

The Environmental Profile of Clinker, Cement, and Concrete: A Life Cycle Perspective Study Based on Ecuadorian Data

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Table S1. Summary of processes taken from Ecoinvent database for LCIA Clinker in Ecuador

Input/output inventory item	OpenLCA - Ecoinvent database
Raw Materials	
Clay	clay pit operation clay APOS, U - RoW
Limestone	limestone production, crushed, for mill limestone, crushed, for mill APOS, U - RoW
Steel Slag	electric arc furnace slag
Copper Slag	copper slag
Fluorite	fluorspar production, 97% purity fluorspar, 97% purity APOS, U - GLO
Iron ore	iron ore mine operation, 46% Fe iron ore, crude ore, 46% Fe APOS, U - GLO
Clay	clay pit operation clay APOS, U - RoW
Limestone	limestone production, crushed, for mill limestone, crushed, for mill APOS, U - RoW
Fuels and energy	
Oil and lubricants	market for lubricating oil lubricating oil APOS, U - RoW
Diesel	diesel production, low-sulfur, petroleum refinery operation diesel, low-sulfur APOS, U - CO
Petroleum Coke	petroleum coke production, petroleum refinery operation petroleum coke APOS, U - RoW
Biomass	biowaste
Used oils	waste mineral oil
Municipal solid waste	municipal solid waste
Other flows	
Steel 18/8, hot rolled	market for steel, chromium steel 18/8, hot rolled steel, chromium steel 18/8, hot rolled APOS, U - GLO
Tap water	market for tap water tap water APOS, U - PE
Cement Factory	market for cement factory cement factory APOS, U - GLO
Refractory brick, basic, packed	market for refractory, basic, packed refractory, basic, packed APOS, U - GLO
Refractory brick, fireclay, packed	market for refractory, fireclay, packed refractory, fireclay, packed APOS, U - GLO
Refractory brick, high aluminum oxide, packed	market for refractory, high aluminium oxide, packed refractory, high aluminium oxide, packed APOS, U - GLO
Industrial machinery	market for industrial machine, heavy, unspecified industrial machine, heavy, unspecified APOS, U - RoW
Transport	
Transport, Truck > 32 tonnes, EURO3	transport, freight, lorry >32 metric ton, EURO3 transport, freight, lorry >32 metric ton, EURO3 APOS, U - RoW
Transport, Maritime, in bulk for dry products	transport, freight, sea, bulk carrier for dry goods transport, freight, sea, bulk carrier for dry goods APOS, U - GLO
Transportation, bands	transport, freight, conveyor belt transport, freight, conveyor belt without electricity APOS, U - GLO

Table S2. Summary of processes taken from Ecoinvent database for LCIA Cement in Ecuador

Input/output inventory item	OpenLCA - Ecoinvent database
Raw Materials	
Limestone	limestone production, crushed, for mill limestone, crushed, for mill APOS, U - RoW
Gypsum	gypsum quarry operation gypsum, mineral APOS, U - RoW
Other flows	
Cement Factory	market for cement factory cement factory APOS, U - GLO
Low alloy steel	market for steel, low-alloyed steel, low-alloyed APOS, U - GLO
Transport	
Transport, Truck > 32 tonnes, EURO3	transport, freight, lorry >32 metric ton, EURO3 transport, freight, lorry >32 metric ton, EURO3 APOS, U - RoW
Transport, Maritime, in bulk for dry products	transport, freight, sea, bulk carrier for dry goods transport, freight, sea, bulk carrier for dry goods APOS, U - GLO
Transportation, bands	transport, freight, conveyor belt transport, freight, conveyor belt without electricity APOS, U - GLO

Table S3. Summary of processes taken from Ecoinvent database for LCIA Concrete in Ecuador

Input/output inventory item	OpenLCA - Ecoinvent database
Raw Materials	
Coarse Aggregate	gravel production, crushed gravel, crushed APOS, U - RoW
Natural sand	sand quarry operation, extraction from river bed sand APOS, U - RoW
Crushed Sand	gravel and sand quarry operation sand APOS, U - RoW
Tap water	market for tap water tap water APOS, U - PE
Concrete admixtures	chemical production, organic chemical, organic APOS, U - GLO
Fuels and energy	
Diesel (Building machine)	diesel, burned in building machine diesel, burned in building machine APOS, U - GLO
Diesel (Electric Generator)	diesel, burned in diesel-electric generating set, 10MW diesel, burned in diesel-electric generating set, 10MW APOS, U - GLO
Other flows	
Oil and lubricants	lubricating oil production lubricating oil APOS, U - RoW
Synthetic rubber	market for synthetic rubber synthetic rubber APOS, U - GLO
Concrete mixing factory	market for concrete mixing factory concrete mixing factory APOS, U - GLO
Low alloy steel	market for steel, low-alloyed, hot rolled steel, low-alloyed, hot rolled APOS, U - GLO
Transport	
Transport, Truck > 32 tonnes, EURO3	transport, freight, lorry >32 metric ton, EURO3 transport, freight, lorry >32 metric ton, EURO3 APOS, U - RoW

Table S4. Life cycle inventories of clinker production in Ecuador (per ton of clinker)

