

Supplementary information

Environmental and socio-economic evaluation of a groundwater bioremediation technology using social Cost-Benefit Analysis: application to an in-situ metal(loid) precipitation case study

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Table S1. In-Situ Metal Precipitation (ISMP) Life Cycle Inventory (LCI) for the treatment of 10 m³ of contaminated water during two years. The data and quantities were provided directly by the company TAUW, which developed and implemented the technology during the EU H2020 project GREENER (Grant No. 826312). Note: The products which process were not found in the ecoinvent database were modelled by the authors and are described in Table S2

Description	Quantity	Unit	Process in ecoinvent
STEP 1 – Sampling			
Transport technician	180	Person km	Transport, passenger car, large size, diesel, EURO 5 {RER} transport, passenger car, large size, diesel, EURO 5 Cut-off, U
Sample transport	250	km	Transport, freight, lorry 3.5-7.5 metric ton, EURO3 {RER} market for transport, freight, lorry 3.5-7.5 metric ton, EURO3 Cut-off, U
Sampling filters	2	units	Sampling filter modelled by authors
Plastic tubing	25	m	Plastic tubing LDPE 12 mm modelled by authors
PE bottles	10	units	PE bottle + cap modelled by authors
STEP 2 – Construction			
Concrete drilling	4 holes x 2 h	hour	Machine operation, diesel, < 18.64 kW, generators {GLO} market for machine operation, diesel, < 18.64 kW, generators Cut-off, U
Vacuum extraction	4 holes x ½ h	hour	Machine operation, diesel, >= 18.64 kW and < 74.57 kW, generators {GLO} market for machine operation, diesel, >= 18.64 kW and < 74.57 kW, generators Cut-off, U
Piping HDPE	44	m	Piping HDPE modelled by authors
Bentonite	100	kg	Bentonite {GLO} market for bentonite Cut-off, U
Gravel	100	kg	Gravel, crushed {CH} market for gravel, crushed Cut-off, U
Stainless steel	4	units	Stainless steel tubing modelled by authors
Transport technician	180	Person km	Transport, passenger car, medium size, petrol, EURO 5 {RER} transport, passenger car, medium size, petrol, EURO 5 Cut-off, U
Transport sample	250	km	Transport, freight, lorry 3.5-7.5 metric ton, EURO3 {RER} market for transport, freight, lorry 3.5-7.5 metric ton, EURO3 Cut-off, U
Sampling filters	4	units	Sampling filter modelled by authors
Plastic tubing	50	m	Plastic tubing modelled by authors
PE bottles	20	units	PE bottle + cap modelled by authors
Excavated soil	1,000	m ³	Inert waste {Europe without Switzerland} market for inert waste Cut-off, U
Waste concrete	8,140	g	Waste concrete {Europe without Switzerland} market for waste concrete Cut-off, U
Waste gravel	100	kg	Waste concrete gravel {CH} market for waste concrete gravel Cut-off, U
STEP 3 – Operation & maintenance			
Injection	24	h	Machine operation, diesel, >= 18.64 kW and < 74.57 kW, generators {GLO} market for machine operation, diesel, >= 18.64 kW and < 74.57 kW, generators Cut-off, U
Organic substrate (EOS PRO)	300	kg	EOS PRO modelled by the authors
K ₂ CO ₃	300	kg	Potassium carbonate {GLO} market for potassium carbonate Cut-off, U
Water	4,640	l	Tap water {RER} market group for tap water Cut-off, U
Transport technician	2,520	Person km	Transport, passenger car, medium size, diesel, EURO 5 {RER} transport, passenger car, medium size, diesel, EURO 5 Cut-off, U
Transport sample	250	km	Transport, passenger car, large size, diesel, EURO 5 {RER} transport, passenger car, large size, diesel, EURO 5 Cut-off, U
Sampling filters	52	units	Sampling filter modelled by authors
Plastic tubing	650	m	Plastic tubing LDPE 12 mm modelled by authors
PE bottles	260	units	PE bottle + cap modelled by authors
Silicon tubing	13	m	Silicon tubing modelled by authors
Unpolluted water			
Arsenic	-2,390 µg	1 l	Arsenic, ion – emissions to groundwater
Cadmium	-0.28 µg	1 l	Cadmium (II) – emissions to groundwater
Nickel	-345 µg	1 l	Nickel (II) – emissions to groundwater
Zinc	-83,950 µg	1 l	Zinc (II) – emissions to groundwater

