Options for managing alkaline steel slag leachate: A Life Cycle Assessment

Supplementary Information

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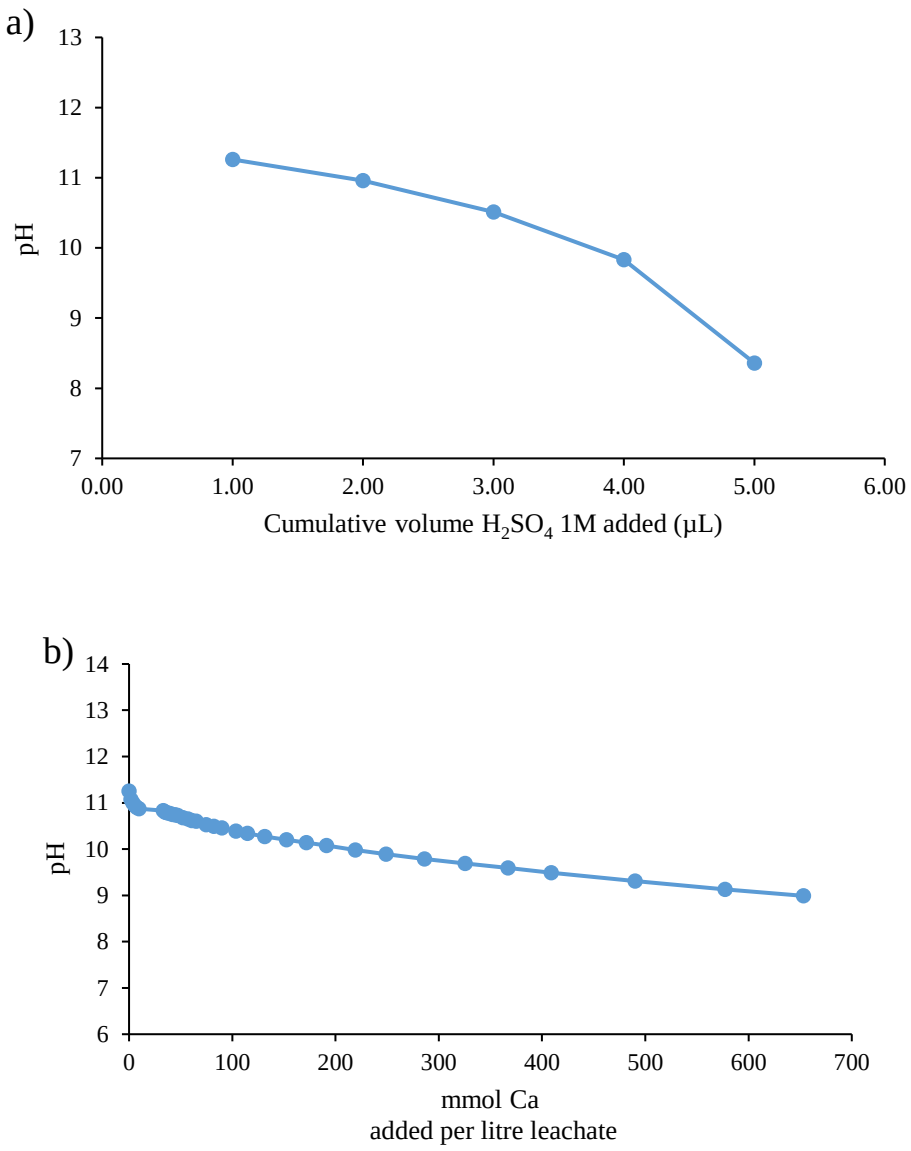

Figure S1. Active dosing of a) H_2SO_4 and b) $CaCl_2$ for treating alkaline steel slag leachate in lab scale experiments (titrations) using synthetic steel slag leachate. The amount needed to lower the leachate pH bellow 9 (regulatory limit) was used in the LCA. The dosage of sulphuric acid was calculated for the most used strength commercially (96%) and was 3 L h^{-1}, while for CaCl2 was 1.011 kg per m^3.

Table S1. Inventory for each scenario considering the construction, operation and maintenance of the treatment options for steel slag leachate considering the functional unit (FU).

