Electronic Supplementary Material (ESI) for Environmental Science: Nano.

Prospective environmental risk assessment of nanocellulose

SUPPLEMENTARY INFORMATION

Table S1 Global and European production volume data (in tons), with Degree of Belief (DoB), used to model the production distribution of the base year 2015.

Reference	**DoB**	**Worldwide [t/a]**	**EU [t/a]**
Future Markets 2015	80%	610	201
Miller 2014 (CelluForce forecast)	20%	6106	2014
Miller 2017 (Market Intel forecast)	20%	20684	6826

Table S2: Share of product categories in 2015 and 2021, using triangular distributions.

Category	**Description of NC use in product category**	**2015**			**2025**		
		Lower boundary	**Mean**	**Upper boundary**	**Lower boundary**	**Mean**	**Upper boundary**
R&D	In pilot scale projects or for research purposes	0.375	0.750	1.000	0.288	0.575	0.863
Paper & board	For printing paper, sheet paper, high strength board…	0.022	0.089	0.134	0.074	0.149	0.223
Packaging	As reinforcement agent in packaging	0.000	0.045	0.067	0.037	0.075	0.112
Filtration market	For water filtration membrane technologies	0.007	0.034	0.051	0.029	0.057	0.086
Rheology modifiers	As thickener, suspension stabilizer	0.007	1.000	0.441	0.005	0.011	0.016
Textiles	In functional fabrics, anti-microbial textiles…	0.045	0.021	0.032	0.018	0.035	0.053
Automotive	As natural fibre composites	0.001	0.014	0.021	0.012	0.024	0.035
Construction and building	In concrete, asphalt…	0.001	0.014	0.021	0.012	0.023	0.035
Coatings & films	As barrier agent	0.001	0.010	0.015	0.008	0.016	0.025
Aerogels	In insulation	0.001	0.003	0.005	0.003	0.005	0.008
Drug delivery	In medical technology and treatments	0.001	0.003	0.004	0.002	0.005	0.007
Medical implants		0.005	0.002	0.004	0.002	0.004	0.006
Tissue engineering		0.002	0.002	0.004	0.002	0.004	0.006
Wound dressings		0.017	0.002	0.004	0.002	0.004	0.006
Lateral flow immunoassay labels		0.001	0.002	0.004	0.002	0.004	0.006
Printed & flexible electronics	In displays, solar or fuel cells, sensors…	0.011	0.002	0.002	0.001	0.003	0.004
Rubber and tire additives	As additive in car tires	0.001	0.002	0.002	0.001	0.003	0.004
Colorants	In paints, textiles, food, cosmetics…	0.022	0.002	0.002	0.001	0.003	0.004
Aerospace and aviation	As natural fibre composites	0.001	0.000	0.001	0.000	0.001	0.001

Major assumptions for numbers presented in Table 1:

Due to the lack of release data relating to nanocellulose-containing products available in the literature, modelling the release of NC during each application's Use and EoL phases required to use data from studies of other nanomaterial-containing products. Therefore, we assume in our work that the matrix into which the nanomaterial is incorporated, and the specific characteristics of the application play a decisive role, rather than the nanomaterial under consideration. Taking the product category 'Textiles' as an example, we assume that the share of nanomaterials released during the Use phase and EoL phase will be the same regardless of whether considering nanocellulose-containing textile or nano-TiO_2-containing textile. Similarly, we assume that allocation to environmental compartments after the Use release and allocation to waste compartments after the EoL release will depend on the considered application, not the nanomaterial.

Table S3: Summary of the waste management. The various waste categories where NC flows into at the EoL of an application will end up in technical compartments, after a number of steps. First, each waste category will either go to Landfill, MMSW, or Sorting. Waste entering MMSW will go into Landfill and WIP. Waste entering Sorting will be treated differently based on the initial waste category, and will end up in Landfill, WIP, Export, Reuse, Reprocessing, or Disposal. Waste entering Disposal will in turn go to Landfill and WIP, in the same share as for MMSW.

