	Technologie		Total CO2 reduction		Total CO2 reduction		CAPEX		CAPEX		OPEX (CO2-red.)		TOTEX		TOTEX 2		Kommentar
			min	max	min	max	min	max	min	max	min	max	min	max	best	worst	
			[kg CO2/t cli]	[kg CO2/t cli]	[kg CO2/t cem]	[kg CO2/t cem]	[Mio EUR]	[Mio EUR]	[EUR/t cem]	[EUR/t cem]	[EUR/t cem]	[EUR/t cem]	[EUR/t cem]	[EUR/t cem]	[EUR/t CO2]	[EUR/t CO2]	
	Reference plant 'Global average data of GCCA'	TRL	(832 kg CO2/t cli)	(832 kg CO2/t cli)													
0	(s. Annex II: Performance data of ref. plant, p. 185)		0,0	0,0	0,0	0,0	320,0	320,0	5,26	5,26	15,5	15,5	20,7	20,7	-	-	(0)
28	Optimisation of operating ball mills	9	0,3	2,0	0,2	1,4	0,015	0,025	0,00025	0,00041	-0,4	-0,1	-0,4	-0,1	-277,6	-461,1	
27	High efficiency Separators	9	1,3	2,5	0,9	1,8	1,5	1,5	0,02	0,02	-0,5	-0,2	-0,5	-0,2	-264,1	-187,3	
22	Variable speed drives for fans	9	0,0	1,9	0,0	1,4	0,1	0,2	0,0	0,0	-0,3	0,0	-0,3	0,0	-247,0	-	
29	Separate grinding of raw material components	9	0,6	0,7	0,4	0,5	2,0	5,0	0,0	0,1	-0,1	0,0	-0,1	0,1	-192,7	259,7	
	HTC, TOTEX including gate fee of 261 EUR for 4,7 t of sewage sludge for the production of 1 ton of hydrochar														-186,7	-112,8	(17)
31	Separate ultra-fine grinding a. blending of cements	4/6	0,2	7,7	0,1	5,5	25,0	25,0	0,4	0,4	-1,4	-1,4	-1,0	-1,0	-178,4	-6.868,3	
32	Waste heat recovery: ORC	9	5,0	8,0	3,6	5,8	15,0	25,0	0,25	0,41	-1,1	-0,6	-0,9	-0,2	-148,2	-52,5	
33	Waste heat recovery: Steam	9	5,0	12,0	3,6	8,6	20,0	30,0	0,33	0,49	-1,6	-0,6	-1,3	-0,1	-147,1	-29,7	
26	Cement grinding w. vertical roller mills a. roller presses	9	3,8	10,1	2,7	7,3	4,0	15,0	0,1	0,2	-1,1	-1,1	-1,0	-0,9	-142,2	-311,9	
27	Alternative fuels replacing conventional fossil fuels	9	28,0	39,0	20,2	28,1	5,0	15,0	0,08	0,25	-4,0	-3,0	-3,9	-2,8	-139,5	-136,6	
28	Waste heat recovery: Kalina Cycle	9	6,0	14,0	4,3	10,1	20,0	30,0	0,33	0,49	-1,7	-0,7	-1,4	-0,2	-136,0	-47,9	
29	Pre-treatment of alternative fuel (grinding, drying)	8/9	11,3	23,6	8,1	17,0	2,0	20,0	0,03	0,33	-2,1	-2,1	-2,1	-1,8	-121,7	-217,7	
30	Pre-combustion chambers and gasification	9	22,0	22,0	15,8	15,8	8,0	12,0	0,13	0,20	-1,9	-1,9	-1,8	-1,7	-111,6	-107,5	
21	Advanced plant control and AI-supported control syst.	8/9	1,9	12,8	1,4	9,2	0,3	5,0	0,0	0,1	-0,8	-0,2	-0,8	-0,1	-86,4	-86,1	
22	Oxygen enrichment technology	9	-11,0	9,0	-7,9	6,5	5,5	11,0	0,09	0,18	-0,4	-2,0	-0,3	-1,8	-47,8	-	(7)
23	Retrofit mono-channel to multi-chanel burner	9	2,2	3,3	1,6	2,4	0,5	0,7	0,01	0,01	-0,1	-0,1	-0,1	-0,1	-47,0	-43,7	
2	Change from long to preheater/precalciner kilns	9	82,8	252,8	59,6	182,0	70,0	100,0	1,15	1,64	-9,1	-2,8	-7,9	-1,2	-43,7	-19,6	(2)
37	Use of lime stone or other materials	9	259,3	259,3	186,7	186,7	8,0	12,0	0,1	0,2	-8,0	-6,0	-7,9	-5,8	-42,1	-31,1	(37)
38	Cements with very high limestone content	5	383,5	383,5	276,1	276,1	8,0	12,0	0,1	0,2	-11,0	-11,0	-10,9	-10,8	-39,4	-39,1	(38)
39	Additional preheater cyclone stage(s)	9	7,0	9,0	5,0	6,5	5,0	8,0	0,08	0,13	-0,3	-0,3	-0,2	-0,1	-35,2	-23,5	
35	Use of natural pozzolanas	9	259,5	259,5	186,8	186,8	8,0	12,0	0,1	0,2	-6,3	-6,3	-6,2	-6,1	-33,0	-32,7	(35)
36	Preheater modific. (cyclones) with lower press. drop	9	3,8	3,8	2,7	2,7	8,0	10,0	0,13	0,16	-0,2	-0,2	-0,1	0,0	-28,7	-16,7	
37	Efficient clinker cooler technology	9	3,0	26,0	2,2	18,7	1,0	3,0	0,02	0,05	-0,5	0,0	-0,5	0,0	-25,8	22,8	
