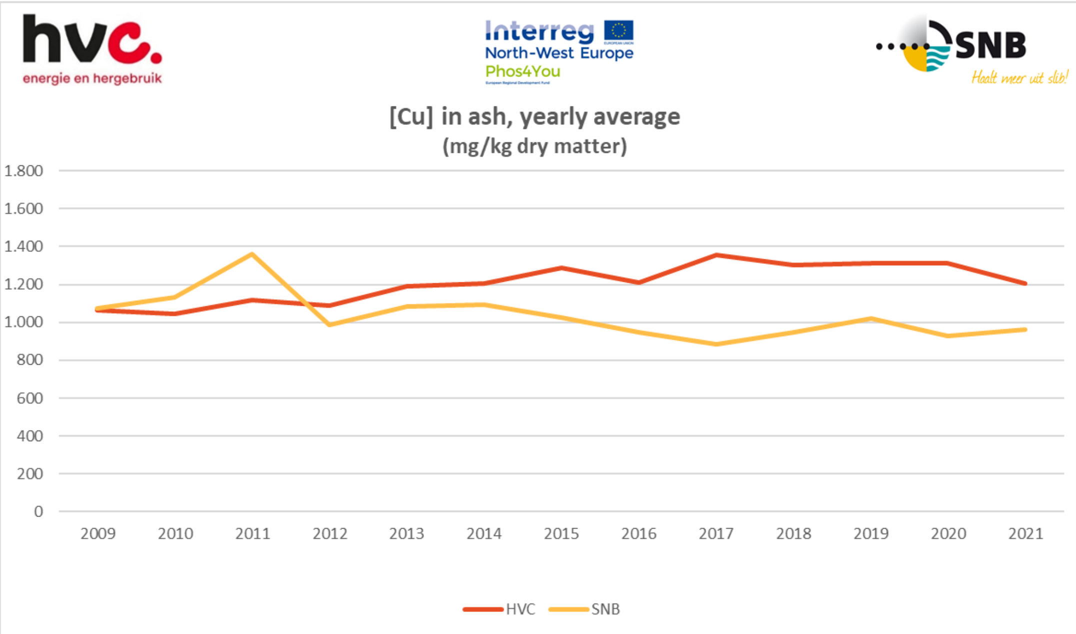
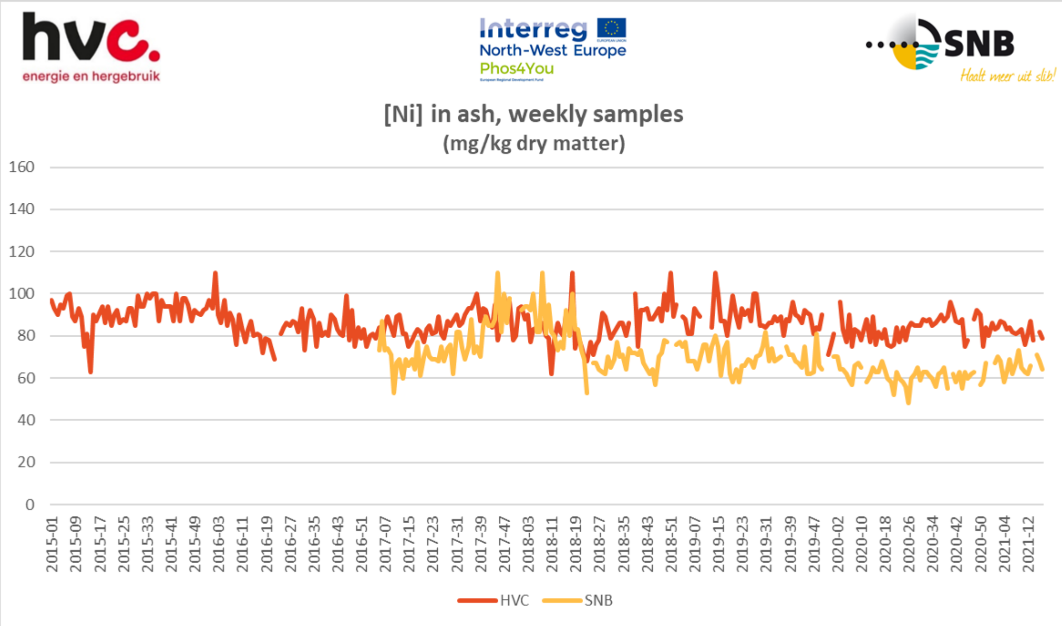
2020-42
2020-50
2021-04
2021-12
HVC
SNB