Waste category	**Allocation to waste compartments**					**Allocation of Sorting to waste compartments**						**Allocation of Disposal to waste compartments**	
	Landfill	**MMSW**	Landfill	WIP	**Sorting**	Landfill	WIP	Export	Reuse	Reprocessing	**Disposal**	Landfill	WIP
CDW	0.21				0.79	0.72				0.28			
WEEE		0.51	0.448	0.552	0.49			0.23		0.27412	0.49588	0.448	0.552
TextW		0.675	0.448	0.552	0.325			0.4	0.1	0.35	0.15	0.448	0.552
PackW		0.287	0.448	0.552	0.713					0.56	0.44	0.448	0.552
PaperW		0.093	0.448	0.552	0.907					0.9188	0.0812	0.448	0.552
MedW		0.8	0.448	0.552	0.2		1						
AviW	0.15				0.85					1			
AutoW	0.114				0.886			0.3		0.7			

Table S4: Model flows for 2015 and 2021. Mean, Q50, Q15, and Q85 values, in tons.

Flows	2015 (tons)				2025 (tons)			
	Mean	Q50	Q15	Q85	Mean	Q50	Q15	Q85
PackW to Sorting_PackW	16.99	12.91	4.38	30.70	244.21	192.56	69.21	434.18
AviW to Landfill	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AviW to Sorting_AviW	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AutoW to Landfill	0.56	0.45	0.17	0.96	8.56	6.51	2.69	14.57
AutoW to Sortting_AutoW	4.33	3.56	1.42	7.38	66.47	51.81	22.12	111.04
PaperW to Sorting_PaperW	89.15	63.87	19.79	167.85	1544.54	1087.12	331.81	2914.80
PaperW to MMSW	9.14	6.36	1.93	17.07	157.76	109.38	33.47	295.43
MedW to MMSW	4.82	2.86	1.06	8.83	119.04	47.44	20.42	207.75
MedW to Sorting_MedW	1.21	0.70	0.26	2.21	29.79	11.67	4.83	51.80
Sorting_PackW to Reprocessing	9.52	7.10	2.41	17.16	136.70	105.78	38.23	244.19
Sorting_PackW to Sorting_Disposal	7.47	5.56	1.83	13.55	107.51	82.08	29.08	193.07
Sorting_WEEE to WEEE_NotExported	0.22	0.18	0.07	0.38	2.94	2.47	1.08	4.90
Sorting_WEEE to Export	0.05	0.04	0.01	0.09	0.67	0.53	0.22	1.14
Sorting_TextW to Sorting_Disposal	1.15	0.55	0.14	2.28	27.66	12.93	3.31	54.24
Sorting_TextW to TextW_Resorting	3.70	1.77	0.45	7.30	89.73	43.09	10.74	177.64
Sorting_TextW to Export	3.17	1.52	0.38	6.28	77.22	35.65	9.18	151.58
Sorting_TextW to Textiles_Use	0.65	0.29	0.07	1.28	15.67	6.77	1.70	30.18
Sorting_CDW to Sorting_Disposal	0.56	0.41	0.14	1.01	7.90	5.94	2.21	14.05
Sorting_CDW to Sorting_CDW_Wood	0.83	0.61	0.21	1.51	11.89	8.98	3.29	21.13
Sorting_CDW to Sorting_CDW_Mineral	1.38	1.03	0.35	2.50	19.77	15.11	5.57	35.46
Sorting_AviW to Reprocessing	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sorting_AutoW to Reprocessing	3.21	2.64	1.05	5.47	49.54	38.36	16.46	82.92
Sorting_AutoW to Export	1.11	0.90	0.35	1.91	16.93	12.83	5.42	28.06
Sorting_PaperW to Reprocessing	81.91	58.39	18.28	154.02	1418.83	997.30	304.36	2668.80
Sorting_PaperW to Sorting_Disposal	7.24	5.05	1.56	13.53	125.71	86.44	26.61	236.20
Sorting_MedW to WIP	1.21	0.70	0.26	2.21	29.79	11.67	4.83	51.80
WEEE_NotExported to Reprocessing	0.08	0.06	0.02	0.14	1.05	0.86	0.37	1.75
WEEE_NotExported to Sorting_Disposal	0.14	0.11	0.04	0.25	1.89	1.58	0.69	3.15
TextW_Resorting to Reprocessing	1.78	0.81	0.21	3.48	43.14	20.38	5.07	85.52
TextW_Resorting to Sorting_Disposal	1.93	0.90	0.23	3.78	46.59	21.46	5.29	91.12
