

Supplementary Materials

Environmental Assessment of Hellisheidi Geothermal Power Plant based on Exergy Allocation Factors for Heat and Electricity Production

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GEOTHERMAL WELL PARAMETERS

Table S1. Main well parameters

Stage	Parameters	Number of wells	Meters drilled, average depth	Meters drilled, total depth
Construction	<i>Total Production wells</i>	54	---	---
	Narrow - Diesel	16	2346	37191
	Narrow - Electricity	0	---	---
	<i>Total Narrow wells</i>	16	---	---
	Wide - Diesel	38	2247	85947
	Wide - Electricity	0	---	---
	<i>Total Wide wells</i>	38	---	---
	<i>Total Reinjection wells</i>	17	---	1968
	Total wells in construction	71	---	123138
Maintenance (Make-up wells)	Narrow - Diesel	1	2346	2531
	Narrow - Electricity	1	2346	2497
	<i>Total Narrow wells</i>	2	---	---
	Wide - Diesel	0	---	---
	Wide - Electricity	28	2247	62342
	<i>Total Wide wells</i>	28	---	---
	Total wells in maintenance	30	---	---

LCA OF HELLISHEIDI POWER PLANT

In this section are included the stages evaluated and referred to 1kWe and 1kWt.

Table S2. Inventory related to Hellisheidi power plant (1kWe or 1kWt)

Process stage	Subprocess	Amount
Construction	Geothermal wells - Construction	(1/Net electricity or heat in 30 years)*Exergy Alloc.(E or H)
	Wellhead equipment - Construction	(1/Net electricity or heat in 30 years)*Exergy Alloc.(E or H)
	Collection pipelines - Construction	(1/Net electricity or heat in 30 years)*Exergy Alloc.(E or H)
	Extraction site-Land use - Construction	(1/Net electricity or heat in 30 years)*Exergy Alloc.(E or H)
	Power plant or heating station buildings - Construction	(1/Net electricity or heat in 30 years)
	Mechanical equipment - Construction	(1/Net electricity or heat in 30 years)
	Abatement (only steel) - Construction	(1/Net electricity or heat in 30 years)*Exergy Alloc.(E or H)
Operation, maintenance and abatement (O&M&A)	Geothermal fluid - Operation	(1/Net electricity or heat in 30 years)*Exergy Alloc.(E or H)
	Abatement (only emissions) - Operation	(1/Net electricity or heat in 30 years)* Exergy Alloc.(E or H)
	Chemicals - Maintenance	(1/Net electricity or heat in 30 years)
	Geothermal wells - Maintenance	(1/Net electricity or heat in 30 years)* Exergy Alloc.(E or H)
	Wellhead equipment - Maintenance	(1/Net electricity or heat in 30 years)* Exergy Alloc.(E or H)
	Collection pipelines - Maintenance	(1/Net electricity or heat in 30 years)* Exergy Alloc.(E or H)
	Extraction site-Land use - Maintenance	(1/Net electricity or heat in 30 years)* Exergy Alloc.(E or H)
End-of-Life	Wells closure of the geothermal plant (dismantling).	(1/Net electricity or heat in 30 years)*Exergy Alloc.(E or H)

LCI FOR THE CONSTRUCTION STAGE OF HELLISHEIDI POWER PLANT

Table S3. Inventory related to geothermal wells (construction)

Construction-Geothermal wells	Ecoinvent 3.6	Amount	Unit
Steel (for well casing)	Steel, low-alloyed {GLO} market for APOS, U	12171910.2	kg
Portland cement (Pre drilling)	Cement, Portland {Europe without Switzerland} market for APOS, U	654000	kg
Portland cement (Well casing)	Cement, Portland {Europe without Switzerland} market for APOS, U	5130409.9	kg
Silica flour (Well casing)	Sand, quartz	2052164.6	kg
Wyoming bentonite (Well casing)	Bentonite {GLO} market for APOS, U	102605.8	kg
Perlite (Well casing)	Perlite {GLO} market for APOS, U	102605.8	kg
Retardant (drilling)	Bitumen seal, polymer EP4 flame retardant {GLO} market for APOS, U	9391	kg
Water binder (drilling)	Acrylic binder, without water, in 34% solution state {GLO} market for APOS, U	23165	kg
Water (from ground, drilling)	Water, groundwater consumption	4171377.2	kg
Drill Soap (drilling)	Foaming agent {GLO} market for APOS, U	74429.99	kg
Bentonite Clay (drilling)	Bentonite {GLO} market for APOS, U	4147475	kg
Caustic soda (drilling)	Sodium hydroxide, without water, in 50% solution state {GLO} market for APOS, U	198165.97	kg