Item	Unit	Value for 1 FU	Phase	Comment	Process (B – Background; F – Foreground)
A-H_2SO_4					
Steel	g	1.9	Construction	Includes the lamella clarifier, pumps, mixer, dosing pump, flocculant preparation unit, filter press and sludge pump. Amounts based on commercial equipments or measured in project and ELCD 3.2 database	Pumping (F) Acid dosing (F) Flocculant dosing (F) Clarification (F) Filter press (F)
Polypropylene (PP)	g	0.4	Construction	For the geotextile membrane and the mixer. Based on the raw material from the ELCD database and the energy needed for moulding (Elduque et al., 2015), assuming an articulated lorry transport 40 t total weight, 27 t max payload of 1.5E-6 t.km (standard distances)	Acid dosing (F) Polishing (F)
Polyethylene high density (PE-HD)	g	2.8	Construction	Includes mix tank, filter press, flocculant preparation unit, 1.5 mm membrane, storage tank. Based on the raw material from the ELCD database and the energy needed for moulding (Elduque et al., 2015), assuming an articulated lorry transport 40 t total weight, 27 t max payload of 1.5E-6 t.km (standard distances)	Acid dosing (F) Flocculant dosing (F) Polishing (F)
Polyvinyl chloride (PVC)	g	0.01	Construction	Fittings and equipment components. Based on the raw material from the ELCD database and the energy needed for moulding (Elduque et al., 2015), assuming	Pumping (F)

Item	Unit	Value for 1 FU	Phase	Comment	Process (B – Background; F – Foreground)
				an articulated lorry transport 40 t total weight, 27 t max payload of 1.5E-6 t.km (standard distances)	
Concrete	m^3	1.5E-5	Construction	Modelled with Portland cement, sand, aggregate, water and energy (Sjunnesson, 2005)	Construction (B)
Excavated materials	g	0.1	Construction	For foundations and polishing pond	Construction (B)
Transport	kg.km	17.5	Construction	Lorry transport, Euro 0, 1, 2, 3, 4 mix, 22 t total weight, 17,3t max payload - RER	Construction (B)
H_2SO_4	g	24.3	Operation	Modelled based on Althaus H.-J., Chudacoff M., Hischier R., Jungbluth N., Osses M. and Primas A. (2007) Life Cycle Inventories of Chemicals. Final report ecoinvent data v2.0 No. 8. Swiss Centre for Life Cycle Inventories, Dübendorf, CH.	Acid dosing (F)
Flocculant	g	5.3E-8	Operation	Acrylic acid modelled based on Althaus H.-J., Chudacoff M., Hischier R., Jungbluth N., Osses M. and Primas A. (2007) Life Cycle Inventories of Chemicals. Final report ecoinvent data v2.0 No. 8. Swiss Centre for Life Cycle Inventories, Dübendorf, CH.	Flocculant dosing (F)
Energy	kWh	0.08	Operation	Includes pumps, mixer, dosing pump, flocculant preparation unit, filter press and sludge pump	Pumping (F) Acid dosing (F) Flocculant dosing (F) Pumping sludge (F) Filter press (F)

Item	Unit	Value for 1 FU	Phase	Comment	Process (B – Background; F – Foreground)
Occupation, industrial area, built up	m^2.a	0.001	Operation		Occupation (B)
Transport	kg.km	0.5	Operation	Small lorry transport, Euro 0, 1, 2, 3, 4 mix, 7,5 t total weight, 3,3 t max payload for a 50 km distance	Transport (B)
Transport	v.km	0.004	Maintenance	Operation, passenger car, diesel, fleet average 2010 for a 50 km distance. The diesel passenger car (fleet average, 2010) was modelled based on Spielmann M., Dones R. and Bauer C. (2007) Life Cycle Inventories of Transport Services. Final report ecoinvent v2.0 No. 14. Swiss Centre for Life Cycle Inventories, Dübendorf, CH.	Transport (B)
A-CO_2					
Steel	g	1.9	Construction	Includes the mixing tank, clarifier, pumps, dosing pump, filter press and sludge pump. Amounts based on commercial equipments or measured in project and ELCD 3.2 database	Pumping (F) CO_2 dosing (F) Clarification (F) Filter press (F)
Polypropylene (PP)	g	0.4	Construction	For the geotextile membrane. Based on the raw material from the ELCD database and the energy needed for moulding (Elduque et al., 2015), assuming an articulated lorry transport 40 t total weight, 27 t max payload of 1.5E-6 t.km (standard distances)	Polishing (F)
Polyethylene high density (PE-HD)	g	2.3	Construction	Includes filter press and 1.5 mm membrane. Based on the raw material from the ELCD	Filter press (F) Polishing (F)