Sorting_CDW_Mineral to Landfill	1.15	0.86	0.29	2.06	16.45	12.45	4.59	29.11
Sorting_CDW_Mineral to Reprocessing	0.23	0.14	0.03	0.44	3.32	2.09	0.50	6.35
Sorting_CDW_Wood to Sorting_Disposal	0.83	0.61	0.21	1.51	11.89	8.98	3.29	21.13
Sorting_Disposal to Landfill	8.67	7.21	2.84	14.79	147.81	120.68	47.87	256.92
Sorting_Disposal to WIP	10.64	8.85	3.49	18.17	181.34	148.17	58.80	315.76
WIP to Burning	807.30	159.30	104.63	2207.07	10147.38	2441.98	1022.01	20104.50
Burning to Elimination	774.99	153.80	99.68	2066.40	9743.99	2318.38	963.28	18909.39
Burning to Remains_burning	32.31	0.03	0.00	27.40	403.39	0.00	0.00	355.56
Remains_burning to Bottom ash	26.03	0.02	0.00	21.88	326.19	0.00	0.00	287.46
Remains_burning to Flyash	6.28	0.00	0.00	5.17	77.20	0.00	0.00	67.79
Bottom ash to Landfill	14.65	0.01	0.00	12.13	183.99	0.00	0.00	160.11
Bottom ash to Reprocessing	11.39	0.01	0.00	9.58	142.19	0.00	0.00	121.25
Flyash to Filterash	6.27	0.00	0.00	5.17	77.19	0.00	0.00	67.78
Flyash to Wastewater	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01
Flyash to Air	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Filterash to Landfill	6.27	0.00	0.00	5.17	77.19	0.00	0.00	67.78
Wastewater to NoSweageSystem	15.77	4.26	2.17	36.33	260.01	79.74	30.84	465.01
Wastewater to SweageSystem	94.60	25.01	13.81	233.75	1547.06	474.85	194.33	2871.52
NoSewageSystem to Surfacewater	3.38	0.91	0.47	7.79	55.72	17.09	6.61	99.64
NoSewageSystem to OnsiteTreat	12.39	3.34	1.71	28.55	204.29	62.66	24.23	365.36
SewageSystem to Subsurface	6.15	1.65	0.85	14.41	100.59	30.49	11.93	178.89
SewageSystem to STPoverflow	3.02	0.82	0.42	6.88	49.46	15.07	5.93	88.39
SewageSystem to Surfacewater	1.61	0.43	0.22	3.67	26.27	8.02	3.10	46.90
SewageSystem to WWTP	83.83	22.18	12.21	206.46	1370.75	420.83	172.28	2547.46
OnsiteTreat to TreatIOnsite	12.39	3.34	1.71	28.55	204.29	62.66	24.23	365.36
WWTP to TreatIII	68.56	18.09	9.97	168.62	1123.14	342.47	139.40	2079.15
WWTP to TreatII	14.68	3.97	2.02	33.33	238.02	72.64	28.62	429.29
WWTP to TreatI	0.58	0.16	0.08	1.37	9.59	2.93	1.13	17.75
TreatI to STPsludge	0.57	0.15	0.08	1.33	9.38	2.86	1.11	17.24
TreatI to STPeffluent	0.01	0.00	0.00	0.03	0.21	0.06	0.01	0.32
TreatII to STPsludge	14.36	3.89	1.97	32.39	232.78	71.12	28.02	418.59
TreatII to STPeffluent	0.32	0.09	0.02	0.64	5.24	1.45	0.32	8.52
TreatIII to STPsludge	67.04	17.72	9.76	164.69	1098.90	334.03	136.38	2026.69
TreatIII to STPeffluent	1.52	0.43	0.12	3.01	24.24	7.01	1.55	37.61
TreatIOnsite to OnsiteSludge	12.11	3.26	1.67	27.80	199.79	61.19	23.59	358.75
TreatIOnsite to Subsurface	0.27	0.08	0.02	0.54	4.51	1.23	0.26	6.93
STPoverflow to Surfacewater	3.02	0.82	0.42	6.88	49.46	15.07	5.93	88.39
STPeffluent to Surfacewater	1.86	0.52	0.19	3.80	29.68	8.78	2.53	48.78
STPsludge to Landfill	8.41	2.24	1.15	19.45	136.87	41.58	16.49	247.59
STPsludge to WIP	25.74	6.99	3.54	58.70	423.66	128.30	49.96	751.14
STPsludge to Sludge treated soil	47.82	12.65	6.83	114.29	780.54	241.28	96.39	1444.41