Flow inventory item	Amount	Unit
Input		
Raw Materials		
Limestone, crushed, for mill	1432.63	kg
Clay 1	175.44	kg
Clay 2	26.56	kg
Clay 3	6.36	kg
Clay 4	0.12	kg
Iron ore, crude ore, 46% Fe	0.41	kg
Fluorspar, 97% purity	0.18	kg
Copper slag	14.37	kg
Slag, unalloyed electric arc furnace steel	0.146	kg
Fuels and energy		
Petroleum coke	88.91	kg
Diesel, low-sulfur	0.32	kg
Electricity, medium voltage	71.24	kWh
Alternative fuels		
Biowaste	18.99	kg
Municipal solid waste	3.24	kg
Waste mineral oil	0.47	kg
Other flows		
Refractory, basic, packed	0.190	kg
Refractory, high aluminium oxide, packed	0.137	kg
Refractory, fireclay, packed	0.082	kg
Steel, chromium steel 18/8, hot rolled	0.059	kg
Lubricating oil	0.047	kg
Tap water	2.76	kg
Industrial machine, heavy, unspecified	0.038	kg
Cement factory	9.45 x10 ⁻⁰⁹	Item(s)
Transport		
transport, freight, conveyor belt	2.11	t*km
transport, freight, lorry >32 metric ton, EURO3	38.36	t*km
transport, freight, sea, bulk carrier for dry goods	449.45	t*km
Output		
Emissions to air		
Carbon dioxide, fossil	842.69	kg
Nitrogen oxides	1.61	kg
Sulfur dioxide	0.058	kg
Particulates, < 2.5 um	0.0046	kg

Table S4. Cont.

Flow inventory item	Amount	Unit
Particulates, > 10 um	0.0033	kg
Particulates, > 2.5 um, and < 10um	0.0017	kg
VOC, volatile organic compounds, unspecified origin	0.077	kg
Ammonia	25.00	mg
Antimony	2.00	mg
Arsenic	5.90	mg
Benzene	88.00	mg
Cadmium	6.00	mg
Carbon monoxide, fossil	0.875	kg
Chromium	8.80	mg
Cobalt	11.80	mg
Copper	14.70	mg
Hydrogen chloride	13.50	mg
Lead	17.60	mg
Mercury	2.80	mg
Nickel	11.80	mg
Thallium	6.00	mg
Vanadium	17.60	mg
Dioxins, measured as 2,3,7,8-tetrachlorodibenzo-p-dioxin	0.097	µg
Solid waste		
Inert waste, for final disposal	0.179	kg
Municipal solid waste	0.044	kg

Table S5. Life cycle inventories of concrete production in Ecuador (per m3 of ready-mixed concrete)

Flow inventory item	Unit	2.5	15	18	21	24	28	30	35	40	45	50	60	80
Raw Materials														
Cement, HE Type	kg	137.69	251.71	275.16	291.09	313.4	331.85	356.81	387.99	455.18	485.8	492.52	544.11	583.53
Gravel, crushed	kg	280.49	725.06	835.11	857	883.19	892.29	935.47	951.68	912.42	848.52	941.76	983.01	886.57
Sand, crushed	kg	228.28	150.55	186.91	265.49	149.32	207.37	363.05	154.04	230.99	122.64	163.01	194.25	295.96
Sand, from river bed	kg	1449.8	954.34	826.94	732.01	768.43	730.49	471.25	670.3	554.11	668.01	553.42	457.33	375.17
Tap water	kg	195.73	190.49	179.16	179.15	184.86	178.71	189.36	162.13	171.25	193.12	173.25	176.94	179.02
Chemical, organic 1	kg	2.92	1.05	1.56	1.49	2.4	2.29	3.15	4.3	6.51	4.5	5.84	8.92	9.14
Chemical, organic 2	kg	0.01	1	1.42	1.83	1.21	1.69	1.15	1.12	0.87	0.56	1.09	0.15	0
Other flows														
Concrete mixing factory	Item	2.58x10 ⁻⁷	2.52x10 ⁻⁷	3.34x10 ⁻⁷	3.23x10 ⁻⁷	3.30x10 ⁻⁷	3.28x10 ⁻⁷	3.16x10 ⁻⁷	2.94x10 ⁻⁷	2.40x10 ⁻⁷	2.78x10 ⁻⁷	2.71x10 ⁻⁷	2.90x10 ⁻⁷	1.47x10 ⁻⁷
Diesel, burned in diesel-electric generating set, 10MW	MJ	9.59	2.02	5.49	3.31	5.23	9.96	1.11	6.32	2.47	5.58	8.97	5.2	0.04
Lubricating oil	kg	0.0499	0.0499	0.0499	0.0499	0.0499	0.0499	0.0499	0.0499	0.0499	0.0499	0.0499	0.0499	0.0499
Steel, low-alloyed, hot rolled	kg	0.0238	0.0238	0.0238	0.0238	0.0238	0.0238	0.0238	0.0238	0.0238	0.0238	0.0238	0.0238	0.0238
Synthetic rubber	kg	0.0636	0.0636	0.0636	0.0636	0.0636	0.0636	0.0636	0.0636	0.0636	0.0636	0.0636	0.0636	0.0636
Fuels and energy														
Electricity	kWh	4.67	4.43	3.99	4.35	3.77	4.17	3.41	4.89	6.51	4.86	5.17	5.74	7.73
Diesel, burned in building machine	MJ	10.78	6.94	9.69	9.09	10	10.06	8.15	8.85	7.64	11.03	7.26	7.38	5.52
Transport														
Transport, freight, lorry >32 metric ton, EURO3	t*km	112.35	145.6	141.8	137.97	166.36	138.07	210.1	134.99	102.33	180.38	116.16	90.21	53.81