34	Use of granulated blast furnace slag	-	618,4	618,4	445,2	445,2	5,0	10,0	0,1	0,2	-11,0	-11,0	-10,9	-10,8	-24,5	-24,3	(34)
35	Alternative decarbonated raw mat.s for clinker prod.	9	98,0	100,0	70,6	72,0	0,0	6,0	0,00	0,10	-1,0	0,0	-1,0	0,1	-13,9	1,4	
48	Carbon Capture best case (Amine Scrubbing, MEA)	8/9	1.100,0	1.100,0	792,0	792,0	200,0	275,0	3,3	4,5	50,0	50,0	53,3	54,5	67,3	68,8	(48)
49	HTC and Torrefaction	7/9	50,6	56,1	36,4	40,4					3,0	5,4	3,0	5,4	74,3	148,2	(17)
50	Fuel switch (coal/petcoke to oil/gas)	9	-120,0	60,0	-86,4	43,2	5,0	15,0	0,08	0,25	5,0	7,0	5,1	7,2	117,6	-	
50	Use fo hydrogen as fuel	6	30,0	30,0	21,6	21,6	2,3	4,5	0,04	0,07	3,4	3,4	3,4	3,5	159,2	160,8	
51	Increase of kiln capacity	9	14,0	20,3	10,1	14,6	290,0	290,0	4,77	4,77	-0,9	-0,6	3,9	4,2	264,6	413,4	(5)
51	CO2 use: Power-to-liquids (Methanol)	8	29,0	54,0	20,9	38,9	185,0	194,0	3,0	3,2	172,1	172,1	175,1	175,3	4.504,1	8.394,1	(51)
50	CO2 use: Power-to-gas (CH4)	9	16,0	20,0	11,5	14,4	18,0	18,0	0,3	0,3	254,2	254,2	254,5	254,5	17.670,5	22.088,2	(50)
1	Improving raw mix burnability	9	3,4	15,4	2,4	11,1	-	-	-	-	-0,6	-0,1	-	-	-	-	(1)
2	Electrification, plasma and other technologies	4	-1.504,0	-304,0	-1.082,9	-218,9	n.av.	n.av.	n.av.	n.av.	n.av.	n.av.	-	-	-	-	(19)
3	Recycled concrete fines as raw mat. for clinker prod.	8	68,0	68,0	49,0	49,0	n.av.	n.av.	n.av.	n.av.	-0,8	-0,8	-	-	-	-	
23	Auxiliary system efficiency	9	2,0	3,0	1,4	2,2	-	-	-	-	-0,6	-0,3	-	-	-	-	
24	Energy management	9	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.av.	n.av.	-	-	-	-	
25	Optimised cement plant op. with renewable power	9	1,0	8,0	0,7	5,8	25,0	25,0	0,4	0,4	n.av.	n.av.	-	-	-	-	
30	Advanced Grinding	1	n.ap / n.av.	n.ap / n.av.	n.ap / n.av.	n.ap / n.av.	n.av.	n.av.	n.av.	n.av.	n.av.	n.av.	-	-	-	-	
32	Increased cement performance (particle size distrib.)	9	0,0	42,4	0,0	30,5	n.ap.	n.ap.	n.ap.	n.ap.	-2,1	-2,1	-	-	-	-	
33	Optimised use of grinding aids	9	0,3	1,1	0,2	0,8	n.ap.	n.ap.	n.ap.	n.ap.	-0,2	-0,1	-	-	-	-	
36	Use of natural calcined pozzolanas	9	213,0	213,0	153,4	153,4	n.av.	n.av.	n.av.	n.av.	-4,5	-4,5	-	-	-	-	(36)
39	Impact of very high/very low lime saturation factor	9	2,0	7,0	1,4	5,0	n.ap.	n.ap.	n.ap.	n.ap.	2,2	2,9	-	-	-	-	(39)
40	Recycled concrete fines as a cement constituent	6	171,0	171,0	123,1	123,1	n.av.	n.av.	n.av.	n.av.	-2,3	0,3	-	-	-	-	
41	Reduction of clinker content by use of fly ash	9	254,0	254,0	182,9	182,9	n.ap.	n.ap.	n.ap.	n.ap.	-2,5	-2,5	-	-	-	-	(41)
42	Reduction of CO2 by efficient use of concrete	4	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	-	-	-	-	(42)
43	Alkali-activated binders	-	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	-	-	-	-	
44	Cements based on carbonates or calciumsilicates	-	200,0	300,0	144,0	216,0	n.av.	n.av.	n.av.	n.av.	n.av.	n.av.	-	-	-	-	
45	Other low carbonate clinkers: Pre-hydrated Ca-silicates	1	n.av.	n.av.	n.av.	n.av.	n.av.	n.av.	n.av.	n.av.	n.av.	n.av.	-	-	-	-	
46	Other low carbonate clinkers: Belite cements	9	32,0	44,0	23,0	31,7	n.ap.	n.ap.	n.ap.	n.ap.	2,7	3,3	-	-	-	-	(46)
47	46, but with (Belite) calcium sulfoaluminate clinker	9	n.av.	n.av.	n.av.	n.av.	n.av.	n.av.	n.av.	n.av.	n.av.	n.av.	-	-	-	-	
49	CO2 use: Basic chemicals, urea, formic acid, …	6/9	n.ap.	n.ap.	n.ap.	n.ap.	n.av.	n.av.	n.av.	n.av.	n.av.	n.av.	-	-	-	-	
