Supplementary Information for

Phosphate Removal Efficiency and Life Cycle Assessment of Different Anode Materials in Electrocoagulation Treatment of Wastewater

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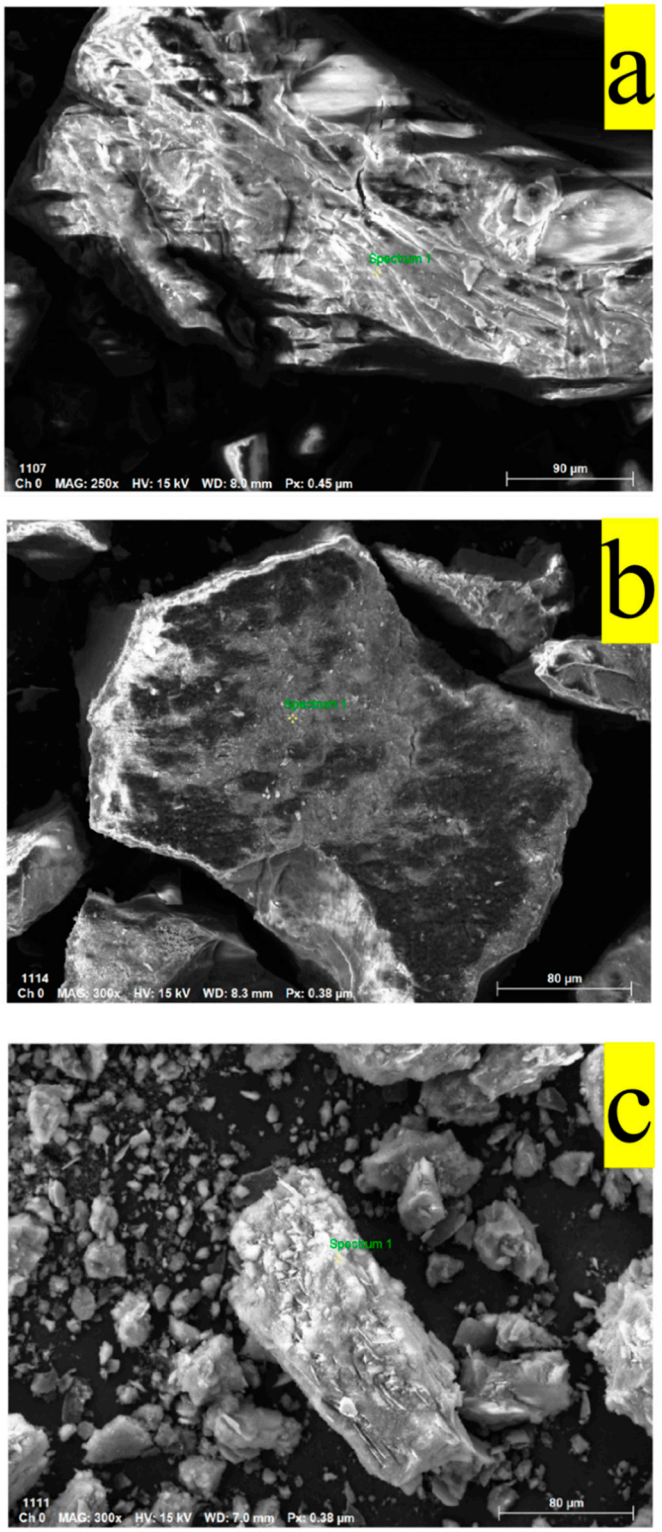
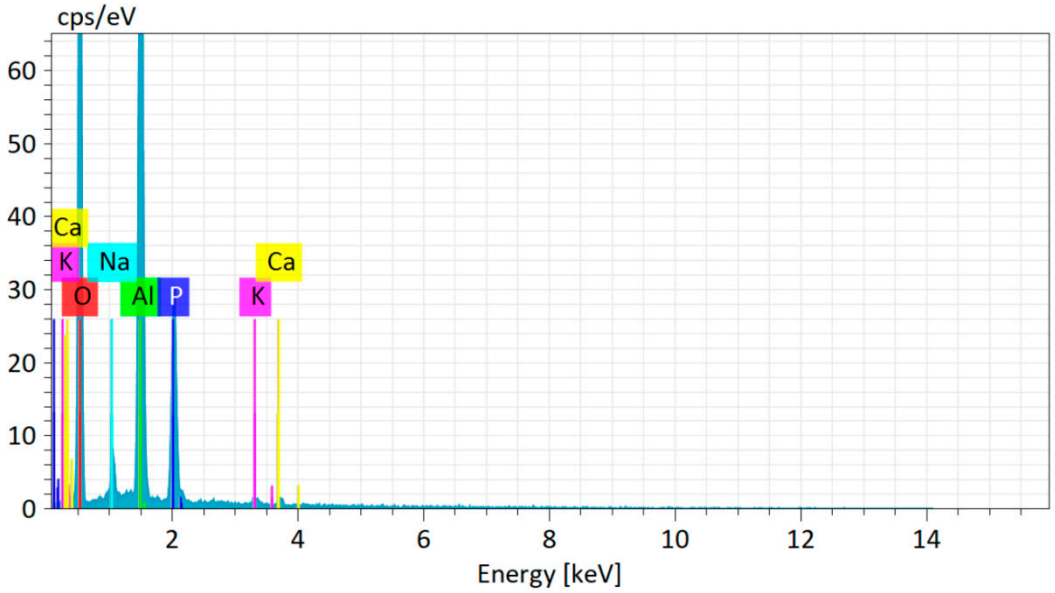
Supplementary Notes

