Table S1. DQR, Process Names and Source Annotation for LCI data in Scenario S1

Process	Input/Output	Material	DQR	Process Name in Ecoinvent3	Source Annotation
Raw materials and coal transportation	Input	Railway transportation	2.2	Transport, freight train {CN}| market	Based on assumptions
	Input	Road transportation	2.2	Transport, freight, lorry 3.5-7.5 metric ton, euro6 {RER}| market	
Raw material pretreatment	Input	Limestone	1.5	Limestone, unprocessed {RoW}| market	Accounted based on on-site investigation and EIA report
	Input	Clay	1.5	Clay {RoW}| market	
	Input	Iron ore	1.5	Iron ore, crude ore, 63% Fe {GLO}| market	
	Input	Sand	1.5	Sand {RoW}| market	
	Input	Electricity	1.5	Electricity, high voltage {CN}| market	
	Output	PM	1.5	/	
Hazardous waste transportation	Input	Road transportation	2.2	Transport, freight, lorry 3.5-7.5 metric ton, euro6 {RER}| market	Based on assumptions
Hazardous waste discharge and storage	Input	Hazardous waste	1.5	/	Accounted based on on-site investigation and EIA report
	Input	Water	1.5	Tap water, at user {RoW}| tap water production and supply	
	Output	NH_3	1.5	/	
	Output	H_2S	1.5	/	
	Output	PM	1.5	/	
Hazardous waste pretreatment	Input	Water	1.5	Tap water, at user {RoW}| tap water production and supply	Accounted based on on-site investigation and EIA report
	Input	Electricity	1.5	Electricity, high voltage {CN}| market	
	Output	NH_3	1.5	/	
	Output	H_2S	1.5	/	
	Output	PM	1.5	/	

Hazardous dosing	Input	Electricity	1.5	Electricity, high voltage {CN}| market	Accounted based on on-site investigation and EIA report
Clinker calcination	Input	Hard coal	1.5	Hard coal {CN}| market	
	Input	Electricity	1.5	Electricity, high voltage {CN}| market	
	Output	CO_2	2.5	/	Estimated based on emission factor method and mass balance
	Output	PM	1.5	/	Accounted based on on-site investigation and EIA report
	Output	SO_2	1.5	/	
	Output	NO_x	1.5	/	
	Output	NH_3	1.5	/	
	Output	HF	1.5	/	
	Output	HCl	1.5	/	
	Output	Cu	1.5	/	
	Output	Zn	1.5	/	
	Output	Cd	1.5	/	
	Output	Pb	1.5	/	
	Output	Cr	1.5	/	
	Output	Ni	1.5	/	
	Output	Mn	1.5	/	
	Output	As	1.5	/	
	Output	Hg	1.5	/	
	Output	H_2S	1.5	/	
	Output	Dioxin	1.5	/	

Table S2. DQR, Process Names and Source Annotation for LCI data in Scenario S2

Process	Input/Output	Material	DQR	Process Name in Ecoinvent3	Source Annotation
Raw materials and coal transportation	Input	Railway transportation	2.2	Transport, freight train {CN}| market	Based on assumptions
	Input	Road transportation	2.2	Transport, freight, lorry 3.5-7.5 metric ton, euro6 {RER}| market	
Raw material pretreatment	Input	Limestone	1.5	Limestone, unprocessed {RoW}| market	Accounted based on on-site investigation and EIA report
	Input	Clay	1.5	Clay {RoW}| market	
	Input	Iron ore	1.5	Iron ore, crude ore, 63% Fe {GLO}| market	
	Input	Sand	1.5	Sand {RoW}| market	
	Input	Electricity	1.5	Electricity, high voltage {CN}| market	
	Output	PM	1.5	/	
Clinker calcination	Input	Hard Coal	1.5	Hard coal {CN}| market	Accounted based on on-site investigation and EIA report
	Input	Electricity	1.5	Electricity, high voltage {CN}| market	
	Output	CO_2	2.5	/	Estimated based on emission factor method and mass balance
	Output	PM	1.5	/	Accounted based on on-site investigation and EIA report
	Output	SO_2	1.5	/	
	Output	NO_x	1.5	/	
	Output	NH_3	1.5	/	
Hazardous Waste Incineration	Input	Electricity	2.8	Electricity, high voltage {CN}| market	Accounted based on Hong et al [2]
	Input	Land occupation	2.8	/	
	Input	Clay	2.8	Clay {GLO}| market	
	Input	Cobblestone	2.8	/	
	Input	Cement	2.8	Cement, unspecified {GLO}| market	

	Input	Lime	2.8	Lime {GLO}| market
	Input	Sodium hydroxide	2.8	Sodium hydroxide, without water, in 50% solution state {GLO}| market
	Input	Fresh water	2.8	Tap water {GLO}| market
	Input	Waste water	2.8	Water, decarbonised {CN}| water production
	Input	Ash	2.8	Flyash brick {RoW}| flyash brick production
	Input	Diesel	2.8	Diesel {GLO}| market
	Input	Natural Gas	2.8	Natural gas, high pressure {GLO}| market
	Input	Active carbon	2.8	Activated carbon, granular {GLO}| market
	Input	HDPE	2.8	Polyethylene, high density, granulate {RoW}| production
	Input	Non-woven fabric	2.8	Fibre, cotton {RoW}| fibre production, cotton, ginning
	Input	Metal-chelate	2.8	Metal working machine, unspecified {RoW}| market
	Input	Sodium sulfide	2.8	Sodium sulfide {GLO}| market
	Input	Sodium thiosulfate	2.8	Sodium sulfate, anhydrite {RoW}| market
	Output (to air)	Carbon dioxide	2.8	/
	Output (to air)	Particulates	2.8	/
	Output (to air)	Sulfur dioxide	2.8	/
	Output (to air)	Nitrogen oxides	2.8	/

