EXECUTIVE SUMMARY:

Life Cycle Assessment of Zircon Sand Production Applied to Ceramic Tiles

On behalf of the Zircon Industry Association (ZIA)

Executive Summary:

The deliverables of the LCA project were twofold: 1. an assessment of the potential environmental impacts of the cradle-to-gate life cycle of zircon sand, and 2. its comparison to a competing product, alumina, in ceramic tiles. In collaboration with Centro Ceramico di Bologna, the study includes an evaluation of different tile mixtures, using alumina as an alternative to zircon as a whitener. Importantly, the zircon LCA was critically reviewed by an independent panel of three experts to ensure conformity to ISO 14040/44 standards.

Results demonstrate that the environmental profile of zircon sand production is driven by energy-related processes, particularly during mining and heavy mineral concentration. Other impacts relate to the generation of thermal energy or combustion of fuel, for drying processes and transportation.

When compared to alumina in super-white tile mixes, zircon-containing mixes show significantly lower environmental impact (20-50% lower) in all but one of the potential impacts assessed in this study.

For zircon milling, the LCA demonstrates that the main differences between zircon and alumina mixtures are closely tied to the environmental performance of regional grid electricity production. Analysis shows that, even considering worst case scenario for zircon mixtures and the best case for alumina mixtures, the conclusions of the study remain valid.

1. Goal and Scope of the Study

The study provides a cradle-to-gate life cycle inventory (LCI) and potential environmental impact data, plus a comparison between zircon and alumina in ceramic tiles (porcelain stoneware). Zircon or alumina act as whitening agents in tile mixtures and are used in different quantities to achieve various grades of whiteness. The content of these agents in the mixture impacts the relative proportions of other components, like clay, feldspar and kaolin.

In this LCA, two functional units were used: -

1. *Zircon LCA*: zircon production average – 1kg of zircon sand.
2. *Comparison*: alumina vs zircon tile mixture – 1kg of mix used for porcelain stoneware ceramic tile production, with a specific and measurable whiteness level called "super-white".

Centro Ceramico consulted many tile manufacturers to identify the super-white grade level as that with a mean value of L>85.

2. Methodology

The systems under study are termed "cradle-to-gate". The zircon sand LCA includes mining and mineral separation only. For the comparison step, zircon flour production (mining, separation and milling), alumina flour production (bauxite mining, refining, milling) and the tile body mixture preparation (i.e. production of feldspar, clay etc.) and all considered. Centro Ceramico developed six mixture recipes, three each for zircon and alumina, based on a comparable whiteness level. The tile production steps following the mixture preparation.

The reference year used was 2015. The geographical scope for the zircon LCI is global where the zircon mining companies involved in this study represent >77% of worldwide zircon sand production. The geographical scope for the comparison (zircon/alumina milling and mixture preparation) considers production in Europe, where the milling plants involved in this study represent ca 64% of European capacity. The alumina primary data, used for the comparison and obtained from the European Aluminium Association (EAA) environmental profile, represents the European context and covers 84% of European production.

Company data (‘primary data’) were obtained using questionnaire templates, which were sent to data providers at participating companies. Each returned questionnaire was cross-checked for completeness and plausibility using mass balance, stoichiometry. The LCA model was then created using the GaBi 8 Software system for life cycle engineering, developed by thinkstep AG. The GaBi LCI database provided the life cycle inventory data for the raw and process materials necessary for modelling of the product systems: zircon, alumina and the tile application.

The impact assessment was based on the CML2001 (January 2016) impact assessment methodology framework.

3. Results

Stage 1: Zircon Sand Production Average Results:

Overall life cycle results per kg of global average zircon sand are presented below.