Item	Unit	Value for 1 FU	Phase	Comment	Process (B – Background; F – Foreground)
				database and the energy needed for moulding (Elduque et al., 2015), assuming an articulated lorry transport 40 t total weight, 27 t max payload of 1.5E-6 t.km (standard distances)	
Polyvinyl chloride (PVC)	g	0.005	Construction	Fittings and equipment components. Based on the raw material from the ELCD database and the energy needed for moulding (Elduque et al., 2015), assuming an articulated lorry transport 40 t total weight, 27 t max payload of 1.5E-6 t.km (standard distances)	Pumping (F)
Concrete	m^3	1.1E-5	Construction	Modelled with Portland cement, sand, aggregate, water and energy (Sjunnesson, 2005)	Construction (B)
Excavated materials	g	0.06	Construction	For foundations and polishing pond	Construction (B)
Transport	kg.km	17.5	Construction	Lorry transport, Euro 0, 1, 2, 3, 4 mix, 22 t total weight, 17,3t max payload - RER	Construction (B)
CO_2	g	2.1E-4	Operation	Modelled based on Althaus H.-J., Chudacoff M., Hischier R., Jungbluth N., Osses M. and Primas A. (2007) Life Cycle Inventories of Chemicals. Final report ecoinvent data v2.0 No. 8. Swiss Centre for Life Cycle Inventories, Dübendorf, CH.	CO_2 dosing (F)
Energy	kWh	0.1	Operation	Includes pumps, mixer, dosing pump, flocculant preparation unit, filter press and sludge pump	Pumping (F) CO_2 dosing (F) Flocculant dosing (F) Pumping sludge (F) Filter press (F)

Item	Unit	Value for 1 FU	Phase	Comment	Process (B – Background; F – Foreground)
Transport	kg.km	0.007	Operation	Small lorry transport, Euro 0, 1, 2, 3, 4 mix, 7,5 t total weight, 3,3 t max payload for a 50 km distance	Transport (B)
Occupation, industrial area, built up	m^2.a	9.5E-04	Operation		Occupation (B)
Transport	v.km	0.004	Maintenance	Operation, passenger car, diesel, fleet average 2010 for a 50 km distance. The diesel passenger car (fleet average, 2010) was modelled based on Spielmann M., Dones R. and Bauer C. (2007) Life Cycle Inventories of Transport Services. Final report ecoinvent v2.0 No. 14. Swiss Centre for Life Cycle Inventories, Dübendorf, CH.	Transport (B)
A-$CaCl_2$					
Steel	g	4.4	Construction	Includes the lamella clarifier, pumps, mixer, dosing pump, silo, flocculant preparation unit, filter press and sludge pump. Amounts based on commercial equipments or measured in project and ELCD 3.2 database	Pumping (F) $CaCl_2$ dosing (F) Flocculant dosing (F) Clarification (F) Pumping sludge (F) Filter press (F) Polishing (F)
Polypropylene (PP)	g	0.4	Construction	For the geotextile membrane and the mixer Based on the raw material from the ELCD database and the energy needed for moulding (Elduque et al., 2015), assuming an articulated lorry transport 40 t total weight, 27 t max payload of 1.5E-6 t.km (standard distances)	