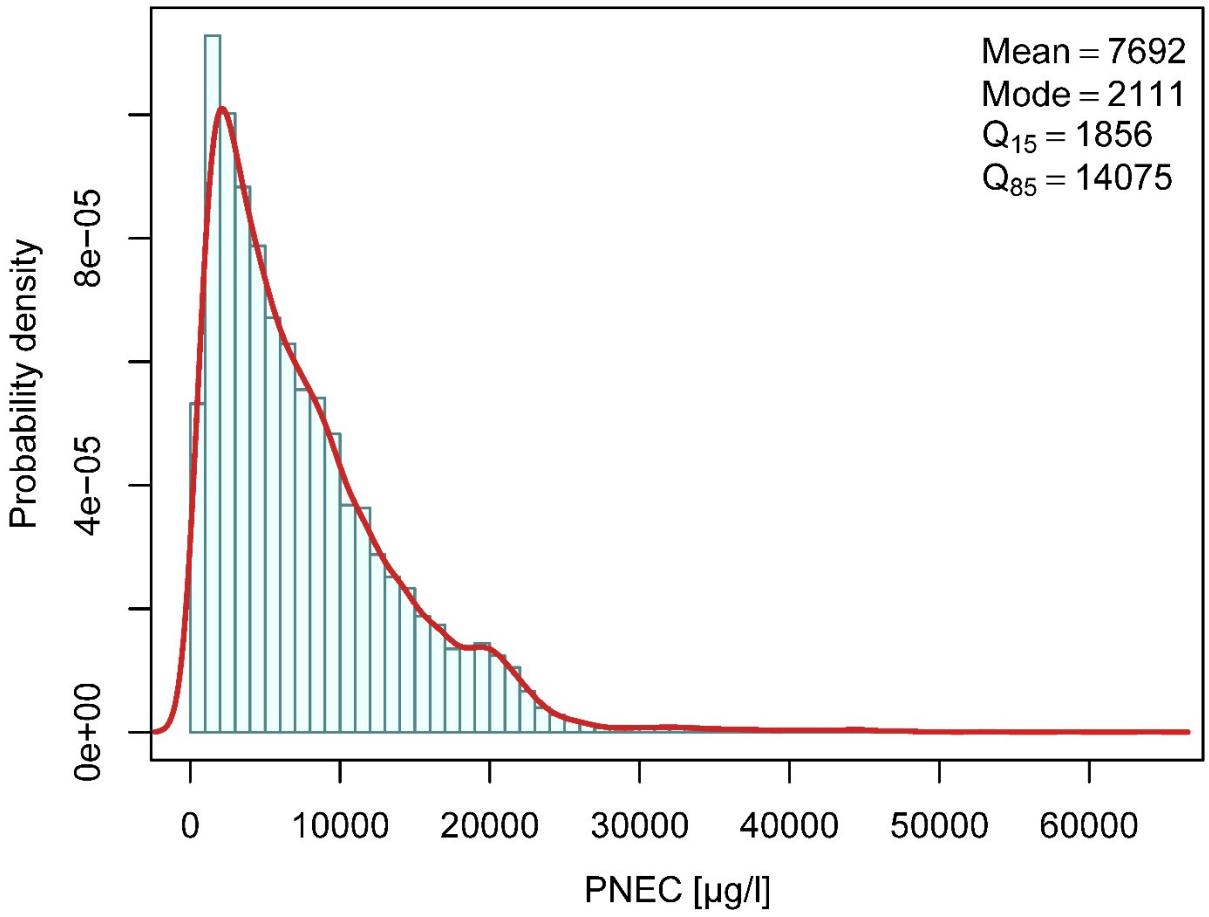
Table S5: Aquatic toxicity data for nanocellulose.