Environmental indicator (per kg zircon sand)	Value
Abiotic Depletion Elements: ADPe [kg Sb eq.]	1,1E-07
Abiotic Depletion Fossil: ADPf [MJ]	3,8E+00
Acidification potential: AP [kg SO2 eq.]	2,6E-03
Eutrophication potential: EP [kg Phosphate eq.]	2,4E-04
Global Warming Potential: GWP [kg CO2 eq.]	3,2E-01
Ozone Depletion Potential: ODP [kg R11 eq.]	6,8E-12
Photochemical Ozone Creation Potential: POCP [kg Ethene eq.]	1,5E-04
Primary Energy Demand: PED [MJ]	4,0E+00
Water consumption [kg]	2,0E+01

Table 1: Life cycle results for 1 kg of global average zircon sand

The figure below shows the contribution of single processes.

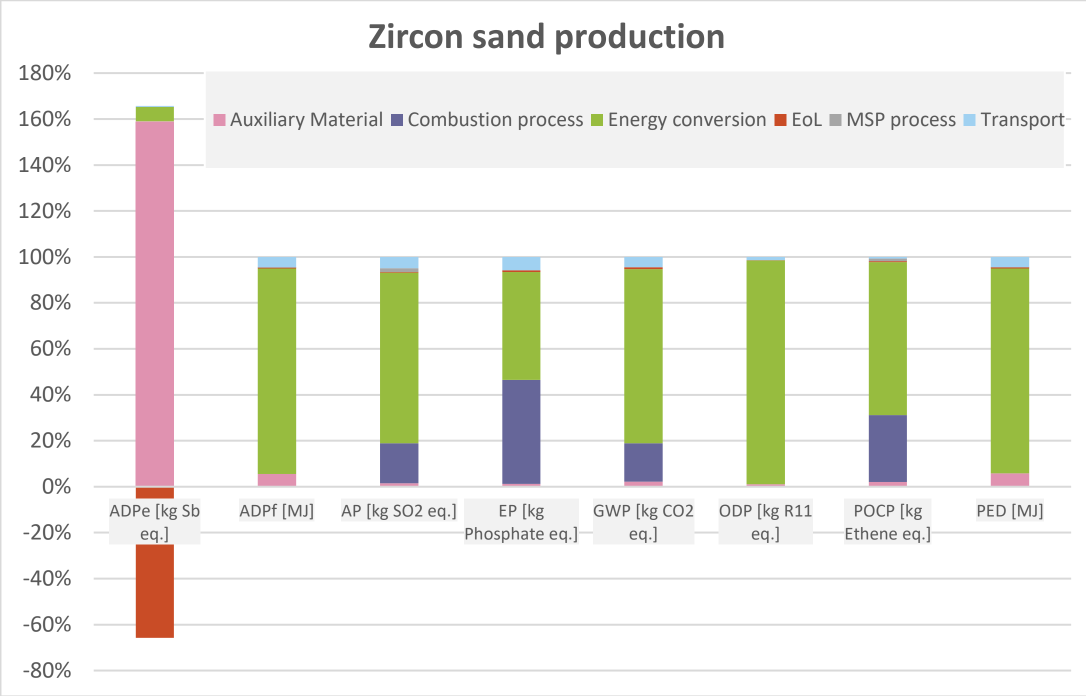

Figure 1: Potential impacts contribution for total zircon sand production

The main energy conversion process, in terms of impact, is electricity production (between 85% and 99%). The importance of electricity, considering every indicator, is directly linked to each country's own grid mix. The main emissions contributing to impacts are:

- GWP: carbon dioxide (91%) and methane (8%),
- AP: nitrogen oxides (22%) and sulphur dioxide (77%),
- EP of energy process is mainly from nitrogen oxides (97%).
- POCP: carbon monoxide represents only 3% of POCP potential impact connected with energy processes, CO is 20% of the entire POCP when combustion processes are used during mining and MSP operations. POCP for energy production is also driven by nitrogen oxides (24%) and sulphur dioxide (60%).
- ADPe is mainly driven by auxiliary materials' consumption (tyres and batteries), with high consumption of elementary resources and elements like lead (82%) silver (12%) and zinc (4%). EoL credits relate to the disposal and recovery processes of these kinds of auxiliary materials.
- Transport, for haulage of HMC to the MSP, and for zircon sand to the port, only have a minor contribution (<6%) to environmental impacts.

