

Supplementary Material for

Technical, Environmental, and Cost Assessment of Granite Sludge Valorisation

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Figure S1. Differential particle size distribution of GS sample.

Table S1: Life Cycle Inventory assumptions for Granite block sawing.

Table S2. Inventories for LCA and LCC of GS disposal in a landfill (Scenario 1). All values are referred to a 1 m² granite slab (Functional Unit).

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Table S5: Sensitivity analysis of the environmental impacts calculated according to the ReCiPe Midpoint (H) method for Scenario 1, Scenario 2, and Scenario 3 considering different transport distances. Light red and dark green cells indicate the highest and the lowest values of impact. All values are referred to the functional unit 1 m² granite slab. (Cut-off 0.1%).

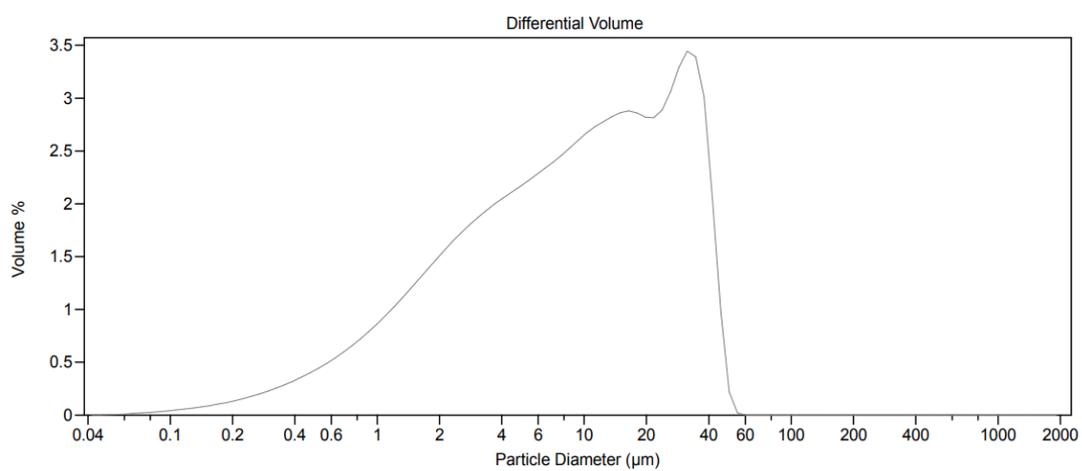


Figure S1. Differential particle size distribution of GS sample.

Table S1: Life Cycle Inventory Assumptions for Granite block sawing.

Assumption	Description
1	Scenarios 1-3 were elaborated considering that 5 granite blocks of approximately 8 m ³ each enter the plant per month and are moved by a crane bridge to a Diamond Multi-Circular Saw (DMCS), where they are cut into slabs of 20 mm width [30].
2	The “granite pulp” produced during sawing, which is made mainly of granite sawdust and water used for cooling, is sent to a decanter, where, in the presence of a flocculant, is partially settled. The liquid fraction obtained is sent back to the sawing circuit, whereas the solid fraction proceeds to a filter press for final dewatering. During cutting, 49.5 t per year of granite scrap is produced and introduced in the market. Neither additional environmental credits nor further economic revenue was considered for the granite scrap.
3	The amount of freshwater needed as cooling water was calculated considering that the hydraulic circuit of the saw machine is filled with 38.4 m ³ of freshwater, which is pumped from the company's private well at the starting-up of the DMCS. Approximately 650 L per day of the same freshwater is added to the circuit to compensate for the water losses associated with the residual moisture present in sludge and the water evaporated during the sawing operations (Figure 1a-c). The impact associated with the depletion of the freshwater needed to initially fill up the circuit is equally divided for the sawing equipment lifetime (20 years).
4	In Scenario 1, 4.2 m ³ per week of filter-pressed granite sludge, characterized by moisture content of 23.5 % W_{H_2O}/W_{sludge} and bulk density of approximately 2290 kg/m ³ , is produced and sent to landfill, whereas the water separated in the filter-press goes back to the sawing circuit (Figure 1a). The transportation of the granite sludge is performed with a EURO4 truck of 16-32 t load capacity, for an average distance of 20 km from the plant.
5	In Scenario 2, the entire amount of GS produced by the plant (approx. 500 t per year) was used as a substitute for feldspar in the production of ceramic paste. In ceramic paste formulations, feldspar is commonly the second most important ingredient after clay [40], being in the flooring sector the main constituent [39]. It was assumed that GS is used in this scenario as it is (moisture content of 23.5% $W_{H_2O}/W_{granite\ sludge}$), without any additional drying step, since the ceramic production process is performed in a liquid state. In this Scenario 2, no additional transportation was considered.

Table S1: Cont.