Supplementary Note 1: SEM-EDS test data

The SEM test results are as follows:



Supplementary Figure S1 SEM test results of three metal electroflocculation products: a) aluminum, b) iron, and c) magnesium.

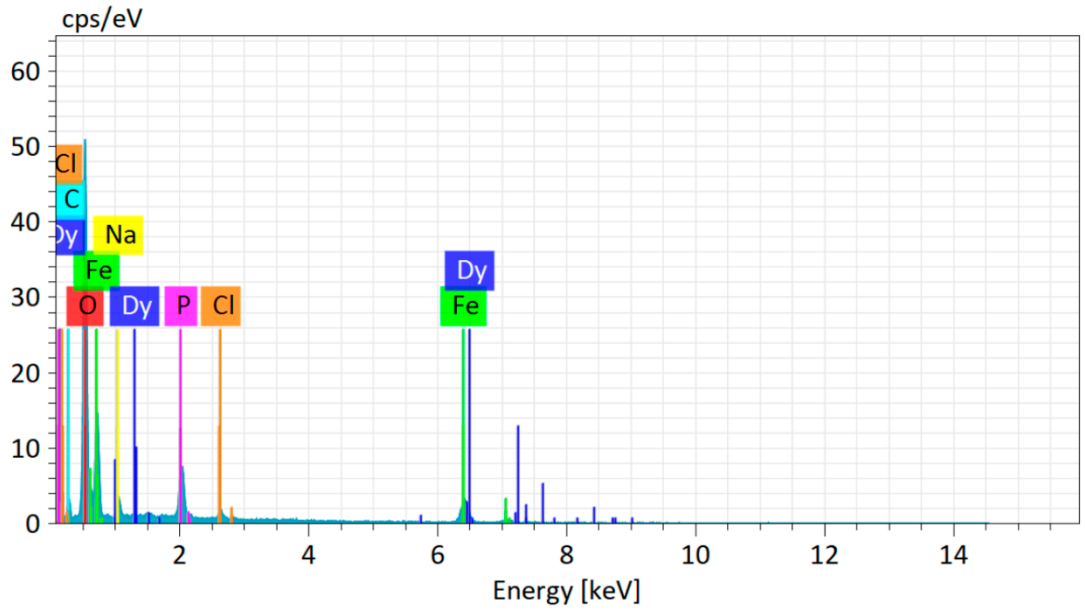


Supplementary Figure S2 EDS results of electrocoagulation products of aluminum metal electrode.