hvc.
energie en hergebruik
Interreg
North-West Europe
Phos4You
SNB
Haalt meer uit slib!
[Cr] in ash, yearly average
(mg/kg dry matter)
300
250
200
150
100
50
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
HVC
SNB


hvc.
energie en hergebruik
Interreg
North-West Europe
Phos4You
SNB
Haalt meer uit slib!
[Cu] in ash, weekly samples
(mg/kg dry matter)
1.800
1.600
1.400
1.200
1.000
800
600
400
200
0
2015-01 2015-08 2015-15 2015-22 2015-29 2015-36 2015-43 2015-50 2016-03 2016-10 2016-17 2016-24 2016-31 2016-38 2016-45 2016-52 2017-07 2017-14 2017-21 2017-28 2017-35 2017-42 2017-49 2018-04 2018-11 2018-18 2018-25 2018-32 2018-39 2018-46 2019-01 2019-08 2019-15 2019-22 2019-29 2019-36 2019-43 2019-50 2020-04 2020-11 2020-18 2020-25 2020-32 2020-39 2020-46 2020-53 2021-06 2021-13
HVC
SNB


hvc.
energie en hergebruik
Interreg
North-West Europe
Phos4You
SNB
Haalt meer uit slib!
[Cu] in ash, yearly average
(mg/kg dry matter)
1.800
1.600
1.400
1.200
1.000
800
600
400
200
0
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021
HVC
SNB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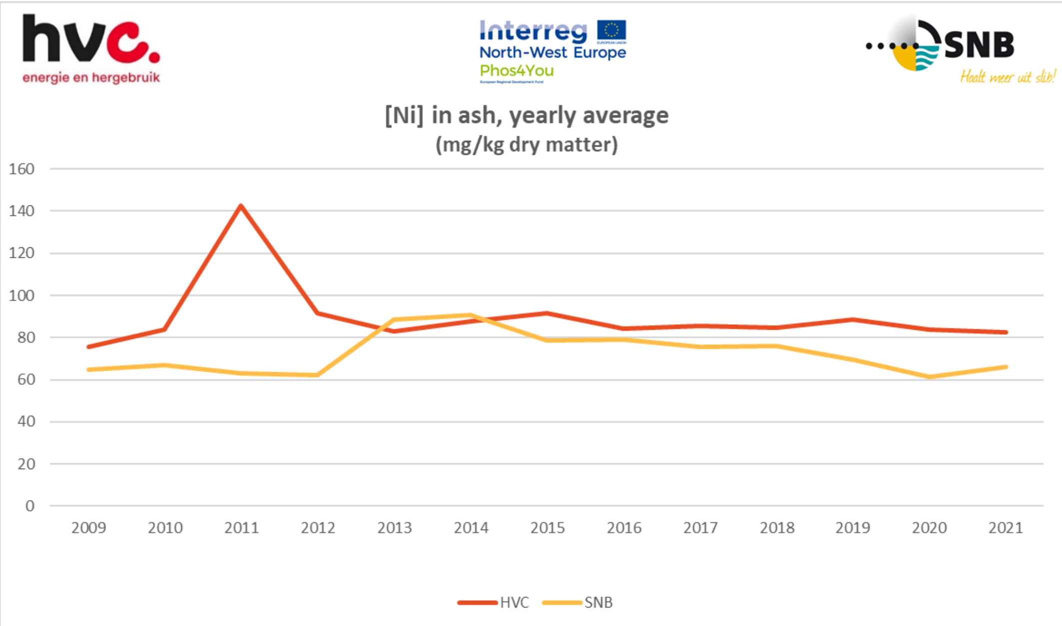
Interreg North-West Europe Phos4You
SNB Haalt meer uit slib!
[Ni] in ash, weekly samples