The figure below describes the relative contribution of the mining and MSP / concentration processes. Mining is the most relevant processes for all potential impacts, particularly for ADPe, EP, ODP and POCP.

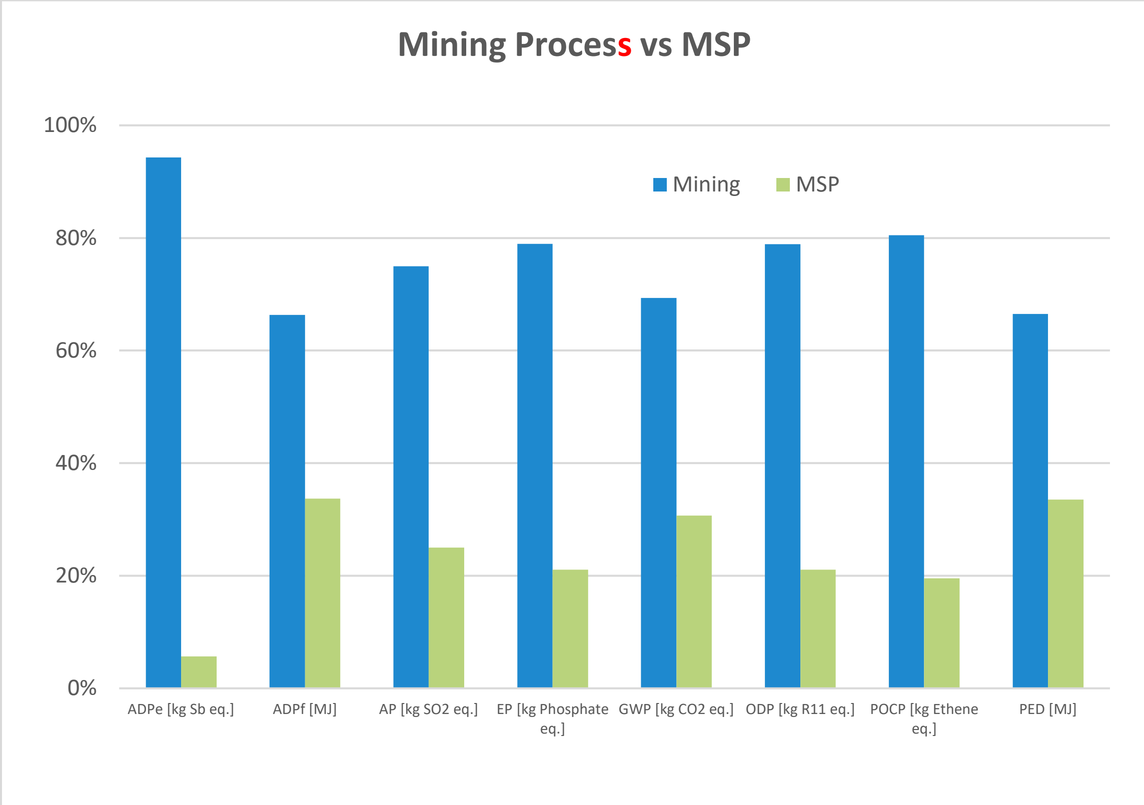

Figure 2: Mining and MSP relative contribution

Stage 2: Zircon / Alumina Tile Mixture Comparison:

The following three mixture comparisons were made:

Table 1. Ceramic tile recipes with zircon and alumina

	Range		Zircon mixtures			Alumina mixtures		
	Zircon	Alumina	A	B	C	A	B	C
Alumina	0%	3% - 6%	0,00	0,00	0,00	0,05	0,06	0,04
Clay	20% - 25%	20% - 25%	0,22	0,22	0,21	0,21	0,21	0,22
Feldspar	50% - 55%	53% - 60%	0,52	0,53	0,52	0,55	0,56	0,54
Kaolin	15% - 20%	15% - 20%	0,16	0,15	0,17	0,16	0,15	0,16
Sand	5% - 10%	2% - 8%	0,07	0,06	0,08	0,03	0,02	0,04
Zircon	2% - 4%	0%	0,03	0,04	0,02	0,00	0,00	0,00

Overall life cycle results for 1 kg of ceramic tile mixture are presented and compared below.