Spectrum	Oxygen	Sodium	Aluminium	Phosphorus	Potassium	Calcium
Spectrum 1	58.41	2.42	27.40	10.63	0.57	0.56

Spectrum1

Element	Atomic number	Net value	Qual-ity[%]	Normalized quality[%]	Atom[%]	Abs.error[%] (1 sigma)	rel.error[%] (1 sigma)
Oxygen	8	15048	60.86	58.41	70.98	8.20	13.48
Aluminium	13	18633	28.55	27.40	19.75	1.39	4.87
Phosphorus	15	6288	11.08	10.63	6.67	0.49	4.46
Sodium	11	1080	2.52	2.42	2.05	0.24	9.39
Potassium	19	228	0.6	0.57	0.28	0.09	15.81
Calcium	20	183	0.58	0.56	0.27	0.10	17.37
		Total:	104.20	100	100		

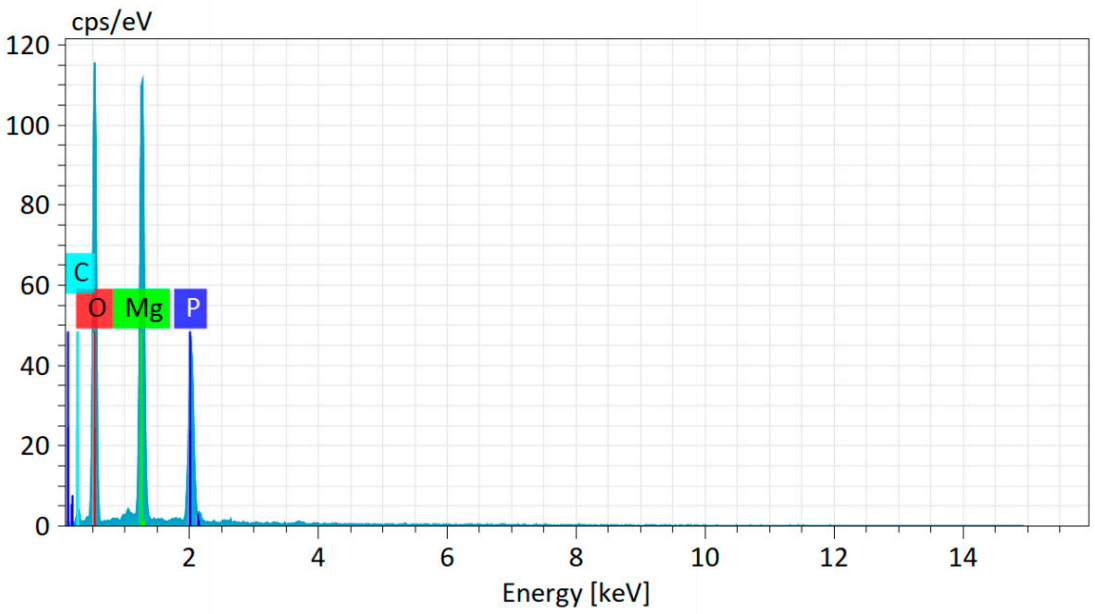


Supplementary Figure S3 EDS results of electrocoagulation products of iron metal electrodes.