Author	Dose descriptor	Test organism	Concentration (µg/l)	Exposure time (h)	AF time	AF no-effect	Species sensitivity (µg/l)
Harper et al. 2016	NOEC	*D.rerio*	250000	120	10	1	10000
Harper et al. 2016	HONEC	*D.rerio*	172000	120	10	1	172000
Harper et al. 2016	HONEC	*D.rerio*	200000	120	10	1	200000
Harper et al. 2016	HONEC	*D.rerio*	200000	120	10	1	200000
Harper et al. 2016	HONEC	*D.rerio*	200000	120	10	1	200000
Harper et al. 2016	HONEC	*D.rerio*	200000	120	10	1	200000
Harper et al. 2016	HONEC	*D.rerio*	200000	120	10	1	200000
Harper et al. 2016	HONEC	*D.rerio*	200000	120	10	1	200000
Harper et al. 2016	HONEC	*D.rerio*	200000	120	10	1	200000
Harper et al. 2016	HONEC	*D.rerio*	250000	120	10	1	250000
Harper et al. 2016	HONEC	*D.rerio*	250000	120	10	1	250000
Kovacs et al. 2010	EC50	*H.attenuata*	na	96	10	10	60000
Kovacs et al. 2010	IC25	*P.subcapitata*	na	72	1	10	120000
Kovacs et al. 2010	IC25	*C.dubia*	1000000	48	10	10	200000
Kovacs et al. 2010	LC50	*C.dubia*	5000000	48	10	10	300000
Kovacs et al. 2010	EC50	*H.attenuata*	na	96	10	10	360000
Kovacs et al. 2010	IC25	*A.fischeri*	na	0.25	10	10	460000
Kovacs et al. 2010	LC50	*C.dubia*	1000000	48	10	10	1000000
Kovacs et al. 2010	IC25	*C.dubia*	1000000	48	10	10	1000000
Kovacs et al. 2010	IC25	*C.dubia*	1000000	48	10	10	1000000
Kovacs et al. 2010	IC25	*C.dubia*	1000000	48	10	10	1000000
Kovacs et al. 2010	IC25	*C.dubia*	1000000	48	10	10	1000000
Kovacs et al. 2010	LC50	*D.magna*	1000000	48	10	10	1000000
Kovacs et al. 2010	LC50	*D.magna*	1000000	48	10	10	1000000
Kovacs et al. 2010	LC50	*O.mykiss*	1000000	96	10	10	1000000
Kovacs et al. 2010	LC50	*O.mykiss*	1000000	96	10	10	1000000
Kovacs et al. 2010	LC50	*O.mykiss*	1000000	96	10	10	1000000
Kovacs et al. 2010	LC50	*C.dubia*	5000000	48	10	10	1400000
Kovacs et al. 2010	IC25	*C.dubia*	2000000	48	10	10	1400000
Kovacs et al. 2010	LC50	*C.dubia*	5000000	48	10	10	1600000