(mg/kg dry matter)
0
20
40
60
80
100
120
140
160
HVC
SNB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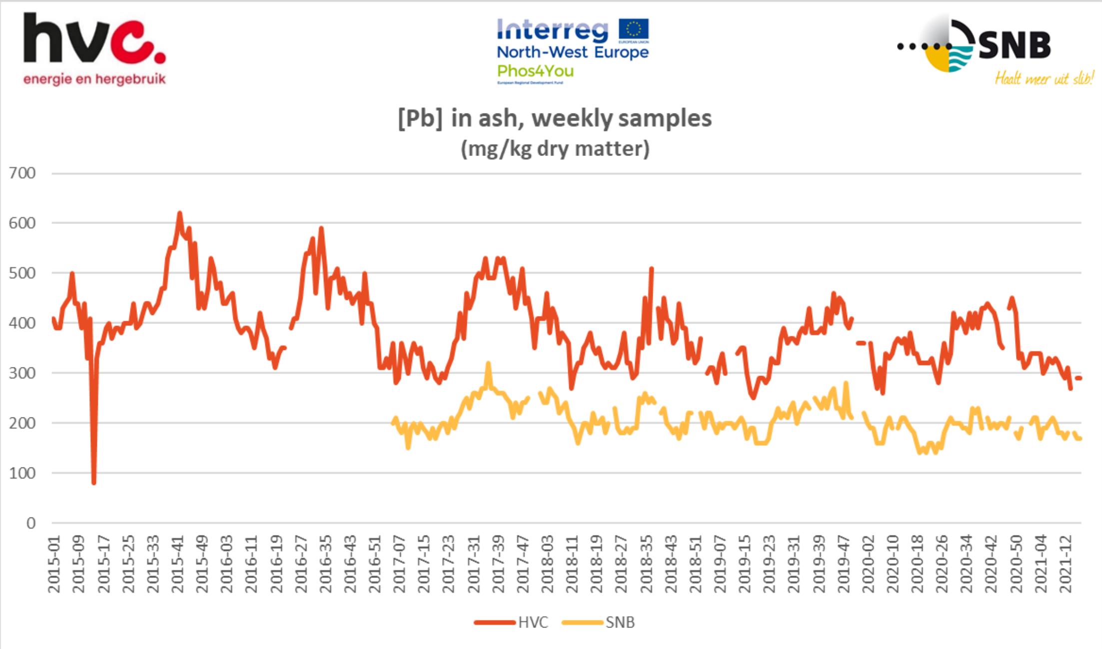
Interreg North-West Europe Phos4You
SNB Haalt meer uit slib!
[Ni] in ash, yearly average
(mg/kg dry matter)
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
HVC
SNB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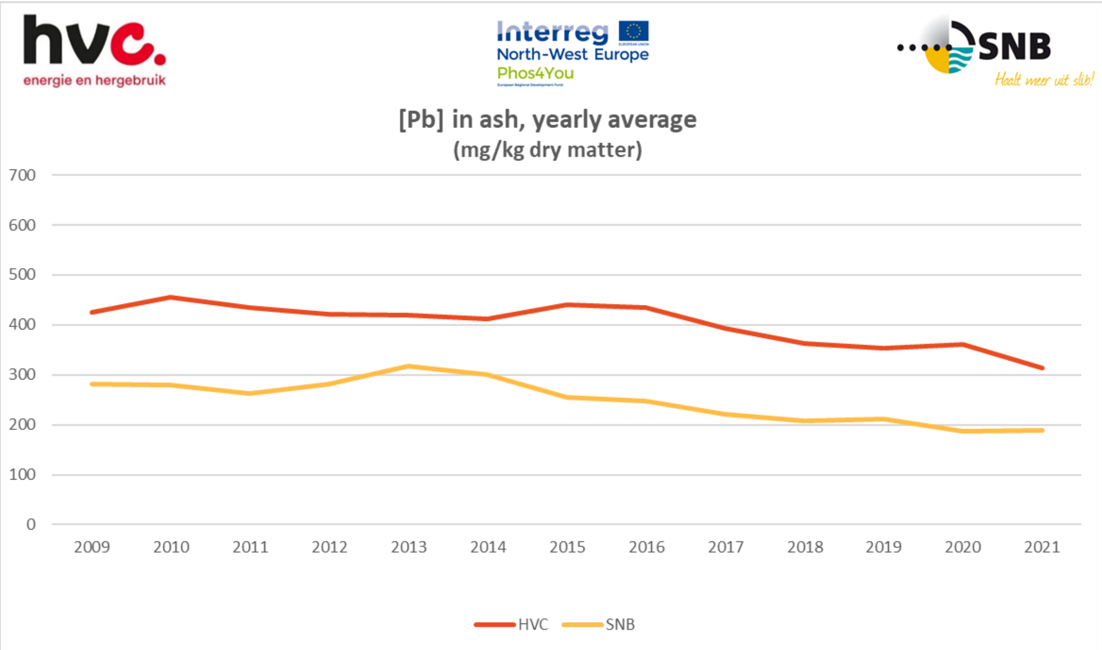
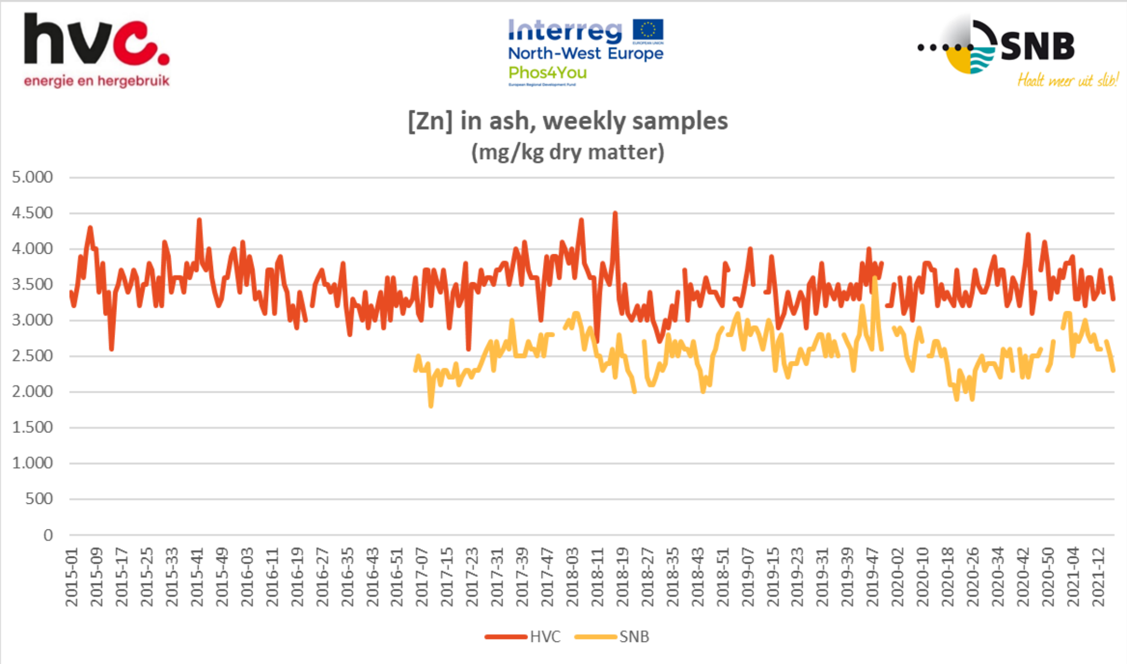
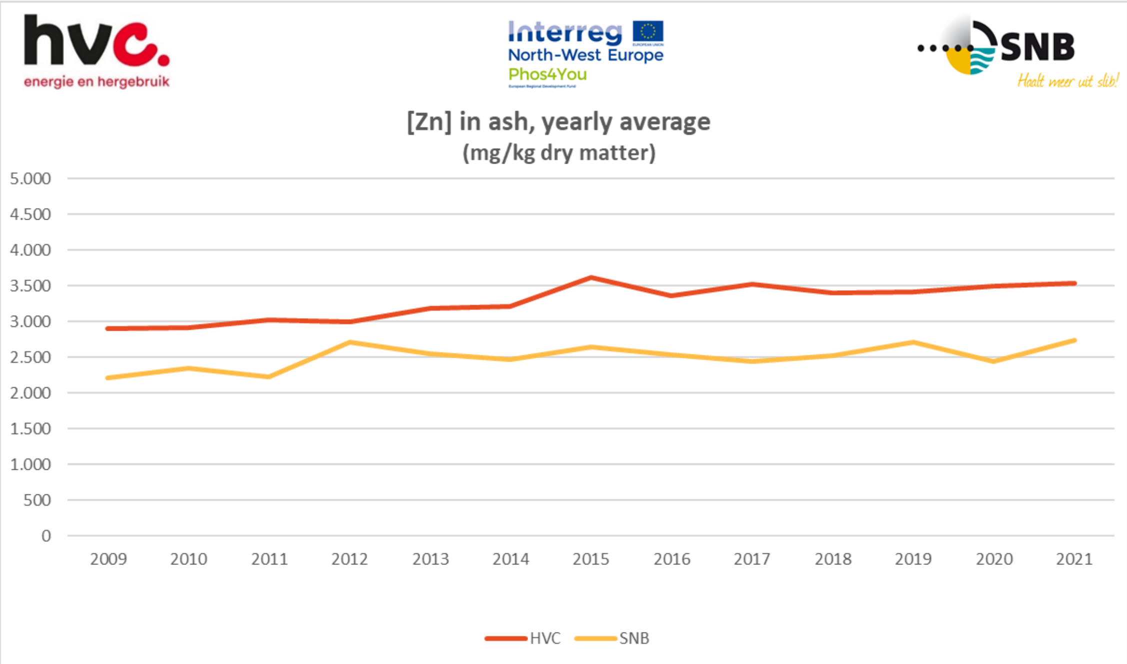
Interreg North-West Europe Phos4You
SNB Haalt meer uit slib!
[Pb] in ash, weekly samples
(mg/kg dry matter)
HVC
SNB