Spectrum	Carbon	Oxygen	Sodium	Phosphorus	Chlorine	Iron	Dysprosium
Spectrum 1	7.34	58.73	1.54	3.34	0.63	16.59	11.84

Spectrum1

Element	Atomic number	Net value	Quality[%]	Normalized quality[%]	Atom[%]	Abs.error[%] (1 sigma)	rel.error[%] (1 sigma)
Oxygen	8	17535	73.80	58.73	75.78	9.76	13.22
Iron	26	2217	20.84	16.59	6.13	0.92	4.41
Dysprosium	66	1005	14.88	11.84	1.50	1.26	8.47
Carbon	6	841	9.22	7.34	12.61	2.39	25.92
Phosphorus	15	3709	4.19	3.34	2.22	0.22	5.16
Sodium	11	1013	1.93	1.54	1.38	0.19	10.01
Chlorine	17	571	0.79	0.63	0.37	0.99	11.20
		Total:	125.66	100	100		



Supplementary Figure S4 EDS results of electrocoagulation products of magnesium metal electrode.

Spectrum	Carbon	Oxygen	Magnesium	Phosphorus
Spectrum 1	6.59	55.35	25.44	12.61

Spectrum1

Element	Atomic number	Net value	Quality[%]	Normalized quality[%]	Atom[%]	Abs.error[%] (1 sigma)	rel.error[%] (1 sigma)
Oxygen	8	14911	62.95	55.35	63.33	8.49	13.48
Magnesium	12	17620	28.94	25.44	19.16	1.60	5.52
Phosphorus	15	8724	14.34	12.61	7.45	0.61	4.29
Carbon	6	453	7.50	6.59	10.05	2.32	30.93
		Total:	125.66	100	100		

Supplementary Note S2: Life cycle assessment

The goal and scope of the LCA study in this work are shown in Supplementary Table 1. The system boundary of LCA was set as “cradle to grave”, water emissions, and treatment effluent. Based on the experimental procedure, we assumed that the input water emissions, i.e., the simulated water configured for the experiment, were so close to the composition of the real phosphorus-containing wastewater that the difference between the two can be ignored. For the phosphorus-containing sludge produced by the experiment, in Section 3.1.4, Sludge Analysis, it is shown that the composition of the sludge can be simply summarised as follows: under the action of electricity, the phosphorus-containing sludge is the floc produced by a series of chemical reactions between the anode material and the P, O, C, and other elements in the phosphorus-containing wastewater; the LCA focuses on the "cradle to grave", and this floc is produced throughout the whole experimental process and is the "grave" product of the whole experimental process, and its impact on the environment was included in the midpoint and endpoint of the output of LCA. The function unit was set at $1m^3$ simulated wastewater containing phosphorus and and a mass distribution of 100% of treated water. Open LCA software (V.2.0.3) was used to compare and analyze the effect categories, with input inventory models obtained based on the Ecoinvent V.3.9.1 database. Potential midpoint environmental impacts were evaluated using ReCiPe 2016 Midpoint (H), and potential endpoint ecological impacts were assessed using ReCiPe 2016 (V.1.03) Endpoint (H). A total of 18 indicators were used to assess midpoint impacts: fine particulate matter formation, fossil resource scarcity, freshwater ecotoxicity, freshwater eutrophication, global warming, human carcinogenic toxicity, human non-carcinogenic toxicity, ionizing radiation, land use, marine ecotoxicity, marine eutrophication, mineral resource scarcity, ozone formation–human health, ozone formation–terrestrial ecosystems, stratospheric ozone depletion, terrestrial acidification, terrestrial ecotoxicity, and water consumption. Three indicators were used to assess endpoint impacts: total: ecosystem quality - ecosystem quality; total: human health - human health; total: natural resources - natural resources.