Table S4. Inventory related to wellhead equipment (construction)

Construction-Wellhead equipment	Ecoinvent 3.6	Amount	Unit
Excavation	Excavation, hydraulic digger {GLO} market for APOS, U	213000	m ³
Fill	Excavation, hydraulic digger {GLO} market for APOS, U	71000	m ³
Concrete	Concrete, normal {GLO} market for APOS, U	3067200	kg
Steel	Steel, low-alloyed {GLO} market for APOS, U	1034754	kg
Stainless steel	Steel, chromium steel 18/8 {GLO} market for APOS, U	1136	kg
Aluminium	Aluminium, primary, ingot {RoW} market for APOS, U	86478	kg

Table S5. Inventory related to collection pipeline (construction)

Construction-Collection pipeline	Ecoinvent 3.6	Amount	Unit
Excavation	Excavation, hydraulic digger {GLO} market for APOS, U	648000	m ³
Fill	Excavation, hydraulic digger {GLO} market for APOS, U	298800	m ³
Concrete	Concrete, normal {GLO} market for APOS, U	25920000	m ³
Steel	Steel, low-alloyed {GLO} market for APOS, U	7092000	kg
Aluminium	Aluminium, primary, ingot {RoW} market for APOS, U	223200	kg

Rockwool	Rock wool {GLO} market for APOS, U	1548000	kg
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Table S6. Inventory related to extraction site-land use (construction)

Construction-Extraction site-Land use	Ecoinvent 3.6	Amount	Unit
Land use for drilling operations	Area of land occupied by extraction site	1065	m ²
Land use for drilling operations	Area of Transformation, from forest	6390	m ²
Land use for drilling operations	Area of Transformation, to mineral extraction site	6390	m ²
Land use for drilling operations	Water, well, in ground	237140	kg

Table S7. Inventory related to power plant buildings (construction)

Construction-Power plant buildings	Ecoinvent 3.6	Amount	Unit
Excavation	Excavation, hydraulic digger {GLO} market for APOS, U	647208	m ³
Filling	Excavation, hydraulic digger {GLO} market for APOS, U	740229	m ³
Concrete	Concrete, 40MPa {RoW} market for concrete, 40MPa APOS, U	66175200	kg
Steel	Steel, low-alloyed {GLO} market for APOS, U	3956271	kg
Stainless steel	Steel, chromium steel 18/8 {GLO} market for APOS, U	223614	kg
Aluminium	Aluminium, cast alloy {GLO} market for APOS, U	174831	kg
Copper	Copper {GLO} market for APOS, U	45450	kg
Rockwool	Stone wool {GLO} market for stone wool APOS, U	179982	kg
Plastic	Polyethylene, high density, granulate {GLO} market for APOS, U	220887	kg
Asphalt	Mastic asphalt {GLO} market for APOS, U	10940724	kg

Table S8. Inventory related to heating station buildings (construction)

Construction-Heating station buildings	Ecoinvent 3.6	Amount	Unit
Excavation	Excavation, hydraulic digger {GLO} market for APOS, U	102011	m ³
Fill	Excavation, hydraulic digger {GLO} market for APOS, U	74879	m ³
Concrete	Concrete, normal {GLO} market for APOS, U	7980000	kg
Steel	Steel, low-alloyed {GLO} market for APOS, U	2933714	kg
Stainless steel	Steel, chromium steel 18/8 {GLO} market for APOS, U	33516	kg
Aluminium	Aluminium, primary, ingot {RoW} market for APOS, U	39102	kg
Copper	Copper {GLO} market for APOS, U	8778	kg
Mineral wool	Rock wool {GLO} market for APOS, U	33117	kg
Asphalt	Mastic asphalt {GLO} market for APOS, U	235410	kg

Table S9. Inventory related to mechanical equipment for electricity (construction)