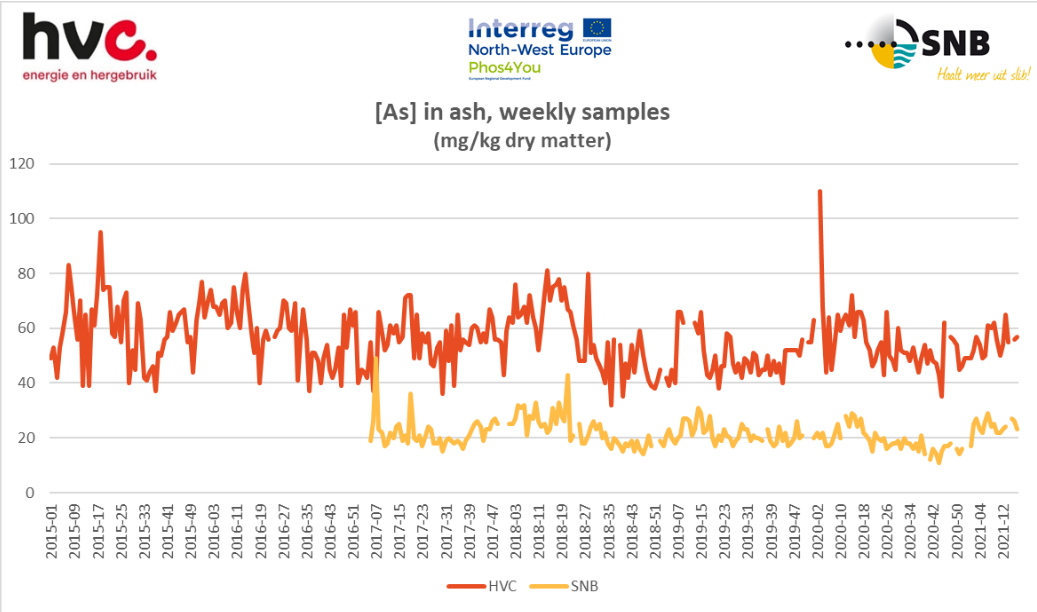

hvc. energie en hergebruik
Interreg North-West Europe Phos4You
SNB Haalt meer uit slib!
[Pb] in ash, yearly average
(mg/kg dry matter)
HVC
SNB



energie en hergebruik
Interreg North-West Europe Phos4You
SNB
Haalt meer uit slib!
[Zn] in ash, weekly samples
(mg/kg dry matter)
5.000
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
500
0
HVC
SNB



energie en hergebruik
Interreg North-West Europe Phos4You
SNB
Haalt meer uit slib!
[Zn] in ash, yearly average
(mg/kg dry matter)
5.000
4.500
4.000
3.500
3.000
2.500
2.000
1.500
1.000
500
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
HVC
SNB