Supplementary Table S1 Goal and scope definition of this LCA study

Goal	
Reason for conducting the study	1.This LCA looks at 18 midpoint indicators as well as 3 endpoint indicators to produce data for each evaluation indicator. 2.This LCA compares the midpoint and endpoint indicators of three anode electrocoagulation material for the treatment of phosphorus-containing simulated wastewater to derive the anode material with the lowest environmental impact.
Audience	Industrial stakeholders, the research community, and the public
Application	Provide technical and theoretical support for carbon emission reduction policies and the circular economy
Provide technical and theoretical support for carbon emission reduction policies And the circular economy	Yes, the results are to be compared and disclosed to the public through this article’s publication
Scope	

Product system	electrocoagulation treatment of wastewater
Functional unit	1m^3 simulated wastewater containing phosphorus
System boundary	Cradle to grave; see Fig. 3 in the main text
Allocation	A mass distribution of 100 % of treated water
Assumptions	Ignoring differences between simulated and actual effluents
Requirements on data and quality	Foreground data were obtained from simulation experiments and the background processes were chosen based on Ecoinvent V.3.9.1 in Open LCA 2.0.3 to cover the technological representativeness
LCIA methodology	ReCiPe 2016 Midpoint (H) for Midpoint;ReCiPe 2016 (V.1.03) Endpoint (H) for Endpoint
Impact categories	
Fine particulate matter formation	kg PM2.5 eq
Fossil resource scarcity	kg oil eq
Freshwater ecotoxicity	kg 1,4-DCB
Freshwater eutrophication	kg P eq
Global warming	kg CO_2 eq
Human carcinogenic toxicity	kg 1,4-DCB
Human non-carcinogenic toxicity	kg 1,4-DCB
Ionizing radiation	kBq Co-60 eq
Land use	m^2a crop eq
Marine ecotoxicity	kg 1,4-DCB
Marine eutrophication	kg N eq
Mineral resource scarcity	kg Cu eq
Ozone formation, human health	kg NO_x eq
Ozone formation, terrestrial ecosystems	kg NO_x eq
Stratospheric ozone depletion	kg CFC11 eq
Terrestrial acidification	kg SO_2 eq
Terrestrial ecotoxicity	kg 1,4-DCB
Water consumption	m^3
total: ecosystem quality - ecosystem quality	species.yr
total: human health - human health	DALYs
total: natural resources - natural resources	USD 2013
Report requirements	To present the outcome via journal publication which is openly accessible to everyone.

Supplementary Table S2 Cradle-to-grave LCA results of Scenario 1: functional unit = 1m^3 simulated wastewater containing phosphorus

Impact category	Reference unit	Consumption of anodes	Consumption of electricity	Total
Fine particulate matter formation	kg PM2.5 eq	0.000147498	0.000563628	0.000711126
Fossil resource scarcity	kg oil eq	0.041301898	0.086345477	0.127647375
Freshwater ecotoxicity	kg 1,4-DCB	0.001620257	0.019221067	0.020841324
Freshwater eutrophication	kg P eq	3.9809E-05	7.19503E-05	0.000111759
Global warming	kg CO_2 eq	0.049634668	0.394559543	0.444194212
Human carcinogenic toxicity	kg 1,4-DCB	0.002680571	0.0112677	0.013948271
Human non-carcinogenic toxicity	kg 1,4-DCB	0.057796467	0.242822662	0.30061913
Ionizing radiation	kBq Co-60 eq	-0.001752074	0.050699958	0.048947884
Land use	m^2a crop eq	-0.001479993	0.011725034	0.010245041
Marine ecotoxicity	kg 1,4-DCB	0.002269572	0.024004444	0.026274016
Marine eutrophication	kg N eq	3.51507E-06	5.69705E-06	9.21212E-06
Mineral resource scarcity	kg Cu eq	8.87358E-05	3.12206E-05	0.000119956
Ozone formation, human health	kg NO_x eq	0.000218048	0.001024677	0.001242725
Ozone formation, terrestrial ecosystems	kg NO_x eq	0.000272748	0.001036176	0.001308923
Stratospheric ozone depletion	kg CFC11 eq	1.54061E-08	9.78478E-08	1.13254E-07
Terrestrial acidification	kg SO_2 eq	0.000197083	0.001238429	0.001435512
Terrestrial ecotoxicity	kg 1,4-DCB	0.063515541	1.12732021	1.190835751
Water consumption	m^3	-8.38781E-05	0.001338391	0.001254513
total: ecosystem quality - ecosystem quality	species.yr	2.30623E-10	1.68239E-09	1.91302E-09
total: human health - human health	DALYs	1.60874E-07	8.17331E-07	9.78205E-07
total: natural resources - natural resources	USD 2013	0.008745767	0.014100939	0.022846706