52	CO2 use: Enhanced Oil or Gas Recovery	9	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	-	-	-	-	
53	CO2 use: Algae capture and fuel production	7	750,0	750,0	540,0	540,0	n.av.	n.av.	n.av.	n.av.	n.av.	n.av.	-	-	-	-	
54	Natural Carbonation	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	(54)
55	Enforced (re)carbonation/mineralisation	6/9	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	n.ap.	-	-	-	-	

Erläuterungen:
CAPEX, OPEX, TOTEX basierend auf 2030 Angaben

Klinker Kapazität t/Tag	6000	2.190.000 t/a
Abschreibungsdauer Invest [a]	20	
Klinker Zement Faktor:	0,72	
Zement Kapazität t/Tag	8333	3.041.667 t/a

Remarks:
(0) reference scenario
(1) Ssaving potential of this measure is limited. Addition of small quantities can improve product quality, larger quantities will affect quality and the kiln operation through increased coating formation. Additional costs of mineralisers and/or fluxing agents need to be considered carefully.
(2) The dry process with cyclone preheaters and precalciner is the state-of-the-art technology for cement clinker production. Nevertheless, many long dry or long wet
(5) Only applicable for new investments (as shown in table). As the clinker-specific energy requirement is directly dependent on the dimension of the clinker kiln, an increase of the kiln capacity is linked to a reduction of specific CO2 emis
(7) The oxygen enrichment technology is established in some cement plants in order to improve production capacity in periods of high market demand and has not been applied to reduce CO2 emissions so far, but the use of enriched combustion air may result in fuel savings and thereby avoids CO2 production.
(17) ohne Entsorgungseinnahmen, Angabe Dr. Ruppert: nur HTC zwischen 103 und 178 EURt CO2; CAPEX in OPEX integrated.
(17) including gate fee: 1 ton of sewage sludge results in 210 kg of hydrochar, 4,76 t of sew. sludge -> 1 ton of hydrochar; gate fee sew sludge 55 EUR/t (for 4,76 t 261 EUR)
(34) Reduction fo clincer content in cement by use of granulated blast furnace slag. Cements containing granulated blast furnace slag (GBFS) are very common. Their production involves blending by the separately ground clinker and GBFS or inter-grinding the two constituents. As compared to Portland cement less clinker is needed per
(35) Reduction of clincer content in cement by use of natural pozzolanas; data in comparision to portland cement.
(36) Compared to portland cement.
(37) Compared to portland cement.
(38) Compared to portland cement.
(39) Compared to portland cement.
(41) Compared to portland cement.
(42) Compared to portland cement.
(46) Compared to portland cement.
(48) Capture rate 95 %.
(50) The costs for the installation of a power-to-gas plant are the same – both for the installation in an existing cement plant and in a new cement plant.
(51)
(54) Carbonation is the formation of calcium carbonate from calcium-containing hydration products in the hardened cement paste of concrete. The rate of carbonation is low in normal concrete under ambi- ent conditions (0.04% CO2 in air) and usually only a few centimetres of the concrete cover are affected. The Intergovernmental Panel

Assumption for HTC-scenario: biomass content of fuel mix in the cement plant, 20% increase and substitution rate.