Equipment	Amount
Power HP_HPS - Steam separators	1
Power HP_HPM - Moisture removers	1
Power HP_HPTG - Turbine generator_45MW	1
Power HP_CT - Cooling tower	1
Power HP_Pump1	1
Power HP_Pump2	1
Power LP_LPS - Steam separators	1
Power LP_LPM - Moisture removers	1
Power LP_LPTG - Turbine generator	1
Power LP_LPC - Condenser	1
Power LP_CT - Cooling tower	1
Power LP_Pump3	1
Power LP_Pump4	1
Power HP_HPC – Condenser PwP	1*Exergy_Alloc.(E)

Table S10. Inventory related to mechanical equipment for heating (construction)

Equipment	Amount
Heating_HWST - District Heating Water Tank, DHT	1
Heating_HWP - Hot water pump	1
Heating_ET - electrical transformer	1
Heating_DHHX - Heat exchanger for district heating water	1
Heating_DA - Deaerator	1
Heating_CWST - Cold Water Tank, CWT	1
Heating_CWP - Cold water pump	1
Power HP_HPC – Condenser DH	1*Exergy_Alloc.(H)

Table 11. Inventory related to mechanical equipment for electricity production_High Pressure (construction)

Material	Ecoinvent 3.6	HP_HPS	HP_HPM	HP_HPTG	HP_CT	HP_Pump1	HP_Pump2	HP_HPC
Steel	Steel, low-alloyed {GLO} market for APOS, U			2182829.24	241650.44			
Stainless steel	Steel, chromium steel 18/8 {GLO} market for APOS, U	57799.15	33028.09	3686.54	44680.81	23.85	644.21	393229.88
Aluminium	Aluminium, cast alloy {GLO} market for APOS, U			68850.00				
Copper	Copper {GLO} market for APOS, U			77014.23	18520.09	179.33	4844.59	
Titanium	Titanium dioxide {RER} market for APOS, U							140895.00
Mineral wool	Stone wool {GLO} market for stone wool APOS, U	45400.86	25943.35					
Plastic	Polyethylene, high density, granulate {GLO} market for APOS, U				2337.43			
GRP	Glass fibre reinforced plastic, polyamide, injection moulded {GLO} market for APOS, U				556308			
Transformer oil	Lubricating oil {RER} market for lubricating oil APOS, U			184410				

Table 12. Inventory related to mechanical equipment for electricity production_Low Pressure (construction)

Material	Ecoinvent 3.6	LP_LPS	LP_LPM	LP_LPTG	LP_LPC	LP_CT	LP_Pump3	LP_Pump4
Steel	Steel, low-alloyed {GLO} market for APOS, U			266790.24		40275.07		
Stainless steel	Steel, chromium steel 18/8 {GLO} market for APOS, U	5504.68	33028.09	450.58	60863.33	7446.80	3.69	152.32
Aluminium	Aluminium, cast alloy {GLO} market for APOS, U			8415.00				
Copper	Copper {GLO} market for APOS, U			9412.85		3086.68	27.77	1145.46
Titanium	Titanium dioxide {RER} market for APOS, U							
Mineral wool	Stone wool {GLO} market for stone wool APOS, U	4323.89	4323.89					
Plastic	Polyethylene, high density, granulate {GLO} market for APOS, U					389.57		
GRP	Glass fibre reinforced plastic, polyamide, injection moulded {GLO} market for APOS, U					92718.00		
Transformer oil	Lubricating oil {RER} market for lubricating oil APOS, U			22539.00				

Table 13. Inventory related to mechanical equipment for heating (construction)

Material	Ecoinvent 3.6	HWST	HWP	ET	DHHX	DA	CWST	CWP
Steel	Steel, low-alloyed {GLO} market for APOS, U		9448.32	9448.32	0	5107.2		1532.16
Stainless steel	Steel, chromium steel 18/8 {GLO} market for APOS, U	120	0	0	79959.6	21100.45	240	9994.95
Aluminium	Aluminium, cast alloy {GLO} market for APOS, U		0	0	688.94	242.06		0
Copper	Copper {GLO} market for APOS, U		46.47	0	744	0		7.53
Titanium	Titanium dioxide {RER} market for APOS, U		0	0	3630.9	1024.1		0
Mineral wool	Stone wool {GLO} market for stone wool APOS, U							
Plastic	Polyethylene, high density, granulate {GLO} market for APOS, U	44.33	0	0	0	0	101.97	0

Table 14. Inventory related to Abatement unit during electricity and heating production (Construction)

Material	Ecoinvent 3.6	Amount	Unit
Steel	Steel, low-alloyed {GLO} market for APOS, U	13907.7	kg

LCI FOR THE OPERATION AND MAINTENANCE STAGE OF HELLISHEIDI POWER PLANT

In this stage, inputs and outputs related to the geothermal fluid are included per 1kg of geothermal fluid. The total amount of geothermal fluid in 30 years of operation is 9.93E11 kg.