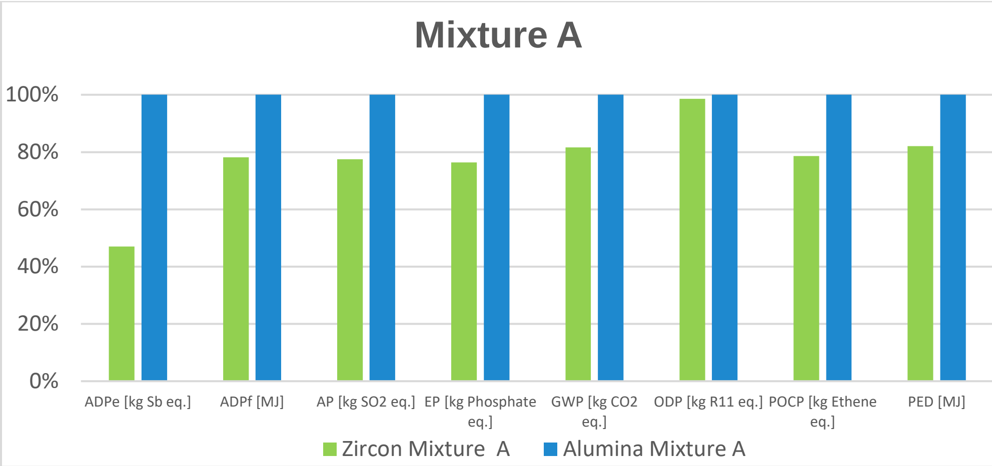

Figure 3: Comparison results, 1 kg of Mixture A

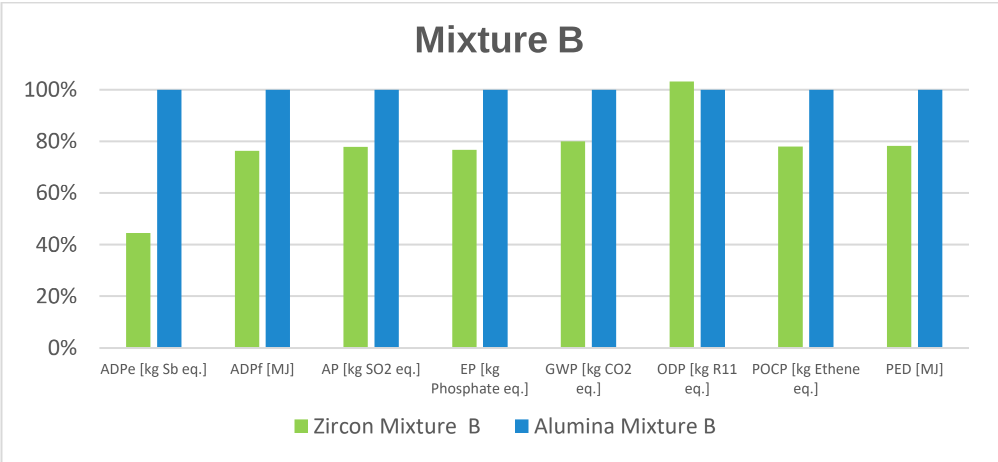

Figure 4: Comparison results, 1 kg of Mixture B

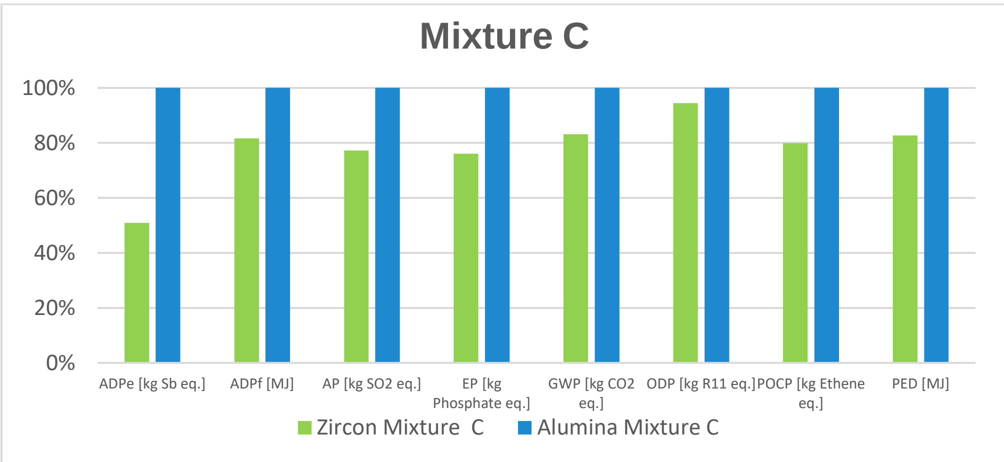

Figure 5: Comparison results, 1kg of Mixture C

In each case, the alumina-containing mixtures have higher environmental burdens, some significant, when compared to the zircon-containing mixtures for the impact categories assessed. The difference for ODP is less only because ODP is driven by electricity consumption at the zircon milling process.

Alumina has much higher impacts in the categories studied due to the primary refining (Bayer) of the bauxite ore. Moreover, in the case of alumina use, the mixture to be atomised needs more feldspar to reach the same degree of vitrification because of the alumina grain size. Alumina milling is not a relevant stage for potential impacts related to the mixture preparation, whereas milling impacts are more relevant for zircon due to electricity consumption at the mill, plus thermal energy for the drying process when wet milling is used. Electricity consumption creates 76% of ODP, driven by those EU countries that consume electricity from nuclear power sources, and 54% of ADPe. Transport from the zircon mine to milling plants has an impact on AP (26%), EP (29%) and POCP (11%). Transoceanic shipping is the main contribution due to emissions from fuel combustion. Carbon monoxide, NMVOC (non-methane volatile organic compounds) and sulphur oxides are emissions that contribute to POCP, nitrogen oxides and NMVOC to EP, nitrogen oxides and sulphur oxides to AP.

Scenario analysis was performed to compare different sets of assumptions or modelling choices (e.g. thermal energy and electricity consumption and type of fuel). The analyses showed that, even considering the best case for an alumina mixture and worst case for a zircon mixture, the zircon-containing mix has a GWP 16% lower than the alumina mix, AP 21% lower, and EP 23% lower. Only ODP is at a similar order of magnitude for the two scenarios.