hvc. energie en hergebruik
Interreg North-West Europe Phos4You
SNB Haalt meer uit slib!
[As] in ash, weekly samples
(mg/kg dry matter)
120
100
80
60
40
20
0
2015-01
2015-09
2015-17
2015-25
2015-33
2015-41
2015-49
2016-03
2016-11
2016-19
2016-27
2016-35
2016-43
2016-51
2017-07
2017-15
2017-23
2017-31
2017-39
2017-47
2018-03
2018-11
2018-19
2018-27
2018-35
2018-43
2018-51
2019-07
2019-15
2019-23
2019-31
2019-39
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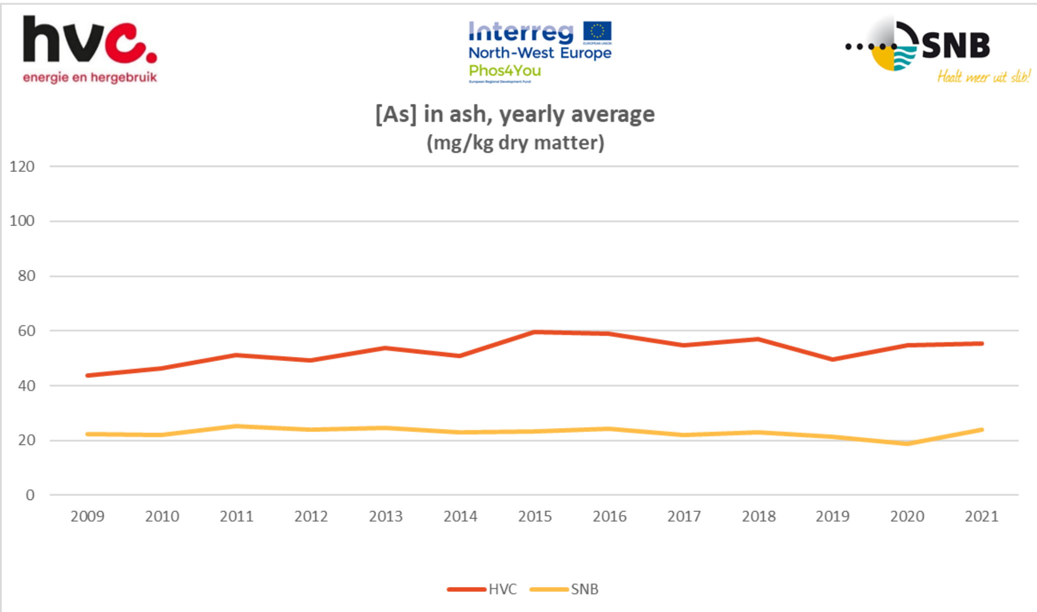
2021-04
2021-12
HVC
SNB