Item	Unit	Value for 1 FU	Phase	Comment	Process (B – Background; F – Foreground)
Polyethylene high density (PE-HD)	g	2.7	Construction	Includes mix tank, filter press, flocculant preparation unit, 1.5 mm membrane, storage tank. Based on the raw material from the ELCD database and the energy needed for moulding (Elduque et al., 2015), assuming an articulated lorry transport 40 t total weight, 27 t max payload of 1.5E-6 t.km (standard distances)	Filter press (F) Polishing (F)
Polyvinyl chloride (PVC)	g	0.01	Construction	Fittings and equipment components. Based on the raw material from the ELCD database and the energy needed for moulding (Elduque et al., 2015), assuming an articulated lorry transport 40 t total weight, 27 t max payload of 1.5E-6 t.km (standard distances)	Pumping (F)
Concrete	m^3	1.5E-5	Construction	Modelled with Portland cement, sand, aggregate, water and energy (Sjunnesson, 2005)	Construction (B)
Excavated materials	g	0.1	Construction	For foundations and polishing pond	Construction (B)
Transport	kg.km	17.5	Construction	Lorry transport, Euro 0, 1, 2, 3, 4 mix, 22 t total weight, 17,3t max payload – RER	Construction (B)
$CaCl_2$	kg	181	Operation	Modelled based on Althaus H.-J., Chudacoff M., Hischier R., Jungbluth N., Osses M. and Primas A. (2007) Life Cycle Inventories of Chemicals. Final report ecoinvent data v2.0 No. 8. Swiss Centre for Life Cycle Inventories, Dübendorf, CH.	$CaCl_2$ dosing (F)
Flocculant	g	5.3E-8	Operation	Acrylic acid modelled based on Althaus H.-J., Chudacoff M., Hischier R., Jungbluth	Flocculant dosing (F)

Item	Unit	Value for 1 FU	Phase	Comment	Process (B – Background; F – Foreground)
				N., Osses M. and Primas A. (2007) Life Cycle Inventories of Chemicals. Final report ecoinvent data v2.0 No. 8. Swiss Centre for Life Cycle Inventories, Dübendorf, CH.	
Energy	kWh	0.08	Operation	Includes pumps, mixer, dosing pump, flocculant preparation unit, filter press and sludge pump	Pumping (F) CO_2 dosing (F) Flocculant dosing (F) Pumping sludge (F) Filter press (F)
Occupation, industrial area, built up	m^2.a	0.001	Operation		Transport (B)
Transport	t.km	0.181	Operation	Small lorry transport, Euro 0, 1, 2, 3, 4 mix, 7,5 t total weight, 3,3 t max payload for a 50 km distance	Occupation (B)
Transport	v.km	0.004	Maintenance	Operation, passenger car, diesel, fleet average 2010 for a 50 km distance. The diesel passenger car (fleet average, 2010) was modelled based on Spielmann M., Dones R. and Bauer C. (2007) Life Cycle Inventories of Transport Services. Final report ecoinvent v2.0 No. 14. Swiss Centre for Life Cycle Inventories, Dübendorf, CH.	Transport (B)
P-P					
Steel	g	0.04	Construction	Includes the pumps	Pumping (F)
Polypropylene (PP)	g	0.22	Construction	For the geotextile membrane. Based on the raw material from the ELCD database and the energy needed for moulding (Elduque	Reedbed (F)

Item	Unit	Value for 1 FU	Phase	Comment	Process (B – Background; F – Foreground)
				et al., 2015), assuming an articulated lorry transport 40 t total weight, 27 t max payload of 1.5E-6 t.km (standard distances)	
Polyethylene high density (PE-HD)	g	2.8	Construction	For the 1.5 mm membrane. Based on the raw material from the ELCD database and the energy needed for moulding (Elduque et al., 2015), assuming an articulated lorry transport 40 t total weight, 27 t max payload of 1.5E-6 t.km (standard distances)	Reedbed (F)
Concrete	m^3	1.0E-5	Construction	For the cascade and settlement basin. Modelled with Portland cement, sand, aggregate, water and energy (Sjunnesson, 2005)	Cascade Aeration (F) Settlement basin (F)
Gravel	g	0.07	Construction	For reedbeds	Reedbed (F)
Excavated materials	g	0.6	Construction	For cascade and reedbeds	Excavation (B)
Transport	kg.km	27.5	Construction	Lorry transport, Euro 0, 1, 2, 3, 4 mix, 22 t total weight, 17,3t max payload - RER	Transport (B)
Occupation, industrial area, vegetation	m^2.a	6.3E-03	Operation		Occupation (B)
Energy	kWh	0.006	Operation		Pumping (F)
Transport	v.km	0.004	Maintenance	Operation, passenger car, diesel, fleet average 2010 for a 50 km distance. The diesel passenger car (fleet average, 2010) was modelled based on Spielmann M., Dones R. and Bauer C. (2007) Life Cycle Inventories of Transport Services. Final report ecoinvent v2.0 No. 14. Swiss Centre for Life Cycle Inventories, Dübendorf, CH.	Transport (B)