Assumption	Description
6	<p>In Scenario 3, the entire amount of GS was considered as a substitute for fine inert filler in the production of concrete mixtures. For this purpose total final drying step of GS was introduced at the sawing plant, since fine aggregates can be worked and mixed with other components successfully only under dried conditions (Beton Liz, 2022). For this reason, 25 t of water (m_{water}) per year must be evaporated.</p>
7	<p>The calculation of the additional energy required for water evaporation was done according to Eq. 1, considering the water specific heat ($c_{p,water}$) of 4.184 kJ/(kg. K), at 298 K (25 °C, T_1), and the evaporation temperature at 375 K (102 °C, T_2);</p> $\Delta H = m_{water} \times c_{p,water} \times \Delta(T_2 - T_1) \quad (\text{Eq.1})$
8	<p>The energy required to evaporate the water from GS is of 2311 kWh/year. For the GS drying, assuming the use of a double fan industrial drying chamber, of 86.05 kW power installed, fuelled with natural gas (NG), and with 50% thermal efficiency, 21056 kWh/y of heat is required. To account for this energy to the process inventory, the Econivent process “Heat production, Natural Gas, at industrial furnace low-NOx> 100 kW , heat district or industrial, Natural Gas Consequencial, U- Europe without Switzerland” was chosen. The GS available for substitution of inert filler after drying and the amount of evaporated water were adjusted accordingly. In this Scenario 3, no additional transportation was considered.</p>
9	<p>For the inventory of LCC, 0.22 €/kWh for electric energy [37] and 0.40 €/kWh for heat [35] were used for the calculation of specific costs.</p>
10	<p>The costs associated with transport and disposal to landfill were based on the data supplied by R.O.P. Regarding workers, it was assumed the presence of one specialized operator whose salary is calculated according to the Portuguese collective contract for machinery operators [38].</p>
11	<p>From a conservative perspective, no further additional revenues were accounted for the GS valorisation pathways 2 and 3, but only the savings obtained from the avoided transport and disposal in a landfill</p>

Table S2. Inventories for LCA and LCC of GS disposal in a landfill (Scenario 1). All values are referred to a 1 m² granite slab (Functional Unit).

Inputs	Value	Cost/Revenue	Reference
Electricity, PT mix, low voltage	4.16 kWh	0.915 €	
Granite block	82.6 kg	7.20 €	
Water process, unspecified, natural origin	13.0 kg	0.00 €	[30]
Water process, unspecified, natural origin (added to)	0.012 kg	0.00 €	
Lubricating oil	3.40×10^{-3}	0.009 €	
Flocculant	8.00×10^{-4}	6.1×10^{-4} €	
Stucco	9.59×10^{-3} kg	0.017 €	Calculated from [30]
Steel	0.021 kg	6.9×10^{-4} €	
Transport, 16-32 t, EURO4		0.16 €	
Disposal to Landfill	0.64 t×km	0.11	[30]
Specialized Worker		0.10 €	[38]
Outputs			
Granite slab	53.7 kg	23 €	-
Granite scrap	3.18 kg		
Granite sludge disposal to landfill	32.15 kg	0.17 €	[30]
Water process, unspecified, natural origin (recirculated)	-0.70 kg		Calculated from [30]
<i>Emissions</i>			
Dust	1.24 kg		Calculated from [3]
Water vapor	4.88 kg		
Steel grit	0.02 kg		

Table S3. Inventories for LCA and LCC of GS valorisation as a substitute for feldspar (Scenario 2). All values are referred to a 1 m² granite slab (Functional Unit).

Inputs	Value	Cost/Revenue	Reference
Electricity, PT mix, low voltage	4.16 kWh	0.915 €	
Granite block	82.6 kg	7.20 €	
Water process, unspecified, natural origin	13.0 kg	0.00 €	
Water process, unspecified, natural origin (added to)	0.012 kg	0.00 €	[30]
Lubricating oil	3.40×10^{-3} kg	9.0×10^{-3} €	
Flocculant	8.00×10^{-4} kg	6.1×10^{-4} €	
Stucco	9.59×10^{-3} kg	0.017 €	Calculated from [3,30]
Steel	0.021 kg	6.9×10^{-4} €	
Specialized Worker		0.10 €	[38]
Output			
Granite slab	53.7 kg	23 €	
Granite scrap	3.18 kg		[30]
Granite sludge	32.15 kg		
Water process, unspecified, natural origin (recirculated)	-0.60 kg		
<i>Avoided product</i>			
Avoided feldspar production	24.50 kg		
Avoided Water process, unspecified, natural origin	7.54 kg		[22,30]
<i>Emissions</i>			
Dust	1.24 kg		Calculated from [3]
Evaporated water	4.88 kg		
Steel grit	0.02 kg		[30]

Table S4. Inventories for LCA and LCC of GS valorisation as a substitute for fine inert filler in the production of concrete mixtures (Scenario 3). All values are referred to a 1 m² granite slab (Functional Unit).