hvc. energie en hergebruik
Interreg North-West Europe Phos4You
SNB Haalt meer uit slib!
[As] in ash, yearly average
(mg/kg dry matter)
120
100
80
60
40
20
0
2009
2010
2011
2012
2013
2014
2015
2016
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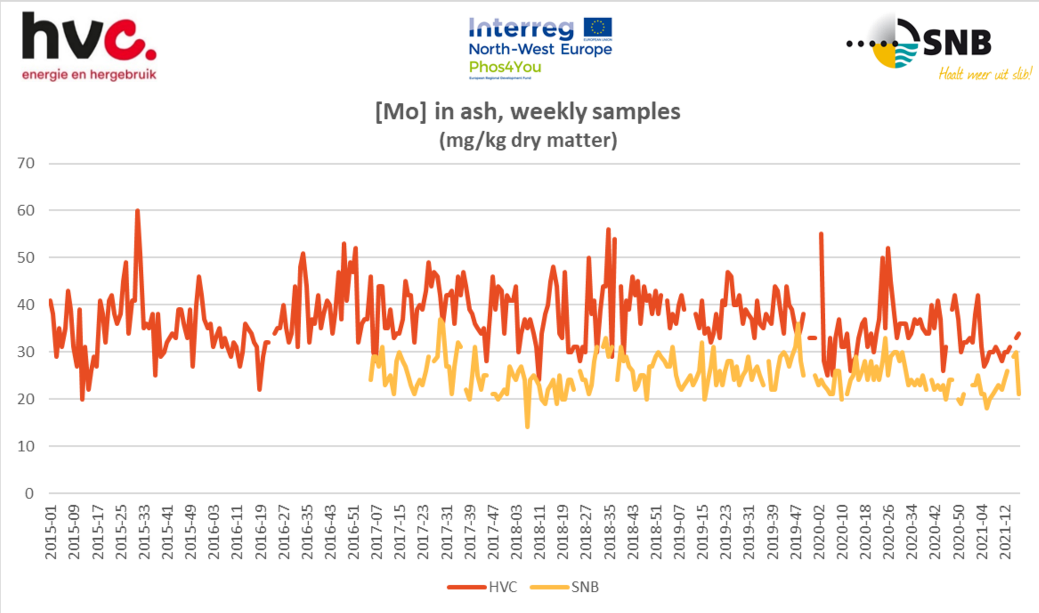
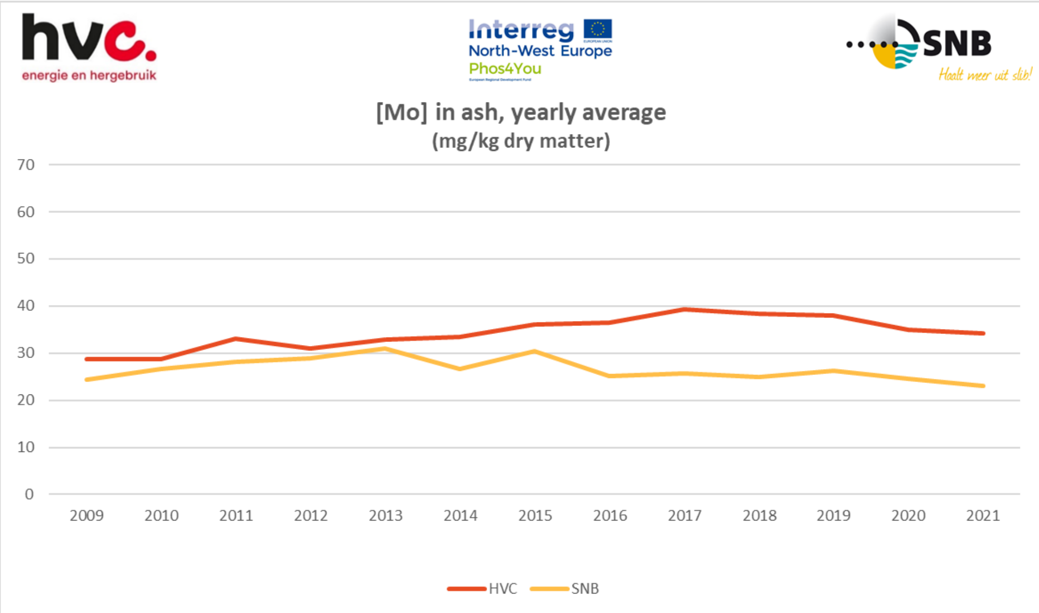
2019
2020
2021
HVC
SNB