Supplementary Table S3 Cradle-to-grave LCA results of Scenario 2: functional unit = 1m^3 simulated wastewater containing phosphorus

Impact category	Reference unit	Consumption of anodes	Consumption of electricity	Total
Fine particulate matter formation	kg PM2.5 eq	0.000656713	0.000570953	0.001227666
Fossil resource scarcity	kg oil eq	0.088900593	0.087467668	0.17636826
Freshwater ecotoxicity	kg 1,4-DCB	0.043277603	0.019470874	0.062748477
Freshwater eutrophication	kg P eq	0.000201467	7.28854E-05	0.000274352
Global warming	kg CO_2 eq	0.36643869	0.399687445	0.766126135

Human carcinogenic toxicity	kg 1,4-DCB	-0.086041346	0.011414141	-0.074627205
Human non-carcinogenic toxicity	kg 1,4-DCB	0.497491567	0.245978512	0.74347008
Ionizing radiation	kBq Co-60 eq	-0.003405037	0.051358882	0.047953844
Land use	m^2a crop eq	0.00229319	0.011877418	0.014170608
Marine ecotoxicity	kg 1,4-DCB	0.056457546	0.024316419	0.080773964
Marine eutrophication	kg N eq	2.20045E-06	5.77109E-06	7.97154E-06
Mineral resource scarcity	kg Cu eq	0.016766075	3.16264E-05	0.016797701
Ozone formation, human health	kg NO_x eq	0.000950026	0.001037995	0.00198802
Ozone formation, terrestrial ecosystems	kg NO_x eq	0.001051805	0.001049642	0.002101447
Stratospheric ozone depletion	kg CFC11 eq	5.2684E-08	9.91195E-08	1.51803E-07
Terrestrial acidification	kg SO_2 eq	0.000895063	0.001254524	0.002149587
Terrestrial ecotoxicity	kg 1,4-DCB	0.851441375	1.141971452	1.993412827
Water consumption	m^3	0.002161815	0.001355786	0.003517601
total: ecosystem quality - ecosystem quality	species.yr	1.55195E-09	1.70426E-09	3.25621E-09
total: human health - human health	DALYs	5.85158E-07	8.27953E-07	1.41311E-06
total: natural resources - natural resources	USD 2013	0.017371228	0.014284202	0.03165543