4. Conclusions

The zircon LCA demonstrates that the environmental profile of zircon sand production is mainly driven by energy-related processes, particularly during mining and heavy mineral concentration. Consequently, country-specific electricity mixes influence the results. Other environmental impacts relate to the generation of thermal energy or combustion of fuel, for drying operations and raw material transportation.

When compared to alumina in super-white tile mixes, zircon-containing mixes show significantly lower environmental burdens in all but one of the potential impacts assessed in this study Differences of ca. 20% for GWP, EP, AP, POCP, ADPf and PED are identified, and ca. 50% for ADPe. ODP is similar in both zircon- and alumina-containing mixes.

Milling affects all the impact categories in this study, mainly due to the higher consumption of electrical and thermal energy used in zircon milling (wet milling in particular) and for the generally finer grain size of zircon used in tile mixtures. The LCA demonstrates that the main differences between zircon and alumina mixtures are closely tied to the environmental performance of regional grid electricity production. Scenario analysis in terms of energy provision performed on GWP, AP, EP, ODP shows that, even considering worst case scenario for zircon mixtures and the best case for alumina mixtures, the conclusions of the study remain valid.

5. Limitations and Recommendations

The study has two limitations:

- The impact of radiation from zircon as a NORM is not assessed due to insufficient data to generate a reliable average for zircon production. Also, this is not considered for alumina production (especially the residual red mud waste stream).
- Secondly, the reference year of alumina production data is 2010 (EAA), which is compared to 2015 zircon sand data in this LCA.

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On behalf of thinkstep AG and its subsidiaries