hvc.
energie en hergebruik
Interreg
North-West Europe
Phos4You
SNB
Haalt meer uit slib!
[Mo] in ash, weekly samples
(mg/kg dry matter)
0
10
20
30
40
50
60
70
2015-01 2015-09 2015-17 2015-25 2015-33 2015-41 2015-49 2016-03 2016-11 2016-19 2016-27 2016-35 2016-43 2016-51 2017-07 2017-15 2017-23 2017-31 2017-39 2017-47 2018-03 2018-11 2018-19 2018-27 2018-35 2018-43 2018-51 2019-07 2019-15 2019-23 2019-31 2019-39 2019-47 2020-02 2020-10 2020-18 2020-26 2020-34 2020-42 2020-50 2021-04 2021-12
HVC
SNB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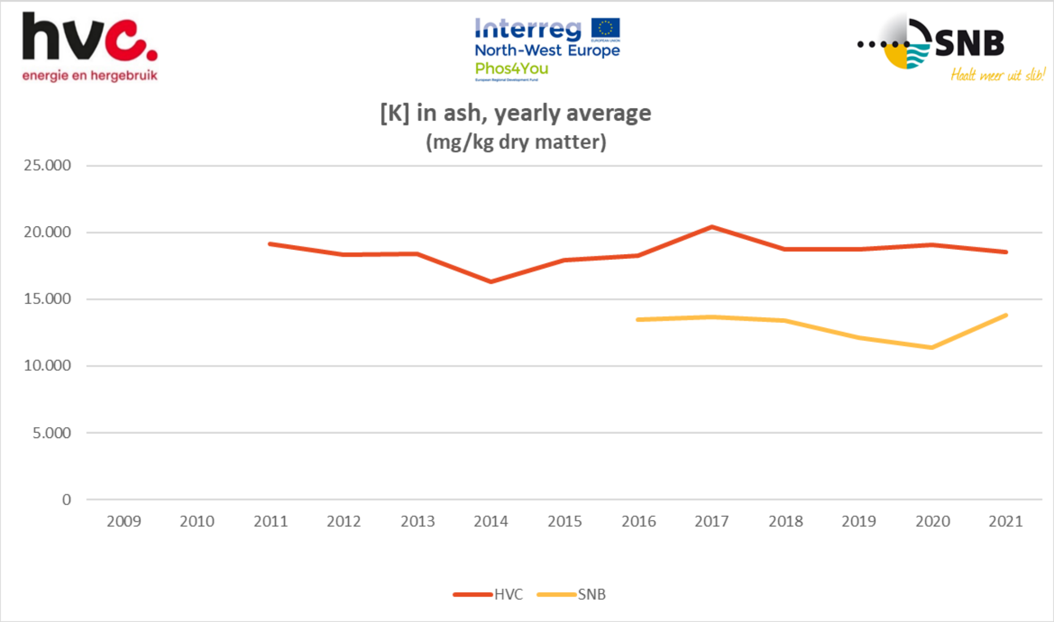
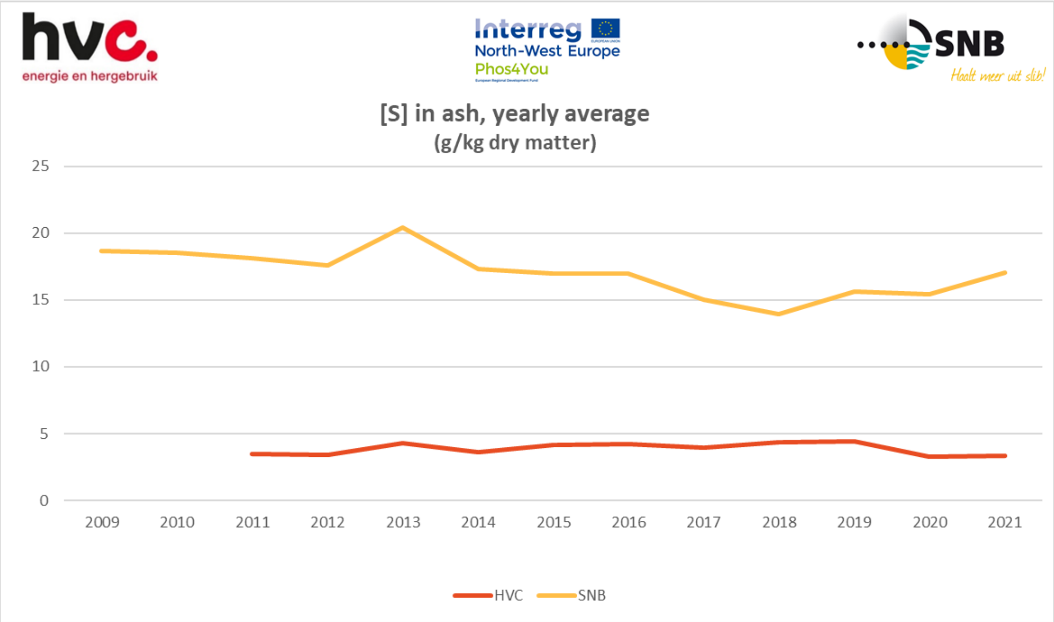
energie en hergebruik
Interreg
North-West Europe
Phos4You
SNB
Haalt meer uit slib!
[Mo] in ash, yearly average
(mg/kg dry matter)
0
10
20
30
40
50
60
70
2009 2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021
HVC
SNB


hvc.
energie en hergebruik
Interreg
North-West Europe
Phos4You
SNB
Haalt meer uit slib!
[K] in ash, yearly average
(mg/kg dry matter)
25.000
20.000
15.000
10.000
5.000
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
HVC
SNB


hvc.
energie en hergebruik
Interreg
North-West Europe
Phos4You
SNB
Haalt meer uit slib!
[S] in ash, yearly average
(g/kg dry matter)
25
20
15
10
5
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
HVC
SNB

References

Boom-besluit, https://wetten.overheid.nl/BWBR0009360/2006-01-010

LAP3, Dutch National Waste plan

Meststoffenbesluit, Dutch Fertiliser Regulation

Milieujaarverslag HVC, 2020

Milieujaarverslag SNB, 2020

Phos4You report weekly and monthly analyses SSA, 2017-2020

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within the INTERREG North-West Europe VB Programme