	Output (to air)	Carbon monoxide	2.8	/
	Output (to air)	Hydrogen chloride	2.8	/
	Output (to air)	Hydrogen fuloride	2.8	/
	Output (to air)	Mercury	2.8	/
	Output (to air)	Arsenic	2.8	/
	Output (to air)	Nickel	2.8	/
	Output (to air)	Lead	2.8	/
	Output (to air)	Chromium	2.8	/
	Output (to air)	Tin	2.8	/
	Output (to air)	Antimony	2.8	/
	Output (to air)	Copper	2.8	/
	Output (to air)	Managanese	2.8	/
	Output (to air)	Dioxins	2.8	/
	Output (to soil)	Flurorine	2.8	/
	Output (to soil)	Mercury	2.8	/
	Output (to soil)	Chromium	2.8	/
	Output (to soil)	Lead	2.8	/
	Output (to soil)	Cadmium	2.8	/
	Output (to soil)	Copper	2.8	/
	Output (to soil)	Zinc	2.8	/
	Output (to soil)	Barium	2.8	/
	Output (to soil)	Nickel	2.8	/
	Output (to soil)	Arsenic	2.8	/

Table S3. Indirect emissions related to FPMF category for Scenarios S1

	Unit	Indirect emissions					
		Transportation of coal and raw material	Raw material pretreatment	Clinker Calcination	Hazardous waste transportation	Hazardous waste pretreatment	Hazardous waste dosing
NH_3	g	1.03	7.48	2.43	0.01	0.00	0.00
NO_x	g	65.78	160.63	179.73	0.80	0.45	0.28
$PM_{2.5}$	g	16.47	32.43	115.24	0.31	0.09	0.06
SO_2	g	60.67	64.25	197.06	0.78	0.39	0.24

Table S4. Indirect emissions related to FPMF category for Scenarios S2

	Unit	Indirect emissions			
		Transportation of coal and raw material	Raw material pretreatment	Clinker Calcination	Hazardous waste incineration
NH_3	g	1.02	7.52	2.62	1.81
NO_x	g	70.13	167.69	192.29	73.01
$PM_{2.5}$	g	25.03	33.85	124.3	6.68
SO_2	g	62.48	70.29	211.40	32.98

Table S5. The characterization factors for the FPMF category used in this study

Material	Unit	ReCiPe 2016	Local LCIA
$PM_{2.5}$	DALY/kton	629	3519.43
Ammonia	DALY/kton	420/151	1050.16
Sulfur dioxide	DALY/kton	270/182	534.99
Nitrogen oxides	DALY/kton	230/69.2	243.43

Note: For ReCiPe 2016 model, values following the slash represent global characterization factors used for part of background data, whereas values preceding the slash represent China-specific characterization factors applied to direct emissions of $PM_{2.5}$ precursors.

Table S6. Emission standards applied for the case plant and for future ULE

	PM (mg/m^3)	SO_2 (mg/m^3)	NO_x (mg/m^3)	NH_3 (mg/m^3)
Cement Production (applied in studied case)	20	100	200	8
Cement Production (for ULE)	10	35	50	/
Hazardous Waste Incineration (applied in studied case during 2002-2020)	80	300	500	
Hazardous Waste Incineration (for ULE)	10	30	80/50	8

Table S7. Environmental impacts based on ReCiPe2016 and local LCIA model with lower-bound CF values within the 95% confidence interval

Category	Unit	S1	S2
FPMF (ReCiPe2016)	DALY	4.16E-04	4.56E-04
FPMF (Local LCIA -Lower limit)	DALY	1.15E-03	1.29E-03
Ratio of results (Local LCIA/ReCiPe2016)		276%	283%
Human health (ReCiPe2016)	DALY	1.35E-03	1.41E-03
Human health (Local LCIA -Lower limit)	DALY	2.08E-03	2.25E-03
Ratio of results (Local LCIA/ReCiPe2016)		154%	159%
Total impact (ReCiPe2016)	/	235%	246%
Total impact (Local LCIA -Lower limit)	/	35.7	38.5
Ratio of results (Local LCIA/ReCiPe2016)		152%	157%

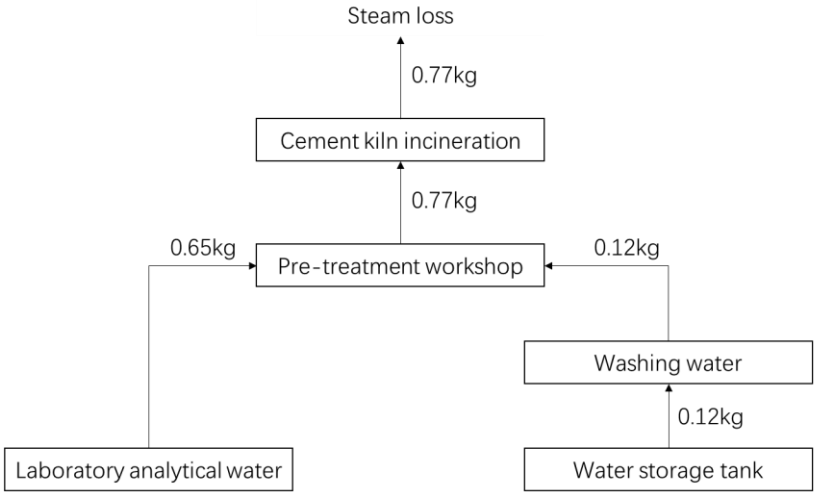

Figure S1. Water and wastewater flow for Scenario S1