Kovacs et al. 2010	IC25	*C.dubia*	2000000	48	10	10	1600000
Kovacs et al. 2010	IC25	*C.dubia*	2000000	48	10	10	2000000
Kovacs et al. 2010	IC25	*C.dubia*	2000000	48	10	10	2000000
Kovacs et al. 2010	LC50	*D.magna*	5000000	48	10	10	2100000
Kovacs et al. 2010	LC50	*D.magna*	5000000	48	10	10	2500000
Kovacs et al. 2010	IC25	*P.subcapitata*	2500000	72	1	10	2500000
Kovacs et al. 2010	EC50	*H.attenuata*	na	96	10	10	2600000
Kovacs et al. 2010	LC50	*C.dubia*	10000000	48	10	10	3200000
Kovacs et al. 2010	LC50	*D.magna*	10000000	48	10	10	3200000
Kovacs et al. 2010	LC50	*T.platyurus*	na	24	10	10	3540000
Kovacs et al. 2010	LC50	*C.dubia*	5000000	48	10	10	4300000
Kovacs et al. 2010	LC50	*C.dubia*	5000000	48	10	10	5000000
Kovacs et al. 2010	LC50	*C.dubia*	5000000	48	10	10	5000000
Kovacs et al. 2010	LC50	*C.dubia*	5000000	48	10	10	5000000
Kovacs et al. 2010	LC50	*C.dubia*	5000000	48	10	10	5000000
Kovacs et al. 2010	LC50	*C.dubia*	5000000	48	10	10	5000000
Kovacs et al. 2010	LC50	*C.dubia*	5000000	48	10	10	5000000
Kovacs et al. 2010	LC50	*C.dubia*	5000000	48	10	10	5000000
Kovacs et al. 2010	LC50	*D.magna*	5000000	48	10	10	5000000
Kovacs et al. 2010	LC50	*D.magna*	5000000	48	10	10	5000000
Kovacs et al. 2010	LC50	*D.magna*	5000000	48	10	10	5000000
Kovacs et al. 2010	LC50	*D.magna*	5000000	48	10	10	5000000
Kovacs et al. 2010	LC50	*D.magna*	5000000	48	10	10	5000000
Kovacs et al. 2010	LC50	*D.magna*	5000000	48	10	10	5000000
Kovacs et al. 2010	LC50	*D.magna*	5000000	48	10	10	5000000
Kovacs et al. 2010	LC50	*D.magna*	5000000	48	10	10	5000000
Kovacs et al. 2010	LC50	*D.magna*	5000000	48	10	10	5000000
Kovacs et al. 2010	LC50	*D.magna*	5000000	48	10	10	5000000
Kovacs et al. 2010	LC50	*D.rerio*	6000000	120	10	10	6000000
Kovacs et al. 2010	LC50	*D.rerio*	6000000	120	10	10	6000000
Kovacs et al. 2010	EC50	*H.attenuata*	6800000	96	10	10	6800000
Kovacs et al. 2010	IC25	*A.fischeri*	10000000	0.25	10	10	10000000
Kovacs et al. 2010	LC50	*O.mykiss*	10000000	96	10	10	10000000
Kovacs et al. 2010	LC50	*T.platyurus*	na	24	10	10	13200000
Ogonowski et al.	NOEC	*D.magna*	20600	504	1	1	2600

2018							
Ogonowski et al. 2018	HONEC	*D.magna*	2060000	48	10	1	2060000
Ong et al. 2017	EC50	*A.fischeri*	100000	0.5	10	10	100000
Ong et al. 2017	EC50	*A.fischeri*	100000	0.5	10	10	100000
Ong et al. 2017	NOEC	*P.subcapitata*	2800000	72	1	1	175000
Ong et al. 2017	NOEC	*P.subcapitata*	1200000	72	1	1	300000
Ong et al. 2017	LC50	*D.rerio*	2000000	120	10	10	2000000
Ong et al. 2017	LC50	*D.rerio*	2000000	120	10	10	2000000
Ong et al. 2017	NOEC	*D.magna*	6000000	48	10	1	6000000
Ong et al. 2017	NOEC	*D.magna*	14000000	48	10	1	7000000
Vartiainen et al. 2011	NOEC	*A.fischeri*	2500000	0.5	10	1	300000
Vartiainen et al. 2011	NOEC	*A.fischeri*	2500000	0.5	10	1	2500000

Figure S1: PNEC distribution resulting from taking the 5th percentile of the PSSD in freshwater.



Figures S2a and S2b: Risk characterization ratio distribution for nanocellulose in European surface water in 2015 (top) and 2021 (bottom).