Inputs	Value	Cost/Revenue	Reference
Electricity, PT mix, low voltage	4.16 kWh	0.915 €	
Heat Production at an industrial furnace, > 100 kW, NG, low-NOx	0.148 kWh	0.592 €	
Granite block	82.6 kg	7.20 €	
Water process, unspecified, natural origin	13.0 kg	0.00 €	[30]
Water process, unspecified, natural origin (added to)	0.012 kg	0.00 €	
Lubricating oil	3.40×10^{-3} kg	9.0×10^{-3} €	
Flocculant	8.00×10^{-4} kg	6.1×10^{-4} €	
Stucco	9.59×10^{-3} kg	0.017 €	Calculated from [3,30]
Steel	0.021 kg	6.9×10^{-4} €	
Specialized Worker		0.10 €	[38]
Output			
Granite slab	53.7 kg	23 €	
Granite scrap	3.18 kg		
Granite sludge	24.5 kg		
Recirculated water	0.60 kg		Calculated from [30]
<i>Avoided product</i>			
Avoided inert filler production	24.5 kg		[22,30]
<i>Emissions</i>			
Dust	1.24 kg	-	Calculated from [3]
Water evaporated (cut)	4.88 kg	-	
Water evaporated (drying)	7.54 kg	-	
Steel grit	0.02 kg	-	

Table S5: Sensitivity analysis of the environmental impacts calculated according to the ReCiPe Midpoint (H) method for Scenario 1, Scenario 2, and Scenario 3 considering different transport distances. Light red and dark green cells indicate the highest and the lowest values of impact, medium and light green intermediate values. All values are referred to the functional unit 1 m² granite slab. (Cut-off 0.1%).

Category of Impact	Unit	Scenario 1		Scenario 2		Scenario 3		
		disposal to landfill	no transport	transport 20 km	transport 50 km	no transport	transport 20 km	transport 50 km
Agricultural land occupation	m ² a	7.7E-03	-7.4E-04	-7.5E-04	-7.8E-04	-1.7E-05	-3.2E-05	-5.5E-05
Climate change	kg CO ₂ - eq	8.1E-01	-1.0E+00	-9.0E-01	-7.3E-01	-5.2E-01	-4.1E-01	-2.5E-01
Fossil depletion	kg oil eq	3.7E-01	-4.5E-01	-4.0E-01	-3.4E-01	-2.1E-01	-1.6E-01	-1.0E-01
Freshwater ecotoxicity	kg 1,4 DCB eq	2.6E-01	1.4E-01	1.4E-01	1.4E-01	1.2E-01	1.2E-01	1.2E-01
Freshwater eutrophication	kg P eq	5.3E-04	3.2E-04	3.5E-04	3.9E-04	3.1E-05	6.0E-05	1.0E-04
Human toxicity	kg 1,4 DCB eq	7.0E+00	5.6E-01	6.1E-01	6.8E-01	1.9E-01	2.4E-01	3.0E-01
Ionising radiation	kg U235 eq	5.1E-02	7.3E-02	8.0E-02	8.9E-02	-4.2E-02	-3.6E-02	-2.7E-02
Marine ecotoxicity	kg 1,4 DCB eq	2.4E-01	1.2E-01	1.2E-01	1.2E-01	1.0E-01	1.0E-01	1.0E-01
Marine eutrophication	kg N eq	1.6E-03	-8.3E-04	-6.4E-04	-3.5E-04	-1.5E-03	-1.4E-03	-1.1E-03
Metal depletion	kg Fe eq	2.1E-01	1.1E-01	1.2E-01	1.3E-01	7.9E-02	8.5E-02	9.3E-02
Natural Land Transformation	m ²	-1.5E-03	1.2E-05	1.4E-05	1.7E-05	-1.1E-04	-1.1E-04	-1.0E-04
Ozone depletion	kg CFC-11 eq	1.5E-07	-1.5E-07	-1.3E-07	-1.1E-07	-1.0E-07	-8.1E-08	-5.4E-08
Particulate matter or mation	kg PM10 eq	1.2E+00	1.2E+00	1.2E+00	1.2E+00	1.2E+00	1.2E+00	1.2E+00
Photochemical oxidant formation	kg NMVOC	5.1E-03	-3.1E-03	-2.5E-03	-1.6E-03	-4.8E-03	-4.3E-03	-3.4E-03
Terrestrial acidification	kg SO ₂ eq	5.1E-03	-1.0E-03	-5.7E-04	1.1E-04	-3.7E-03	-3.2E-03	-2.6E-03
Terrestrial ecotoxicity	kg 1,4 DCB eq	3.4E-04	6.6E-05	1.2E-04	2.0E-04	-4.7E-05	3.0E-06	7.8E-05
Urban land occupation	m ² a	1.3E-01	-2.6E-02	-2.2E-02	-1.5E-02	-3.9E-02	-3.4E-02	-2.7E-02
Water depletion	m ³	2.5E-03	-1.0E-03	-9.1E-04	-7.1E-04	-2.7E-04	-1.4E-04	4.0E-05