Item	Unit	Value for 1 FU	Phase	Comment	Process (B – Background; F – Foreground)
Excavated materials	kg	0.03	Maintenance	Sludge removal (10 m^3) every 5 years	Excavation (B)
Transport	kg.km	1.5	Maintenance	Lorry transport, Euro 0, 1, 2, 3, 4 mix, 22 t total weight, 17,3t max payload – RER for a 50 km distance	Transport (B)
P-G					
Polypropylene (PP)	g	0.22	Construction	For the geotextile membrane. Based on the raw material from the ELCD database and the energy needed for moulding (Elduque et al., 2015), assuming an articulated lorry transport 40 t total weight, 27 t max payload of 1.5E-6 t.km (standard distances)	Reedbed (F)
Polyethylene high density (PE-HD)	g	2.8	Construction	For the 1.5 mm membrane. Based on the raw material from the ELCD database and the energy needed for moulding (Elduque et al., 2015), assuming an articulated lorry transport 40 t total weight, 27 t max payload of 1.5E-6 t.km (standard distances)	Reedbed (F)
Concrete	m^3	1.0E-5	Construction	For the cascade and settlement basin. Modelled with Portland cement, sand, aggregate, water and energy (Sjunnesson, 2005)	Cascade Aeration (F) Settlement basin (F)
Excavated materials	g	0.6	Construction	For cascade and reedbeds	Excavation (B)
Gravel	g	0.07	Construction	For reedbeds	Transport (B)
Excavated materials	g	0.6	Construction	For foundations	Excavation (B)
Transport	kg.km	27.5	Construction	Lorry transport, Euro 0, 1, 2, 3, 4 mix, 22 t total weight, 17,3t max payload - RER	Transport (B)
Energy	kWh	5.69E-03	Operation	For pumping	Pumping (F)

Item	Unit	Value for 1 FU	Phase	Comment	Process (B – Background; F – Foreground)
Occupation, industrial area, vegetation	m^2.a	6.3E-03	Operation		Occupation (B)
Transport	v.km	5.0E-3	Maintenance	Operation, passenger car, diesel, fleet average 2010 for a 50 km distance. The diesel passenger car (fleet average, 2010) was modelled based on Spielmann M., Dones R. and Bauer C. (2007) Life Cycle Inventories of Transport Services. Final report ecoinvent v2.0 No. 14. Swiss Centre for Life Cycle Inventories, Dübendorf, CH.	Transport (B)
Excavated materials	kg	0.03	Maintenance	Sludge removal (10 m^3) every 5 years	Excavation (B)
Transport	kg.km	1.5	Maintenance	Lorry transport, Euro 0, 1, 2, 3, 4 mix, 22 t total weight, 17,3t max payload – RER for a 50 km distance	Transport (B)

Table S2. Inventory for emissions to agricultural soils from the use of treatment sludge as soil amendments for each treatment option (g per functional unit).

Treatment option	**A-H_2SO_4**	**A-CO_2**	**A-$CaCl_2$**	**P-P**	**P-G**
Ca	47.6	98.5	152.4	74.0	74.0
Mg		3.4	21.2	19.7	19.7
K		1688.2		40.0	40.0
Al	52.1	53.3	53.3	158.1	158.1
Si	9.7		26.7	302.5	302.5
Sr		3.3	3.4	0.7	0.7
Ba			0.03	0.5	0.5
P		8.4	1.8	1.0	1.0
V	0.02		0.2	0.5	0.5