Table 15. Inventory related to Geothermal fluid (Operation)

O&M-Geothermal fluid	Ecoinvent 3.6	Amount	Unit
Inputs			
<i>Resources</i>			
Water	Water, process, well (in ground)	0.09	g/kg Geothermal fluid
Energy	Energy, geothermal	1.41E3	kJ/ kg Geothermal fluid
Outputs			
<i>Emissions</i>			
CO ₂	Carbon dioxide	1.4	g/kg Geothermal fluid
H ₂ S	Hydrogen sulfide	0.36	g/kg Geothermal fluid
H ₂	Hydrogen	1.5E-2	g/kg Geothermal fluid
CH ₄	Methane	2.1E-3	g/kg Geothermal fluid
Heat	Heat, waste	1110	kJ/ kg Geothermal fluid

Table 16. Inventory related to substances for electricity and heating production (Operation)

O&M-substances	Ecoinvent 3.6	Amount	Unit
Groundwater (P)	Water, well, Europe without Switzerland	2.83824E+11	kg
Groundwater (H)	Water, well, Europe without Switzerland	4.12964E+11	kg
Sodium hypochlorite (P)	Sodium hypochlorite, without water, in 15% solution state {RER} market for sodium hypochlorite, without water, in 15% solution state APOS, U	700000	kg
Silica (H)	Sand, quartz	5676	kg

Table 17. Inventory related to substances for Abatement unit during electricity and heating production (Operation)

O&M-emissions	Ecoinvent 3.6	Amount	Unit
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CO ₂ emitted	Carbon dioxide	974726262	kg
H ₂ S emitted	Hydrogen sulfide	131642850	kg

Table 18. Inventory related to machinery component replacement for electricity (Maintenance)

O&M-Machinery replacement	Ecoinvent 3.6	Amount	Unit
Steel	Steel, low-alloyed {GLO} market for APOS, U	819464	kg
Stainless steel	Steel, chromium steel 18/8 {GLO} market for APOS, U	192163	kg
Aluminium	Aluminium, cast alloy {GLO} market for APOS, U	23180	kg
Copper	Copper {GLO} market for APOS, U	34269	kg
Titanium	Titanium dioxide {RER} market for APOS, U	42269	kg
Mineral wool	Stone wool {GLO} market for stone wool APOS, U	23998	kg
Plastic	Polyethylene, high density, granulate {GLO} market for APOS, U	818	kg
GRP	Glass fibre reinforced plastic, polyamide, injection moulded {GLO} market for APOS, U	194708	kg
Transformer oil	Lubricating oil {RER} market for lubricating oil APOS, U	62085	kg

Table 19. Inventory related to machinery component replacement for heating (Maintenance)

O&M-Machinery replacement	Ecoinvent 3.6	Amount	Unit
Steel	Steel, low-alloyed {GLO} market for APOS, U	7661	kg
Stainless steel	Steel, chromium steel 18/8 {GLO} market for APOS, U	33317	kg
Aluminium	Aluminium, cast alloy {GLO} market for APOS, U	279	kg
Copper	Copper {GLO} market for APOS, U	239	kg
Rockwool	Stone wool {GLO} market for stone wool APOS, U	1397	kg
Plastic	Polyethylene, high density, granulate {GLO} market for APOS, U	44	kg

LCI FOR THE END-OF-LIFE STAGE OF HELLISHEIDI POWER PLANT

Table 20. Inventory related to wells closure of the geothermal plant (End-of-Life)

O&M-Geothermal fluid	Ecoinvent 3.6	Amount	Unit
Diesel	Diesel {Europe without Switzerland} market for APOS, U	2146250	kg
Portland cement	Cement, Portland {Europe without Switzerland} market for APOS, U	2525000	kg
Inert	Unspecified waste, unspecified treatment	505000	kg