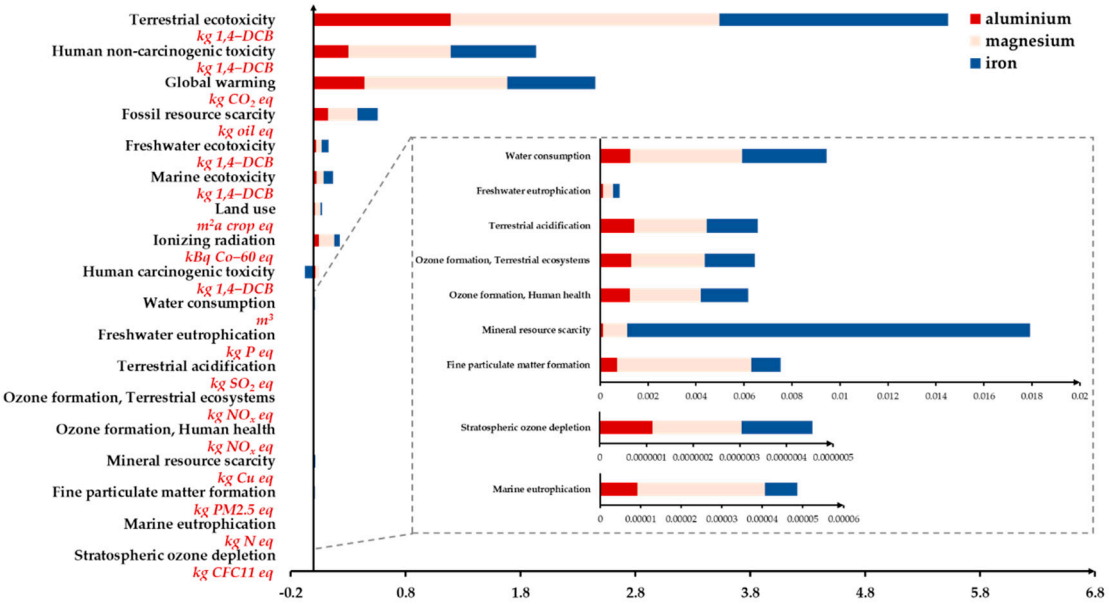
Supplementary Table S4 Cradle-to-grave LCA results of Scenario 3: functional unit = 1m^3 simulated wastewater containing phosphorus

Impact category	**Reference unit**	**Consumption of anodes**	**Consumption of electricity**	**Total**
Fine particulate matter formation	kg PM2.5 eq	0.005103053	0.000484598	0.005587652
Fossil resource scarcity	kg oil eq	0.178864437	0.07423846	0.253102897
Freshwater ecotoxicity	kg 1,4-DCB	0.030944648	0.016525966	0.047470614
Freshwater eutrophication	kg P eq	0.000367905	6.18617E-05	0.000429767
Global warming	kg CO_2 eq	0.903083543	0.339235983	1.242319526
Human carcinogenic toxicity	kg 1,4-DCB	0.021220531	0.009687788	0.030908319
Human non-carcinogenic toxicity	kg 1,4-DCB	0.68117873	0.20877504	0.88995377
Ionizing radiation	kBq Co-60 eq	0.084893704	0.043591013	0.128484717
Land use	m^2a crop eq	0.039389564	0.010080996	0.04947056
Marine ecotoxicity	kg 1,4-DCB	0.040541044	0.020638637	0.061179681
Marine eutrophication	kg N eq	2.6532E-05	4.89823E-06	3.14302E-05
Mineral resource scarcity	kg Cu eq	0.000989976	2.6843E-05	0.001016819
Ozone formation, human health	kg NO_x eq	0.002064544	0.000881001	0.002945545