Table S2. Description of the products for the In Situ Metal Precipitation (ISMP) implementation at field scale that were not found in theecoinvent database and were modelled by the authors based on the data provided directly by the company TAUW

Sampling filter modelled by the authors			
Polypropylene	66 cm ³ (density 0.9) = 59.6 g		Polypropylene, granulate {RER} polypropylene production, granulate Cut-off, U
Extrusion	59.6 g	1 p	Extrusion, plastic pipes {RER} extrusion, plastic pipes Cut-off, U
Nylon	43.3 g		Nylon 6 {RER} market for nylon 6 Cut-off, U
Waste polypropylene	59.6 g		Waste polypropylene {BE} market for waste polypropylene Cut-off, U
Waste nylon	43.3 g		Waste plastic, mixture {BE} market for waste plastic, mixture Cut-off, U
Plastic tubing LDPE 12 mm modelled by the authors			
Polyethylene	45.7 g		Polyethylene, low density, granulate {RER} polyethylene production, low density, granulate Cut-off, U
Extrusion	45.7 g	1 m	Extrusion, plastic pipes {RER} extrusion, plastic pipes Cut-off, U
Waste polyethylene	45.7 g		Waste polyethylene {RER} market group for waste polyethylene Cut-off, U
PE bottle + cap modelled by the authors			
Polyethylene	25 g		Polyethylene, high density, granulate {RER} polyethylene production, high density, granulate Cut-off, U
Extrusion	25 g	1 p	Extrusion of plastic sheets and thermoforming, inline {GLO} market for extrusion of plastic sheets and thermoforming, inline Cut-off, U
Waste polyethylene	25 g		Waste polyethylene {BE} market for waste polyethylene Cut-off, U
Piping HDPE modelled by the authors			
Polyethylene	626 g		Polyethylene, high density, granulate {RER} polyethylene production, high density, granulate Cut-off, U
Extrusion	626 g	1 m	Extrusion, plastic pipes {RER} extrusion, plastic pipes Cut-off, U
Waste polyethylene	626 g		Waste polyethylene {RER} market group for waste polyethylene Cut-off, U
Stainless steel tubing modelled by the authors			
Stainless steel	16,700 g		Steel, chromium steel 18/8, hot rolled {GLO} market for steel, chromium steel 18/8, hot rolled Cut-off, U
Rubber seal	12.6 g	1 p	Synthetic rubber {GLO} market for synthetic rubber Cut-off, U
Waste stainless steel	16,700 g		Steel and iron (waste treatment) {GLO} recycling of steel and iron Cut-off, U
Waste rubber	12.6 g		Waste rubber, unspecified {Europe without Switzerland} market for waste rubber, unspecified Cut-off, U
EOS PRO modelled by the authors			
Soybean oil refined	59.8 kg	100 kg	Soybean oil, refined {US} soybean oil refinery operation Cut-off, U
Tap water	40.2 kg		Tap water {RER} market group for tap water Cut-off, U
Silicon tubing modelled by the authors			
Silicone	2.7 g Diam ext 2 mm Diam int 1 mm Density 1.14 Yield extrusion 0.996	1 m	Silicone product {RER} silicone product production Cut-off, U
Extrusion	2.7 g		Extrusion, plastic pipes {RER} extrusion, plastic pipes Cut-off, U
Waste silicone	2.7 g		Waste, from silicon wafer production {DE} treatment of waste, from silicon wafer production, underground deposit Cut-off, U

Table S3. Cost data provided by TAUW gathered from the real field pilot demonstration performed at the industrial site and separated for each stage of the project's life cycle