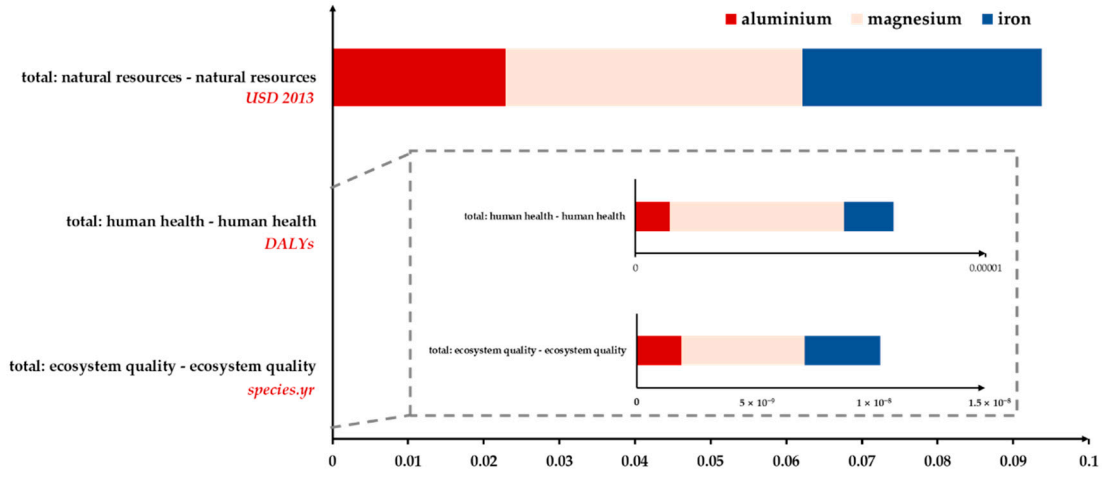
Ozone formation, terrestrial ecosystems	kg NO_x eq	0.002157029	0.000890887	0.003047916
Stratospheric ozone depletion	kg CFC11 eq	1.06717E-07	8.4128E-08	1.90845E-07
Terrestrial acidification	kg SO_2 eq	0.00193729	0.001064781	0.003002072
Terrestrial ecotoxicity	kg 1,4-DCB	1.36872251	0.969251881	2.337974392
Water consumption	m^3	0.0035234	0.001150727	0.004674128
total: ecosystem quality - ecosystem quality	species.yr	3.87343E-09	1.4465E-09	5.31993E-09
total: human health - human health	DALYs	4.28227E-06	7.02728E-07	4.985E-06
total: natural resources - natural resources	USD 2013	0.027152715	0.012123762	0.039276476

Supplementary Table S5 Cradle-to-grave LCA results of comparison of scenarios 1-3: functional unit = 1m^3 simulated wastewater containing phosphorus

Impact category	**Reference unit**	**Scenario 1**	**Scenario 2**	**Scenario 3**
Fine particulate matter formation	kg PM2.5 eq	0.000711126	0.001227666	0.005587652
Fossil resource scarcity	kg oil eq	0.127647375	0.17636826	0.253102897
Freshwater ecotoxicity	kg 1,4-DCB	0.020841324	0.062748477	0.047470614
Freshwater eutrophication	kg P eq	0.000111759	0.000274352	0.000429767
Global warming	kg CO_2 eq	0.444194212	0.766126135	1.242319526
Human carcinogenic toxicity	kg 1,4-DCB	0.013948271	-0.074627205	0.030908319
Human non-carcinogenic toxicity	kg 1,4-DCB	0.30061913	0.74347008	0.88995377
Ionizing radiation	kBq Co-60 eq	0.048947884	0.047953844	0.128484717
Land use	m^2a crop eq	0.010245041	0.014170608	0.04947056
Marine ecotoxicity	kg 1,4-DCB	0.026274016	0.080773964	0.061179681
Marine eutrophication	kg N eq	9.21212E-06	7.97154E-06	3.14302E-05
Mineral resource scarcity	kg Cu eq	0.000119956	0.016797701	0.001016819
Ozone formation, human health	kg NO_x eq	0.001242725	0.00198802	0.002945545
Ozone formation, terrestrial ecosystems	kg NO_x eq	0.001308923	0.002101447	0.003047916
Stratospheric ozone depletion	kg CFC11 eq	1.13254E-07	1.51803E-07	1.90845E-07
Terrestrial acidification	kg SO_2 eq	0.001435512	0.002149587	0.003002072
Terrestrial ecotoxicity	kg 1,4-DCB	1.190835751	1.993412827	2.337974392
Water consumption	m^3	0.001254513	0.003517601	0.004674128
total: ecosystem quality - ecosystem quality	species.yr	1.91302E-09	3.25621E-09	5.31993E-09
total: human health - human health	DALYs	9.78205E-07	1.41311E-06	4.985E-06
total: natural resources - natural resources	USD 2013	0.022846706	0.03165543	0.039276476



Supplementary Figure S5 Analysis of the contribution of midpoint environmental impact indicators based on all scenarios. (Actual value.)



Supplementary Figure S6 Analysis of the contribution of endpoint environmental impact indicators based on all scenarios. (Actual value.)