Project phase	Concept	Description	Cost	Data quality indicator
Initial sampling	Field sampling	Preparation, execution and transportation to lab	1,300.00 €	II calculated
	Analysis and injection design	Lab experiments and design	14,500.00 €	I measured
	Transport	Technician and sample transport	300.00 €	I measured
	Waste	Residues from sampling	70.00 €	I measured
Total initial sampling			16,170.00 €	
Construction	Installation - PVC 1" Wells	Drilling, raw materials, installation and supervision	8,000.00 €	I measured
	Monitoring	Time 0 coordination and evaluation	5,400.00 €	I measured
	Transport	Technician and samples transport	1,900.00 €	I measured
	Waste	Residues from time 0	200.00 €	I measured
Total construction			15,400.00 €	
Operation	Injection 1	Planning, execution, raw materials and coordination	16,900.00 €	I measured
		Organic substrate, K ₂ CO ₃ , water mixing	700.00 €	III estimated
	Post injection 1	Planning, execution and analysis during the project lifecycle	13,000.00 €	I measured
	Injection 2	Planning, execution, raw materials and coordination	13,300.00 €	I measured
		Organic substrate, K ₂ CO ₃ , water mixing	1,100.00 €	III estimated
	Post injection 2	Planning, execution and analysis during the project lifecycle	21,000.00 €	I measured
	Equipment		15,000.00 €	I measured
	Transport	Technician and samples transport	2,100.00 €	I measured
Waste	Residues in 2 years	1,800.00 €	I measured	
Total operation			85,550.00 €	
General	Safety / Personal protection	IPEs, face masks, apparel	1,000.00 €	III estimated
	Administration		9,000.00 €	III estimated
Total general			10,000.00 €	

Table S4. Environmental prices: ReCiPe 2016 midpoints, in € 2021 per unit for EU27

Impact category	Unit	Below	Central	Upper
Global warming	kg CO2 eq	0.05	0.13	0.16
Stratospheric ozone depletion	kg CFC11 eq	15.2	29.1	69.6
Ionizing radiation	kBq Co-60 eq	0.00275	0.00422	0.00594
Ozone formation, Human health	kg NOx eq	1.38	2.17	2.98
Ozone formation, Terrestrial ecosystems	kg NOx eq	0.416	0.416	0.526
Fine particulate matter formation	kg PM2.5 eq	61.7	99.2	138.1
Terrestrial acidification	kg SO2 eq	2.66	5.27	9.3
Freshwater eutrophication	kg P eq	2.56	3.74	10.13
Marine eutrophication	kg N eq	7.64	14.25	27.6
Terrestrial ecotoxicity	kg 1,4-DCB	0.00045	0.00064	0.00083
Freshwater ecotoxicity	kg 1,4-DCB	0.0148	0.0209	0.0271
Marine ecotoxicity	kg 1,4-DCB	0.0022	0.0032	0.0041
Human carcinogenic toxicity	kg 1,4-DCB	2.7	3.99	6.01
Human non-carcinogenic toxicity	kg 1,4-DCB	0.048	0.071	0.106
Land use	m2a crop eq	0.07	0.099	0.128
Mineral resource scarcity	kg Cu eq	0	0.014	0.0826
Fossil resource scarcity	kg oil eq	0	0.028	0.163
Water consumption	m ³	0	0.407	0.811

Table S5. Environmental prices: EF midpoints, in € 2021 per unit for EU27

Impact category	Unit	Value
Climate change	kg CO2-eq	0.13
Ozone depletion	kg CFC11 eq	29.1
Particulate matter	disease inc.	890,182
Ionising radiation	kBq U-235 eq	0.00071
Photochemical ozone formation	kg NMVOC eq	1.48
Acidification	mol H+ eq	2.04
Eutrophication, freshwater	kg P eq	3.74
Eutrophication, marine	kg N eq	14.25
Eutrophication, terrestrial	mol N eq	0.331
Water use	m ³ depriv.	-
Land use	Pt	-
Resource use, fossils	MJ	-
Resource use, minerals and metals	kg Sb eq	-
Human toxicity, non-cancer	CTUh	-
Human toxicity, cancer	CTUh	-
Ecotoxicity, freshwater	CTUe	-

Table S6. Environmental Prices for Heavy metals in freshwater

Substance	EP Lower €2021/kg	EP central €2021/kg	EP Upper €2021/kg
As	233.00	3,288.00	15,494.00
Cd	4.22	43.20	197.00
Fe	-	0.00	0.01
Ni	13.10	49.70	184.00
Zn	6.45	245.00	1,213.00